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CARBOREP
CAR BODY REPAIR

TRAINING HANDBOOK

08/08/2019

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PROJECT CONSORTIUM

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CARBOREP

European Harmonized Training for Personnel working with Car Body Repair Technology

2016-1-UK01-KA202-024374

IO3: ECBRT CURRICULUM ADAPTATION AND DEVELOPMENT

OF TRAINING MATERIALS

Index

Foreword

The present document is the European Car Body Repair Technician Handbook.

This handbook comprises two Competence Units: Competence Unit 1 "Steel Structural Body Construction – Welding Repair"; and Competence Unit 2 "Steel/Aluminium/Multimaterial Structural Body Construction – Adhesive Bonding and Mechanical Fasteners Repairs".

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Competence Unit 1

1. Steel Structural Body Construction – Welding Repair

1.1 MATERIALS USED IN THE MANUFACTURE OF VEHICLE BODIES

A typical volume production car body comprises stamped metal parts, extrusions and cast components. The are found in the upper car body structure, chassis and sub-frames. The car body may differ in its structure and parts included between different manufacturers, *e.g. body-in-white,* monocoque or chassis and cabin type design, but below is what can be considered a common skeleton for medium to high volume production cars, see Figure 1:

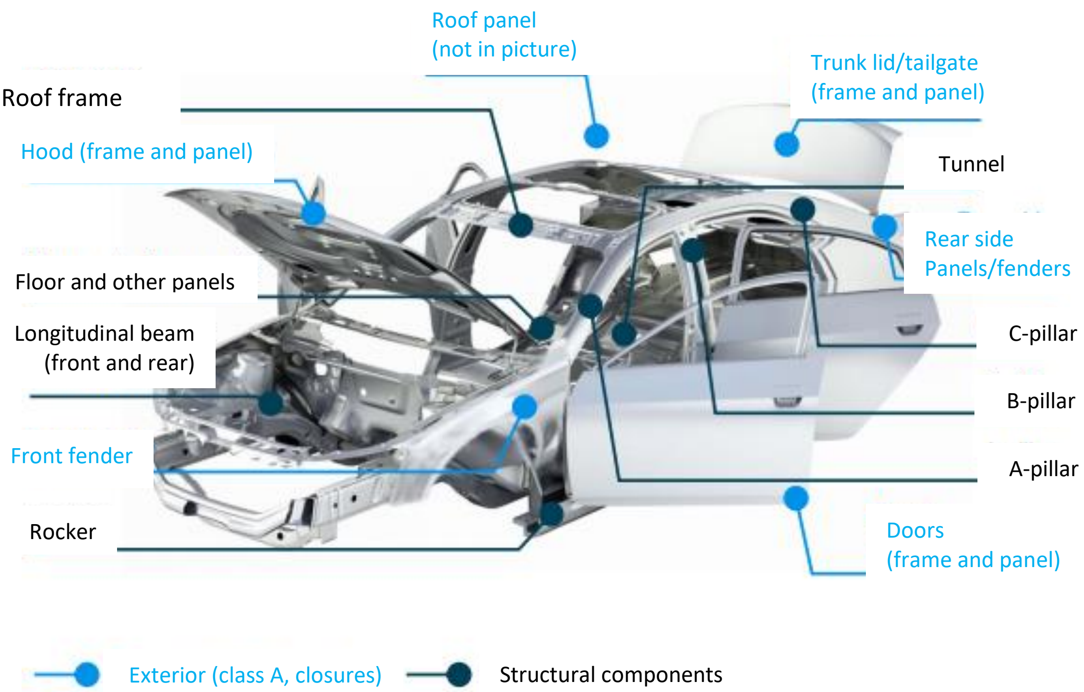


Figure 1 - Car Body Parts Identification. Source: https://www.rolandberger.com/publications/publication_pdf/roland_berger_global_automotive_stamping_study_e_20170210.pdf

Different sets of components in the car body perform different roles, such as; ensuring crash safety, passenger comfort or improving vehicle performance. Higher strength materials have limited formability and are usually used in non-visible areas where a high level of structural integrity is required, for instance in high load zones. While lower strength more formable materials are usually used for visible panels that require complex shapes and high-quality surface finishes (*e.g.* door panels) or for bolt on crash crumple zones where their energy absorption capability is paramount (*e.g.* inner reinforcement' bumpers). Regardless of the materials used, the distribution of different strength materials throughout the car body is employed to, primarily, minimize cost and weight while complying with mechanical properties design requirements.

Despite the trend over the past few decades towards the use of different materials in car body elements, especially aluminium, most production cars mainly have steel parts. Aluminium's use, despite being more expensive, is due to its reduced mass density, which in many cases, maintains the required mechanical properties. Other cars, typically high-end vehicles, use exotic materials such as carbon fibre and trends in magnesium use are also starting to begin.

Often within the same manufacturer, different models have different predominant materials in the car body, exemplified by Audi and their A1, A8, and R8 Coupé, shown in Figures 2, 3 and 4. Without prior knowledge of the vehicle, it is not possible to state definitely what the material a given part is made of. Visual inspection may enable identification of the material; however, it should be complemented with data sheet analysis, to find, for instance, the specific steel family and its corresponding properties, treatment and coatings.

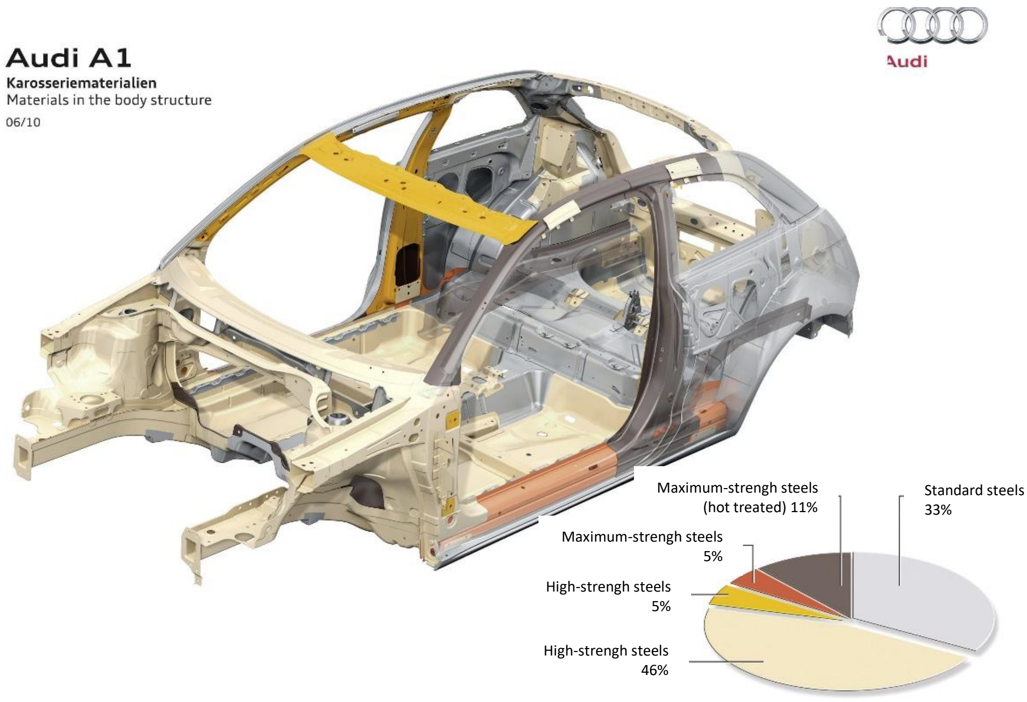


Figure 2 - Audi A1 Steel Intensive Car Body. Source: https://www.audi-mediacenter.com/en/leightweight-construction-246

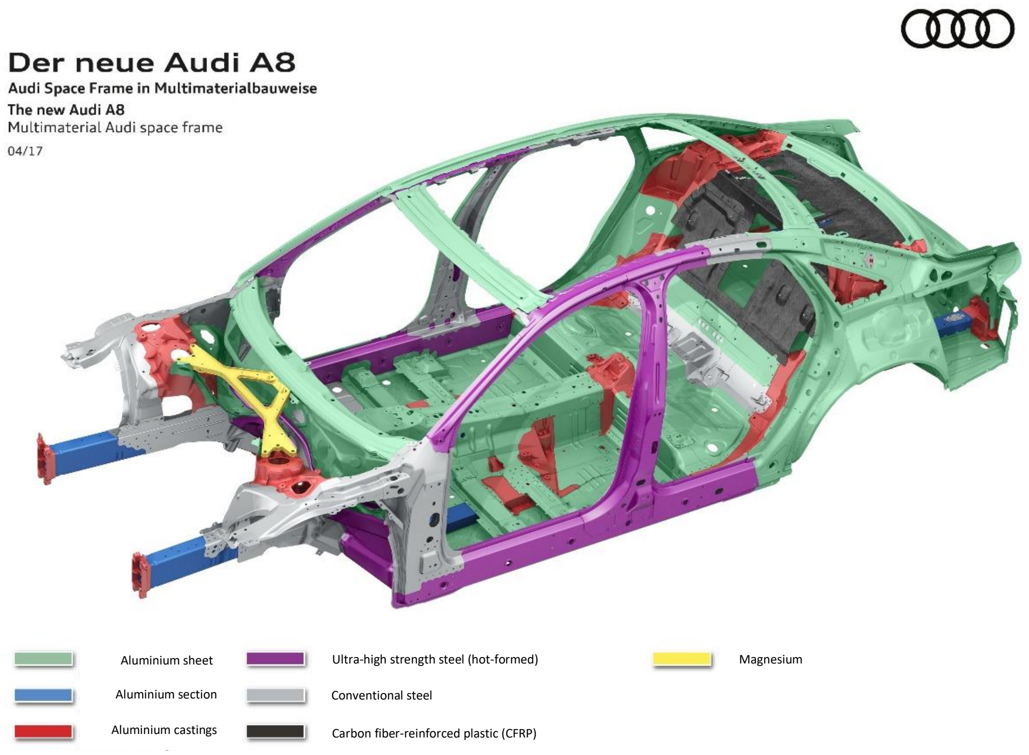


Figure 3 - Audi A8 MultiMaterial Car Body. Source: https://www.audi-mediacenter.com/en/presskits/techday-body-structure-7469

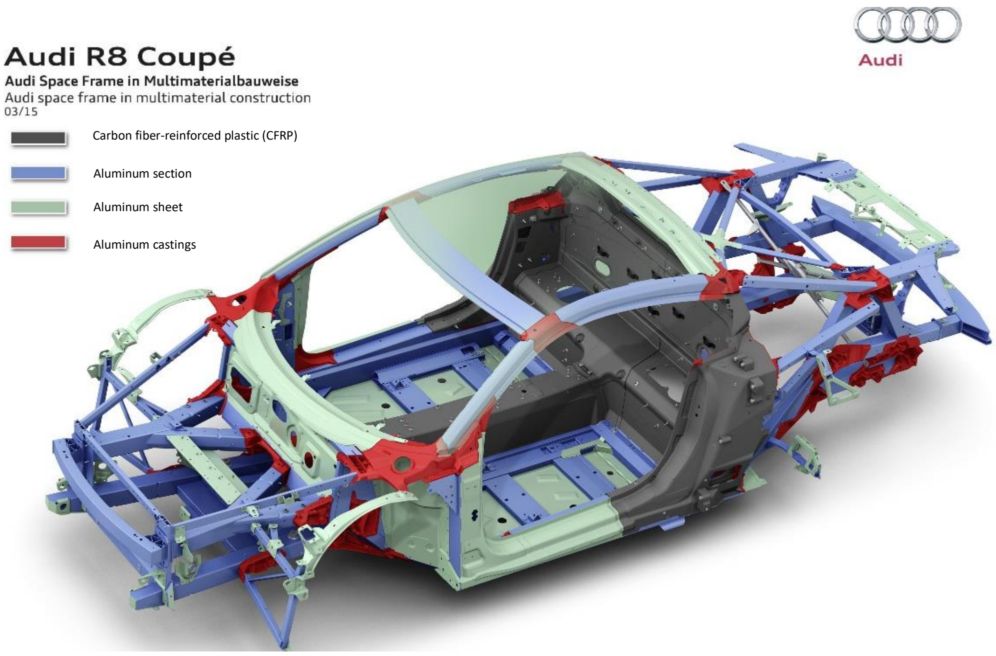


Figure 4 - Audi R8 Aluminium Intensive Car Body. https://www.audi-mediacenter.com/en/leightweight-construction-246

Next, we will review examples of the distribution of steel grades in a car body, followed by the welding repair techniques that may be applied to those different steels. Figure 5 demonstrates the variety of different joining methods that can be present in a car body.

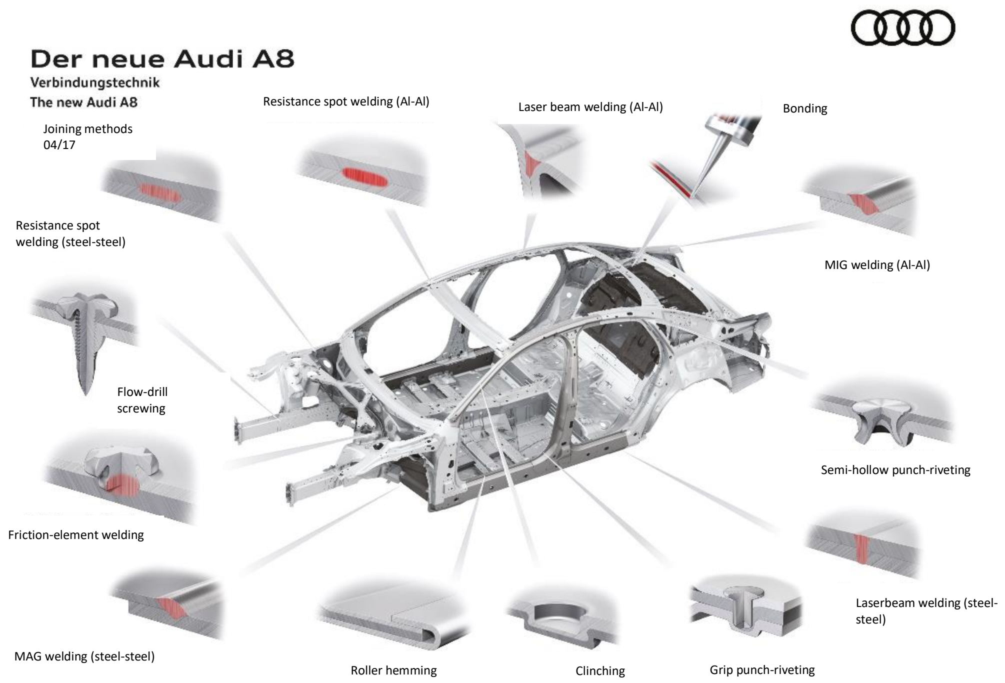


Figure 5 - Audi A8 - Joining Methods. Source: https://www.audi-mediacenter.com/en/leightweight-construction-246

Figures 6-11 show the distribution of different steels in the car body based on their strength.

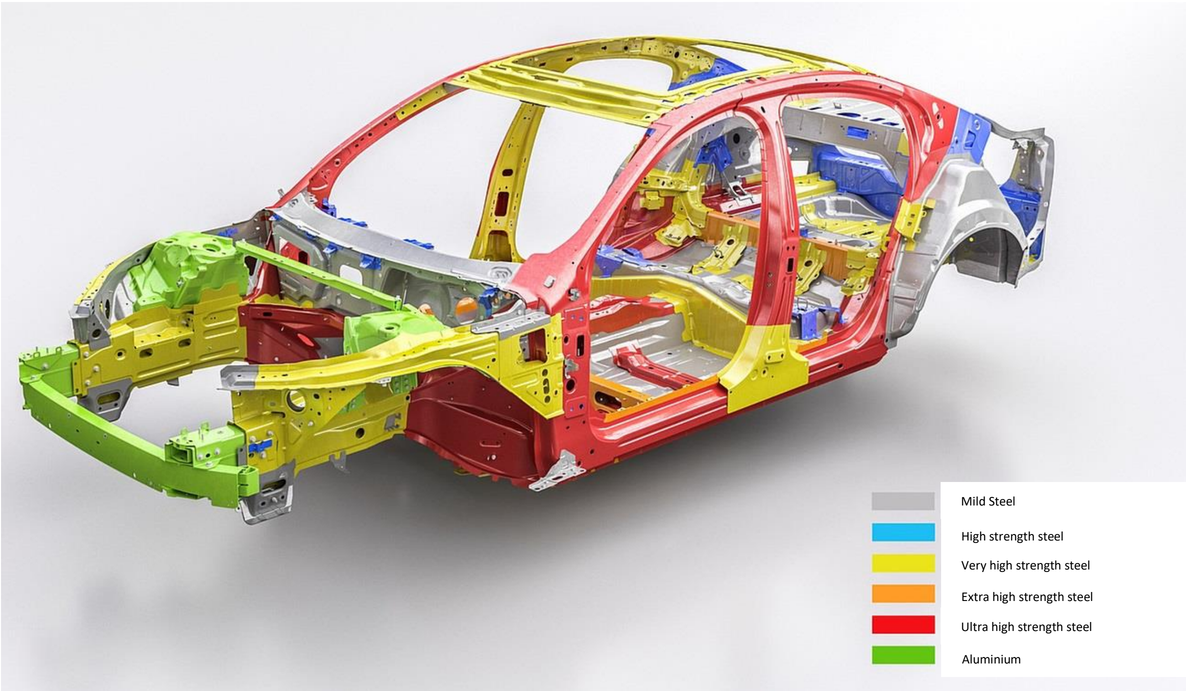


Figure 6 - Volvo S60 Body Structure. Source: http://www.boronextrication.com/tag/body-structure/

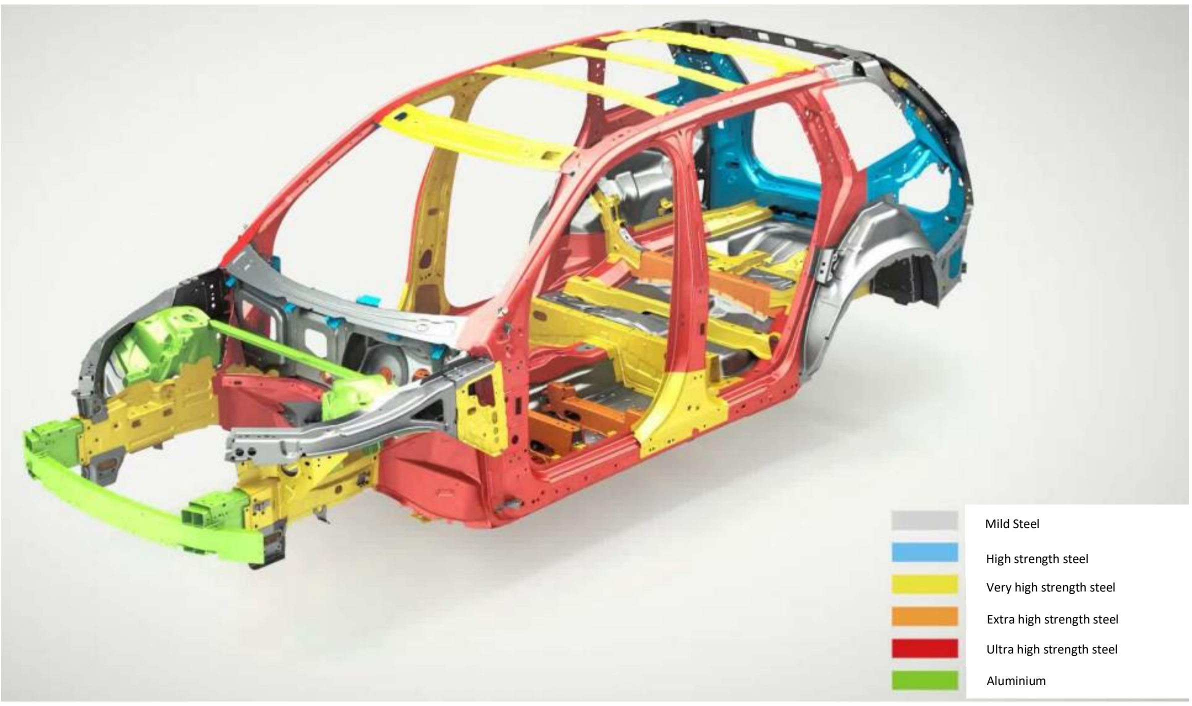


Figure 7 - Volvo XC90 Body Structure. Source: http://www.boronextrication.com/tag/body-structure/

In Figure 7, despite the steel chassis, door and hood panels are made of Aluminium. This bolt on solution for dissimilar material integration is a common method used to achieve a weight reduction without the complexity of having to directly weld or rivet aluminium into a steel structure.

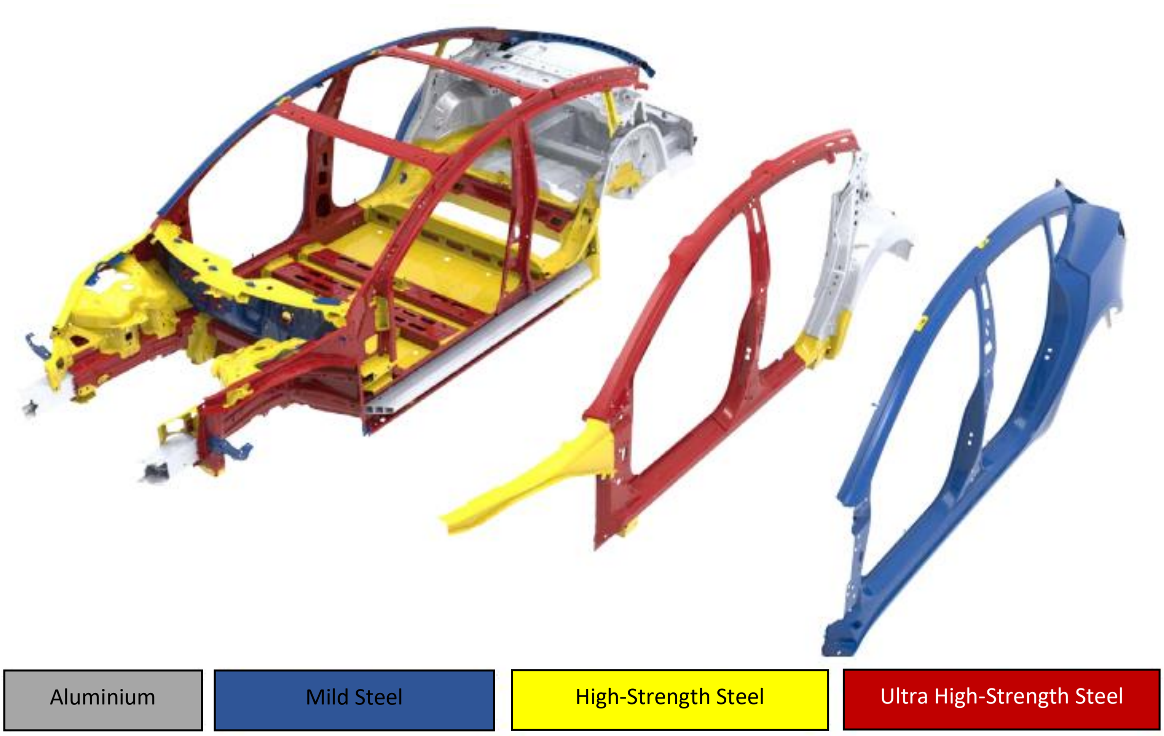


Figure 8 - Tesla Model 3 Body Structure. Source: http://www.boronextrication.com/tag/body-structure/

Figure 9 - Chevrolet Colorado Body Structure. Source: https://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2014/mar/0311-colorado.html

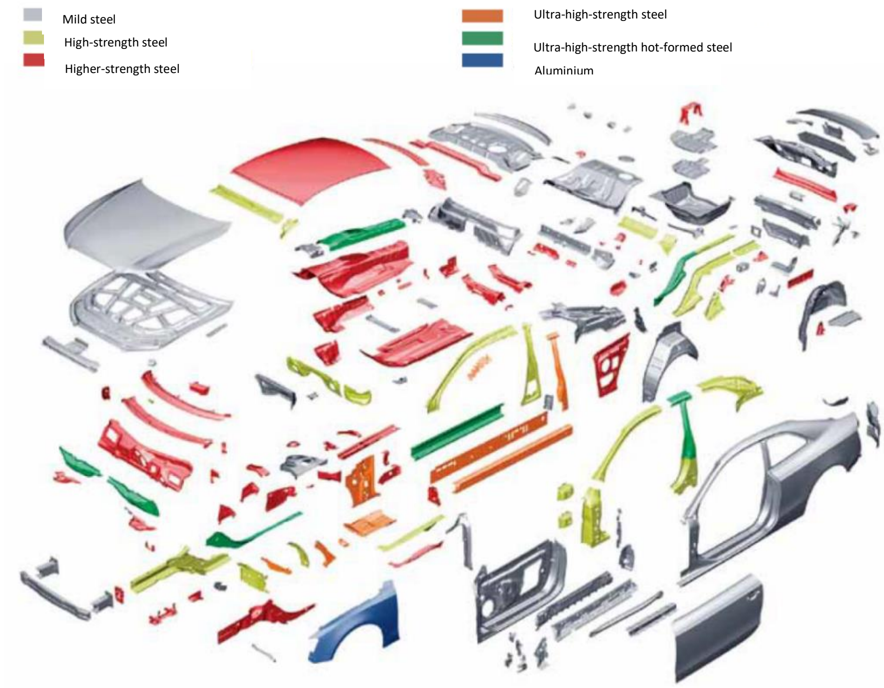


Figure 10 - Car Body Parts Exploded View. Source: https://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2014/mar/0311-colorado.html

As seen in the previous figures, there are numerous different families of steel grades used in vehicle manufacture, nearly all of these grades can be classified as mild steels.

However, the properties of the individual grades can vary dramatically, as can the welding and joining performance. The definitions and names of each grade are based around either; the microstructure, the mechanical properties or the production processes used for the specific material. Individual car companies often have their own preferred terms and codes for material grades, which further complicates material identification. However, it is possible to group the steel grades into families where the grades have similar properties. Within a specific family mechanical properties (ultimate tensile strength, yield, elongation etc. will fall into a range of values). The materials within a specific family can be handled in a similar way when it comes to manufacturing, or more specifically joining in vehicle body repair.

For the purpose of this document four steel grade families will be referred to:

- **Drawing, deep drawing and high formability steels:** These steels have fully ferritic microstructures and usually have very low carbon contents. These materials are designed for very high fomability and often have a high surface quality making them suitable for outer panels or highly formed interior components. The steels typically offer few challenges for welding and can be joined by all common processes.
- **High-Strength Steel (HSS):** Have mainly ferritic microstructures, but in order to achieve enhanced mechanical properties (ultimate tensile strengths from 350 – 550MPa) a fine grain size is required. Specific alloying additions are employed to refine grains and strengthen the microstructure but still retain good formability. Importantly for welding, carbon contents remain low in these materials. Within this family common material grades include high strength low alloy steels (HSLA), Carbon Manganese steels (CMn) and some higher strength bake hardening and rephosphorised grades. These materials are typically easy to weld and present few problems in vehicle manufacture. All three welding processes can be used in vehicle repair.

- **Advanced-High-Strength Steel (AHSS):** is a generic group of metals with ultimate tensile strength greater than 550 MPa. The microstructures of these materials can be a mixture of ferrite, austenite, martensite and bainite. Specific chemical compositions and multiphase microstructures resulting from combinations of heat treatments and other strengthening mechanisms means a range of strength, ductility and toughness may be achieved. This steel family includes steels such as Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Transformation-Induced Plasticity (TRIP), and Twinning-Induced Plasticity (TWIP). For instance, DP steels are commonly used in the crash zone given their high-energy absorption capability. Some AHSS may require specific welding parameters (e.g. TRIP or TWIP), but in general this family of materials can still be welded without particular difficulty. AHSS is very commonly be welded to other AHSS and even mild steels by means of Resistance Spot Welding (in many modern vehicles more than 50% of the welds contain one or more AHSS material). All three welding processes can be used to repair these materials but caution should be taken to reduce potential distortion resulting from the high heat input of the welding. Also, high hardness phases can result from welding, which may reduce the fracture toughness of welds.

- **Ultra-High-Strength Steel (UHSS):** characterized by having tensile strength of at least 780 MPa. UHSS grades have a predominantly martensitic microstructure, small proportions of other phases may be present. UHSS includes Dual Phase (DP), Complex-Phase (CP), Induced Plasticity (TRIP), Hot-Formed (HF) also known as press hardened steels (PHS), Martensitic (MS or MART). UHSS has similar welding properties to AHSS but with higher strength (and a resulting lower ductility). An example of UHSS use is MS steels are used as structural elements such as B pillars for their extremely high-strength characteristic. In principal these materials are all still weldable, but the effect of heat the properties of the weld and surrounding heat affected zone can in some cases severely deteriorate the integrity of a joint. For these materials thorough knowledge of the specific steel should be acquired to decide which welding procedures to execute.

It is important to introduce **steel coatings** used in the automotive industry, since they influence whether a given joining method may or may not be applied, and in which conditions. Coatings are mainly used to alter a surface's properties, such as adhesion, wettability, colour and texture, and corrosion or wear resistance. In the automotive industry, steel coatings primarily aim to enhance corrosion resistance.

Many metallic coatings include zinc, either in a pure zinc coating or in a zinc alloy coating. Zinc works as a sacrificial anode for protecting the steel against corrosion, given its anodic potential dissolution when compared to iron.

- **Electrogalvanizing:** coating is bonded to the surface by running current through a solution of a zinc anode and a steel conductor.
- **Hot-dip Galvanization:** creates a metallurgical bond between the base metal and the coating by immersing the steel part in molten zinc. When exposed to the atmosphere, pure zinc reacts with oxygen, creating a chain reaction that results in zinc carbonate ($ZnCO_3$).
- **Galvanneal Coating:** a combination of a hot-dip galvanization and an annealing process that results in the formation a zinc-iron alloy. This alloy is created due to the heat exchange in the annealing furnace which promotes diffusion between the iron and zinc layers.
- **Aluminized Steel:** creates a metallurgical bond between the base metal and the aluminium-silicon alloy in a hot-dip process. Widely used in exhaust systems.

When welding galvanized steel, one must be aware of the problems that arise from the volatilization of zinc in the coating, *e.g.* spatter, porosity, fumes, and potential weld cracking.

When short-circuiting or spray metal transfer is used as the joining method, the volatilized zinc rising from the plate surface causes the arc to become unstable and generate considerable spatter. Moreover, zinc vapor can be trapped in the solidifying weld puddle, causing porosity.

Unlike a galvanized coating, an aluminium coating is not volatile, but it does produce a high-melting-point oxide. This oxide may interfere with arc stability, cause spatter, and prevent good surface wetting which in turn creates poor bead shape.

In current welding methods, zinc is often removed from the joint surfaces before the weld or the joint is gapped to allow vapor to escape. Gas Metal Arc Welding performance can be enhanced by carefully choosing the wire size and type.

Compared to steels, aluminium alloys are specially regarded as a lightweight alternative. Other advantages include its good durability and corrosion resistance. On the other hand, its weldability is still an issue and great care must be taken when choosing welding parameters, tool geometry, thermal cycles during welding and post-weld heat treatment, so that the desired microstructure and strength may be achieved. Nevertheless, the use of joining techniques that do not resort to heat, *e.g.* mechanical joining and adhesive bonding, enables the growth of aluminium parts used in the automotive industry.

Aluminium is often joined by combining mechanical joints, such as self-piercing rivets, with adhesive bonding, which often meets the mechanical properties' requirements in many areas of the car body. Recent technology advancements enable the use of many welding techniques, namely Resistance Spot Welding and Arc Welding.

Similarly to steel grades, different Aluminium alloys have disparate inherent mechanical properties and, therefore, vehicle applications. Here, three Aluminium alloys will be referred to, given the fact that these are the most frequently used in the automotive industry.

- **5000 Al-Mg:** characterized by having great strength-to-weight ratio and formability properties. Common applications include the use of: 5182 in interior body panels given its good formability and stress corrosion cracking performance; and 5022, with higher strength and formability, in bonnets, roofs, doors and fenders.
- **6000 Al-Mg-Si:** by far the most common Aluminium alloy used in the automotive industry, given its higher strength when compared to the previous alloy. It is heat-treatable, highly formable and reasonably well weldable. For instance, 6063 is used in seat frames and roof railings.
- **7000 Al-Zn-Mg:** target of recent developments to achieve greater strength-alloys. Besides its greater cost, it has the downside of having poorer corrosion properties, which may be an issue when welded. 7003 and 7046 alloys may be used in bumper reinforcements and impact beams.

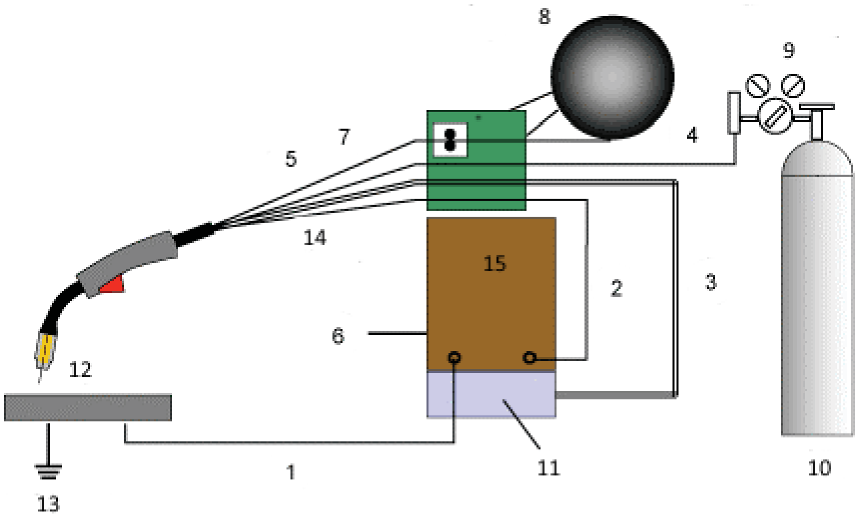
1.2 MAG WELDING AND GMAW BRAZING

Weld brazing is the joining of metals with a process similar to fusion welding using a filler metal with a lower melting point than the parent metal and without intentionally melting the parent metal.

Metal Active Gas (MAG) welding (EN ISO 4063 process 135) and Gas Metal Arc Weld (GMAW) Brazing (EN ISO 4063 process 973) can be applied to repair the damaged body of an automobile.

1.2.1 MAG Welding and GMAW Brazing Overview

MAG Welding Equipment



8.

Figure 11 - Diagrammatic representation of MAG welding equipment.1. Return lead, 2. Welding current cable, 3. Cooling water in and out, 4. Shielding gas from cylinder, 5. Wire electrode in liner, 6. Primary input power, 7. Gun switch circuit, 8. Wire electrode supply, 9. Shielding gas regulator and flowmeter, 10. Shielding gas supply, 11. Cooling unit (optional) 12. Welding gun or torch, 13. Safety earth (Seek HSE guidance), 14 Cable assembly, 15 Power source. Source: TWI

Figure 12 -Power source-transformer/rectifier (constant voltage type); 2. Inverter power source.; 3 Power hose assembly (liner, power cable, water hose, gas hose); 4 Liner; 5 Spare contact tips; 6 Torch head assembly; 7 Power-return cable and clamp.; 8 15kg wire spool (copper coated and uncoated wires); 9 Power control panel;10 External wire feed unit. Source: TWI

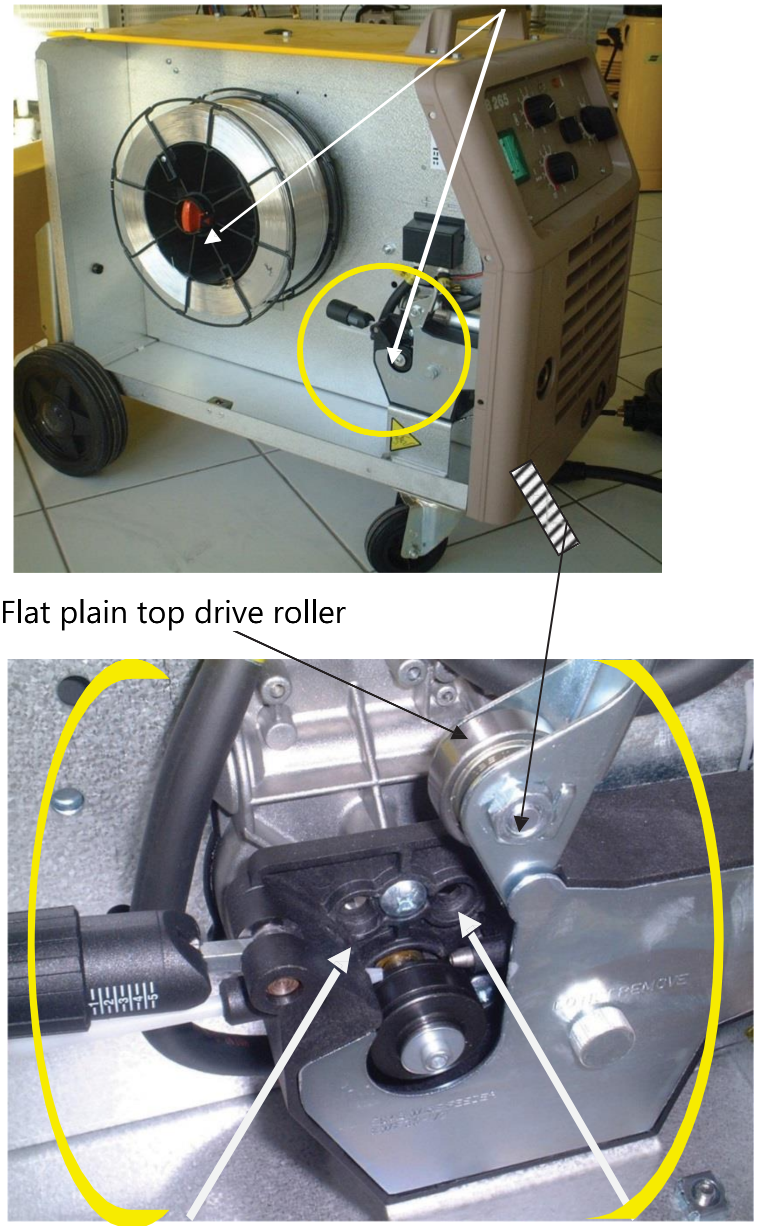


Figure 13 – Typical welding equipment. Source: TWI

The MAG wire drive assembly

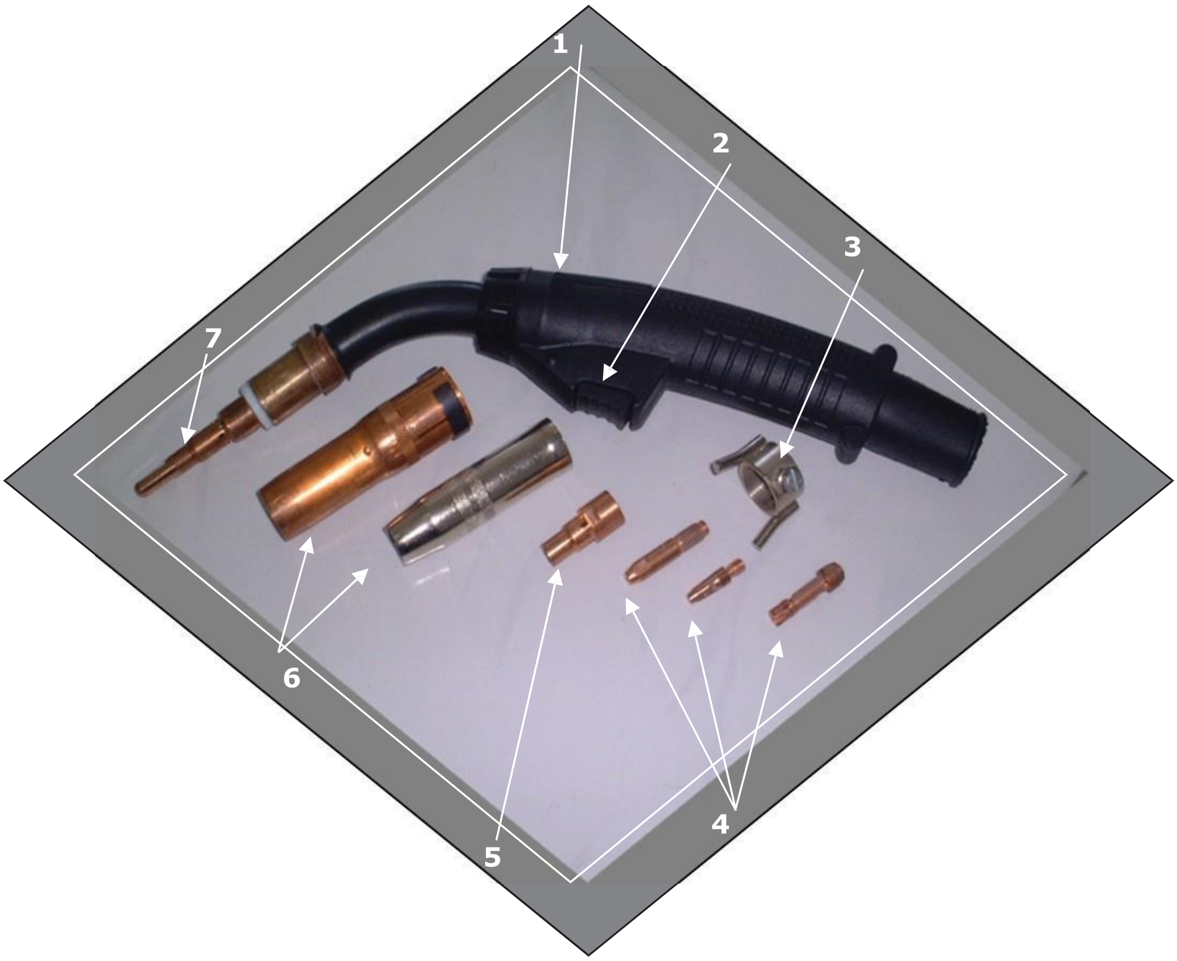


Figure 14 - Torch body; 2 On/off or latching switch; 3 Spot welding spacer attachment; 4 Contact tips; 5 Gas diffuser; 6 Gas shrouds; 7 Torch head assembly (minus the shroud). Source: TWI

Welding and brazing consumables

Most metallic materials can be welded using the MAG welding process, provided it is possible to manufacture a wire consumable. The main considerations when selecting consumables for MAG welding (i.e. filler wire and shielding gas composition) are:

- Composition to suit parent material
- Mechanical properties required
- Deposition rate
- Welding position

- Bead appearance and penetration profile
- Quality issues, e.g. wire feedability
- Cost issues

Both wire and shielding gas composition are essential variables in MAG welding/brazing and will, therefore, influence the process performance.

Wire electrode selection

Key characteristics:

- Wires are available in a wide range of compositions to suit different metallic materials, e.g. ferritic steels, austenitic stainless steels, aluminium alloys, nickel alloys, titanium alloys
- MAG wires are normally specified by composition
- Wires are typically supplied with diameters in the range 0.8mm to 2.4mm
- Wire are normally available on 15kg reels, but large packs (up to 250kg) are available for robotic welding to minimise downtime in wire change operations
- The wire is often layer wound to ensure smooth feeding
- Solid wires are commonly used, but tubular cored wires may offer added benefits for some applications

Figure 15 - Spool of MAG welding wire. Source: Lincoln Electric

Wire composition

Selection of the appropriate composition of the wire electrode can be a difficult task. For most applications, wires are designed to give weld metals with matching composition to the base material. In practice, this means that wire compositions tend to be slightly over-alloyed to compensate for the burn-off of alloying elements in the arc. The composition can also be modified for operation under a particular shielding gas mixture, particularly for metal-cored and flux-cored wires.

The selection of consumables should be confirmed by welding trials and procedure qualification testing in accordance with the applicable application Code or Standards.

The main sources of information are:

- Electrode manufacturer's handbook
- Electrode manufacturer's technical department
- Parent material manufacturer
- Previous experience or procedures
- Experts in your EWF member society (www.ewf.be)

Carbon and low alloy steels

Solid wires for welding steels with active shielding gases are deoxidised with manganese and silicon to avoid porosity. There may also be titanium and aluminium additions. Mild steel filler wires are available with different levels of deoxidants, known as double or triple de-oxidised wires. More highly deoxidised wires are more expensive but are more tolerant of the plate surface condition, e.g. mill scale, surface rust, oil, paint and dust. There may, therefore, be a reduction in the amount of cleaning of the steel before welding.

These deoxidiser additions yield a small amount of 'glassy' slag on the surface of the weld deposit, commonly referred to as silica deposits. These small pockets of slag are easily removed with light brushing; but when galvanising or painting after welding, it is necessary to use shot blasting. During welding, it is common practice to weld over these small islands since they do not represent a thick slag, and they usually spall off during the contraction of the weld bead. However, when multipass welding, the slag level may build up to an unacceptable level causing weld defects and unreliable arc starting.

Steel wires usually have a flash coating of copper to improve current pick-up and to extend the shelf life of the wire. However, the copper coating can sometimes flake off and be drawn into the liner and wire feed mechanism, particularly if there is misalignment in the wire feed system. This may cause clogging and erratic wire feed. Uncoated wires are available as an alternative, although electrical contact may not be as good as with copper-coated wires, and contact tip operating temperatures may be higher.

Wire type

Different types of wire are available for use with MAG equipment, depending on the manufacturing route. The wire can be a solid wire or of tubular construction. With tubular wires, it is possible to modify the chemistry of the wire contents to adjust the burn-off rate, improve arc stability and to produce a flux. Tubular wires are chiefly available for carbon steels, low alloy steels and stainless steels. For the majority of applications, solid wires perform adequately, although the main advantage over tubular wires for many users is the lower cost of procurement.

Wire diameter

Selection of the appropriate wire diameter is dependent on a number of factors, chiefly:

- Mode of metal transfer
- Welding current
- Deposition rate

These factors are primarily governed by the application and productivity requirements.

The rate at which the wire is fed into the arc and the current that is required to burn it off must be balanced to maintain an equilibrium arc length. This relationship is a characteristic property of each filler wire and shielding gas composition and wire diameter. This diagram shows a series of burn-off curves for different diameter mild steel wires.

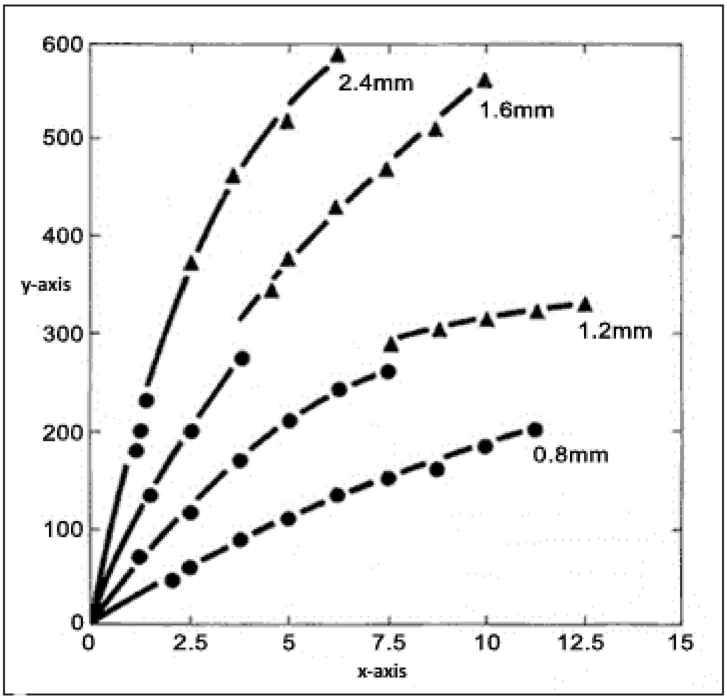


Figure 16 - Burn-off curves. Note that these are for mild steel with CO 2 shielding gas

y-axis: Current –A, x-axis: Wire feed rate (m/min). Source: TWI

It can be seen that each wire size can be operated over a range of currents and that these ranges of application overlap. The electrode manufacturer usually specifies the typical current ranges of operation for a particular wire size. It is then a case of ensuring that the welding current is in the mid-upper range of current-carrying capability.

In general, smaller diameter wires have a higher specific current load (up to 300A/mm2) and so achieve higher deposition efficiency at the same welding current. Therefore, where manufacturer's information is not available, for a given welding current, the smallest applicable wire diameter should be selected. However, smaller wire diameters require higher wire feed speeds to reach the same currents and it may be beyond the capability of the wire feed unit to deliver the wire consistently. The wire is less stiff, which may itself cause feeding problems. Smaller diameter wires also cost more than larger wires because they are more expensive to produce.

When operating near the spray transfer range, operating fluctuations, e.g. erratic wire feed, may cause intermittent crossing of the spray threshold, which may result in globular transfer and spatter. In this case, it may be beneficial to choose a smaller diameter wire, which will then operate well above the spray transition current.

Larger diameter wires, e.g. 1.4, 1.6, and 2.4mm, are capable of operating at higher current levels and therefore give higher deposition rates if the joint design permits such high currents, e.g. fillet welding in the PA position.

It is also necessary to consider the dynamic output characteristics of the power source. For example, if there is no inductance control on the power source, better process stability may be achieved by selecting a smaller diameter wire rather than a larger diameter wire and tolerate spatter.

Storage of wires

It is essential that all consumable wires are in first-class condition. This is particularly so for MAG welding where process stability relies on consistency of wire feed and electrical contact. In order that this can be achieved and maintained, the following control measures may be necessary:

- The wire should be in a clean condition with the minimum of grease and drawn-in dirt. Therefore, when not in use, reels should be returned to the stores and not left on equipment for long periods. Dust covers should be used, if available.
- If a wire has been left on the equipment for a short period of time, it is good practice to run off at least one layer of wire to remove the worst of any surface oxidation or contamination that may have occurred.
- For storage, consideration should be given to factors such as humidity, temperature, stacking and identification, and recording of issue/return and date

of purchase. Reels should be stored at a temperature above the dewpoint of the local area. Particular attention should be paid to storage and identification of partly used reels of wire in fabrication shops or on site.

On receipt, it is common to record the trade name, brand name, specification, grade and batch numbers of wires. The need for adequate records will depend on the criticality of the job to be welded.

Gases

For welding all grades of steels, controlled addition of oxygen or carbon dioxide (CO_2) to generate a stable arc and give good droplet wetting. Because these additions react with the molten metal they are referred to as active gases, hence metal active gas (MAG) welding is the technical term when referring to welding steels.

Shielding gases for arc welding and brazing are specified according to EN ISO 14175 'Welding consumables – Gases and gas mixtures gases for fusion welding and allied processes'. However, many welders are more familiar with the trade names of gases they use, rather than the composition or classification. The classification code can be used to identify the shielding gas on a welding procedure specification, but the range of approval is normally restricted to the nominal composition used in the procedure qualification test.

100%CO_2

CO_2 gas cannot sustain spray transfer as the ionisation potential of the gas is too high it gives very good penetration but promotes globular droplet transfer also a very unstable arc and lots of spatter.

Argon +15-20%CO_2

The percentage of CO_2 or oxygen depends on the type of steel being welded and the mode of metal transfer used. Argon has a much lower ionisation potential and can sustain spray transfer above 24 welding volts. Argon gives a very stable arc, little spatter but lower penetration than CO_2. Argon and 5-20%CO_2 gas mixtures give the benefit of both gases, ie good penetration with a stable arc and very little spatter. CO_2 gas is much cheaper than argon or its mixtures and is widely used for carbon and some low alloy steels.

Argon +1-5%CO_2

Widely used for stainless steels and some low alloy steels. At least 2% CO_2 or 1% O_2 in argon is required to stabilise the arc roots and to promote wetting of the weld pool. Many shielding gas mixtures for carbon and low alloy steels contain both CO_2 and O_2.

The arc that is formed at low levels of CO_2 , up to 5%, can be relatively cold and is best suited to welding thin sheet material. Low CO_2 content gases, typically less than 5%, are characterised by a pronounced 'finger' penetration, as shown in the top image, especially at high current levels.

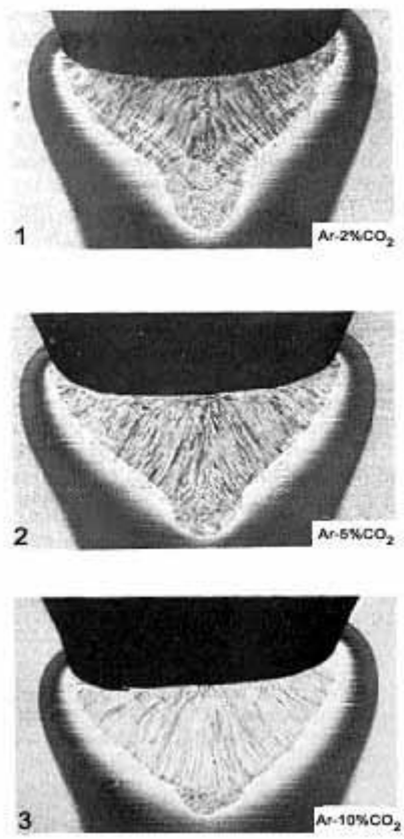


Figure 17 - Change in penetration profile with increasing CO2 content in Ar-CO2 gas mixtures. Source: TWI

Argon-CO_2 mixtures produce a relatively sharp threshold level and stable spray transfer mode compared with pure CO_2. The minimum argon content to support axial spray transfer is 80% argon, 20% CO_2. It also follows that for pulse transfer, mixtures with 20%CO_2 or less should be used. Argon-CO mixtures are also more tolerant of the voltage setting and generate substantially lower spatter levels. The surface tension of the weld pool is reduced.

Since the degree of melting increases significantly with increase in CO_2 content, thicker material is normally welded with up to 25% CO_2. The weld penetration increases with increasing CO_2 content and the extent of the finger decreases. However, the level of spatter also increases with the CO_2 content, so that a general purpose gas mixture of 10 to 15% CO_2 provides a compromise between fusion profile and stability for general purpose welding. Typical flow rates are 12-18l/min.

Argon-O_2 mixtures

The addition of oxygen is an alternative to CO_2 for stabilising the arc and promoting wetting-in of the weld pool; 2% O_2 provides an oxidising atmosphere equivalent to 5%CO_2 and produces similar benefits of greater stability and smoother weld bead profile. Oxygen generates a stiffer arc than CO_2 , which can help to minimise undercutting; it is therefore ideally suited to the spray transfer mode, having a well-defined transition level. At high current levels, it produces the characteristic 'finger' type weld bead penetration.

Argon-helium-CO_2 -O_2 mixtures

Helium has a higher ionisation potential than argon. This produces a higher arc voltage, and the arc formed is considerably hotter than with argon-based gases. When substituted for argon in argon-CO_2 mixtures, this can often promote higher welding speeds and improve the weld bead penetration profile (deeper bowl-shaped penetration and a flatter surface profile). These mixtures are particularly suitable for mechanised welding, but are more expensive than argon-based mixtures.

This chart summarises the gas mixtures for different transfer modes and steel thicknesses; blue is a cooler gas mixture; red is a hotter mixture.

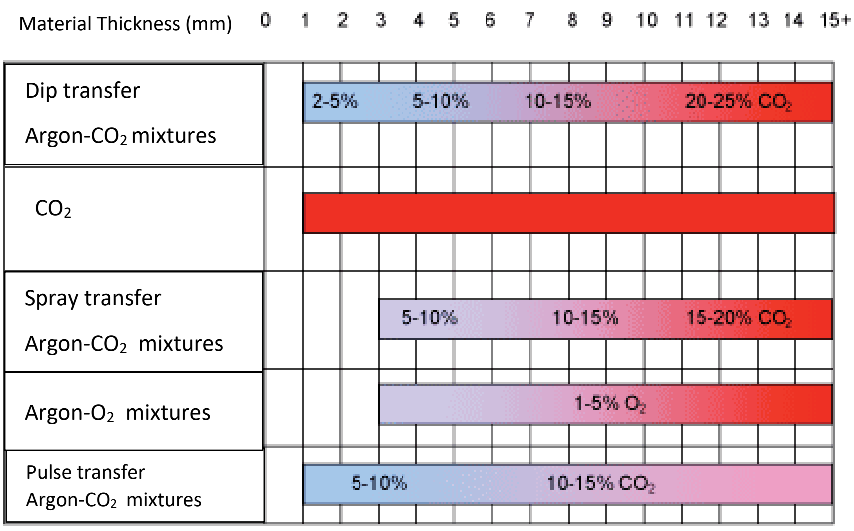


Figure 18 - Active shielding gas mixtures for MAG welding of carbon, C-Mn and low alloy steels. Blue is a cooler and red a hotter mixture gas. Source: TWI

A hotter gas mixture minimises the risk of lack of fusion defects in dip transfer, and cold lapping defects in spray transfer. Hotter gas mixtures are likely to yield higher speeds, and are suitable for thick material, mechanised applications and downhand applications, particularly fillet welds. Colder mixtures are suited for thin sheet and all-positional welding with low heat input transfer modes. When using a low heat input welding condition on thicker material, it is advisable to select a hotter gas mixture to help minimise the risk of defects. When using spray transfer, there is a minimal risk of lack of fusion defects, and a colder gas mixture may be beneficial to optimise metal transfer and bead profile.

For pulse transfer, a compromise between achieving good metal transfer characteristics and reducing the risk of lack of fusion defects, but maintaining low heat input and arc stability, is necessary.

Gas mixtures with helium instead of argon give a hotter arc, more fluid weld pool and better weld profile. These quaternary mixtures permit higher welding speeds but may not be suitable for thin sections.

Selection of shielding gases for MAG welding and brazing is primarily dependent on the material type and metal transfer mode (and hence material thickness). However, it is not always possible to specify precise compositional ranges for gas mixtures for specific materials or applications. The choice of gas is often a compromise between achieving stable metal transfer, minimising the risk of defects and obtaining the desired bead profile, penetration and considering any metallurgical effects of oxidation. The economics of shielding gas selection should also be considered, because considerable benefits in welding speed and reduction in reject rates may be achievable by choosing a more expensive gas mixture. The shielding gas specified in the welding procedure or repair instruction should always be used.

Shielding gas mixtures for MAG welding - summary

Metal	Shielding gas	Reaction behaviour	Characteristics
Carbon steel	Argon-CO_2	Slightly oxidising	Increasing CO_2 content gives hotter arc, improved arc stability, deeper penetration, transition from 'finger'-type to bowl-shaped penetration profile, more fluid weld pool giving flatter weld bead with good wetting, increased spatter levels, better toughness than CO_2. Min 80% Argon for axial spray transfer. General purpose mixture: Argon-10-15%CO_2.
	Argon-O_2	Slightly oxidising	Stiffer arc than Ar-CO_2 mixtures, minimises undercutting, suited to spray transfer mode, lower penetration than Ar-CO_2 mixtures, 'finger'-type weld bead penetration at high current levels. General purpose mixture: Argon-3%CO_2.
	Argon-helium-CO_2	Slightly oxidising	Substitution of helium for argon gives hotter arc, higher arc voltage, more fluid weld pool, flatter bead profile, more bowl-shaped and deeper penetration profile and higher welding speeds, compared with Ar-CO_2 mixtures. High cost.
	CO_2	Oxidising	Arc voltages 2-3V higher than Ar-CO_2 mixtures, best penetration, higher welding speeds, dip transfer or buried arc technique only, narrow working range, high spatter levels, low cost.

Table 1 – Summary.

Setting the correct flow rate

One of the functions of the shielding gas is to prevent weld contamination by excluding the surrounding air. The flow rate of the gas is, therefore, an important parameter: set too low, the shielding atmosphere is merely diluted air and ineffective; set too high, it can cause turbulence in the gas stream and lead to air entrainment.

Correct selection of welding gun nozzle diameter is dependent on the size of the weld pool that must be protected; so, at higher welding currents, larger nozzles and flow rates are required.

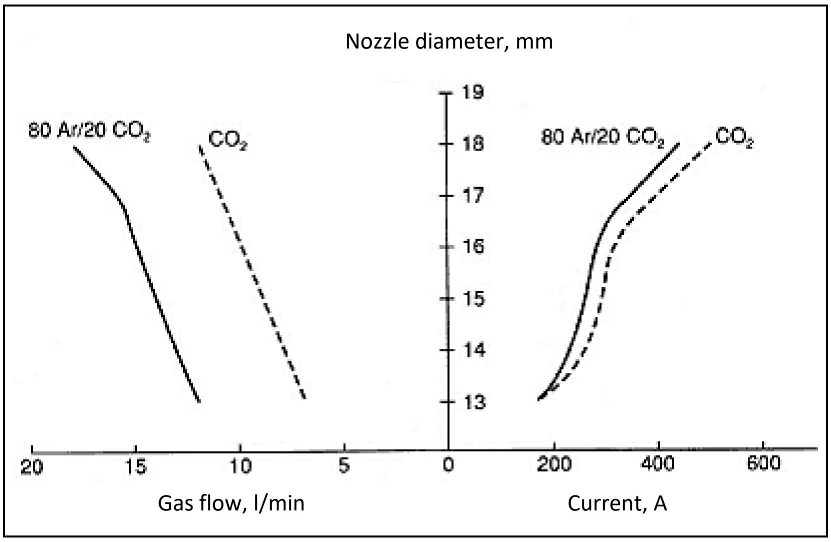


Figure 19 - Typical gas flow rates for different nozzle diameters and welding currents (weld pool sizes). Source: TWI

The gas flow should be increased slightly in draughts, or where the nozzle diameter, nozzle to plate distance, current, arc voltage and welding speed increase. Wide weaves should be avoided since porosity can result from inadequate gas shielding.

In the workshop

Welding equipment

Visual check to ensure the welding equipment is in good condition.

Electrode wire

The diameter, specification and quality of wire are the main inspection headings. The level of de-oxidation of the wire is an important factor with single, double and triple de-oxidised wires being available.

The higher the level of de-oxidants in the wire, the lower the chance of porosity in the weld. The quality of the wire winding, copper coating and temper are also important factors in minimising wire feed problems.

Drive rolls and liner

Check the drive rolls are the correct size for the wire and that the pressure is hand tight or just sufficient to drive the wire. Excess pressure will deform the wire to an ovular shape making it very difficult to drive through the liner, resulting in arcing in the contact tip and excessive wear of the contact tip and liner.

Check that the liner is the correct type and size for the wire. One size of liner generally fits two sizes of wire, ie 0.6 and 0.8, 1 and 1.2, 1.4 and 1.6mm diameter. Steel liners are used for steel wires and Teflon for aluminium wires.

Contact tip

Check the contact tip is the right size for the wire being driven. Check the contact tip frequently for the amount of wear, and replace the contact tip regularly.

Connections

Check that all connections in the welding circuit are secure and that cables are in good condition.

Gas and gas flow rate

The type of gas used is extremely important to MAG welding and brazing, as is the flow rate from the cylinder which must be adequate to give effective shielding. Confirm the gas composition against the welding/brazing procedure requirements and set the gas flow rate.

Other variable welding parameters

Checks should be made for correct wire feed speed, voltage, speed of travel and all other essential variables of the process given on the approved welding/brazing procedure.

Safety checks

Check the current carrying capacity or duty cycle of equipment and electrical insulation. Check that extraction systems are functioning correctly and positioned to avoid exposure to fumes. Check the availability and condition of all necessary PPE and screens.

Welder

Check that the welder is qualified to weld the procedure being used.

Setting up the workshop for welding and brazing:

Documentation: Which documents do you need to have before welding and brazing?

Health, safety and environment documents:

....

....

Welding and brazing documents:

....

....

Personal Protective Equipment: List the PPE you require and perform the pre-use inspection.

....

....

....

Ventilation and extraction equipment: Perform the pre-use inspection, position and operate the equipment.

Notes:

MAG welding/brazing equipment: Perform the pre-use inspection, check maintenance and calibration records, disassemble and reassemble the welding torch, and install the consumable.

Notes:

Your practical training will start with bead on plate and will be guided by your welding instructor to progress through the following joint types and welding positions with sufficient test pieces to achieve consistent confidence and joint quality:

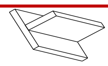
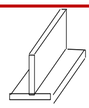
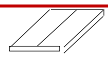
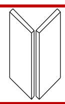
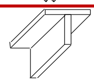
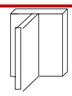
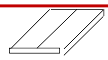
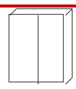
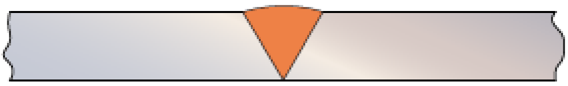
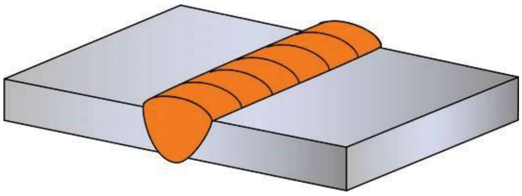
Practical welding training					Material group 1 (ISO/TR 15608)
No.					Process 135 & 973
	Type of weld	Recommended material thickness [mm]	Welding position	Sketch	Remarks
1	Bead on plate	Unlimited	PA / PF / PG		process 135 & 973
2	Fillet weld, T-joint	t > 1	PA		single layer
3	Fillet weld, T-joint	t > 1	PB		single layer, welding around the corner
4	Butt weld	t > 1	PA		Single-sided, no backing, multi-layer
5	Fillet weld, corner joint	t > 1	PG		single layer, full penetration
6	Fillet weld, T-joint	t <= 1,2	PD		single layer
7	Fillet weld, T-joint	t <= 1,2	PG		single layer
8	Butt weld	t <= 1,2	PE		single-sided, no backing
9	Butt weld	t <= 1,2	PG		Single-sided, no backing

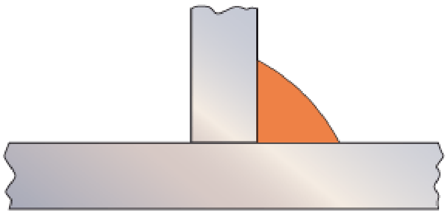
Table 2 – Joint types. Source: TWI

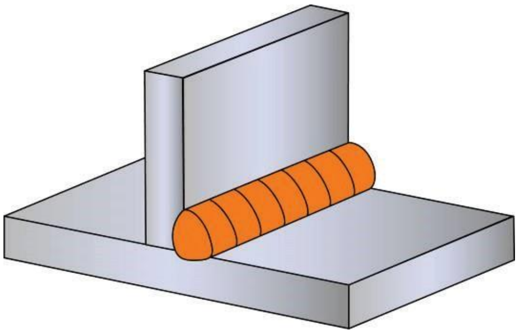
These various joint types may be joined by only two weld types. Firstly, the butt weld where the weld is within the plane of the components being joined and secondly, the fillet weld where the weld is completely or mostly outside the plane of the components.





Butt weld





Fillet weld

Figures 20 and 21 – Butt and Fillet weld

Fillet welds are probably the most common type of weld, they may be used to make T, corner and lap joints.

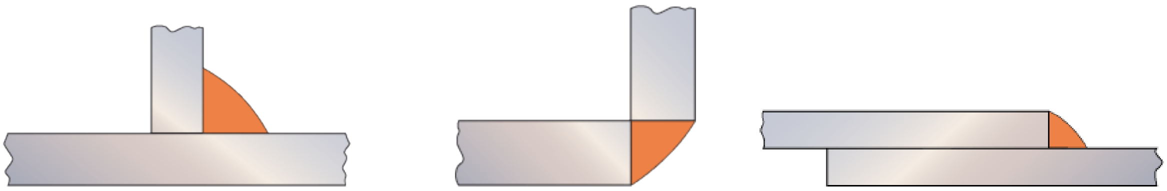


Figure 22 – T-joint fillet weld, Corner joint fillet weld and Lap joint fillet weld. Source: TWI

A fillet weld is approximately triangular in shape, the size being defined by the weld throat or leg length as shown in.

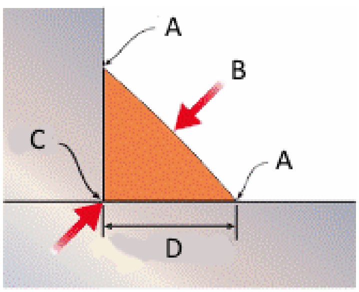
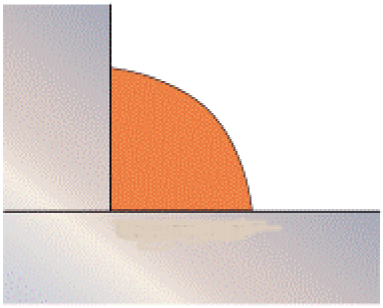
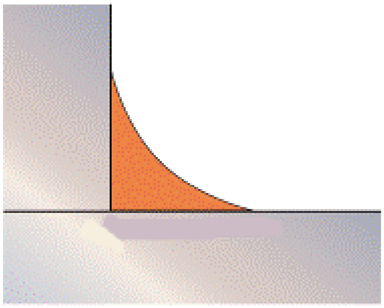


Figure 23 – Fillet weld. A. Toe; B. Throat(a); C. Root; D. Leg length (z). Source: TWI





Convex Fillet

Concave Fillet

Figure 24 and 25 - Terms used to describe features of a fillet weld. Source: TWI

Fillet welds sizes should be specified preferably by referring to the throat thickness 'a' although the leg length 'z' is often used and can be easier to measure during weld inspection. Conventionally, the leg lengths are regarded as being of equal dimensions, the weld forming an isosceles triangle in cross section.

The convex fillet is generally undesirable because:

a) the junction of the weld metal with the parent metal at the weld toe can form a significant stress raiser and will adversely affect both fatigue life and brittle fracture resistance;

b) the excess weld metal in the cap costs both time and money to deposit without contributing to joint strength.

The concave fillet weld can be beneficial with respect to fatigue strength and, if required, the minimum throat thickness MUST be specified.

Fillet welds are less expensive to make than butt welds as there is no requirement to cut or machine a weld preparation.

To enable thicker plate to be joined by 'spot welding' a circular or elongated hole may be machined through the top plate, enabling either a plug or a slot weld to be made by filling the hole with weld metal. Whilst this may seem to be a simple and easy process the strength of this type of joint depends upon full fusion of the weld metal with the vertical wall of the hole cut into the upper plate. As with a fillet weld, lack of fusion in this area will result in a reduction in the throat thickness of the joint. It is therefore essential that the welder directs the welding arc into the bottom corner of the joint and does not simply puddle the weld metal into the hole. With small diameter plug welds this can be a difficult and skilled operation and welders need to be adequately trained to ensure that they can achieve full fusion.

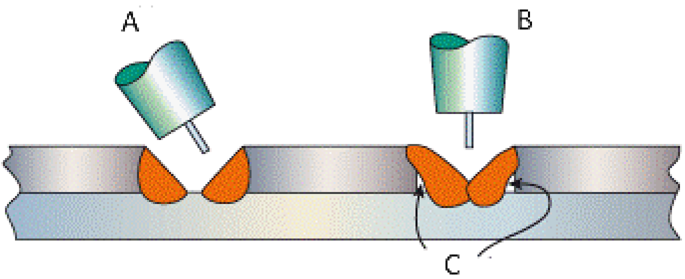


Figure 26 – Torch Angle. A. Correct torch angle, B. Incorrect torch angle, C. Lack of fusion. Source: TWI

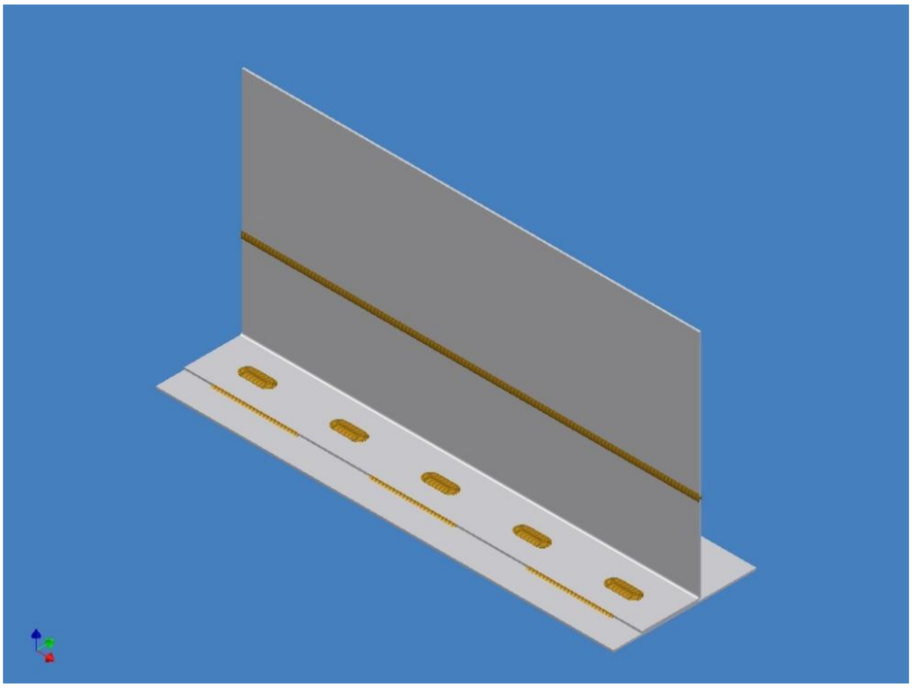


Figure 27 - Plug and slot welds. Source: TWI

Since the strength of the plug or slot weld is determined by the throat it may not be necessary to fill the hole completely unless the weld must be flush with the surface of the plate for cosmetic reasons. Besides being unnecessary from the point of view of joint strength, a completely filled hole will have high residual stresses. These may cause unacceptable distortion and will increase the risk of cold cracking in carbon and low alloy steels.

1.2.2 MAG Welding and GMAW's Processes

The MAG welding process is a versatile technique suitable for both thin sheet and thick section components in most metallic materials.

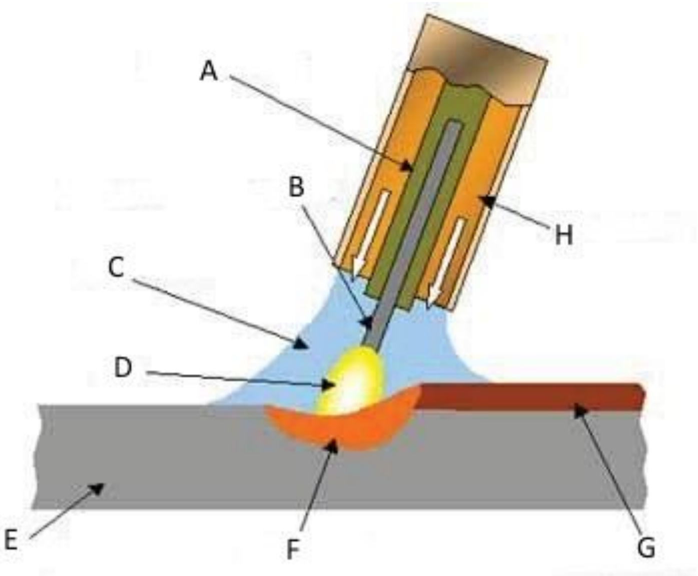


Figure 28 - The MAG welding process. A. Contact tube, B. Consumable electrode, C. Gas Shield, D. Arc, E. Workpiece, F. Weld pool, G. Weld metal, H. Gas Nozzle. Source: TWI

An arc is struck between the end of the consumable electrode and the workpiece, melting both to form a weld pool. The consumable wire serves as the source of heat (via the arc at the wire tip) and filler metal for the joint and is fed through a copper contact tube (also called a contact tip), which conducts welding current into the wire. The weld pool is protected from the surrounding atmosphere by a shielding gas fed through a nozzle surrounding the wire. Shielding gas selection depends on the material being welded and the application. The wire is fed from a reel by a motor drive and the welder moves the welding gun or torch along the joint line. The process offers high productivity and is economical because the consumable wire is continuously fed.

The MAG process uses semi-automatic equipment. It is called semi-automatic because the wire feed rate and arc length are controlled automatically but the travel speed and wire position are under manual control.

The Gas Metal Arc Weld Brazing process is a variant of the MAG welding process, where the MAG equipment is used with braze welding consumables. These filler wires are normally of the silicon or phosphor-bronze type for braze welding steels. The braze welding consumables melt at a lower temperature than the parent material and form a brazed joint, where the filler metal wets the surface of the plate rather than fusing with it. The joint strength is not as good as that of the parent material. The process is often used for cosmetic welds in thin sheet material, where low heat input is desirable.

The most common application of the Gas Metal Arc Weld Brazing process in automotive repair is typically used in areas that are difficult to access with a resistance spot welding gun or for attaching replacement body panels, when drilling or machining through the top sheet is used to produce a plug or socket weld.

1.2.3 Specifications of Gas Metal Arc Weld Brazing

The braze welding process is a variant of the MAG welding process, where the majority of the process-essential variables are identical to conventional MAG welding processes. However, in the braze welding process, the melting point of the filler wires is significantly lower with relation to the melting point of the parent material. During the arc welding process, the filler wire melts at temperatures typically over 1600°C, whereas for brazing the wire melts at less than 1000°C.

As in the standard MAG welding process, a continuously fed wire electrode is melted by an arc formed between the electrode and the workpiece, but no significant melting or fusion of the parent metal occurs because of the lower temperature. The molten metal flows into the gap between the parts to be joined and solidifies after wetting either across or between the surfaces via capillary action to form the solid joint. An example of a joint formed by the MAG brazing process is shown below.

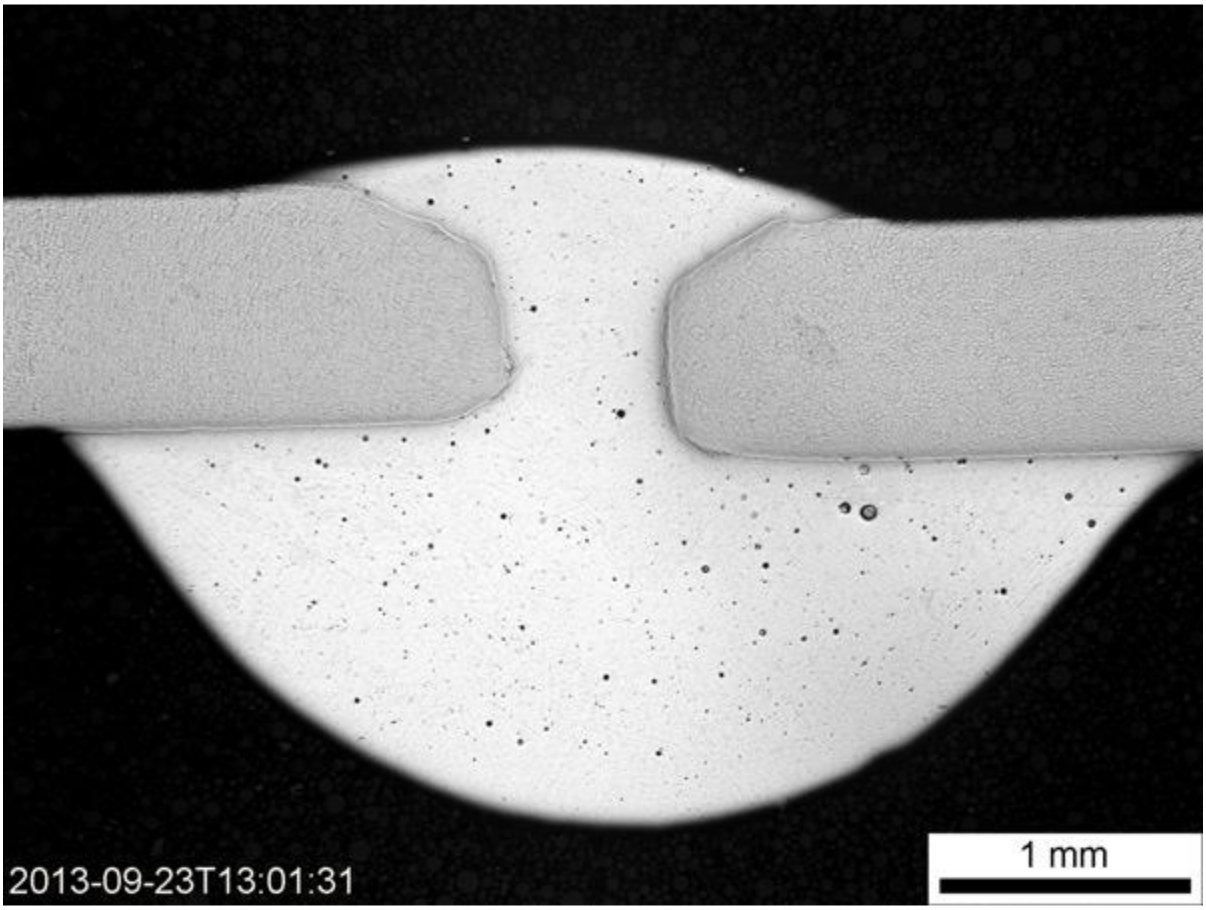


Figure 29 - An open butt gas metal arc brazed joint. Source: TWI

The lower current and voltage also result in energy savings, and mean that very thin sheet (down to 0.2mm) can be welded. However, this process is not suitable for use on thick materials, with an upper thickness limit of approximately 3mm. It is also necessary to ensure sufficient access for the brazing torch and the associated gas shroud, so joint design needs to be carefully considered.

1.2.4 Characteristics of Gas Metal Arc weld brazing and MAG welding

The braze welding process is considered an excellent choice for the joining of coated (eg. galvanized) thin sheet steels. These steels, when welded using a traditional arc-welding process produce large quantities of zinc vapour. This has several negative effects. Firstly, the vapour can cause defects in the weld such as pores or gas voids reducing the strength of the welded joint. Secondly, the loss of zinc from the surface of the parent plate results in a significant reduction in its corrosion resistant properties, sometimes necessitating re-coating of the steel.

The welding process also introduces significant heat into the base metal, resulting in significant distortion and a wide heat-affected zone. These effects can be reduced by using a brazing process, due to the lower heat needed to melt the filler wires compared to a standard welding process. The reduced damage to the zinc coating means that it will still provide galvanic protection to the base steel even in the 1–2mm region around the joint where the coating has been lost. This also produces less zinc containing welding fume.

A TWI investigation into the use of arc brazing for the joining of 1mm-thick galvanised DP600 sheet with a CuSi3 filler metal showed that, with the correct joint fit-up and suitable process parameters, the strength of the joint is capable of overmatching the ultimate tensile strength (UTS) of the parent plate. The adhesion of the braze material on the top and bottom surfaces of the DP600 plate provides sufficient strength such that the overall joint has a UTS greater than 600MPa, despite the UTS of the filler being approximately 350MPa.

The joining process and consumables specified in the welding or brazing procedure or repair instruction must always be used.

1.2.5 Braze welding preparation in car body repair

Ensure the surfaces to be welded are metallically clean, while taking care to not damage any coating. A range of joint configurations can be used, including butt, lap and tee-fillets. The joint design needs to be constructed so as to provide good wetting and capillary action of the braze material and to ensure that the stresses are not placed directly into the braze metal as tensile stresses. The stress needs to be supported through the adhesive surfaces of the braze metal to the parent sheet. A gap on the order of 0.5–1mm between the components to be joined will allow successful flow of the braze metal into the joint, improving adhesion and increasing the strength of the joint. However, it is important to note that too large a joint gap, especially for butt joints, will result in all of the stress on the component being realised as a tensile strength in the braze filler, resulting in joint failure at a lower UTS.

The power source is likely to be operating at lower output than would usually be used for standard MAG welding and can also be used with pulsed or direct current. A short circuiting arc is typically used. Because of the nature of the brazing process, the braze weld bead will not have as shallow an appearance as a weld bead. It is not necessary to increase the current to flatten out the braze bead as this will reduce the value of brazing as a low-heat-input process.

It is necessary to very carefully select and control the process parameters as the high fluidity of the copper-based braze results in a much more "moveable" weld pool. This can easily over-penetrate or form an undesirable bead appearance if not controlled.

The torch is used in a "pushing" orientation (of approximately 70–80°) to allow preheating of the plate and removal of any coating ahead of the weld pool, with the torch positioned symmetrically between the two joint surfaces (eg at 45° for a tee-fillet). This torch angle also reduces the probability of excessive penetration either through the gap or into the parent metal.

1.2.6 MAG and GMAW technical application in car body repair

MAG process primary variables

- Welding current/wire feed speed.
- Voltage.
- Gases.
- Travel speed and electrode orientation.
- Inductance.

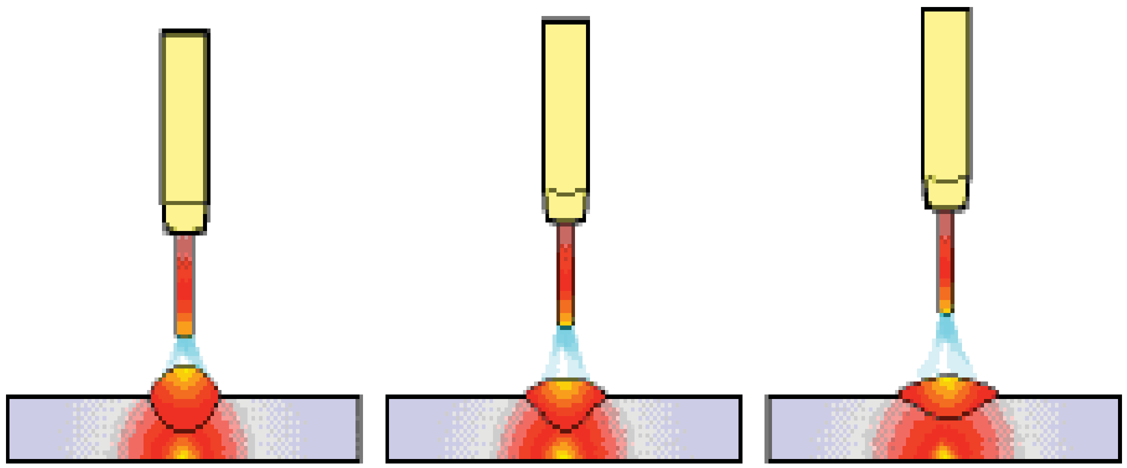
- Contact tip to work distance (CTWD).
- Nozzle to work distance.
- Shielding gas nozzle.
- Type of metal transfer.

Wire feed speed

Increasing wire feed speed automatically increases the current in the wire. Wires are generally produced in 0.6, 0.8, 1, 1.2, 1.4 and 1.6mm diameter.

Voltage

The most important setting in spray transfer as it controls the arc length. In dip transfer it also affects the rise of current and the overall heat input into the weld. Increase both wire feed speed/current and voltage will increase heat input. Welding connections need to be checked for soundness as any loose ones will result in resistance and cause a voltage drop in the circuit and will affect the characteristic of the welding arc. The voltage will affect the type of transfer achievable but this is also highly dependent on the type of gas being used.



a 22V *b 23V* *c 24*

Figure 30 - The effect of arc voltage: aIncreasing arc voltage; b Reduced penetration, increased width; c Excessive voltage can cause porosity, spatter and undercut. Source: TWI

The effect of arc voltage:

a. Increasing arc voltage;
b. Reduced penetration, increased width;
c. Excessive voltage can cause porosity, spatter and undercut.

Travel speed and electrode orientation

Faster travel speed results in less penetration, a narrower bead width and higher risk of undercut.

Figure 31 - The effect of increasing travel speed. Source: TWI

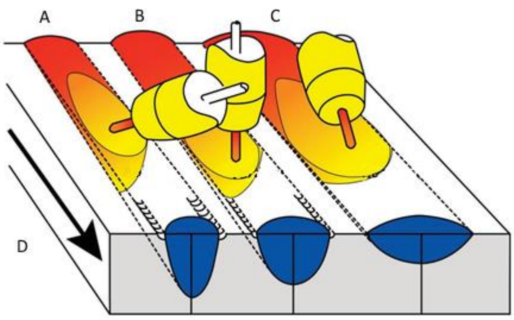


Figure 32 - A. Trailing, B. Vertical, C. Leading, D. Direction of travel. Source: TWI

Penetration	Deep	Moderate	Shallow
Excess weld metal	Maximum	Moderate	Minimum
Undercut	Severe	Moderate	Minimum

Table 3 - Effect of torch angle.

Effect of contact tip to workpiece distance

CTWD has an influence over the welding current because of resistive heating in the electrode extension. The welding current required to melt the electrode at the required rate to match the wire feed speed reduces as the CTWD is increased. Long electrode extensions can cause lack of penetration, for example, in narrow gap joints or with poor manipulation of the welding gun. Conversely, the welding current increases when the CTWD is reduced. This provides the experienced welder with a means of controlling the current during welding but can result in variable penetration in manual welding with a constant voltage power source.

At short CTWDs, radiated heat from the weld pool can cause overheating of the contact tube and welding torch which can lead to spatter adherence and increased wear of the contact tube.

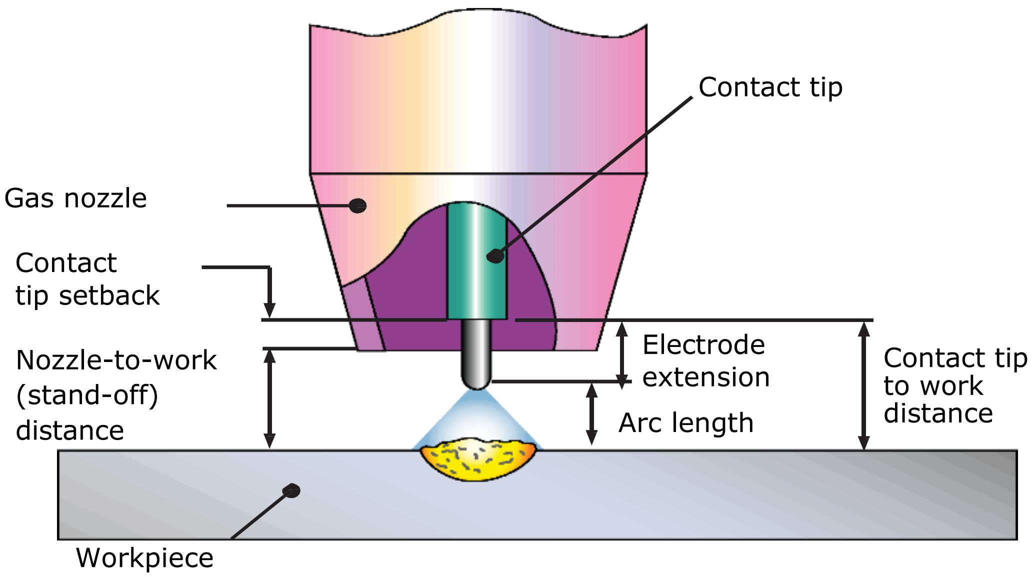


Figure 33 - Contact tip to workpiece distance; electrode extension and nozzle to workpiece distance. Source: TWI

As the electrode extension is increased the burn-off rate increases for a given welding current due to increased resistive heating. Increasing the electrode extension, eg. in mechanised applications, is therefore one way of increasing deposition rates, as the wire feed speed is increased to maintain the required welding current.

Resistive heating depends on the resistivity of the electrode, the electrode extension length and wire diameter, so is more pronounced for welding materials that have high resistivity, such as steels. The electrode extension should be kept small when small diameter wires are being used to prevent excessive heating in the wire and avoid the resulting poor bead shape.

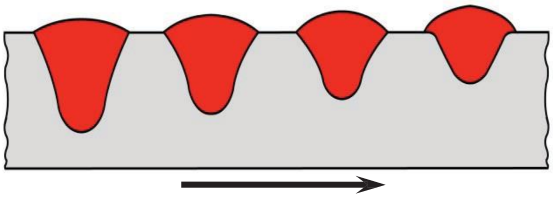


Figure 34 - Effect of increasing electrode extension. Source: TWI

The electrode extension should be checked when setting-up welding conditions or fitting a new contact tube. Normally measured from the contact tube to the workpiece.

Suggested CTWDs for the principal metal transfer modes are:

Metal transfer mode	CTWD, mm
Dip	10-15
Spray	20-25
Pulse	15-20

Table 4 -Metal Transfer Mode. Source: TWI

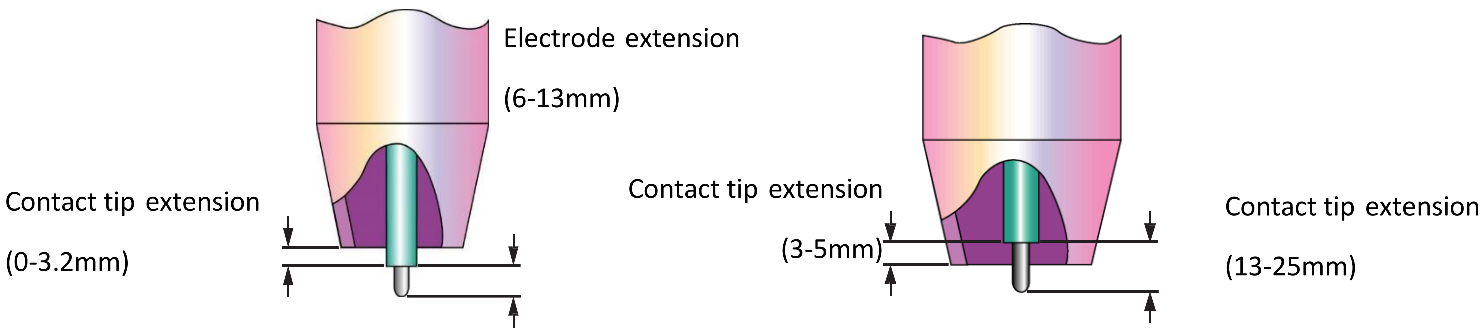


Figure 35 - Suggested contact tip to work-piece distance.Source: TWI.

Effect of nozzle to work distance

Nozzle to work distance has a considerable effect on gas shielding efficiency with a decrease stiffening the column. The nozzle to work distance is typically 12-15mm. If the CTWD is simultaneously reduced, however, the deposition rate at a given current is decreased and visibility and accessibility are affected; so in practice a compromise is necessary. The following gives suggested settings for the mode of metal transfer being used.

Metal transfer mode	Contact tip position relative to nozzle
Dip	2mm inside to 2mm protruding
Spray	4-8mm inside
Spray (aluminium)	6-10mm inside

Table 5 – Effect of nozzle to work distance. Source: TWI

Shielding gas nozzle

The purpose of the shielding gas nozzle is to produce a laminar gas flow to protect the weld pool from atmospheric contamination. Nozzle diameters range from 13-22mm and should be increased in relation to the size of the weld pool. Therefore, larger diameter nozzles are used for high current, spray transfer application and smaller diameter for dip transfer. The flow rate must also be tuned to the nozzle diameter and shielding gas type to give sufficient weld pool coverage. Gas nozzles for dip transfer welding tend to be tapered at the outlet of the nozzle.

Joint access and type should also be considered when selecting the required gas nozzle and flow rate. Too small a nozzle may cause it to become obstructed by spatter more quickly and if the wire bends on leaving the contact tube, the shielding envelope and arc location may not coincide.

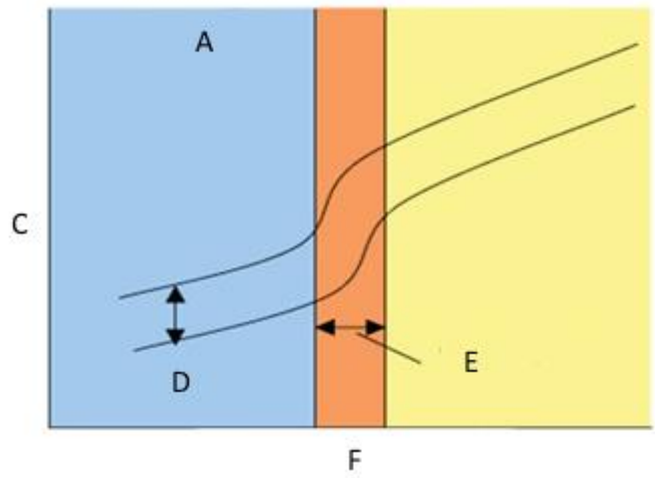


Figure 36 - Arc characteristic curve. A. Dip transfer, B. Spray transfer, C. Arc Voltage – V, D. Operating range, E. Transition region - Globular transfer, F. Welding Current – A. Source: TWI

Key characteristics of dip transfer

- Metal transfer by wire dipping or short-circuiting into the weld pool
- Relatively low heat input process
- Low weld pool fluidity
- Used for thin sheet metal above 0.8mm and typically less than 3.2mm, positional welding of thicker section and root runs in open butt joints
- Process stability and spatter can be a problem if poorly tuned.
- Lack of fusion of poorly set-up and applied.
- Not used for non-ferrous metals and alloys.

Figure 37 - Dip transfer. Source: TWI

In dip transfer the wire short-circuits the arc 50-200 times/second and this type of transfer is normally achieved with CO_2 or mixtures of CO_2 and argon gas + low amps and welding volts <24V.

Key characteristics of spray transfer

- Free-flight metal transfer
- High heat input
- High deposition rate
- Smooth stable arc
- Used on steels above 6mm and aluminium alloys above 3mm thickness

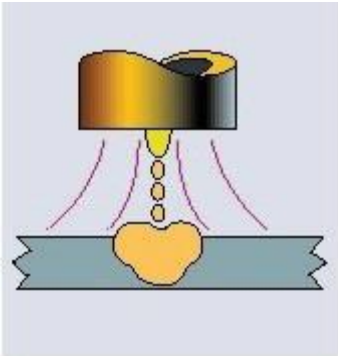


Figure 38 - Spray transfer. Source: TWI

Spray transfer occurs at high currents and voltages. Above the transition current, metal transfer is a fine spray of small droplets projected across the arc with low spatter levels. The high welding current produces strong electromagnetic forces (pinch effect) that cause the molten filament supporting the droplet to neck down. Droplets detach from the tip of the wire and accelerate across the arc gap. The frequency with which the droplets detach increases with the current. The droplet size equates to the wire diameter at the threshold level but decreases significantly as the welding current increases. At very high currents (wire feed speeds), the molten droplets can start to rotate (rotating transfer). The arc current is flowing during the drop detachment resulting in maximum penetration and a high heat input. When the correct arc voltage to give spray transfer is used, the arc is short with the wire tip 1-3mm from the surface of the plate.

With steels it can be used only in downhand butts and H/V fillet welds but gives higher deposition rate, penetration and fusion than dip transfer because of the continuous arc heating. It is mainly used for steel plate thicknesses >3mm but has limited use for positional welding due to the potential large weld pool involved.

Key characteristics pulsed transfer

- Free-flight droplet transfer without short-circuiting over the entire working range
- Very low spatter
- Lower heat input than spray transfer
- Reduced risk of lack of fusion compared with dip transfer
- Control of weld bead profile for dynamically loaded parts
- Process control/flexibility
- Enables use of larger diameter, less expensive wires with thinner plates – more easily fed (particular advantage for aluminium welding)

Pulsing the welding current extends the range of spray transfer operation well below the natural transition from dip to spray transfer. This allows smooth, spatter-free spray transfer at mean currents below the transition level, eg 50- 150A and at lower heat inputs. Pulsing was introduced originally to control metal transfer by imposing artificial cyclic operation on the arc system by applying alternately high and low currents.

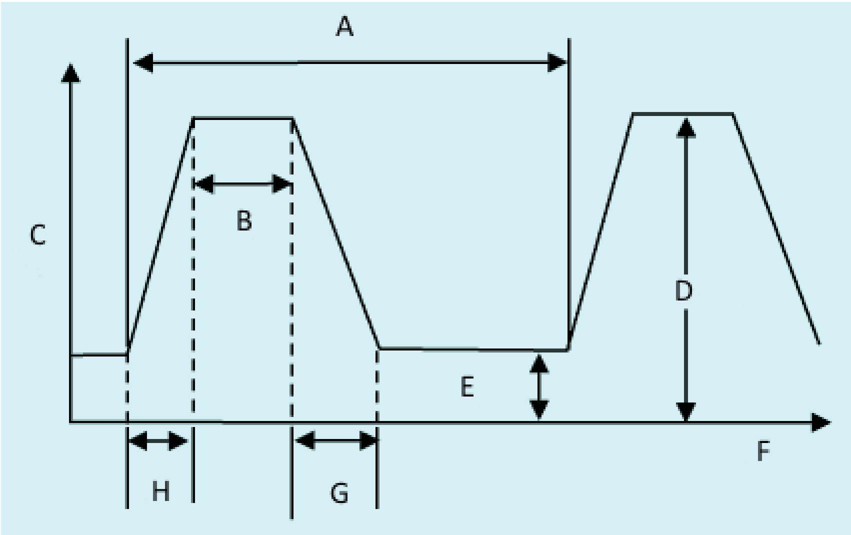


Figure 39 - Pulsed welding waveform and parameters. A. 1/Frequency, B. Peak time, C. Current – A, D. Peak Current, E. Background current, F. Time – ms, G. Fall time, H. Rise time. Source: TWI

A low background current (typically 20-80A) is supplied to maintain the arc, keep the wire tip molten, give stable anode and cathode roots and maintain average current during the cycle. Droplet detachment occurs during a high current pulse at current levels above the transition current level. The pulse of current generates very high electromagnetic forces which cause a strong pinch effect on the metal filament supporting the droplet the droplet is detached and projected across the arc gap. Pulse current and current density must be sufficiently high to ensure that spray transfer (not globular) always occurs so that positional welding can be used.

Pulse transfer uses pulses of current to fire a single globule of metal across the arc gap at a frequency of 50-300 pulses/second. It is a development of spray transfer that gives positional welding capability for steels, combined with controlled heat input, good fusion and high productivity and may be used for all sheet steel thickness >1mm, but is mainly used for positional welding of steels >6mm.

Key characteristics of globular transfer

- Irregular metal transfer
- Medium heat input
- Medium deposition rate
- Risk of spatter
- Not widely used in the UK can be used for mechanised welding of medium thickness (typically 3-6mm) steel in the flat (PA) position.

Synergic

Is a term meaning working together and was originally designed to establish correct pulse parameters in MIG/MAG welding over a range of wire diameters and gas mixtures. Manually adjusting pulse parameters was problematic with many variables to adjust; pulse peak, pulse time, background current and background time.

Consequently, to arrive at the correct arc condition was time consuming and fraught with errors.

With the advancement in electronically controlled power sources and subsequent CPU inverter controlled systems, it has allowed manufacturers to produce a one knob control system. Therefore, all parameters previously mentioned can be controlled via a one knob control operation to establish the correct arc condition as determined by the manufacturers of the power source. In essence, as the knob is turned the wire feed increases, possibly voltage (and all pulse parameters) change to keep a balanced arc condition.

The manufacturers, have predetermined synergic curves based on material type, wire diameter and gas mixture. To facilitate set up, this information is programmed in by the user and a unique curve is produced based on the inputs. The user can then adjust, via one knob control, up and down the synergic curve. Most machines however have an option to adjust the voltage of the synergic curve if required. In addition, once an acceptable welding condition is found, most manufacturers have the ability to save to memory for later re- call.

The globular transfer range occupies the transitional range of arc voltage between free-flight and fully short-circuiting transfer. Irregular droplet transfer and arc instability are inherent, particularly when operating near the transition threshold. In globular transfer a molten droplet several times the electrode diameter forms on the wire tip, gravity eventually detaches it when its weight overcomes surface tension forces and transfer takes place often with excessive spatter. Before transfer the arc wanders and its cone covers a large area, dissipating energy.

There is a short duration short-circuit when the droplet contacts with the molten pool but rather than causing droplet transfer it occurs as a result of it. Although the short-circuit is of very short duration, some inductance is necessary to reduce spatter, although to the operator the short-circuits are not discernible and the arc has the appearance of a free-flight type.

To further minimise spatter levels, it is common to operate with a very short arc length and in some cases a buried arc technique is adopted. Globular transfer can only be used in the flat position and is often associated with lack of penetration, fusion defects and uneven weld beads because of the irregular transfer and tendency for arc wander.

Inductance

When MAG welding in the dip transfer mode, the welding electrode touches the weld pool causing a short-circuit during which the arc voltage is nearly zero. If the constant voltage power supply responded instantly, very high current would immediately begin to flow through the welding circuit and the rapid rise in current to a high value would melt the short-circuited electrode free with explosive force, dispelling the weld metal and causing considerable spatter.

Inductance is the property in an electrical circuit that slows down the rate of current rise. The current travelling through an inductance coil creates a magnetic field that creates a current in the welding circuit in opposition to the welding current. Increasing inductance will also increase the arc time and decrease the frequency of short-circuiting.

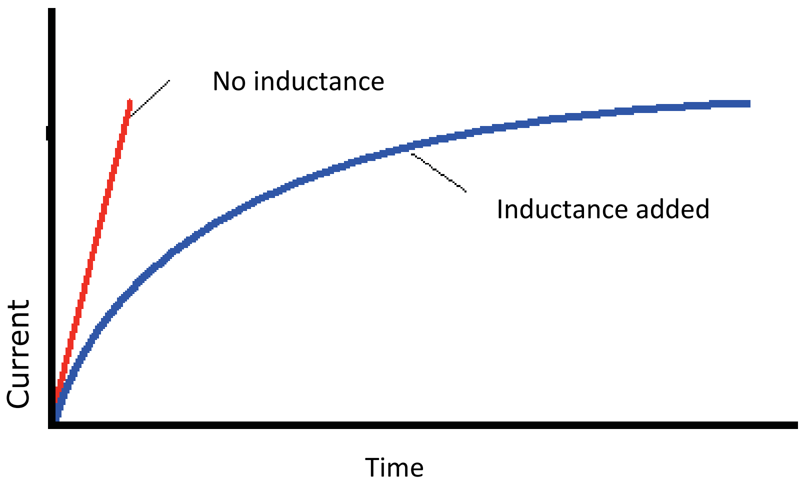


Figure 40 - Relationship between inductance and current rise. Source: TWI

There is an optimum value of inductance for each electrode feed rate. Too little inductance results in excessive spatter, too much and current will not rise fast enough and the electrode is not heated sufficiently causing the electrode to stub into the base metal. Modern electronic power sources automatically set inductance to give a smooth arc and metal transfer.

1.2.7 Health and Safety, and Environmental Safety

Working in a safe manner, to protect yourself, others and the vehicle you are working on, is an essential consideration in any welding operation. The responsibility for safety is on all individuals but especially the welders, not only for their own safety, but also to avoid endangering other people. Your employer has an important responsibility for ensuring that health, safety and environment (HSE) legislation is complied with and safe working practices are implemented. If you cannot assure your own safety and the safety of others in the work area, then stop welding and do not start welding again until the risk has been controlled.

Your employer should ensure compliance with all appropriate documents, for example:

- Legislation – EU OSH Directives.
- Standards – OHSAS 18001.
- Company Health, Safety and Environment Management Systems.
- Work instructions – permits to work, risk assessment documents, etc.

The workshop environment

The employer needs to ensure that the lighting conditions are adequate for the work undertaken - giving extra lighting where necessary. Welders stand for long periods of time, since they must keep a very steady hand position, and this means that they can become quite cold if the workshop is not sufficiently well heated. Conversely in hot weather, the environment can become unbearably hot, and the welder must wear protective clothing. Both overheating and underheating can cause discomfort, and a loss of efficiency and productivity.

Housekeeping is extremely important to avoid slips, trips and falls, damage to equipment and fire.

There are many aspects of welding safety that the welder needs to consider:

- Electric shock.
- Electromagnetic Fields
- Heat and light.
- Fumes and gases.
- Noise.
- Gas cylinder handling and storage.
- Working at height or in restricted access.
- Mechanical hazards: trips, falls, cuts, impact from heavy objects.

Electric shock

Contact with metal parts that are electrically live can cause injury or death because of the effect of the shock upon the body or because of a fall as a result of the reaction to electric shock.

The electric shock hazard associated with arc welding may be either from the primary 230 or 460V mains supply or from the output voltage at 60-100V. Primary voltage shock is very hazardous because it is much greater than the secondary voltage of the welding equipment. Electric shock from the input voltage can occur by touching a lead inside the welding equipment with the power to the welder while the body or hand touches the welding equipment case or other earthed metal. Only a qualified electrician should remove the casing of a welding power source. Residual circuit devices (RCDs) connected to circuit breakers of sufficient capacity will help protect personnel from the danger of primary electric shock.

The transformed power is available from terminals on the front of the welding set. Heavy-duty cables are attached to these terminals to carry the welding current to the torch or electrode holder and to bring a return path from the work or metal workbench to the other terminal. This return is often referred to as the earth or ground and there may be secondary earthing arranged so that the work is at zero volts. Secondary voltage shock occurs when touching a part of the electrode circuit – perhaps a damaged area on the electrode cable – while another part of the body touches the other side of the welding circuit (the work or welding earth) at the same time.

Whilst most welding equipment is unlikely to exceed an OCV of 100V, electric shock, even at this level, can be serious. The welding circuit should be fitted with low voltage safety devices to minimise the potential of secondary electric shock.

It is important that the welding cables can carry the maximum possible output of the welding set without overheating as overheating can damage the insulation, leading to an increased risk of electrical shock.

Installation of welding equipment should be carried out by suitably qualified staff who must check that the equipment is suitable for the operation and connected in accordance with the manufacturer's recommendations. The welder is responsible for checking the equipment (cable, welding torch and coupling devices) daily for damage and reporting defects. All external connections should be clean and tight and checked each time a reconnection is made. The welding return clamp should be connected directly to the workpiece, as close as possible to the point of welding.

Welder actions for safe practice and avoidance of electric shock:

- Do not wear jewellery (especially rings) or metallic watch straps

- Wear protective clothing including insulating safety boots, gloves, boots and overalls
- Check daily, and after each reconnection, that all external connections are clean and tight
- Stand or kneel on a mat of insulating material which should be kept dry
- Place the welding power source outside the working environment
- Ensure qualified support staff are in close proximity outside the working space to give first aid and switch off the electrical supply
- When welding outside, check the power source protection rating is adequate for the environment and do not weld in the rain without a suitable cover
- When welding the vehicle directly, ensure that the vehicle is electrically safe; a competent auto electrician has isolated the batteries and any hybrid power systems, and disconnected sensitive electronics units

Electromagnetic Fields

Welding processes may produce low frequency fields that have a detrimental effect on the mental and physical health of the exposed workers. The possible effects include stimulation of muscles, nerves or sensory organs and transitory symptoms such as vertigo or retinal phosphenes. These effects may affect the ability of the worker to work safely.

Electromagnetic fields may be sub-divided into magnetic and electric fields and for most welding processes, it is the magnetic field which is significant.

Exposure to electromagnetic fields may cause direct biophysical effects, including:

- thermal effects such as tissue heating.
- non-thermal effects such as the stimulation of muscles, nerves or sensory organs.
- Limb currents.

Indirect effects of EMF include:

- interference with medical electronic devices such as pacemakers.

- projectile risk from ferromagnetic objects in static magnetic fields.
- initiation of detonators.
- ignition of flammable materials by sparks caused by induced fields.
- contact currents.

Welder actions for safe practice and avoidance of welding EMF:

- Follow the guidance from the employer's workplace assessment
- Do not wrap welding cables around body
- Do not stand in coiled welding cables

Heat

As MAG welding relies on melting metal to effect a joint, it follows that the metal will in part be very hot. All metals conduct heat to a greater or lesser degree so the area heated to a temperature that will cause skin burns is much larger than the weld bead itself. It is a wise precaution to assume that all metal on a welding workbench or adjacent to a weld in a car body is hot. Temperature indicating sticks should be used to check that material is cool enough to handle. It is not safe to pat metal with the bare hand to check its temperature.

The welding arc creates sparks, with the potential to cause flammable materials near the welding area to ignite and cause fires. The welding area should be clear of all combustible materials and it is good practice for all personnel working in the vicinity of welding to know where the nearest fire extinguishers are and the correct type of fire extinguisher to use if a fire does break out.

Welding may also produce spatter, globules of molten metal expelled from the weld area. These can cause serious burns, so protective clothing, such as welding gloves, flame retardant coveralls and leathers must be worn around any welding operation to protect against heat and sparks. It is most important that traps in clothing are avoided. Trousers should not have turn-ups and should not be tucked into boots – very serious injury can occur if spatter drops inside a work boot.

Radiant heat from welding can be quite intense, particularly when welding at high current and duty cycle is taking place. Sufficient air movement is required to keep the welder at a sensible temperature especially important when working in restricted access areas where reflected heat will intensify the effect. Welders should also take water regularly to avoid potential dehydration.

Welder actions for safe practice and avoidance of effects of welding heat:

- Ensure that appropriate PPE is available, fit for use and correctly worn
- Ensure that combustible trim is removed from the vicinity of the joint and that the car is protected, where necessary, with fire resistant blankets

Light

Light radiation is emitted by the welding arc in three principal ranges:

Type	Wavelength, nanometres
Infra-red (heat)	>700
Visible light	400-700
Ultra-violet radiation	<400

Table 6 – principal ranges of light radiation.

Ultra-violet radiation (UV) light

All arc processes generate UV and excess exposure causes skin inflammation and possibly skin cancer or permanent eye damage. However, the main risk amongst welders and others in welding workshops is inflammation of the cornea and conjunctiva, commonly known as arc eye or flash.

Arc eye is caused by UV radiation which damages the outmost protective layer of cells in the cornea. Gradually the damaged cells die and fall off the cornea exposing highly sensitive nerves in the underlying cornea to the comparatively rough inner part of the eyelid. This causes intense pain, usually described as sand in the eye. The pain becomes even more acute if the eye is then exposed to bright light.

Arc eye develops some hours after exposure, which may not even have been noticed. The sand in the eye symptom and pain usually lasts for 12-24 hours, longer in more severe cases. Fortunately, it is almost always a temporary condition. In the unlikely event of prolonged and frequently repeated exposures, permanent damage can occur.

Treatment of arc eye is simple: rest in a dark room. A qualified person or hospital casualty department can administer various soothing anaesthetic eye drops which can provide almost instantaneous relief. Prevention is better than cure and wearing safety glasses with side shields will considerably reduce the risk of this condition. The welder should always have a full face screen with the approved shade of protective lens for the process in hand.

Effect of ultra-violet light on the skin

The UV from arc processes does not produce the attractive browning effect of suntan; but results in acute reddening and irritation caused by changes in the minute surface blood vessels. In extreme cases, the skin may be severely burned and blisters form. The reddened skin may die and flake off in a day or so. Where there has been intense prolonged or frequent exposure, skin cancers can develop.

Visible light

Intense visible light particularly approaching UV or blue light wavelengths passes through the cornea and lens and can dazzle and, in extreme cases, damage the network of optically sensitive nerves on the retina. Wavelengths of visible light approaching the infra-red have slightly different effects but can produce similar symptoms. Effects depend on the duration and intensity of exposure and to some extent, upon the individual's natural reflex action to close the eye and exclude the incident light. Normally this dazzling does not produce a long-term effect.

Infra-red radiation (IR)

Infra-red radiation is of longer wavelength than the visible light frequencies and is perceptible as heat. The main hazard to the eyes is that prolonged exposure (over a matter of years) causes a gradual but irreversible opacity of the lens. Fortunately, the IR radiation emitted by normal welding arc causes damage only within a comparatively short distance from the arc. There is an immediate burning sensation in the skin surrounding the eyes should they be exposed to arc heat. The natural human reaction is to move or cover up to prevent the skin heating, which also reduces eye exposure.

Arc radiation

The welder must be protected from light radiation emitted from the arc by a hand or head shield and protective clothing. The shield is fitted with filter glass, dark enough to absorb infrared and ultraviolet rays. Filter glasses conform to EN 169 and are graded according to a shade number. This specifies the amount of light allowed to pass through - the lower the number, the lighter the filter. The shade number is selected according to welding process and current level.

Welder actions for safe practice and avoidance of effects of welding light:

- Do not strike an arc unless welders and welders' assistants are wearing suitable protective clothing and eye protection
- Do not strike an arc unless other workers in the vicinity and passers-by are protected by opaque or properly filtered screens around your work area

Fumes and gases

Fume is a mixture of particles generated by vaporisation, condensation and oxidation of substances transferred through the welding arc. The particles are very small and remain suspended in the air for long periods, where they may be breathed. Small particles are respirable; they may penetrate the innermost regions of the lung where they have the most potential to do harm. If inhaled. Welding fume is carcinogenic and there is no safe exposure level for inhalation.

Toxic fume may be created also from paint finishes, coatings, adhesive bond lines and urethane foam in the vicinity of the welded joint.

Carbon monoxide (CO) and CO2 may be generated in MAG welding from the shielding gas, with CO2 undergoing reaction in the vicinity of the arc to form CO.

CO is the more hazardous of the two gases and can cause a reduction in the oxygen carrying capacity of the blood that can be fatal. In lower concentrations it causes headache and dizziness, nausea and weakness. However, the amounts of CO and CO2 generated by welding processes are small and generally do not present an exposure problem.

Other gases may be introduced to the work area from shielding gas. Remember that gases that are heavier than air are likely to collect in inspection pits.

The following aspects are likely to influence the degree to which the welder is exposed to fume and gases:

- welding position
- location and type of workplace

Thus, welders using the same process may be exposed to different levels of fume. The risks for each job should, therefore, be assessed individually.

Welding position

The welding position (flat, vertical, horizontal or overhead) and proximity of the welder to the fume plume affect exposure. As the welder naturally bends over the workpiece, the flat position induces the highest level of fume in the breathing zone. The welder should adopt a working position which ensures that his head is away from the plume.

Figure 41 - Location and type of workplace. Source: TWI

Welding in a large workshop, or outdoors, prevents build-up of fume and gases. However, in a small workshop, fume will not be readily dispersed and the welder may be subjected to a higher than average exposure. Working in confined spaces, in particular, requires an efficient, monitored, ventilation system so exposure is controlled and there is no depletion of oxygen in the working atmosphere

Control of welding fume

The most efficient way of controlling exposure to welding fume is its removal at source. There are several methods of removing fume close to the weld:

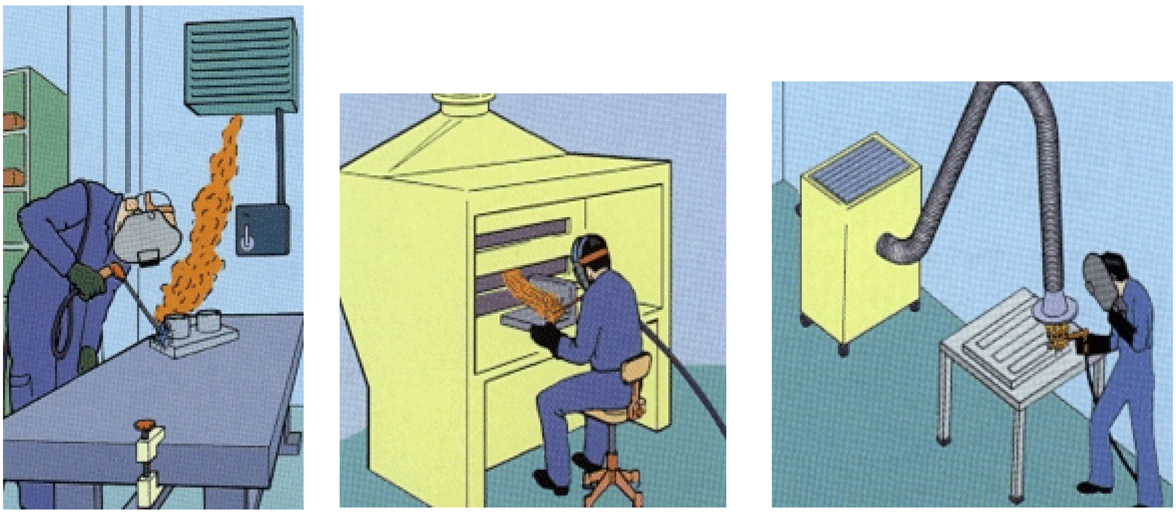


Figure 42 - Extracted benches, Extracted booth and Local exhaust ventilation (LEV). Source: TWI

Figure 43 - On-gun extraction. A. Extraction slot, B. Inert gas shield, C. Gas and electrode wire feed. Source: TWI

As local exhaust ventilation (LEV) and on-gun extraction systems are never 100% efficient, especially when welding awkward structures, general ventilation may also be necessary to control the background level of fume.

As each type of extraction equipment has limitations, it is important to select the right equipment for each job. It is also essential that welders are adequately trained to use the equipment and adopt good working practices. Supervision is needed to ensure the equipment is being used effectively and to minimise background fume level in the workshop.

As a rule of thumb, if the air is visibly clear and the welder is comfortable, the ventilation is probably adequate.

Respiratory protection equipment (RPE)

Where fume needs to be controlled, LEV should always be used to achieve as much control as possible. If LEV is not possible, or there is still unacceptable exposure, RPE is needed. RPE should always be the least preferred means of control because it only protects the wearer. Other methods are all aimed at preventing exposure whereas RPE is essentially curative. There are two types of RPE:

- respirators - workshop air cleaned before being inhaled
- air-supplied - air supply is separate from workshop atmosphere

Selection of suitable RPE will require the advice of an expert who can make the selection based on fume concentration, presence of toxic gases and whether there is a oxygen deficient atmosphere.

Welder actions for safe practice and avoidance of fume and gases:

- check that the ventilation and extraction equipment is working correctly and is regularly maintained, for example, cleaning and replacing filters according to manufacturer's recommendations
- place the extraction hood or nozzle to capture the fume without disturbing the gas shield
- reposition the extractionhood at appropriate intervals to ensure fume continues to be effectively extracted
- if possible, remove paint, coating or insulation from the workpiece before welding
- before using RPE, consult expert in choice of respirator
- get personally fitted with an RPE to ensure that it provides adequate protection
- follow your training in use of an RPE and its maintenance and cleaning
- use the systems put in place by your management for control of equipment and training

Noise

Exposure to loud noise can permanently damage hearing, cause stress and increase blood pressure. Working in a noisy environment for long periods can contribute to tiredness, nervousness and irritability. If the noise exposure is greater than 85 A-weighted decibels, averaged over an eight-hour period then hearing protection must be worn and annual hearing tests carried out. The employer has the responsibility of ensuring that workers wear the protection. If noise levels are between 80 and 85dB(A) averaged over eight hours, hearing protection must be available and given to workers if they ask for it.

Normal welding operations are not associated with excessive noise level problems. The noise associated with welding is usually due to ancillary operations such as chipping, grinding and hammering. Hearing protection must be worn when carrying out, or when working in the vicinity of, these operations.

Gas handling and storage

The cylinders contain gas at up to 300 bar and care must be exercised to ensure that they cannot fall and sever the valve from the top. The sudden release of energy turns the cylinder into a high powered missile capable of passing through block walls, demonstrated most graphically by the Discovery Channel's Mythbusters. A video has been posted on YouTube (www.youtube.com/watch?v=ejEJGNLTo84).

Shielding gas cylinders must be in purpose built cradles with secure chaining to avoid toppling. One person should not handle gas cylinders on their own, as they weigh up to 100kg and there is a real risk of loss of control. Transportation around a workshop should be in a trolley designed for the purpose.

Pressure regulators must be fitted to gas cylinders to extract the gas at a usable pressure. Regulators must be appropriate for the job: rated at least as high as the maximum pressure of the cylinder and designated for the specific gas.

Tubes carrying the gas to the welding torch should be pressure hoses designed for the job. Hoses should be checked for leaks by using diluted detergent around all fittings. Leakage of shielding gas is not as safety critical as leakage of fuel gas, but the weld quality can be compromised if leaks develop. For a similar reason, hoses should be purged for some minutes prior to starting work to eliminate any moisture adsorbed onto the inner wall.

Mechanical hazards

The environment in which a welder works has a number of hazards not specific to the welding process itself. Manual handling of heavy awkward metal components is often required. Thinner, lighter metal sheet may have sharp edges. Slips, trips and falls may be more likely as welding often requires thick cables to be spread across the floor.

Standard workshop safety and protection practice should be used to counter these problems. Welders need training in materials handling, both manual and with mechanical lifting assistance; protective gloves, helmets, overalls and boots must be worn; cabling on the floor should be minimised and clearly signed or marked as a trip hazard.

There are hazards that are a direct result of the joining process, as during welding, sparks and molten metal can be ejected. These are most common in arc welding but can also occur in resistance processes. Personal protective equipment (PPE) must be worn by the welder. All clothing should be fire resistant and use of leather aprons, jackets, chaps, etc is recommended.

Grinding is commonly used in preparing metal for welding and during cleaning and rectification of deposited metal. Wheel and angle grinders are favourite tools for their speed of removal of material. These create a hazard, not only for the operator but for adjacent and passing personnel, as the ejected material may be thrown some distance. Obviously the operator needs adequate protection with clothing, gloves, full-face shields and sometimes a dust mask but the whole area also needs screening with curtains to protect others. Fireproof blankets may be used to protect the vehicle from grinding sparks, and care needs to be taken to prevent cross contamination between vehicles and materials in the workshop.

One of the more serious dangers is from the persistent use of hand-held portable power tools, such as grinders, sanders, impact wrenches, and air chisels, which can lead to long-term illness – hand-arm vibration syndrome, also known as 'white finger' or 'dead hand'. Employers are encouraged to purchase only power tools designed and constructed to reduce the risk of vibration, and are required to conduct an assessment and identify measures to eliminate or reduce the risk. You are required to use these power tools only as instructed, and you should report any symptoms, includinmg tingling and numbness in fingers, not being able to feel things properly, loss of strength in hands, fingertips going white, and becoming red and painful on recovery.

- Use the appropriate personal protective equipment and check it is fit for purpose before carrying out welding/brazing operations.
- Protect the vehicle and its contents effectively when carrying out welding/brazing operations.
- Prepare material and align to enable suitable join to be achieved. Mating flanges must be treated following manufacturer's procedure before joining.
- Select, set up and use the correct tools and equipment for carrying out welding/brazing operations.
- Ensure that the tools, equipment and Personal Protective Equipment (PPE) you require are in a safe working condition.
- Set up your equipment to carry out welding/brazing operations, checking suitability of gas/filler wire and size for material to be joined, parameters are set correctly, consumables are correct, feed rollers and welding tips are in good condition.
- Carry out welding/brazing operations following recognised repair methods, test procedures and provide test coupons on equivalent material in accordance with relevant standards, manufacturer's specifications, methods and procedures, your workplace procedures and all health, safety and legal requirements.
- Avoid damaging other components, panels and surfaces on the vehicle and the surrounding work area.
- Recognise when your weld/braze is not forming correctly and what action needs to

  be taken.
- Carry out welding/brazing operations within the agreed timescale and report any delays in completing your work to the relevant person(s) promptly.
- Inspect and assess weld/braze quality in accordance with specified standards.
- Check integrity of weld/braze and record the type of joint achieved on the appropriate paper work.
- Make sure test pieces are recorded and stored.
- Dress the joint area without reducing material thickness and protect the repaired area to inhibit corrosion where applicable.

- Clean and store Personal Protective Equipment (PPE) and equipment in appropriate manner, report any equipment maintenance or consumable replenishment requirements to the relevant person(s)..
- Report any additional faults you notice during the course of your work to the relevant person(s) promptly.
- Clean and restore the vehicle and work area by removing screens and protective materials used during welding/brazing, dispose of waste in accordance with environmental requirements.
- Complete work records accurately, in the format required and pass them to the relevant person(s) promptly.

1st Practical Training

Practical MAG Welding Task - Metal transfer mode and inductance

- Deposit a fillet weld on a ferritic steel plate, in horizontal vertical position (PB).
- Select optimum welding parameters, and assess the use of pulse, dip & spray transfer modes:

(Continue on the next page)

Mode of Transfer	Pulse	Spray	Dip
Current Value (A)			
Voltage (V)			
Induction			
Spatter Levels			
Angular distortion			
Weld Run N^0.			
Weld Profile			
Toe Blend			
Asymmetry of leg lengths			
Travel speed			
Productivity			

Sketches

Notes:

Table 7 - Metal transfer mode and inductance

Joint quality

- Recognise when your weld/braze is not forming correctly and apply remedial actions:

Flaw type	Sketch/description	Cause	Remedy
Lack of fusion			
Lack of wetting			
Slag inclusions			
Asymmetrical seam			
Excessive penetration			
Insufficient penetration			
End crater crack			

Table 8 – Joint Quality.

Distortion

Because welding involves highly localised heating of joint edges to fuse the material, non-uniform stresses are set up in the component because of expansion and contraction of the heated material. Initially, compressive stresses are created in the surrounding cold parent metal when the weld pool is formed due to the thermal expansion of the hot metal (heat affected zone) adjacent to the weld pool. However, tensile stresses occur on cooling when the contraction of the weld metal and the immediate heat affected zone is resisted by the bulk of the cold parent metal.

The magnitude of thermal stresses induced into the material can be seen by the volume change in the weld area on solidification and subsequent cooling to room temperature. For example, when welding CMn steel, the molten weld metal volume will be reduced by approximately 3% on solidification and the volume of the solidified weld metal/heat affected zone (HAZ) will be reduced by a further 7% as its temperature falls from the melting point of steel to room temperature.

If the stresses generated from thermal expansion/contraction exceed the yield strength of the parent metal, localised plastic deformation of the metal occurs. Plastic deformation causes a permanent reduction in the component dimensions and distorts the structure.

Distortion occurs in six main forms:

- Longitudinal shrinkage
- Transverse shrinkage
- Angular distortion
- Bowing and dishing
- Buckling
- Twisting

The principal features of the more common forms of distortion for butt and fillet welds are shown next.

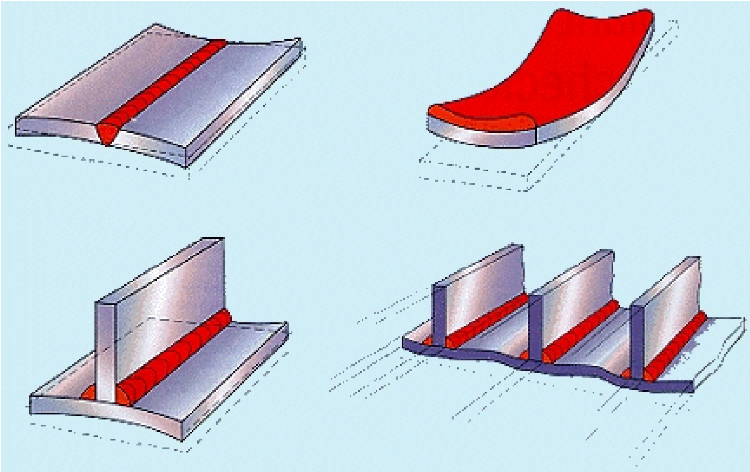


Figure 44- Contraction of the weld area on cooling results in both transverse and longitudinal shrinkage. Source: TWI

Non-uniform contraction (through thickness) produces angular distortion in addition to longitudinal and transverse shrinkage.

Use of restraint

Because of the difficulty in applying pre-setting and pre-bending, restraint is the more widely practised technique of controlling distortion. The basic principle is that the parts are placed in position and held under restraint to minimise any movement during welding. When removing the component from the restraining equipment, a relatively small amount of movement will occur due to locked-in stresses.

When welding assemblies, all the component parts should be held in the correct position until completion of welding. Welding with restraint will generate additional residual stresses in the weld which may cause cracking. When welding susceptible materials, a suitable welding sequence will reduce this risk.

Restraint is relatively simple to apply using clamps, jigs and fixtures to hold the parts during welding. Always apply the clamps, jigs and fixtures specified in the welding/brazing instruction or repair procedure.

Before, during and after welding/brazing

1. Use the appropriate personal protective equipment and check it is fit for purpose before carrying out welding/brazing operations.

2. Protect the vehicle and its contents effectively when carrying out welding/brazing operations.

3. Prepare material and align to enable suitable join to be achieved. Mating flanges must be treated following manufacturer's procedure before joining.

4. Select, set up and use the correct tools and equipment for carrying out welding/brazing operations.

5. Ensure that the tools, equipment and Personal Protective Equipment (PPE) you require are in a safe working condition.

6. Set up your equipment to carry out welding/brazing operations, checking suitability of gas/filler wire and size for material to be joined, parameters are set correctly, consumables are correct, feed rollers and welding tips are in good condition.

7. Carry out welding/brazing operations following recognised repair methods, test procedures and provide test coupons on equivalent material in accordance with relevant standards, manufacturer's specifications, methods and procedures, your workplace procedures and all health, safety and legal requirements.

8. Avoid damaging other components, panels and surfaces on the vehicle and the surrounding work area.

9. Recognise when your weld/braze is not forming correctly and what action needs to

be taken.

10. Carry out welding/brazing operations within the agreed timescale and report any delays in completing your work to the relevant person(s) promptly.

11. Inspect and assess weld/braze quality in accordance with specified standards.

12. Check integrity of weld/braze and record the type of joint achieved on the appropriate paper work.

13. Make sure test pieces are recorded and stored.

14. Dress the joint area without reducing material thickness and protect the repaired area to inhibit corrosion where applicable.

15. Clean and store Personal Protective Equipment (PPE) and equipment in appropriate manner, report any equipment maintenance or consumable replenishment requirements to the relevant person(s).

16. Report any additional faults you notice during the course of your work to the relevant person(s) promptly.

17. Clean and restore the vehicle and work area by removing screens and protective materials used during welding/brazing, dispose of waste in accordance with environmental requirements.

18. Complete work records accurately, in the format required and pass them to the relevant person(s) promptly.

1.3 RESISTANCE SPOT WELD JOINING TECHNOLOGY

Resistance spot welding is a process for the joining of metals with heat generated by the passage of localized current through the work piece. Resistance spot welding (EN ISO 4063 process 21) can be applied to repair the damaged body of an automobile.

1.3.1 The Resistance Spot Welding Process

Resistance welding can be defined as a process whereby a force is applied to sheet metal surfaces and in which the heat for welding is produced by the passage of electric current through the electrical resistance at, and adjacent to, these surfaces. It is a well-established process, having an excellent track record for producing quality joints in sheet materials. In the European automotive industry alone, over 150 million resistance spot welds are made each day. The process is used for joining sheet materials and uses copper alloy electrodes to apply pressure and convey the electrical current through the work pieces. Heat is developed mainly at the interface between the sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The molten pool is constrained by the pressure applied by the electrodes and the surrounding solid metal.

Spot welding in a high volume vehicle production line

Spot welding equipment is relatively low cost compared to other joining techniques. The equipment requires very little maintenance and hardware can have production lives spanning decades. The application of resistance welding is usually not technically demanding and production machines can be run successfully by relatively low skill level staff.

Spot welding offers a number of advantages over other joining techniques, including very high production speeds, which make it one of the cheapest production joining processes. Welding rates of up to 40 welds per minute can be achieved in robotic spot welding lines. The spot welding process is extremely fast, with cycle times of a fraction of a second. This means low energy levels are required. Due to localised heating of a small area, there is a reduced heat input into components, this minimises thermal distortion and warping, compared to many continuous heating processes. Spot welding is traditionally a very easy technique to automate. In automotive production lines the car body passes between robot cells, where robots manipulate light weight welding guns to join components. Due to the nature of spot welding, where the electrodes apply the welding force as well as the welding current, no extra clamping mechanisms are required. The spot welding electrodes are both clamp and welding source, no arc welding, laser welding or adhesive process can offer in process clamping without the introduction of extra clamping mechanisms holding the parts to join in position.

In spot welding production a degradation of the copper electrode tips is inevitable. In uncoated steels 100's to 1000's of welds can be made without a need to repair the tip surface. But when welding zinc coated steels (as are common for automotive components), electrode degradation occurs much more rapidly. This is due to zinc and zinc oxide deposition on the surface of the electrode tips, which produces increasingly rich brass phases (zinc and copper alloy). With brass, zinc and zinc oxide build-up on the electrodes, the thermal and electrical properties are affected, the tips soften and deform and the weld integrity slowly deteriorates. Automated electrode tip dressing equipment is used to resolve this issue. Tip dressers employ a bladed cutter, which removes the outer surface of the electrode and returns the shape back to the original profile. In a high volume production line, one or more tip dressing units is located within each production cell. The robots within the cell visit the tip dresser at predetermined intervals to maintain their electrode tips, which in turn maintains the consistency of weld quality.

100% reliable spot weld quality is never achieved in volume production, due to the broad range of material combinations being spot welded in a car and process variations introduced by: electrode tip wear, component fit up, component surface condition. Weld quality is maintained by good process control, together with periodic testing of samples. While a number of in process monitoring systems have been developed, there is still a desire to produce a low cost, reliable and robust in-process weld quality monitor, in order to reduce or eliminate periodic destructive tests. Some welding controllers incorporate feedback control systems that monitor current and voltage (resistance) on the welding machine and, with limited setting up, allow automatic, in-process adaption of the welding procedure (time and current) to maintain weld quality for different thickness and material stack-up combinations, for example. While not necessarily guaranteeing weld quality completely, these controllers can provide some correction for variation in other process factors, such as surface contamination, current shunting and part fit-up (these issues will be discussed later). Over the last 20 years, advances in monitoring and control have led to wide spread use of ‘Adaptive control’ in resistance spot welding lines. Adaptive control systems monitor the welding current, voltage and dynamic resistance profile and alter the input voltage and current to match an idealised profile of a perfect weld. By doing this, adaptive control systems can compensate for poor fit up, electrode tip damage and surface contamination of components, to maintain a more reliable weld quality. More advanced adaptive control systems are also able to extend or decrease welding time to ensure the total thermal input in weld remains consistent across a production run.

1.3.2 Resistance Spot Welding Technical Overview

Resistance welding is one of the oldest welding processes and offers a number of advantages over other techniques, including speed and energy efficiency. Resistance welding can be used on very thin or thick sections.

The heat generated depends on the current (I), the duration of the current (t) and the resistance (R), and may be expressed as:

HEATING = I2Rt

The resistance is a function of the size, shape and material of the electrodes, the force applied, and the resistivity and surface condition of the material to be welded (Fig.1).

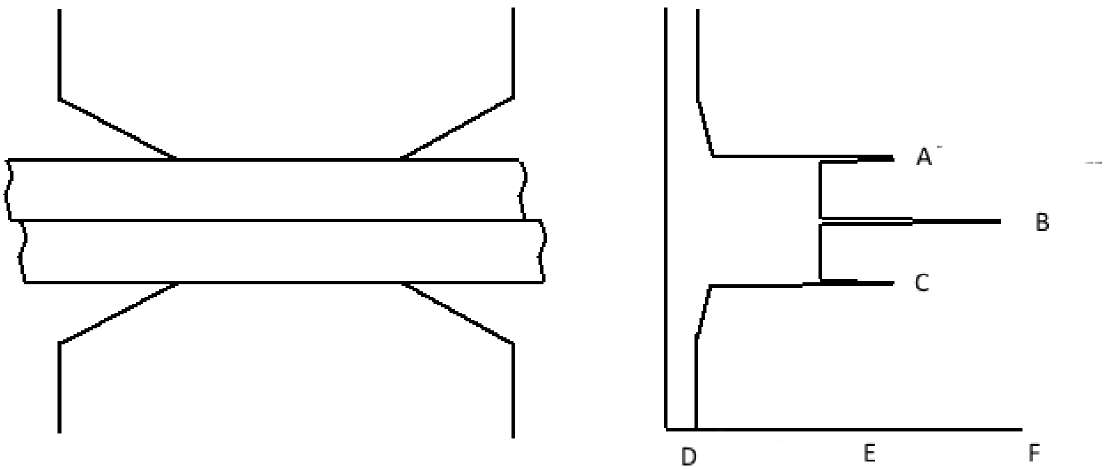


Figure 45 - Material and interface resistances before welding. Electrode contact, B. Sheet interface, C. electrode contact, D. Low, E. Resistance, F. High. Source: TWI

The resistance spot welding process uses shaped copper alloy electrodes to concentrate the welding current and force. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget. The pressure at the electrode tip contains the molten pool. However, if the molten pool has grown too large, molten metal will be expelled as weld splash. Fig.2 shows the proportions of a good spot weld.

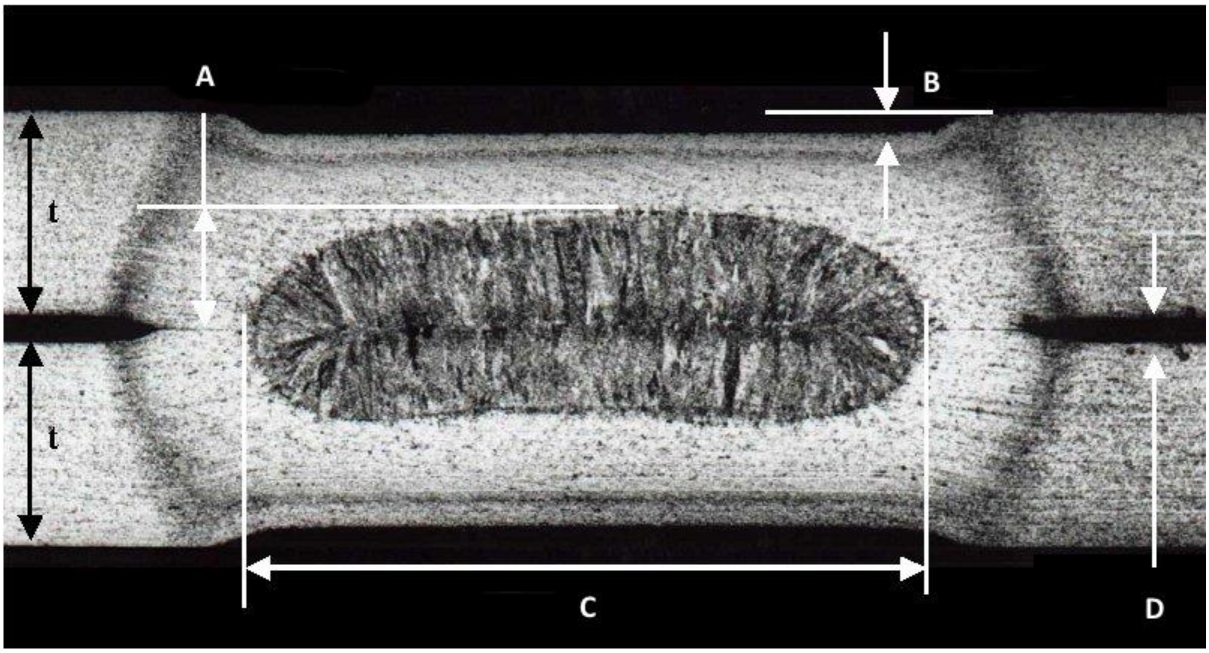


Figure 46 - Cross section showing proportions of a good spot weld. Detailed requirements depend on application standard. A. Penetration, B. Indentation, C. Nugget diameter, D. Sheet separation. Source: TWI

Typical spot weld quality requirements are:

Electrode tip diameter	5√ t
Target weld diameter	5√ t
Minimum weld diameter*	4√ t
Maximum indentation	10 to 20% t
Maximum sheet separation	10% t
Nugget penetration	20 to 80% t

Table 9 – Spot weld quality requirements. Source: TWI

*Based on the thinner material thickness in a dissimilar thickness combination.

Equipment

A resistance spot welding machine is shown schematically. It comprises the following parts:

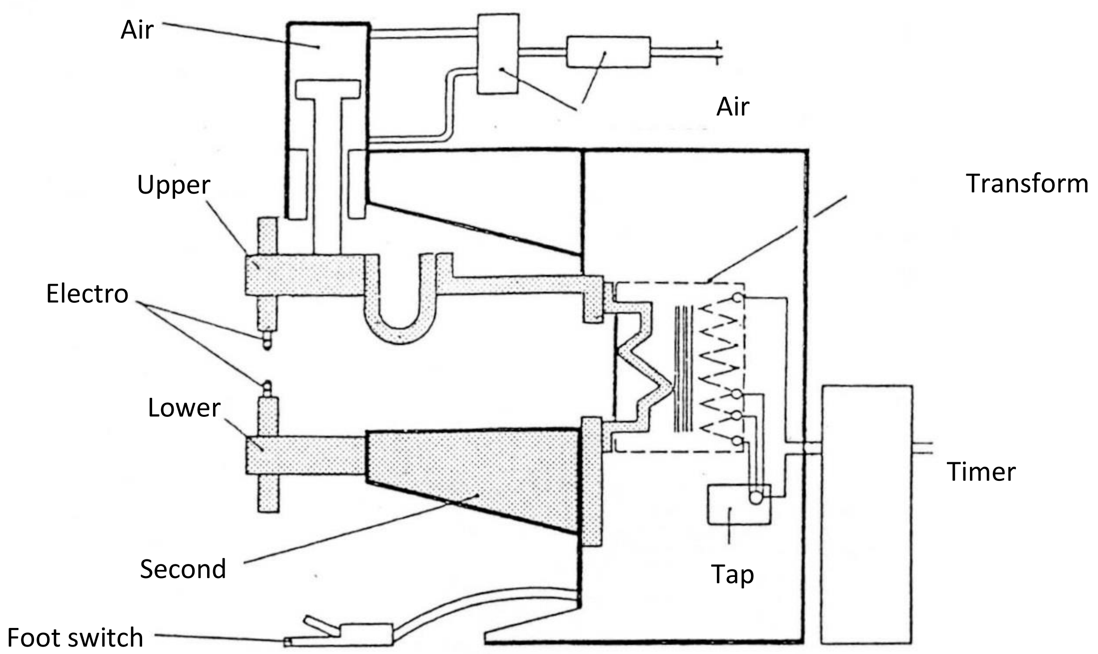


Figure 47 - Pedestal spot welding machine. Source: TWI

Lightweight resistance spot welding guns can be manipulated manually or by robots, a typical gun has the same components as a pedestal welder but is smaller and more compact.

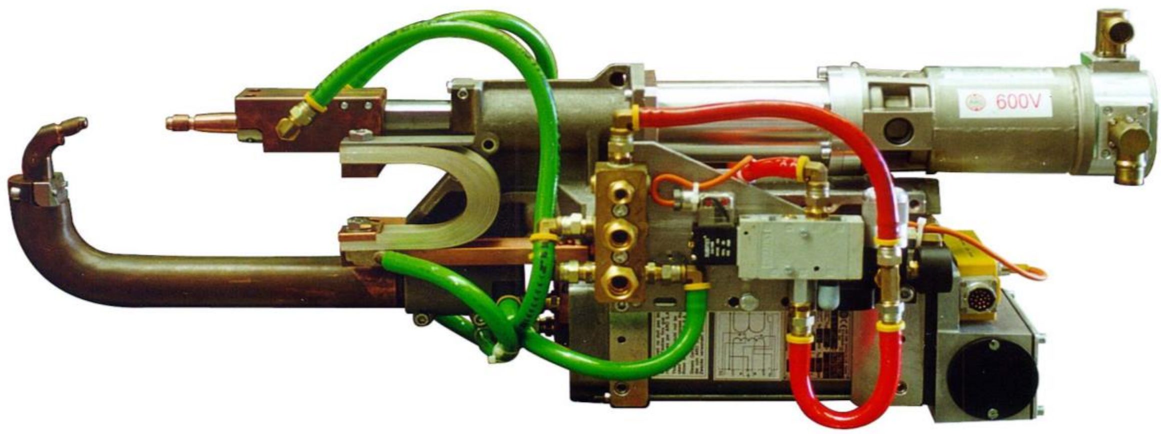


Figure 48 – Resistance Spot Welding Gun. Source: TWI

Frame structure: This provides mechanical rigidity of the machine.

- **Force application system:** This usually comprises a controlled air supply to a cylinder but can be hydraulic or spring application. Some welding guns have servomotor force systems. The pneumatic control comprises a water trap and oiler (if fitted), a regulator and pressure gauge, and solenoid valves.

- **Timer/controller:** This controls the timed sequences for the welds, switches the welding current on and off, and also provides fine current control.

- **Transformer:** This reduces the medium voltage primary input (415V mains supply) to the low voltage secondary (2-20 volts) used for welding (Fig.7). The turns ratio of the transformer is the number of turns of the mains primary conductor (usually between 20 and 200) divided by the number of turns of the heavy secondary conductor (usually 1 or 2). This is the ratio by which the mains voltage is stepped down and the mains current is stepped up.

  e.g. turns ratio = 100: 1

  if mains voltage = 400V, then secondary voltage = 4V

  if primary current = 100A, then welding current = 10,000A

Note: The secondary voltage may be considered as constant, because mains voltage and turns ratio are nominally constant. Therefore, the current which flows in the welding circuit depends on the resistance of the circuit.

by Ohms law: Voltage (V) = Current (I) x Resistance (R)

Thus, for a given voltage, an increase in the resistance of the secondary circuit (welding machine) causes a reduction in the welding current.

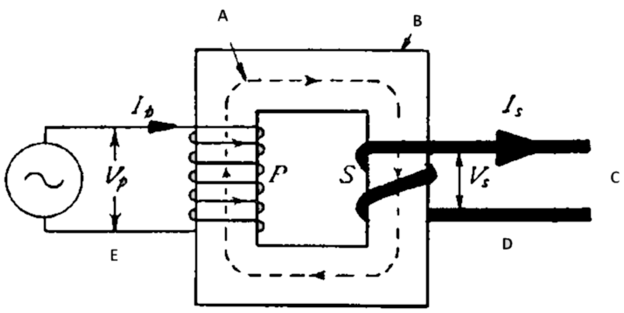


Figure 49 - Welding transformer. A. Magnetic Flux, B. Transformer core, C. Welding machine, D. Secondary Circuit, E. Primary circuit. Vp – primary mains voltage, Ip – primary current. Vs – secondary welding voltage, Is – welding current. Source: TWI

Power Supplies

The welding current in a resistance welding machine is generally made available via a transformer with various tapping winding ratios, and can be of the following types. In each case typical waveforms are shown.

Single phase ac: Generally connected across two phases of the mains supply giving approximately 415V primary voltage, but low power portable guns may be connected to the usual mains supply.

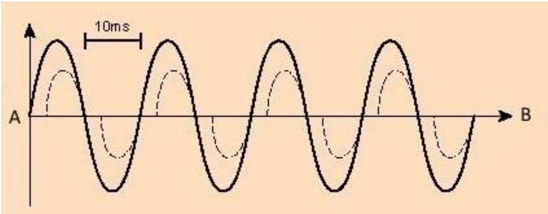


Figure 50 - Single phase ac current waveform. A. Current, B. Time Source: TWI

Medium frequency/dc: Primary current from all three mains phases are rectified to give approximately 600V dc. This is then chopped to a medium frequency using transistors (typically 1000Hz at 600V). This current is then transformed using a light-weight integral welding transformer and rectified on the secondary side to give dc welding current. This current profile type is common in more modern welding guns used in vehicle production lines.

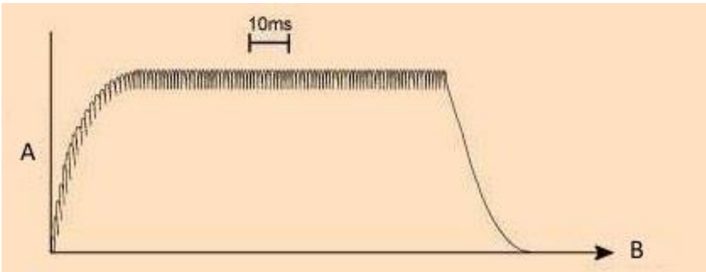


Figure 51 - Medium frequency inverter dc current waveform. A. Current, B. Time Source: TWI

Capacitor discharge: A short duration dc pulse is achieved by discharging a bank of capacitors through a welding transformer. A low power demand is required to charge the capacitors. Capacitor discharge spot welding is becoming more popular and power supplies for joining both thin and heavier gauge materials are now available.

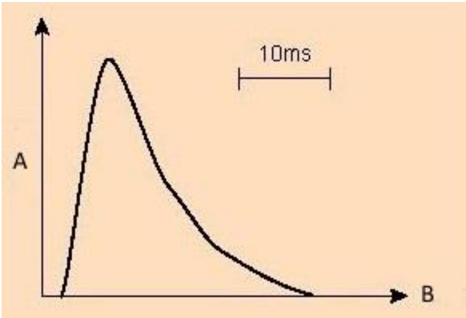


Figure 52 - Capacitor discharge current waveform. A. Current, B. Time Source: TWI

Program

A Spot welding program consists of time periods that are programmed on the timer controller.

Time: Depending upon the weld timers programing interface type, the time setting will either be in 'cycles' or in 'ms' (milli seconds). The following conversion allows an operator to understand the time interval of the program settings.

1cycle = 1/50sec or 20msec. (10cycles = 0.2sec)

1 ms = 1/1000 sec

Squeeze time: the time set to ensure the set welding force is achieved before current flow. Some timers are also equipped with a pre-squeeze time setting.

Weld time: The time for which the current is flowing is commonly referred to as the 'weld time' although some systems use 'heat time' instead. This is the time for which the welding current is switched on. When spot welding steels, a weld time of 10 cycles/mm of the single sheet thickness is a reasonable starting point.

Hold time (forge): the time the electrodes are held together under pressure after the weld time. 5-10 cycles is normally adequate for thin materials.

Cool time: the current off time between successive current pulses in pulsation welding or seam welding.

Off time: the time used for repeat welding such as stitch welding. The time between the end of the hold time on one weld and the start of the squeeze time on the next, during which the electrodes are re-positioned. This programming feature is not commonly used in repair welding.

When using pulsed welding, the weld times may be set independently or the weld and cool times alternate for the set number of pulses.

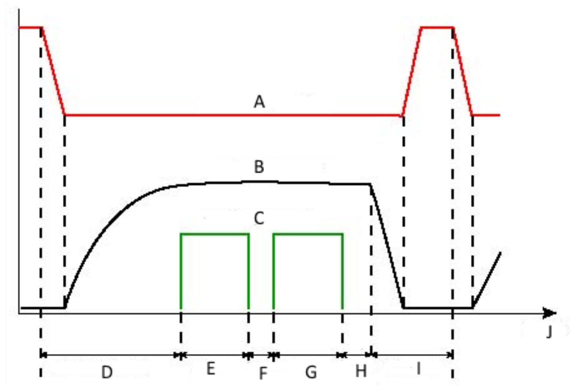


Figure 53 - Time and pressure diagram for spot welding showing two current pulses. A. Electrode position, B. electrode force, C. welding current, D. Squeeze time, E. Weld time 1, F. Cool time, G. Weld time 2, H. Hold time, I. Off time, J. Time. Source: TWI

Electrode Force

Each material being welded will have its own optimum electrode force, depending on the electrode tip size used for a particular sheet thickness.

The electrode force required for low carbon steel is normally

1.4 to 2.0kN per mm of the single sheet thickness

The electrode force (N) = electrode tip pressure (N/mm^2) x tip contact area (mm^2). (Note: 1kg force is approximately 10 Newtons (N) or 1 deca Newton (daN)).

The electrode tip pressures for these and other materials are summarised below:

Material Type	Multiplying factor	Welding pressure range, N/mm^2	Electrode force, kN per mm of single sheet thickness
Uncoated low carbon steel	1	70-100	1.4 – 2.0
Coated low carbon steel	1.2 - 1.5	100-160	2.0 – 3.2
High strength low alloy steels	1.2 - 1.5	100-160	2.0 – 3.2

Table 10 - Summary of electrode tip pressures. Source: TWI

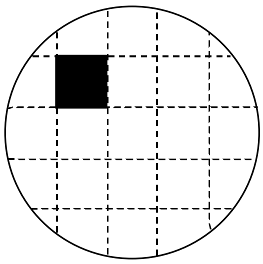


Figure 54 - 5mm diameter electrode tip. Source: TWI

$20mm^2$ contact area

Force = $20mm^2$ x $70N/mm^2$ = 1.4kN

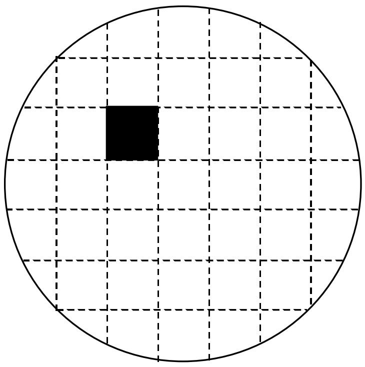


Figure 55 - 7mm diameter electrode tip Source: TWI

$40mm^2$ contact area

Force = $40mm^2$ x $70N/mm^2$ = 2.8kN

Example of the effect of tip diameter on area of contact and electrode force required. Electrode force may be set up approximately by multiplying the cylinder air pressure by the area of the piston on which the air acts. Figures 54 and 55 give a guide to the calculation of electrode force for cylinders of different sizes. Any counter pressure, internal shaft or lever linkage system (e.g. scissors gun) would have to be taken into account. True electrode force should be verified using a load cell.

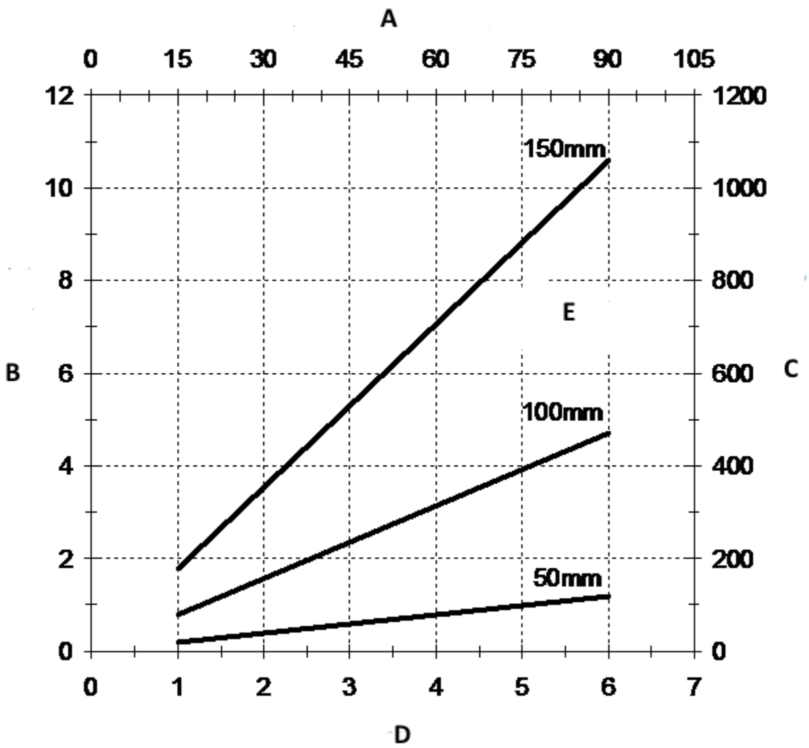


Figure 56 - Electrode force determined for selected cylinder diameters. A. Air pressure, psi, B. Electrode force, kN, C. Electrode force, kg, D. Air pressure, bar, E. cylinder diameter. Source: TWI

- Adequate squeeze time should be allowed to ensure the set electrode force is achieved prior to current flow
- Extra electrode force may need to be applied to compensate for poor part fit-up.
- Where possible, the rate of electrode approach should be controlled sufficiently to avoid hammering of the electrodes as this adversely affects electrode life.
- Avoid welding on large machines with low air pressure, where the follow-up characteristics of the welding head may be adversely affected.

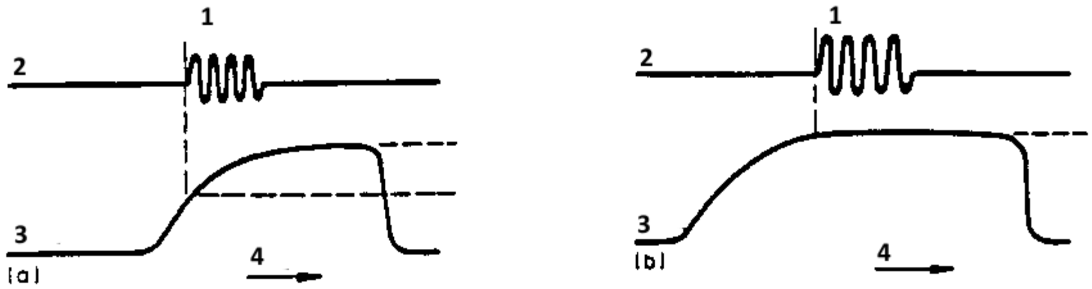


Figure 57 - The importance of allowing welding force to stabilise before applying current. a) force build up time too short, b) appropriate force build up time. 1. Current initiation, 2. Weld current, 3. Force, 4. Time. Source: TWI

Influence of squeeze time setting:

a) Squeeze time too short;

b) Squeeze time correct.

Welding Current

Control of welding current is achieved by transformer tappings (winding ratios) and by the percentage heat control (phase shift control). The transformer tapping alters the turns ratio of the transformer by giving a different voltage to the transformer and therefore a variation in welding current.

The percentage heat control (phase shift control) delays the firing of the electronic switching which reduces the amplitude of the welding current. The effect of tap and heat setting changes is shown in the figure.

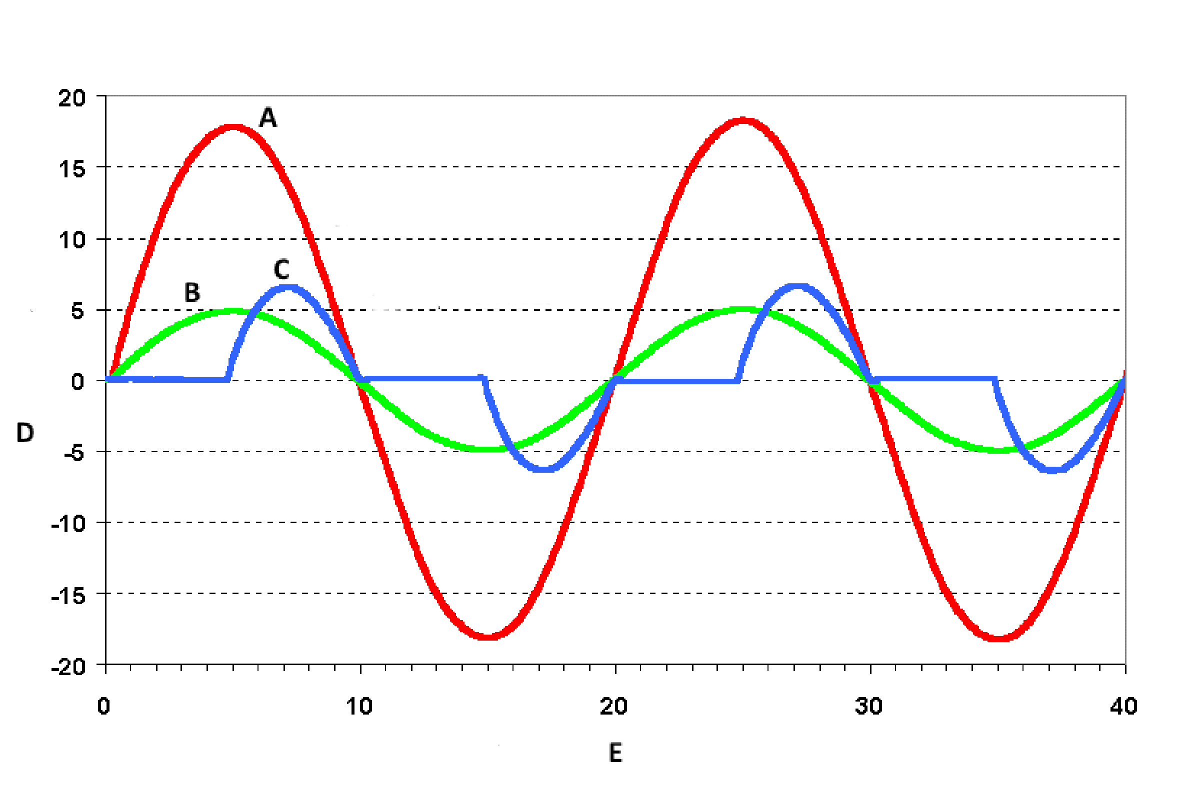


Figure 58 - Control of welding current in single phase ac by tap change and phase shift control. A. High tap/high heat, B. Low tap/high heat, C. High tap/low heat, D. Welding current, kA, E. Welding time, msec. Source: TWI

The rms current (root mean square) is the equivalent dc current for an alternating waveform and is the value normally indicated on a current meter.

Welding current is affected by variation of mains voltage or changes in the resistance or inductance of the secondary circuit (e.g. wear in jumper cables or flexibles). Timers often have a means of feedback control of current to maintain a constant value, If the measured current falls compared to the present value, the phase shift control is automatically adjusted to correct the deviation.

ELECTRODES

Materials

The electrode materials in general use are copper alloys developed to combine high strength with a much higher softening temperature, while maintaining reasonable conductivity. The table gives details of the major alloys.

- Use the correct electrode materials for the job in hand.
- Do not use unidentified electrode materials.
- Generally do not use mixed electrode materials.
- Electrode Shape
- Depends on component and access limitations.
- Commercial types are shown in Fig.14 and 15.
- Where possible use straight, centre tip electrodes and avoid angled electrodes.
- Electrode alignment, wear and tip dressing are likely to be more difficult with offset or angled tips.

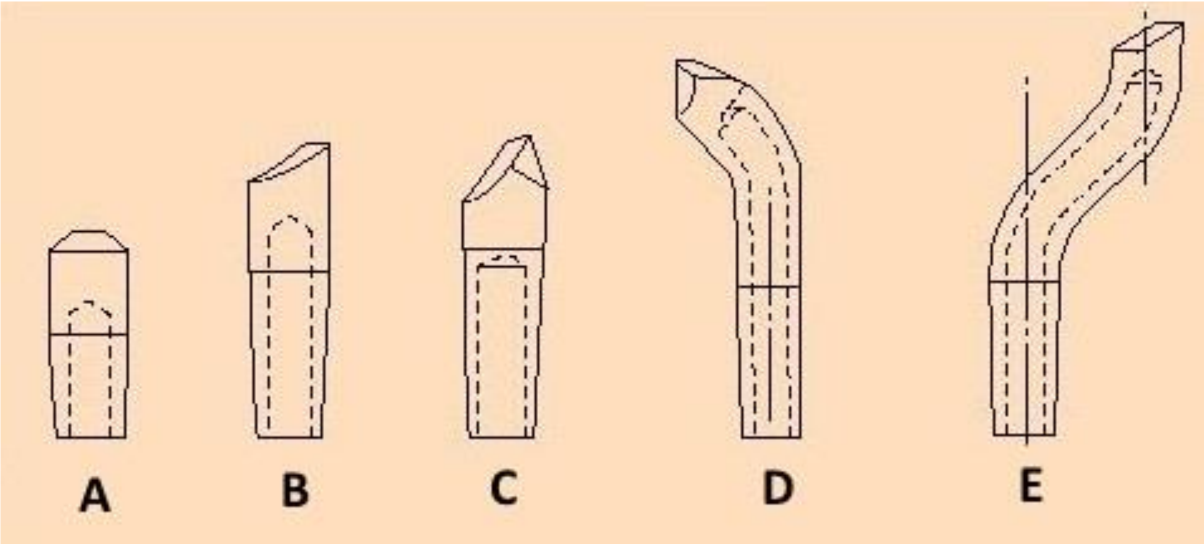


Figure 59 - Commercial electrode shapes, usually used on stationary pedestal spot welders. A. Vertical centre, B. Vertical offset, C. Angle offset, D. Cranked offset, E. Double bend offset. Source: TWI

Material		Alloy Type	Nominal Composition %	Softening Temperature °C	Electrical Conductivity % I.A.C.S.+	Hardness min HV	Typical Application Areas
Group	Type						
	-	Zirconium/copper	0.1Zr/Cu	~500	92*	120	Aluminium alloys, uncoated and coated steels
	2/1	Chromium/copper	1Cr/Cu	500	78	120	Uncoated and coated steels
	2/2	Chromium/ zirconium/copper	1Cr/0.1Zr/Cu	525	75	120	Uncoated and coated steels

+I.A.C.S - International Annealed Copper Standard

* = typical values

Table 1. Most widely used electrode materials (based on BS4577, ISO 5182 and commercial data).

Table 11 - Properties of common spot welding electrode materials. Source: TWI

Note: for most spot welding applications in steel A2/1 or A2/2 electrodes are used.

Shank Diameter

- Select largest diameter which will fit workpiece and electrode holder. Minimum recommended shank diameter is 3 x tip diameter.
- Greater electrode wear will occur with smaller shank diameters, especially when welding coated steels.

Electrode Tip

- A truncated cone tip is normally recommended, but various other shapes have been used successfully (Fig.15).
- Domed tips are easier to align but suffer more rapid wear.
- Pointed tips are sometimes used for gun welders.
- The electrode tip diameter should approximate to $5\sqrt{t}$ (t = sheet thickness of thinnest sheet, or second thinnest for 3 thicknesses).

Electrode Holders and Adaptors

- Ensure tapers match. Replace worn or leaking components.
- Ensure the taper on both the electrode and holder are smooth and clean. A thin film of grease makes the electrodes easier to remove.
- Use the correct tools for removing electrodes to avoid damage.
- Do not use a steel hammer on the electrodes or holders during alignment, a soft mallet may be used.

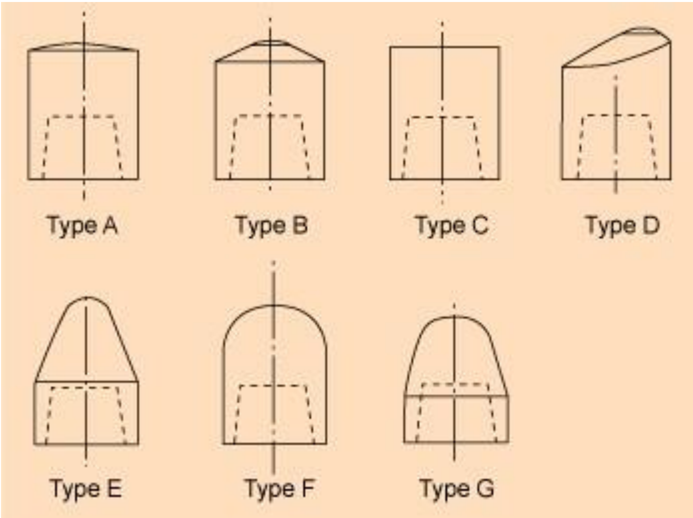


Figure 60 - Alternative electrode cap shapes, usually used on portable spot welding guns Source: TWI

Water Cooling

- Electrode life is critically dependent on water cooling.
- All male electrodes or female cap holders have an internal cooling passage.
- The cooling tube should be cut at an angle and positioned close to the back face of the electrode tip
- Female caps can be changed without switching off the cooling water, but the cooling is less efficient because of the additional interface. It is normally recommended to drill through the male holder to allow water to be directed onto the back face of the electrode.
- The water supply to the electrodes should not be in series with water supplied in other parts of the machine and should not be subject to a back pressure preventing proper flow.
- A minimum flow rate of 4 l/min is recommended for uncoated steels and higher for coated steels and thicker sections. A water flow switch or indicator is recommended.
- Ensure the water is fully turned on and that the supply is free from restrictions or leaks.
- The temperature of the cooling water affects electrode life. A maximum inlet temperature of 20°C and a maximum outlet temperature of 30°C are recommended.
- A water flow switch or indicator is recommended.

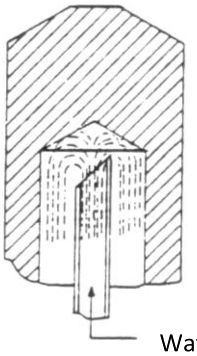


Figure 61 - Arrangement for electrode water cooling. Source: TWI

Electrode Dressing

- Wherever possible use a form tool to restore the electrode tip shape.
- If filing a tip is unavoidable, remove material from the cone angle to restore the desired tip diameter. Remove little or no material from the face to maintain tip alignment.
- Air or electrically operated tip dressers are available for either manual or automatic application.

Weld Quality Requirements

The weld quality requirements are normally specified for a component, either based on a customer or international standard. Under some circumstances, the standard requirements are modified to satisfy fitness for purpose.

The following factors are normally considered to describe spot welding quality:

Weld size: Nominal weld diameter is $5\sqrt{t}$ where t = sheet thickness, mm. The minimum acceptable diameter is normally 70 or 80% of this value. Note: in a repair garage destructive testing of spot welds is often not possible.

Weld strength: Shear strength may be specified and the requirements usually relate to the normal weld sizes. Tension or peel strengths are lower than shear and would be more sensitive to weld hardening. **Note:** weld strength testing is almost never possible in a repair garage

Appearance: Excessive indentation, surface splash (weld spurs), edge damage and surface burning or cracking are usually limited.

Metallographic: Nugget penetration, weld hardness, internal cracking and porosity may have specified limits. **Note:** metallographic testing is almost never possible in a repair garage.

Setting –up a spot welding process

In both automotive production and crash repair resistance spot welding is the primary process for joining thin sheet steel. Resistance spot welding is a very fast and reliable process that is readily automated and does not require much operator skill. The greatest technical requirement of resistance spot welding is to ensure that the process is correctly set-up in the first instance. A new resistance spot welding process will be set-up to:

- Manufacture a component for the first time
- Manufacture an existing component from a new material combination
- Repair a component

Despite its apparent simplicity resistance spot welding is influenced by many local variables, variation in welding machine characteristics and the influence of component geometry and fit-up mean that no universal set of parameters can be applied to a given material combination. Although many standards exist advising the range of parameters that should usually be applied for specific materials.

When setting-up a new resistance spot welding process optimum parameters must be sought (usually using a standard as a guideline) and the weld quality must be verified, this is done by destructive testing.

Destructive (peel) testing

The main method for verification of spot weld quality is destructive testing, where-by spot welds are torn apart by an externally applied force and the parent metal breaks away from the weld zone. The weld zone is revealed and assessed for it quality, to ensure it is fit for purpose.

Two main methods of destructive testing are commonly applied:

- Peel test
- Chisel test

Welds are broken apart by the peel test by clamping one of the welded sheets, typically in a vice. The other welded sheet is gripped by either; pliers, pincers or a roller tool and force is applied in such a way that the weld is loaded perpendicular to its original orientation, thus peeling the weld open. A peel test can be performed either manually or be mechanised, in the case of a mechanised test the failure force can be measured.

In a destructive chisel test, a chisel is driven between the sheets separating them and loading the weld. The chisel may have one blade or two separate prongs and the force can be applied manually or via mechanical means. If the chisel test is mechanised the failure force can be measured.

ISO10447 2006 Resistance welding – 'Peel and chisel testing of resistance spot and projection welds' describes the procedure for destructive testing and measurement of resistance spot welds, the German equivalent is DIN EN ISO 10447:2007-09.

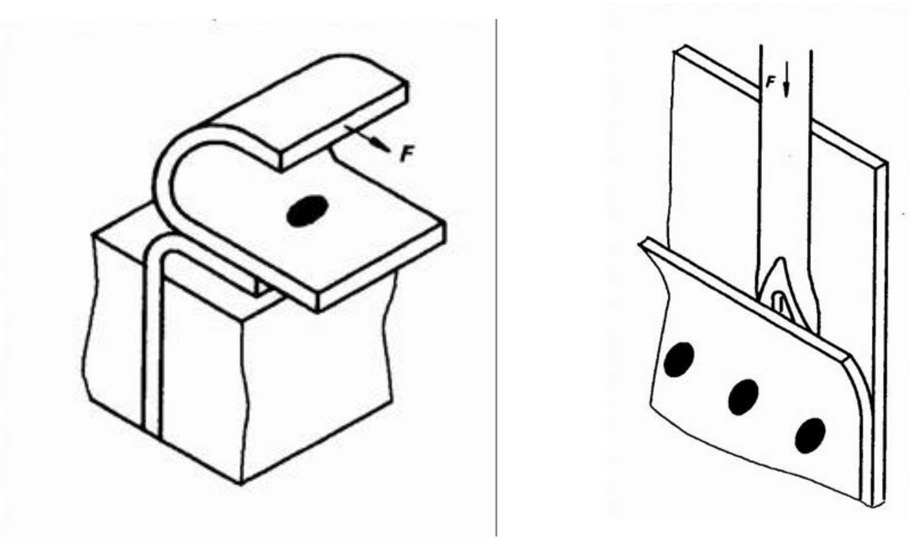


Figure 62 - Chisel test. Source: TWI

Assessing weld quality, weld measurement

Destructive chisel or peel testing results in a weld zone that has been torn out of one the metal sheets, the exposed weld area can be measured. This measurement of weld size is typically used as an indication of weld quality, i.e. whether the weld is fit for its intended purpose.

Spot welds are measured using a Vernier calliper. As spot welds are not always exactly round two measurements should be taken at 90° to one another. The largest and smallest dimensions of the spot weld should be measured as shown in Figure 52. The average weld diameter is calculated as shown below:

Average weld diameter = $d_1 + d_2 / 2$

d_1 = largest weld dimension

d_2 = smallest weld dimension

A minimum average weld diameter is often used for quality control purposes, the weld size is usually related to the sheet thickness. Typical minimum average weld diameters are often $4\sqrt{t}$ or $5\sqrt{t}$, where t = sheet thickness.

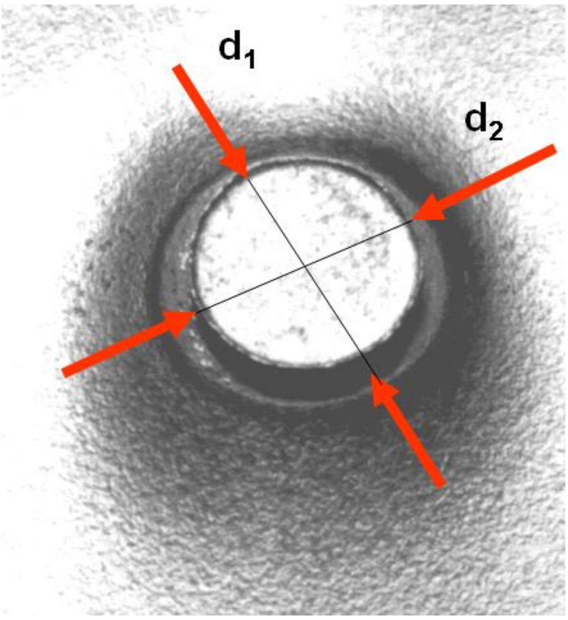


Figure 63 - Measurement of a spot weld. Source: TWI

Spot weld failure modes

In conventional low carbon steel most spot welds that are destructively tested will fail as a 'plug' or 'pull out' failure. A plug is characterised by the weld zone tearing clear of one of the sheets, leaving a visible protrusion that is easily measured.

Higher strength steels and ultra high strength steels can fail as 'interfaces' or 'partial plugs'. In the case of an interface failure the weld will shear directly through its centre leaving half of the weld in each sheet and no protruding plug, Figure 53. In the case of the partial plug the weld zone it's self will partially fracture, then the surrounding sheet will fracture, leaving only a portion of the weld plug protruding from the sheet.

An interface failure is also characteristic of higher strength and thicker steels, in the case of an interface failure the weld will shear directly through its centre leaving half of the weld in each sheet and no protruding plug.

Figure 64 - Plug failure. Source: TWI

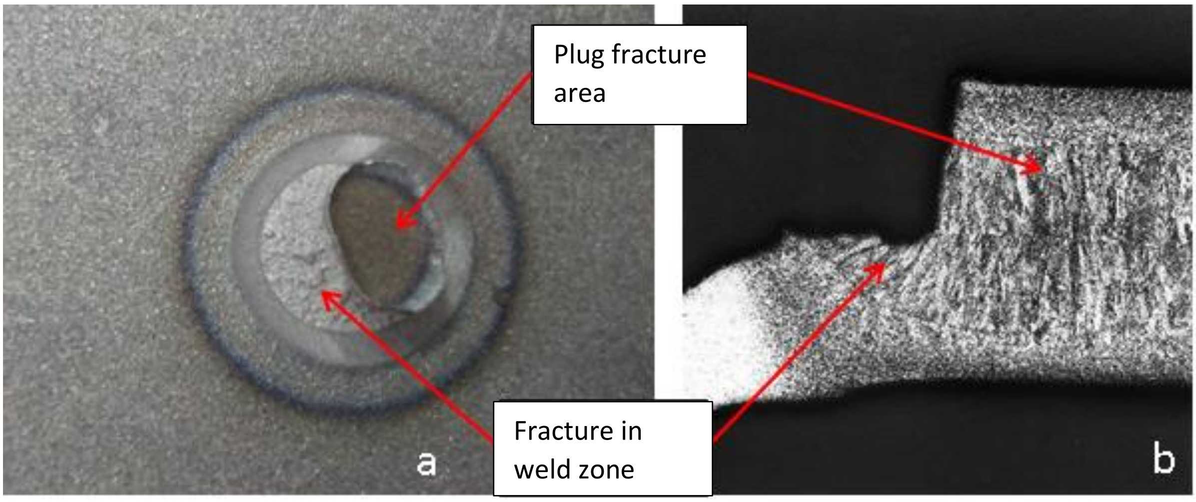


Figure 65 - Partial plug failure , b:cross section of partial plug. Source: TWI

Figure 66 - Interface failure Source: TWI

When measuring the average weld diameter, it is important to be sure the correct dimensions are recorded, several factors need to be taken into account. When measuring a full plug weld failure some of the sheet material may still be attached to the weld zone, this excess material should be folded back to allow accurate positioning of the Vernier calliper.

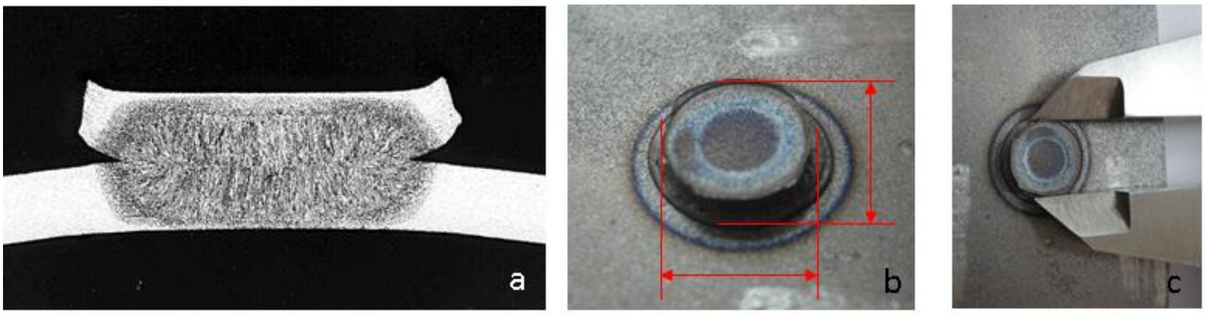


Figure 67 - a. Cross section showing excess sheet material, b: weld dimensions to be measured, c: correct positioning of the Vernier calliper Source: TWI

When measuring a partial plug weld failure the true weld nugget dimensions of the rough fracture surface, this area may be partially covered by the weld plug. In some cases the average diameter of plug area may also be required, this is measured by positioning the Vernier calliper at the largest and smallest plug dimensions, in the same manner as for a conventional plug failure.

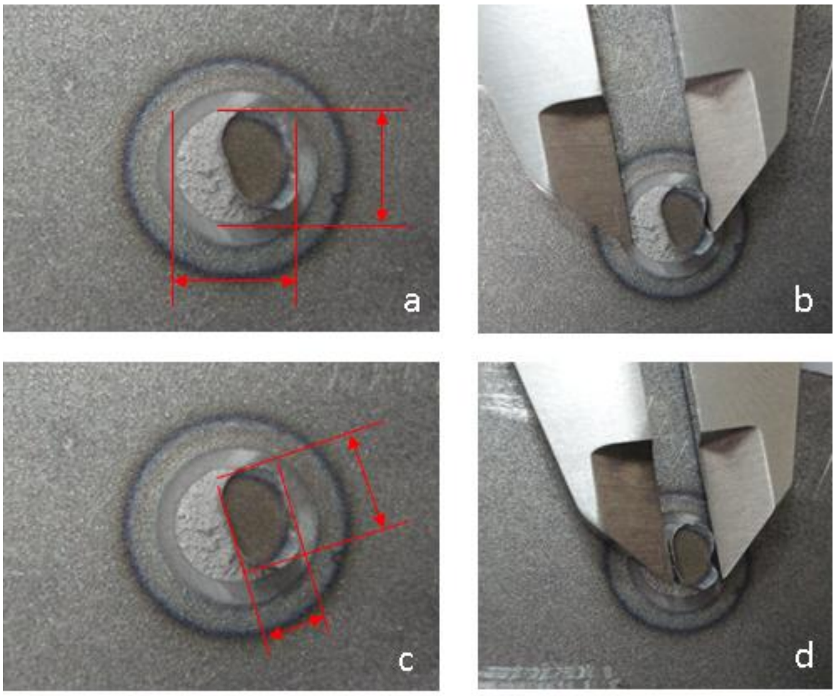


Figure 68 - Measuring a partial plug weld failure. a.Measuring the original weld area of a partial plug, b: correct positioning of the Vernier calliper on the rough fracture surface to give the original weld diameter, c: measuring the plug area of a partial plug, d: positioning the Vernier calliper on the plug. Source: TWI

Weldable Materials

It is possible to weld a wide selection of metals and combinations of metals by resistance welding processes. However, with some combinations, difficulties are encountered because of metallurgical incompatibility, welding temperature ranges, etc. The following materials illustrate the wide applicability of the welding process:

Low carbon and micro-alloyed steel	Readily weldable
High strength and ultra high strength steels	All steels used in car bodies can be joined by resistance spot welding. High strength materials may require longer welding times and higher forces to ensure a good weld can be achieved.
Coated steels	Zinc, iron-zinc and aluminium Silicon (ALSi), coatings can all be satisfactorily welded, although the electrode life is shorter than for uncoated steel due to pick-up of the coating on the electrode. More regular electrode maintenance may be required
Aluminium and its alloys	High welding currents required, the sheet surface condition dominates weld formation, electrode contamination a major problem. Aluminium is not repaired by resistance spot welding outside of OEM facilities

Table 12 - Overview of the spot welding performance of car body materials

Material	Resistivity, μΩcm	Resistance relative to pure copper	Conductivity, %
Pure copper	1.7	1	100
Copper 1% chromium	2.1	1.2	80
Low carbon and high	13.0	17.6	13
strength steels	6	3.6	28
Zinc	72	42	2.4
Stainless steel			

Table 13 - Electrical resistivity and conductivity of electrode materials and weldable sheet materials

Weld Defects And Possible Causes

Expulsion at weld interface (spot weld)

- Dirty material
- Surface oxide or scale
- Poor fit-up of components
- Squeeze time too short
- Electrode force too low
- Poor electrode alignment
- Weld current too high
- Weld time too long
- Poor follow-up of welding head

Expulsion at surface, electrode sticking

- Squeeze time too short
- Electrode force too low
- Dirty material
- Surface oxide or scale
- Tips require dressing
- Poor electrode alignment

Excessive electrode wear

- Weld time too long
- Electrode force too high
- Weld current too high
- Insufficient cooling
- Electrode alloy too soft
- Electrode overheated
- Electrode tip too small

Excessive weld indentation

- Weld time too long
- Electrode force too high
- Weld current too high
- Poor electrode alignment
- Poor fit-up
- Close edge distance
- Weld splash

Small weld/no weld

- Weld time too short
- Electrode force too high
- Weld current too low
- Electrode tip too large
- Poor heat balance
- Welds too close together
- Machine set to 'weld off'
- Dirty material
- Surface oxide or scale
- Weld off switch set
- Controller malfunction
- Poor set-up of tooling

Displaced weld nugget (uneven penetration)

- Electrodes different material
- Electrodes different size
- Electrodes misaligned
- Poor heat balance

Cracks in weld nugget

- Hold time too short

- Electrode force too low
- Poor follow-up
- No (or incorrectly set) dual force/current decay (aluminium alloy)

1.3.3 Health and safety, and environmental safety

Working in a safe manner, to protect yourself, others and the vehicle or components you are working on, is an essential consideration in any welding operation. The responsibility for safety is on all individuals but especially the welding operator, not only for their own safety, but also to avoid endangering other people. Your employer has an important responsibility for ensuring that health, safety and environment (HSE) legislation is complied with and safe working practices are implemented. If you cannot assure your own safety and the safety of others in the work area, then stop welding and do not start welding again until the risk has been controlled.

Your employer should ensure compliance with all appropriate documents, for example:

- Legislation – EU OSH Directives.
- Standards – OHSAS 18001.
- Company Health, Safety and Environment Management Systems.
- Work instructions – permits to work, risk assessment documents, etc.

The workshop environment

The employer needs to ensure that the lighting conditions are adequate for the work undertaken - giving extra lighting where necessary.

Housekeeping is extremely important to avoid slips, trips and falls, damage to equipment and fire.

There are many aspects of resistance welding safety that the welder needs to consider:

- Electric shock.

- Electromagnetic Fields
- Heat
- Fumes and gases.
- Noise.
- Working at height or in restricted access.
- Mechanical hazards: trips, falls, cuts, impact from heavy objects.

Electric shock

Contact with metal parts that are electrically live can cause injury or death because of the effect of the shock upon the body or because of a fall as a result of the reaction to electric shock.

The electric shock hazard associated with resistance spot welding is minimal. Although heat is generated with high current levels, the voltage used in welding is typically in the region of 1 Volt, which is not sufficient to cause a shock. However, the primary side of the transform operates at mains current. Only qualified electrical personnel should work on the transformer primary side. Appropriate sage working procedures must be followed.

It is important that the welding cables can carry the maximum possible output of the welding set without overheating as overheating can damage the insulation, leading to an increased risk of electrical shock.

Installation of welding equipment should be carried out by suitably qualified staff who must check that the equipment is suitable for the operation and connected in accordance with the manufacturer's recommendations. The welder is responsible for checking the equipment (cables, welding guns, electrodes) daily for damage and reporting defects. All external connections should be clean and tight and checked each time a reconnection is made.

Welder actions for safe practice and avoidance of electric shock:

- Do not wear jewellery (especially rings) or metallic watch straps
- Wear protective clothing safety boots, gloves, overalls, eye protection (goggles)
- When welding outside, check the power source protection rating is adequate for the environment and do not weld in the rain without a suitable cover
- When welding the vehicle directly, ensure that the vehicle is electrically safe; a competent auto electrician has isolated the batteries and any hybrid power systems, and disconnected sensitive electronics units

Electromagnetic Fields

Welding processes may produce low frequency fields that have a detrimental effect on the mental and physical health of the exposed workers. The possible effects include stimulation of muscles, nerves or sensory organs and transitory symptoms such as vertigo or retinal phosphenes. These effects may affect the ability of the worker to work safely.

Electromagnetic fields may be sub-divided into magnetic and electric fields and for most welding processes, it is the magnetic field which is significant.

Exposure to electromagnetic fields may cause direct biophysical effects, including:

- thermal effects such as tissue heating.
- non-thermal effects such as the stimulation of muscles, nerves or sensory organs.
- Limb currents.

Indirect effects of EMF include:

- interference with medical electronic devices such as pacemakers.
- projectile risk from ferromagnetic objects in static magnetic fields.
- initiation of detonators.
- ignition of flammable materials by sparks caused by induced fields.

- contact currents.

Welder actions for safe practice and avoidance of welding EMF:

- Follow the guidance from the employer's workplace assessment
- Do not wrap welding cables around body
- Do not stand in coiled welding cables

Note: legal requirements for EMF may vary between countries within Europe

Heat

As resistance spot welding relies on melting metal to effect a joint, it follows that the metal will in part be very hot. All metals conduct heat to a greater or lesser degree so the area heated to a temperature that will cause skin burns is much larger than the weld area itself.

The spot welding process can create sparks and spatter (liquid metal expulsion), with the potential to cause flammable materials near the welding area to ignite and cause fires. The welding area should be clear of all combustible materials and it is good practice for all personnel working in the vicinity of welding to know where the nearest fire extinguishers are and the correct type of fire extinguisher to use if a fire does break out. Weld spatter can cause burns, so protective clothing, such as welding gloves, flame retardant coveralls and leathers can offer protection to exposed skin.

Welder actions for safe practice and avoidance of effects of welding heat:

- Ensure that appropriate PPE is available, fit for use and correctly worn
- Ensure that combustible trim is removed from the vicinity of the joint and that the car is protected, where necessary, with fire resistant blankets

Fumes and gases

Fume is a mixture of particles generated by vaporisation, condensation and oxidation of substances resulting from the welding heat. Fume particles are very small and may remain suspended in the air for long periods, where they may be breathed.

Toxic fume may be created also from oils, paint finishes, coatings, adhesive bond lines plastic materials in the vicinity of the welded joint.

The following aspects are likely to influence the degree to which the welder is exposed to fume and gases:

- welding position
- location and type of workplace

Thus, welders using the same process may be exposed to different levels of fume. The risks for each job should, therefore, be assessed individually.

On-gun extraction

In small volume spot welding fume extraction is not usually required. However, if the materials welded produce heavy fume, extraction may be used. Local exhaust ventilation (LEV) and on-gun (or work piece proximity) extraction systems are never 100% efficient, especially when welding awkward structures, general ventilation may also be necessary to control the background level of fume.

As each type of extraction equipment has limitations, it is important to select the right equipment for each job. It is also essential that welders are adequately trained to use the equipment and adopt good working practices. Supervision is needed to ensure the equipment is being used effectively and to minimise background fume level in the workshop.

As a rule of thumb, if the air is visibly clear and the welder is comfortable, the ventilation is probably adequate.

Noise

Exposure to loud noise can permanently damage hearing, cause stress and increase blood pressure. Working in a noisy environment for long periods can contribute to tiredness, nervousness and irritability. If the noise exposure is greater than 85 A-weighted decibels, averaged over an eight hour period then hearing protection must be worn and annual hearing tests carried out. The employer has the responsibility of ensuring that workers wear the protection.

Normal resistance welding operations are not associated with excessive noise level problems. The noise associated with welding is usually due to ancillary operations such as chipping, grinding and hammering. Hearing protection must be worn when carrying out, or when working in the vicinity of, these operations.

Mechanical hazards

The environment in which a welder works has a number of hazards not specific to the welding process itself. Manual handling of heavy awkward metal components is often required. Thinner, lighter metal sheet may have sharp edges. Slips, trips and falls may be more likely as welding often requires thick cables to be spread across the floor. Standard workshop safety and protection practice should be used to counter these problems. Welders need training in materials handling, both manual and with mechanical lifting assistance; protective gloves, helmets, overalls and boots must be worn; cabling on the floor should be minimised and clearly signed or marked as a trip hazard.

There are hazards that are a direct result of the joining process, as during welding, sparks and molten metal can be ejected. These are most common in arc welding but can also occur in resistance processes. Personal protective equipment (PPE) must be worn by the welder. All clothing should be fire resistant and use of leather aprons, jackets, chaps, etc is recommended.

Grinding is commonly used in preparing metal for welding and during cleaning and rectification of deposited metal. Wheel and angle grinders are favorite tools for their speed of removal of material. These create a hazard, not only for the operator but for adjacent and passing personnel, as the ejected material may be thrown some distance. Obviously the operator needs adequate protection with clothing, gloves, full-face shields and sometimes a dust mask but the whole area also needs screening with curtains to protect others. Fireproof blankets may be used to protect the vehicle from grinding sparks, and care needs to be taken to prevent cross contamination between vehicles and materials in the workshop.

One of the more serious dangers is from the persistent use of hand-held portable power tools, such as grinders, sanders, impact wrenches, and air chisels, which can lead to long-term illness – hand-arm vibration syndrome, also known as 'white finger' or 'dead hand'. Employers are encouraged to purchase only power tools designed and constructed to reduce the risk of vibration, and are required to conduct an assessment and identify measures to eliminate or reduce the risk. You are required to use these power tools only as instructed, and you should report any symptoms, including tingling and numbness in fingers, not being able to feel things properly, loss of strength in hands, fingertips going white, and becoming red and painful on recovery.

Entrapment of body parts of clothing between spot welding electrodes is the main mechanical hazard of resistance spot welding. Ensure that operators and assistants hands and clothing are not in the proximity of the electrodes during closure, as forces greater than 1000N (100kg) are regularly employed, entrapment can result in very severe injury.

In the workshop

Checklist for setting up equipment

Quality Requirements:

- First establish what weld size (minimum diameter) and any other quality requirements are needed for the material and thickness combination being joined.
- Refer to customer standard, in-house standard or national standards, whichever takes precedence.
- Equipment:
- Ensure suitable equipment is chosen to allow the required weld settings to be achieved within the capacity of the machine.
- Ensure that the machine and timer are working correctly and that water cooling is adequate.
- Ensure that any tooling is properly insulated and does not interfere with pressure application or current flow.

Materials:

- Check that the materials meet the required specification.
- Ensure surfaces are free from contamination, rust, paint, etc.
- Make sure that the part fit-up, flange width and edge distance are satisfactory.

Electrodes:

- Decide what tip diameter is required to achieve the target weld size (minimum weld size is usually 70-80% of this value).
- Choose the correct electrode material for the job and an electrode design to suit the access to the part, using electrodes (caps) and holders with an adequate shank diameter.
- Machine or dress electrodes to the required size and ensure electrode alignment is accurate under load on the welding machine.
    - If the electrode condition deteriorates during the job, repair the electrodes with a tip dresser or replace them.

Electrode Force:

- Select the force required which is appropriate for the materials being welded and the electrode tip size being used. Recommended conditions are available. Inappropriate settings can affect weldability and quality.
- Set up force required using a load cell and record the air pressure required to achieve this force.

Weld parameter settings:

- Set up time sequence.
- Squeeze time should be adjusted using a squeeze analyser or initially set long to ensure force is fully achieved before current flow.
- Weld time should be selected according to recommended conditions.
- Hold time is less critical, 5-10 cycles is normally suitable for thin materials e.g. up to 1.5mm thick, and longer for thicker material or where fit-up is poor.

Welding Current:

- Perform test welds on spare material.
  - Make welds at increasing levels of current until the required weld quality is achieved on peel or chisel testing.
- A setting just below that giving weld splash generally gives the best welding tolerance.

Set-up Records:

- It is good practice to record the final set-up conditions used on a job or process sheet.

Setting up the workshop for resistance spot welding:

Documentation: Which documents do you need to have before commencing welding?

Health, safety and environment documents:

……

……………………………………………………………………………………………

Welding standards or quality acceptance documents:

……

……………………………………………………………………………………………

Personal Protective Equipment: List the PPE you must use and perform their pre-use inspection.

……

……………………………………………………………………………………………

Ventilation and extraction equipment (if required): Perform the pre-use inspection, position and operate the equipment.

Notes

Resistance spot welding equipment: Perform the pre-use inspection, check maintenance and calibration records, install the consumable electrodes.

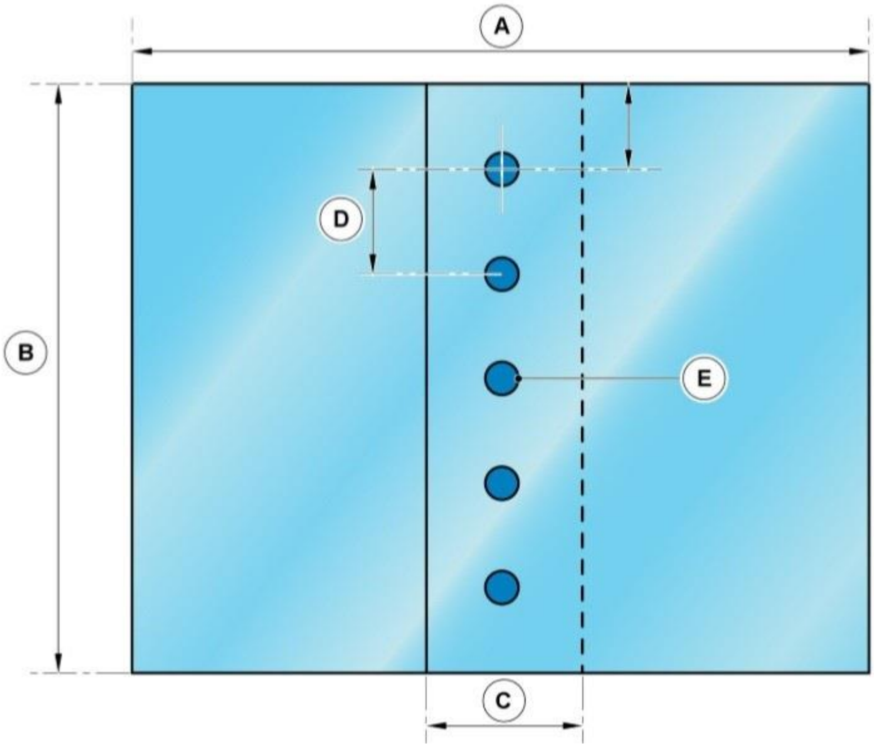
Notes:

2nd Practical Training

Resistance Spot Welding Of Steel To Steel Test Pieces

(2 hours)

Your practical training will involve performing resistance spot welds on two overlapping steel plates. The material shall be two times steel plates of single sheet thickness 0.6 – 1.5mm, the plates may be uncoated or zinc coated.



Item	Description	Item	Description
A	Overall length – 115mm (4.5 inches)	B	Width – 180mm (7.0 inches)
C	Overlap – 35mm (1.3 inches)	D	Pitch – 30 mm (1.1 inches)
E	Resistance spot weld		

Figure 69 - Test piece. Table 14. Source: TWI

Figure 70 - Mole grips / Self-blocking clamps Source: TWI

Figure 71 -Pliers and grips Source: TWI

Figure 72 - Vernier calliper Source: TWI

Consumables
12 steel sheets of 75 x 180 x 0.9 mm.
Tools
Self-blocking clamps.
Resistance spot welding machine.
Pliers or grips
Vernier calliper
Health and Safety
Use: work clothes, gloves, goggles.
Proper ventilation of the place of work is advisable.
Work process
Prepare the test piece
Perform the test piece according to the plan as indicated.
Preparing the plates and clamping

Position the plates in a configuration where one overlaps the other with a flange width of 35mm, as shown in the figure. Clamp the plates in position at both edges with the self-blocking clamps
Setting up the resistance spot welding program
Following the measurements of the test piece, perform the resistance spot weld Select welding parameters according to an instruction or standard, initially select a low current value or heat % Position the test piece between the electrodes and make the first weld If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat %) by approximately 10% of the initial value.
Performing the spot welding test (Part A)
Record all parameters on a test sheet as shown below. Position the test piece between the electrodes and make the first weld (The distance (pitch) between subsequent welds must be 30mm) If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat %) by approximately 50% of the initial value If a weld is made without the occurrence of splash, increase current in small steps (either 0.2kA or + 2.5% heat) Continue increasing current in small steps and welding on test pieces until splash occurs At the end of the test hold one side of the test piece in a clamp and tear the other side open using pliers or grips Measure the spot weld size with a Vernier caliper as shown in the figure. Record the largest and smallest diameter of the weld area and calculate the average, record the data on the data sheet Check to see if the minimum weld size requirement could be met at a stable welding condition before splash (liquid metal expulsion occurred) At the end of welding check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary repair the electrode surface with a tip dressing tool, or replace the electrode with a new one
Repeating the spot welding test (Part B, varied weld time)
In Part A, a spot welding process window was defined for a fixed set of parameters. In Part B, the spot welding parameters will be varied by selecting a weld time either 50% of the time used in part A, or 200% of the time used in part A.
Position the test piece between the electrodes and make the first weld (The distance (pitch) between subsequent welds must be 30mm) If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat %) by approximately 50% of the initial value If a weld is made without the occurrence of splash, increase current in small steps (either 0.2kA or + 2.5% heat)

Continue increasing current in small steps and welding on test pieces until splash occurs At the end of the test hold one side of the test piece in a clamp and tear the other side open using pliers or grips Measure the spot weld size with a Vernier caliper as shown in the figure. Record the largest and smallest diameter of the weld area and calculate the average, record the data on the data sheet Check to see if the minimum weld size requirement could be met at a stable welding condition before splash (liquid metal expulsion occurred) Compare the results to the Part A test to see the influence of weld time on the process At the end of welding check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary repair the electrode surface with a tip dressing tool, or replace the electrode with a new one
Repeating the spot welding test (Part C, varied weld force)
In Part A, a spot welding process window was defined for a fixed set of parameters. In Part C, the spot welding parameters will be varied by selecting a weld force either 50% of the time used in part A, or 200% of the time used in part A.
Position the test piece between the electrodes and make the first weld (The distance (pitch) between subsequent welds must be 30mm) If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat %) by approximately 50% of the initial value If a weld is made without the occurrence of splash, increase current in small steps (either 0.2kA or + 2.5% heat) Continue increasing current in small steps and welding on test pieces until splash occurs At the end of the test hold one side of the test piece in a clamp and tear the other side open using pliers or grips Measure the spot weld size with a Vernier caliper as shown in the figure. Record the largest and smallest diameter of the weld area and calculate the average, record the data on the data sheet Check to see if the minimum weld size requirement could be met at a stable welding condition before splash (liquid metal expulsion occurred) Compare the results to the Part A test to see the influence of weld force on the process At the end of welding check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary repair the electrode surface with a tip dressing tool, or replace the electrode with a new one
Repeating the spot welding test (Part D, varied weld pitch)

In Part D, the spot welding pitch (distance between welds) shall be varied to see the effect on the weld quality
Select preferred welding parameters from Part A, B or C Manufacture an initial spot weld Manufacture the second weld at a pitch of 30mm Manufacture the 3rd weld at a pitch of 60mm Manufacture the 4th weld at a pitch of 10mm At the end of the test hold one side of the test piece in a clamp and tear the other side open using pliers or grips Measure the spot weld size with a Vernier caliper as shown in the figure. Record the largest and smallest diameter of the weld area and calculate the average, record the data on the data sheet Compare the results to the previous tests to see the influence of weld pitch on the weld quality At the end of welding check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary repair the electrode surface with a tip dressing tool, or replace the electrode with a new one

Example spot welding data sheet

<table>
<tr><td colspan="5">Operator Name:

Date:

Welding machine:

Standards / procedures followed:

Vehicle / component:</td><td colspan="2">Material 1:

Material 2:

Material 3:</td></tr>
<tr><td colspan="5">Electrode details

Water cooling

Test piece dimensions:

Weld pitch:

Adhesive used:

Adhesive expiry date:</td><td colspan="2">Squeeze time:

Weld time:

Hold time:

Electrode force / pressure:

Transformer tap:</td></tr>
<tr><td>Weld number</td><td>Current (kA or heat %)</td><td>Weld diameter d1 (mm)</td><td>Weld diameter d2 (mm)</td><td>Average diameter

d1+d2/2 (mm)</td><td>Weld splash (expulsion)</td><td>Comments observations</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Competence Unit 2

Steel/Aluminium/Multimaterial Structural Body Construction – Adhesive Bonding and Mechanical Fasteners Repairs

2.1 MATERIALS USED IN THE MANUFACTURE OF VEHICLE BODIES

The material traditionally and mainly used in the manufacture of vehicle bodies is sheet steel, although it has gradually been giving way to other alternative materials, such as plastic and aluminium. This is due to the optimum properties that these materials show for certain applications.

The bodywork of today's automobile can be taken to be a conglomerate of various types of metals and plastics, each one applied where its properties are most suitable for specific needs and requirements. Many of the solutions adopted nowadays by the majority of automobile manufacturers lead to the coexistence, on one single vehicle body, of diverse materials such as steel, aluminium and plastic, and even composite materials. These materials can also interact together for one single part, giving rise to what are known as hybrid joints.

Steel

Steel is an alloy of iron and carbon with a relatively low carbon content; it is rarely over 1.76%. The fact that this is the material used in the manufacture of vehicle bodies is due to a series of circumstances that turn it into an ideal product for the required needs. In addition, it adapts very well to another series of requirements of the automobile:

- Steel is fit to receive various surface coatings (electrolytic coatings, phosphatisation, etc.) and, finally, a finish with quality paintwork.
- Good resistance to corrosion by use of pre-coated steels (usually zinc coated).

- The possibility of improvements in the final weight of the structure, by using high and ultra-high strength steels.
- Easy to shape.
- Good weldability.

The steels currently in use in the manufacture of vehicle bodies can be of very different types.

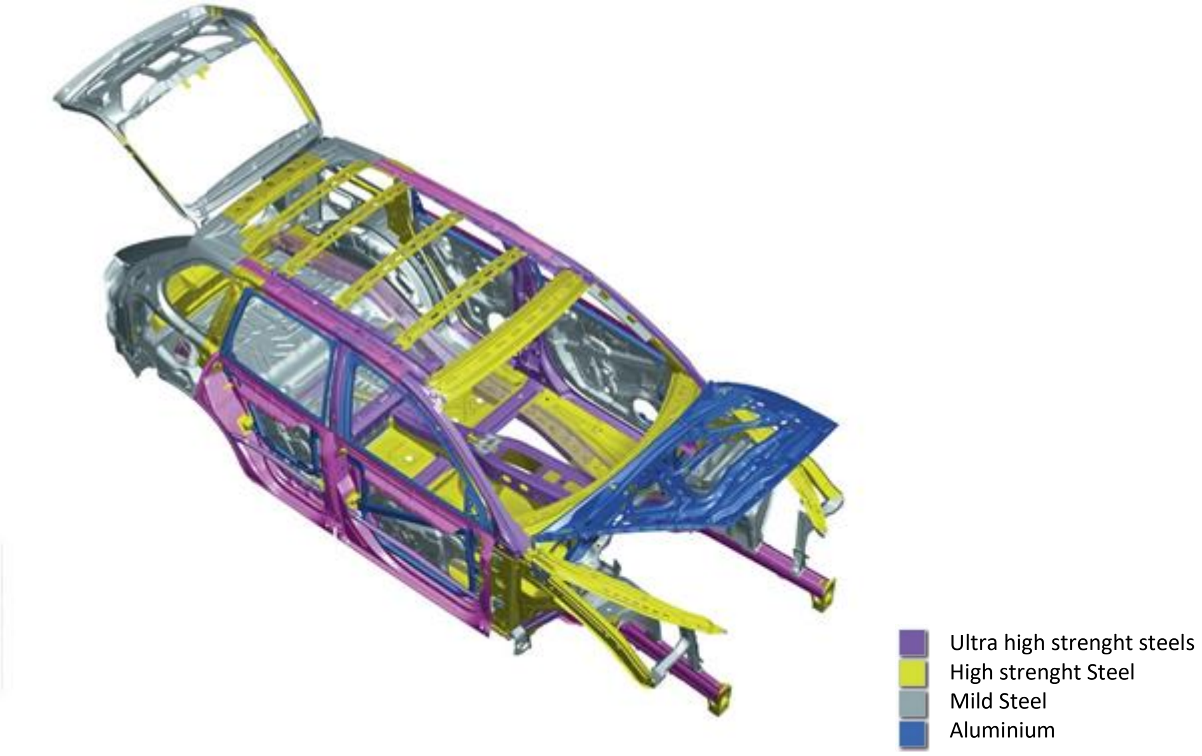


Figure 73 – Steels in car body manufacture. Source: https://www.autosteel.org/-/media/files/autosteel/great-designs-in-steel/gdis-2008/12---advances-in-ahss-for-automotive-applications.ashx

Aluminium

Since the middle of the 1970s, the percentage use of aluminium in automobiles has risen almost threefold. Today, more than a hundred different parts of a vehicle are manufactured with aluminium, and its market penetration continues to grow.

Aluminium is now being used in a large number of vehicles for the manufacture of external panels for large surface areas, such as bonnets and side panels. This has enabled a savings in weight of between 40% and 60%, compared with the same part manufactured in steel.

The benefits of aluminium in regards to weight saving, fuel consumption, safety and environmental impact, are recognised by all the manufacturers.

The combination of low density, high strength and excellent resistance to corrosion make aluminium alloys an attractive material for the manufacture of vehicle body panels and, even for the integral manufacture of vehicle bodies with this material.

There are numerous aluminium alloys with different commercial compositions; however, there are three that are most used in the manufacture of bodywork: copper-aluminium, aluminium-magnesium and aluminium-magnesium-silicon alloys.

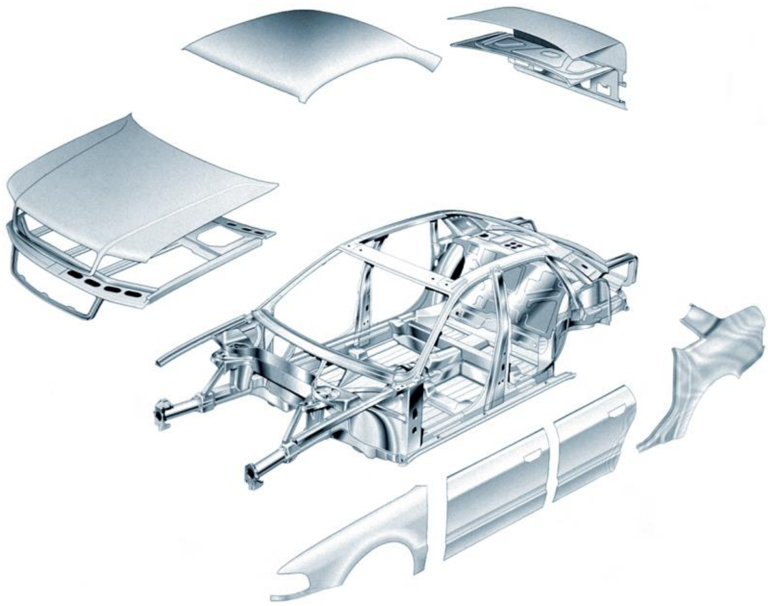


Figure 74 - Complete aluminium vehicle body. Source: https://www.audi.pt/pt/web/pt/modelos/layer/tecnologia/audi-space-frame.html

Among the advantages of aluminium for the manufacture of vehicle bodies, of particular note are:

- Its specific weight is, approximately, a third of that of steel.
- Aluminium oxide forms a thin barrier layer on the metal surface when the metal is exposed to air. If the oxide is scratched or damaged, it quickly reforms giving the metal a high level of natural corrosion protection. However, exposure to salt water can still cause corrosion.

- Aluminium alloys can be recycled easily at the end of their useful life.
- Less energy is needed for reuse than for steel.
- It shapes well.
- It is suitable for joining by means of MIG (Metal Inert Gas) welding.
- It has a high capacity to absorb energy in a crash.
- It is not toxic.

Plastic

It is customary to denominate all compounds of organic nature that are easily deformable when subjected to pressure or temperature under the generic name of *plastics*; however, not all plastics behave this way. Due to the inclusion of a series of additives or reinforcements, in particular glass or carbon fibres, these fibres reinforced composite materials have extremely high strength to weight ratios.

Over the last few decades the use of plastics in industry has increased dramatically.

The automobile industry, needless to say, has not been untouched by this trend, and uses plastic practically to the exclusion of anything else in the manufacture of elements such as bumpers, hubcaps, and a host of parts within the interior of the vehicle. An average typical automobile today owes approximately 120 kg of its weight to these materials, which is around 10% of the total vehicle weight.

Plastic use is not only limited to the manufacture of accessories and small parts; it has also taken on a significant role in the manufacture of panels and vehicle body elements or in the case of fibre reinforced composites, entire vehicle bodies.

The advantages of plastics are:

- Good dent resistance. In this case, plastic bodywork tolerates the impact by flexing slightly, and recovering its original shape after the impact.
- The bodywork is not affected by corrosion, which is a major disadvantage for steel bodywork. Steel corrosion is even responsible for limiting the life of the automobile.

- Plastic vehicle bodies are much lighter than their steel equivalents. For example, it can be stated that a bonnet manufactured in plastic weighs around 9.2kg, while a steel bonnet can reach 17kg.

Composite material

The term "composite material" is reserved for those materials (generally two-phase) made up of two or more different materials which, when properly combined, improve the final properties.

Within the field of composite materials, three types can be distinguished, according to the type of matrix used: organic matrix composites, ceramic matrix composites and metallic matrix composites.

In the automotive sector we are concerned with the ones most often used, organic matrix composites, with an addition of fibres to achieve extremely high strength and stiffness. Fibres are typically made from glass or carbon (and in some instances aramid). The fibres can be arranged in a very wide variety of patterns to achieve the specific mechanical performance requirements.

The matrix plays the role of the joining element, shaping the composite material geometrically. It is normally relatively flexible but not very strong. Its main mission is to keep the fibres united and unified, transmitting the forces of one type of fibre to the other.

As well as ensuring the fibres join together, it also provides hardness, hermetic sealing, and resistance to compression.

2.2 ADHESIVE BONDING IN CAR BODY REPAIR

Adhesive bonding consists of using a non-metallic substance which undergoes a physical or chemical hardening reaction causing the parts to join together through surface adherence (adhesion) and internal strength (cohesion). It is a good practice to ensure that the joining surfaces are properly cleaned, since contaminants may prevent the adhesive from bonding to the base material. The adhesive requires time to cure, which should be taken into account during the repair procedure.

Adhesive bonding enables the joining of different types of materials (*e.g.* steel and aluminium), which is a capability a welding technique often lacks. Another advantage of this joining method is that it does not generate thermally or mechanically weakened zones around a joint.

Although adhesive bonding can be used in many applications within the automotive industry, from sealing to glass bonding, the focus here will be on its use within repair procedures. Adhesive Bonding can be used to attach a replacement component to the vehicle as well in the manufacture of the new part. Structural bonding repairs are possible if the workshop complies with the required conditions. If it cannot be guaranteed that the adhesive can withstand the mechanical stresses predicted, then mechanical fasteners may be used as well.

2.2.1 Types of Adhesives

An adhesive is a material that is capable of establishing bonding processes between two adherent working pieces and developing cohesion strengths. As a result, it provides an internal resistance to the separation of the two pieces, without structural changes being made.

In the field of adhesives, different classifications can be established, taking into account different concepts: physical form, chemical base, physical-chemical characteristics of the joint, structure of the adhesive once cured, etc.

In the field of car body joining, the most frequently used adhesives are organic-synthetic, the curing of which is performed by chemical reaction, epoxy resins (EP), polyurethanes (PUR) and cyanoacrylates (CA). (Regulation UNE-EN 923 lists all the types of adhesives, terms and definitions).

Epoxy resins

Epoxy adhesives are made up of an epoxy resin and a hardener. They consist of one or two parts, monocomponent resins or bicomponent resins. In car body production lines, the main adhesive used is a single component epoxy resin, which cures during the thermal cycle of the vehicle coating process (E-coating). In vehicle repair, the most common adhesive type is the two-component epoxy, where the chemical curing reaction takes place at room temperature.

There are different resins and hardeners, which give rise to a wide variety of formulations and performances.

Their main characteristics are:

- Excellent adhesion on different substrates, such as metals, plastics, ceramics, etc., due mainly to their capacity for moisture absorption and low viscosity.
- If the preparation and application of the adhesive has been correctly undertaken, they generally offer good resistance to faults due to cohesion.
- These resins cure without releasing water or other sub-products, thus avoiding trapping gases and porosities in the join. During curing, only a slight contraction occurs. For two component epoxies, curing is undertaken at ambient temperature, thus allowing the choice of simple and economical drying processes.
- Their curing time varies widely, depending on the type of resin; generally, the ones that have a quick time are more elastic than those with a slow curing time.
- They have good resistance to damp and good chemical resistance.
- They are available in tins for mixing and manual application, or in cartridges for application with a gun and mixing tube.

Polyurethane

Polyurethanes are synthetic polymers based on the chemistry of the isocyanate, which arise from the reaction of a polyol with an isocyanate. They can be in the form of monocomponent or bicomponent adhesives.

✓ **Monocomponent polyurethanes (1K)**

Monocomponent polyurethanes react with the ambient moisture to generate an elastomer rubber. The polymerisation reaction takes place from the outside of the bead towards the inside, and this circumstance limits the thickness of the bead, and has influence on the curing times.

Their main characteristics are:

- Low solvent content.
- Drying by means of the absorption of moisture.
- The drying process is slow and from the outside in.
- High elasticity.
- Sensitivity to ultraviolet rays, which attack and decompose them.
- Their properties, from the structural point of view, are inferior to those of the bicomponent polyurethanes and epoxy resins.
- Available in tubes or bags for application by means of extrusion.
- Applied in window bonding, door panel joining and joint seals.

✓ **Bicomponent polyurethanes (2K)**

Bicomponent polyurethanes polymerise because of the reaction of the isocyanates with the corresponding polyols or amines.

Their main characteristics are:

- They do not need ambient moisture to polymerise. Curing is produced by the chemical reaction of their components.

- Drying process is relatively swift.
- More rigid than monocomponent polyurethanes.
- Sensitivity to ultraviolet rays, which attack and decompose them.
- Normally available in cartridges for application by extrusion.
- Applied for window bonding and the bodywork parts joining, both in steel and in aluminium bodies.

2.2.2 Applications of Adhesive Bonding

Adhesive bonding is used in the automobile body in a multitude of applications, either exclusively or in combination with a complementary mechanical joint (hemming, riveting, resistance spot welding).

- Among the main applications of adhesives in bodywork are the below:
- Hemmed joint fixing of trim elements:
- Sealing joints for rubber.
- Soundproofing coating panels.
- Door trims.
- Trims to roofs, etc.

Joining of metallic elements to each other, with a complementary mechanical joint where needed; for instance, joining of door and bonnet panels to their frameworks, bonding of wings, etc.

Joining of plastic materials to each other in vehicle bodies which have panels built with this type of material.

In addition, and above all, adhesives have an ever-broader presence in the manufacture of vehicle bodies, in applications such as:

Glass-metal joints. The most representative case is the bonding of windscreens, a technique that increases the rigidity of the vehicle body at the same time as improving the sealing and the retention of the windscreen itself in the event of a collision. The use of adhesives for this type of join helps to increase the torsional rigidity of the vehicle body by 10%.

Many of the closing panels of the vehicle body are made up of an external panel joined to an inside framework all along its periphery, by means of mechanical crimping. Today, adhesives are being used in these tabs, which means an improvement in strength, in rigidity and in anti-corrosive protection.

Plastic-metal joints. Adhesives enable the joining of two different materials such as plastic and metal. This solution is adopted often in vehicle bodies that combine external panels manufactured in polymer materials on steel frameworks.

Likewise, they have a very important field of application in the manufacture of insulation and in vehicle bodies for industrial vehicles, such as buses, caravans, etc.

In repair shops devoted to the repair of vehicle bodies, more and more diverse operations turn to the use of adhesives. Examples include the replacement of bonded glass, the total or partial replacement of external elements made of metal or compound materials (resins with fibreglass and carbon fibre), the replacement of structural elements and the repair shop of plastic materials.

Figure 75 - Bicomponent adhesives. Source: CESVIMAP

Figures 77-79 demonstrate where adhesives are used in a car body. Not only are they purely illustrative, they also concern the original manufacturer application. During repair procedures other areas may be subject to adhesives.

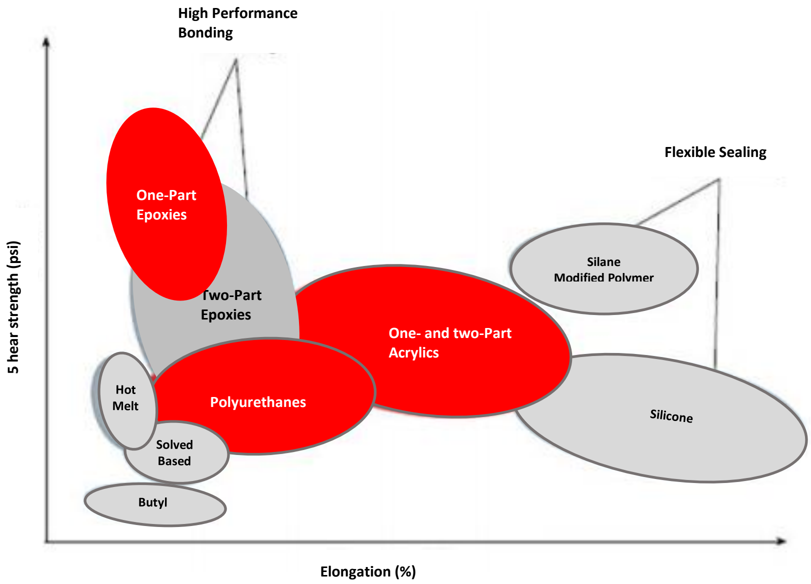


Figure 76 - Adhesive Shear Strength vs Elongation Chart. Source: https://www.european-aluminium.eu/resource-hub/aluminium-automotive-manual/

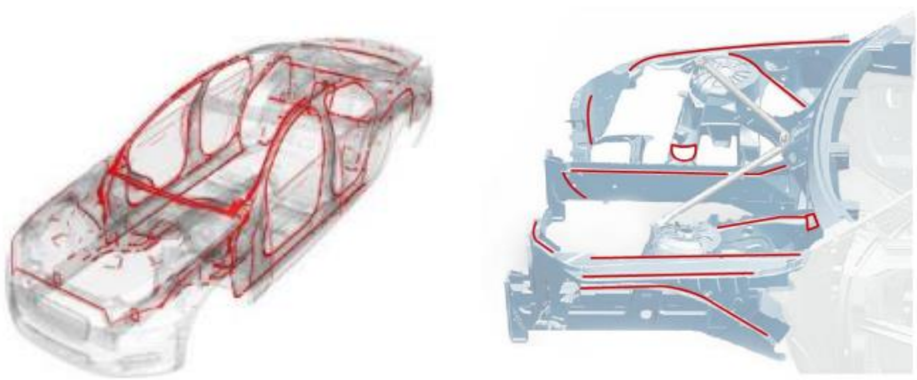


Figure 77 - Jaguar XJ Adhesive Bonding & BMW 5 series Adhesive Bonding. Source: https://www.european-aluminium.eu/resource-hub/aluminium-automotive-manual/

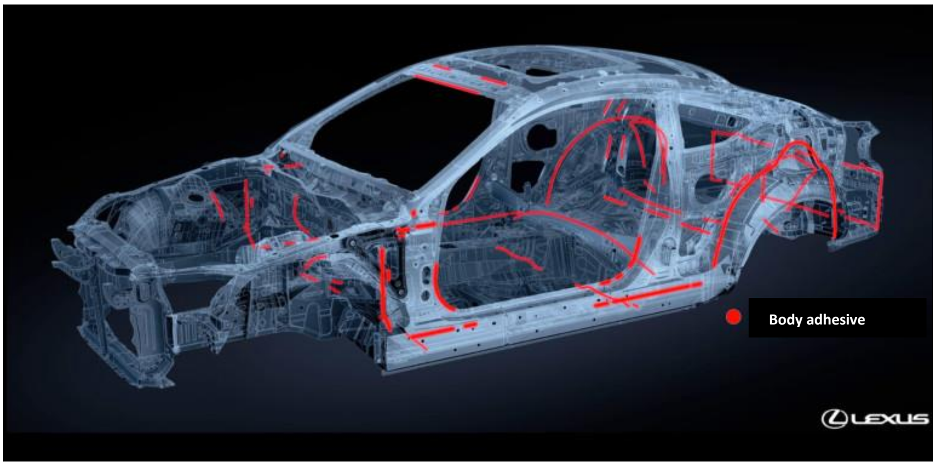


Figure 78 - Lexus RC Adhesive Bonding – body adhesive in red. Source: https://blog.lexus.co.uk/

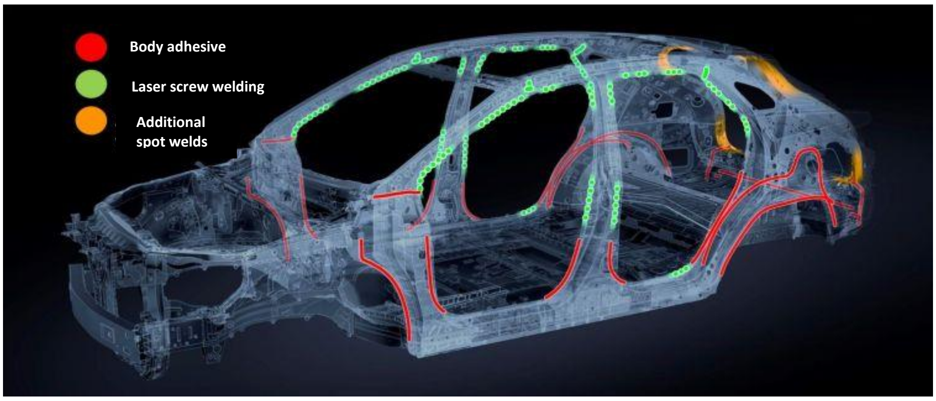


Figure 79 - Lexus RX Adhesive Bonding Source: https://blog.lexus.co.uk/

2.2.3 The characteristics of adhesives

In general terms, an adhesive is a product that is available as a semi-fluid or paste, it is non-metallic, with capacity to bond materials if their surfaces are brought into contact. After the bonding process, the adhesive reaches a final solid state that is capable of establishing forces of attraction to resist the tensions that tend to produce their separation.

It is interesting to note that the different joining techniques and processes do not generally compete with each other, but should rather be considered as complementary.

Advantages of adhesives bonding

Adhesive bonds have a series of advantages over other joining systems, making their use in a wide range of applications particularly attractive. Below is a list of the main advantages and disadvantages of adhesive bonds, which should serve as an aid when choosing the most suitable joining method.

In design:

- The main advantage of the use of adhesives, as opposed to other joining techniques such as welding, riveting or mechanical joins, is a uniform distribution of tensions, without the presence of points of concentration that could provoke premature failure of the material due to fatigue.

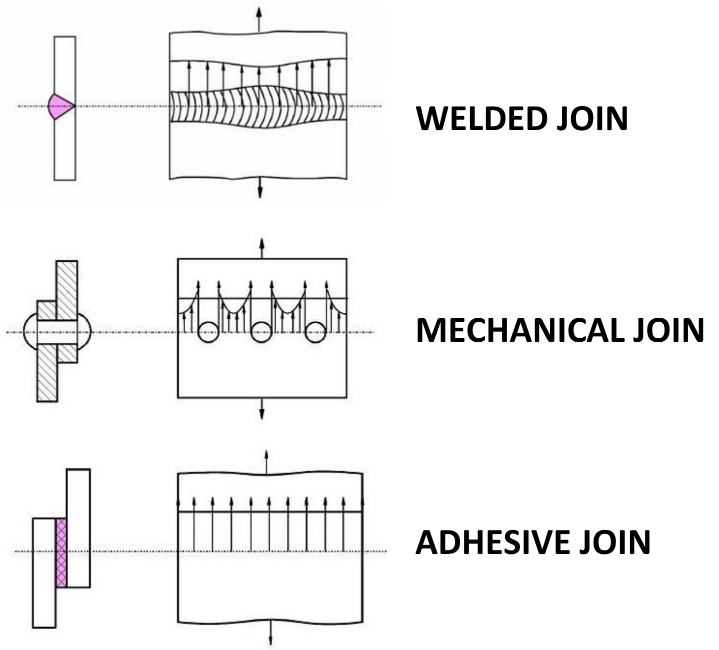


Figure 80 - Distribution of forces. Source: CESVIMAP

- Adhesives can join materials of a different nature together. When joining metals of different electrochemical properties, the join acts as insulation, avoiding corrosion problems.
- This technique provides joints with a suitable balance of rigidity and strength.
- It behaves well in regards to fatigue.
- It provides smoother joints, without marks or unevenness.

- It provides lighter structures, with potential for weight saving.
- It enables the joining of very thin materials.
- **In production:**
- One single operation can combine bonding with sealing.
- It eliminates the problems caused by heat in the welding processes (corrosion, structural changes in the material, deformations, etc.).
- It provides very clean bonded joints, avoiding the need for further finishing or "dressing" operations to the joint.
- Adhesive application can be automated, optimising operation times.

In service:

- Joint corrosion is reduced.
- Behaviour in regards to fatigue is improved.
- Car body's structural stiffness, energy absorption in crash and noise vibration harshness properties are improved.

Limitation of adhesives bonding

Among the main limitations involved with the use of adhesives, are the following:

- Limited resistance to temperature, with strength decreasing as temperature increases. As a result, adhesives cannot be used in joints that will be subjected to high temperatures. However, car body structural adhesives usually have guaranteed properties in the range of -30oC to + 85oC, which represents the expected extremes of car driving environment.
- The bonding process depends on time, with a minimum bonding period that must be respected. The joint has to be fixed in place by a jig or additional spot weld or fastener until the adhesive has cured or shows a minimum strength so that it can be manipulated.
- Polymer adhesives are not as strong as metal. To make up for that lack of strength, the technique is to increase the area of contact surface.
- The parameters and conditions required to achieve a good bonded joint, such as pressure, temperature and bonding periods are very precise, as the process tolerance can be small.
- Adhesives have very high shear strengths, but weak when loaded in peel or cleavage mode, and this has to be taken into account when designing the

joint. For this reason, the joints must be designed specifically for use with adhesives, and operators should not adapt other joints **designed for** other joining systems.

- Adhesives have limited stability and storage life, and expiry dates and storage environment requirements must be respected.
- The properties of adhesive joints can change over time because of adhesive aging and environmental exposure. These effects need to be taken into account when designing a process.

2.2.4 Comparison with other joining methods

Joining techniques are applied to achieve a series of requirements, amongst which the following factors are of importance:

- The nature of the materials to be joined, where an appropriate joining technique should be selected, which is suited to the material characteristics.
- Structural needs, various joining process exhibit differing behaviours under differing loading modes
- Accessibility in the area to be joined, different joining processes have specific geometric and special requirements and in tight spaces not all processes can be applied. Likewise, some processes require only single sided access whereas other processes require access from both sides.
- Repair or how often the joining elements should be replaced.
- Degree of freedom in design of the parts.

Normally, in the manufacture of automobiles, we speak of assembly when referring to parts that have a fixed joining system - generally welding, and of mounting when the reference is to parts that have a joining system that allows easy dismounting and mounting.

All the joining systems found in a vehicle body can be classified into three main groups:

- **Removable joints**: these enable the parts that they join to be removed as often as required.

- **Articulated joints**: these allow a certain freedom of movement between the elements that are fitted together.
- **Fixed joints**: these do not allow separation of the joined elements once the joint has been carried out. To remove them, the joining system would have to be destroyed, causing damage to the parts joined together.

Main Joining Systems Used In Vehicle Body Manufacture	
FIXED JOINTS	• Welding – Resistance spot welding – MIG/MAG welding – MIG-Brazing – Laser welding Rivets – Blind rivets – Self-piercing rivets. • Adhesives • Folded or hemmed joints • Clinching
REMOVABLE JOINTS	• Screwed joints Bolted joints Clips and fasteners

Table 15 – Main Joining Systems used in vehicle body manufacture

Resistance spot welding is widely used in the manufacture of high volume flat sheet metal products; a steel automobile is a good example of this. In the automotive sector, it has been the main joining method for many years, to the extent that a typical steel vehicle body carries between four and six thousand resistance spot welds

The main explanation for this situation lies in the advantages that its use provides, among which we would highlight:

- Speed of operation, with less than a second needed per weld, as well as the possibility of automating the whole process.

- Low level of deformation and structural changes in the material, since heating is small and localised.
- High final joint strength.
- No call for going over or final finishing operations.
- Ease of handling and low training costs in manual operations.
- Easy subsequent dismounting.
- Greater anti-corrosive guarantees.

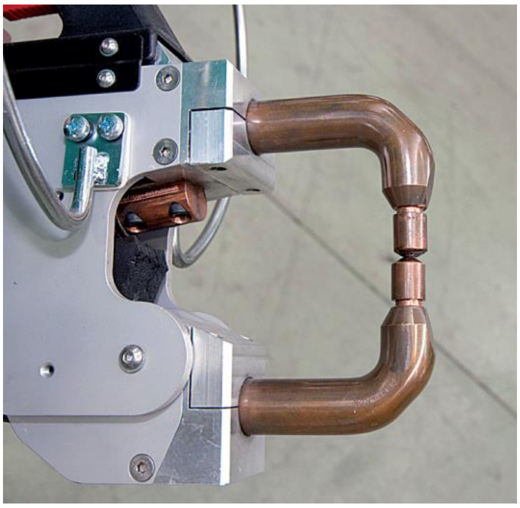


Figure 81 - Spot welding electrodes. Source: CESVIMAP

Figure 82 - Test on the characteristics of the spot, subjecting it to a shearing force until breakage. Source: CESVIMAP

LASER welding

LASER stands for Light Amplification by Stimulated Emission of Radiation. In other words, this is a light (electromagnetic wave) with special characteristics.

The high intensity beam of light carries a very large density of energy in a small area, this energy can be used to melt metal very rapidly and form a weld.

Lasers can be used as a close-coupled system, where a robot manipulates a welding head, or as a remote system where a scanner translates the beam at extremely high speed within a defined area. The laser welding process is commonly used on steel components without an added filler wire; this process is termed autogenous laser welding. A filler wire can be used in much the same as the MIG/MAG process for both steel and aluminium. Another very common laser application is laser brazing, where a copper alloy filler wire is used to make very smooth cosmetic finish joints that can be found on the exterior surface of a vehicle.

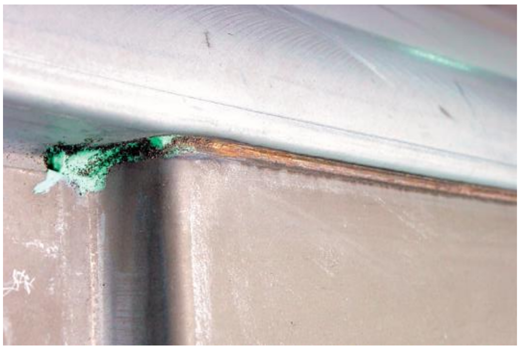


Figure 83 - Laser brazed roof. Source: CESVIMAP

Riveting

Riveting is one of the oldest joining techniques in existence, and at the same time one of the most tested. In general, it consists of joining two or more elements by means of metal pins. In a modern car, the main riveting process is called self-piercing riveting, which is used to punch a rivet into two or more sheets of metal and flare the rivet into a die to lock the joint in place. Also used in car manufacture are blind rivets (or pop rivets), which are pushed into holes previously made in the sheets to be joined. The formation of two heads at the ends of the pins keeps the elements solidly joined.

The use of rivets is a very versatile joining method, characterised by the fact that:

- It can be used on different materials; in this sector, it is applied on steel, aluminium and plastics.
- It can be used for different purposes, not only as a joining element.
- It is available in a great variety of shapes, sizes and finishes.
- Production cost is significantly more expensive than resistance spot welding.

Figure 84 - Blind rivets. Source: CESVIMAP

Figure 85 - Self-piercing rivets. Souce: CESVIMAP

Hemming or Folded joins

Hem flange joints are made from two pieces of sheet metal by folding the edges back on each other one or more times. These joints are made, generally, on thin pieces of steel or aluminium metal, on thicknesses of between 0.5 and 0.9 mm.

It is the typical joining system for door panels, which are hemmed all around their edges, combined with a semi-structural adhesive to reinforce the joint.

It is, therefore, a shaping technique using cold plastic deformation. The quality of the results and the minimum radius of folding will depend on factors like the type and properties of the material to be folded, the thickness of the sheet metal and the utensil, and the parameters of the shaping process.

In these types of joints, the hermetic seal of the joint can be guaranteed by means of suitable polyurethane or epoxy sealants.

In manufacture, hem flange operations are performed either in a simple pressing operation or on parts that are more complex by a series of robotic rollers. In vehicle repair, the sheet metal workers will perform hemming manually with the combined action of a dolly and hammer.

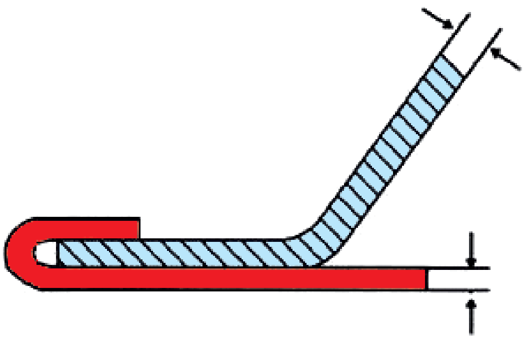


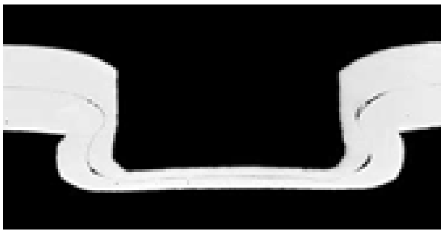
Figure 86 - Folded joint. Source: CESVIMAP

Clinching

Clinching is a technique for joining materials directly, generally sheet metal, by means of a process of local shaping, which does not call for any further joining element.

A punch is applied to the two pieces of sheet metal to be joined, pushing them inside the body of a die; the materials deform and flare to create an interlocked joint. This results in the creation of a "button" closing the two pieces of sheet metal together.

This technique can be used for aluminium sheets, steel sheets or multi-material joins, in other words, a combination of aluminium and steel.



Figures 87 and 88 - Linch joint. Source: TWI Ltd.

Hybrid adhesives

This is a technology which has the main attributes of structural and of instantaneous adhesives, created with a hybrid technology; this allows quick and lasting repairs to be performed, as well different substrates to be joined under all types of circumstances. In addition, these adhesives offer major solutions to different challenges and offer greater performance and versatility, ensuring optimum and safe functioning for users. Among the most important characteristics to be highlighted, are that this technology has excellent strength in extreme conditions of temperature and moisture, high tenacity, great filling capacity, with very short setting times, as well as being odourless and not being inflammable, reducing handling risks.

Figure 89 - Hybrid adhesives. Source: CESVIMAP

Acrylate

These are a special type of acrylic adhesives; their curing is undertaken by means of the reaction with the moisture contained in the substrate, while the join is kept under pressure.

Among their main characteristics, those of particular note are:

- Capacity to harden at room temperature, without call for catalysts.
- High speed of join execution, with very short handling times.
- Wide versatility, with a great range of substrates.
- They need only a small quantity of adhesive.
- They have low capacity to fill in loose gaps.
- The joins show low resistance to impact and to temperature.

This type of adhesive is usually suitable for bonding plastics and rubbers.

2.2.5 Mechanical testing

The object of mechanical testing is to determine the mechanical characteristics of, strength, elasticity deformation, deformation and behaviour and reliability over time.

In 1979, Schliekelmann performed a test on the comparison of resistance to fatigue of different joining methods of the same sizes. The results show that a riveted joint tolerates 211,000 cycles of life to fatigue, a joint that is riveted and bonded with elastic adhesive 420,000 cycles, and a joint that is riveted and bonded with bicomponent epoxy 1,500,000 cycles.

For these reasons, the manufacturers subject adhesives to test methods and models of durability prediction.

2.2.6 Adhesives technical application in car body repair

According to regulation UNE-EN 923, **adhesion** is the state in which two surfaces are kept joined by means the joining of surfaces, and **cohesion** is the state in which particles of a simple substance join by means of intermolecular forces. To ensure a successful joint, it is vital for there to be intimate contact between the substrate and the adhesive.

One of the requisites needed, although not sufficient by itself, so that adhesion between two materials can take place is that the material ‘wets’ the other, and this depends on the surface energy of the substrate and on the surface tension of the liquid. If the wettability of a surface to the adhesive is good, then the adhesive spreads naturally, in the case of poor wettability the adhesive will not spread and will stand up off the surface with a high edge angle.

Figure 90 - Contaminated substrate (poor wetting), Clean substrate (good wetting). Source: CESVIMAP

The viscosity of a fluid characterises its capacity to flow, depending on its cohesion, in other words the resistance that its molecules show to separation and its speed of movement.

Design of the joint

From a mechanical and strength point of view, the use of adhesives brings a series of advantages over thermal joints (welding) and mechanical joints (rivets, screws, ...); adhesive joints provide a uniform distribution of stresses, instead of local peaks of high stress as are found with spot welds and rivets.

The behaviour of adhesives depends on the type of load to which they are subjected. In general, adhesive joints are very resistant to shearing stress, compression and traction; however, their strength in peel and cleavage can be much weaker.

With regards to peel loading, the stress is concentrated into a small area at the edge of the joint, and local mechanical overload occurs, the resulting crack then propogales easily through the joint line. A joint is particularly susceptible to failure in peeling / cleavage mode when one or more of the substrates joined is flexible.

In cleavage loading, the stress acts on one of the sides of the joint, and the rest of the joint remains with barely any tension. Generally, joints with rigid substrates are more likely to suffer cleavage failure. From this point of view, the joints produced with adhesives must be designed so that they are mainly loaded in shear and compression, and the design of joints should avoid peel and cleavage loading. To a lesser degree, traction forces should also be avoided, since if the loads do not act in a perfectly axial manner, they will lead to tearing stresses.

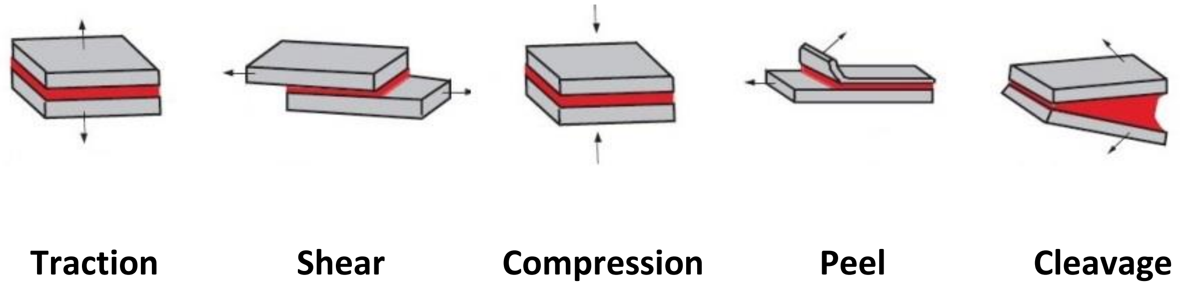


Figure 91 – Adhesives Behaviour. Source: CESVIMAP

The basic premises in the design of a joint with an adhesive are:

- The strength of the joint, which is dictated by:

  - ✓ The bonding area.
  - ✓ Strength of the adhesive.
  - ✓ Strength of the substrate.
  - ✓ Distribution of stresses.

- The joined area must be large enough to withstand the load to which the joint will be subjected when put into service.
- The adhesive coat must be of the appropriate thickness. The strength of the joint decreases, in many cases, with greater adhesive thickness. However, in the case of flexible or gap filling adhesives large thicknesses may be required.
- The joint design should be such that the joint is only subjected to shear and/or compression loading.

In a vehicle body the majority of components are made of thin sheets of metal, the types of joint most often used are flat stacked joints with overlapping flange areas. For their design, advantage is taken of the ease that the sheet metal (above all mild steel sheets) offers for bending and curving, and a range of configurations can be obtained to avoid the appearance of peeling and tearing forces in the joint.

Substrate surface preparation

Adhesion is a surface phenomenon, in other words, of intimate contact between adhesive and substrate. Any foreign body will cause interferences and will hinder this contact. For this reason, not preparing the surface properly will lead to adherence failures, which normally translate into unacceptable results.

In general, the objectives sought with surface preparation, as a prior step to the adhesion process, are:

- To eliminate the formation of a "weak coat" on the substrate.
- To maximise intimate contact between adhesive and substrate.
- To create a specific topography of the surface, which will increase contact and serve as mechanical anchorage for the adhesive.
- To protect the surface of the substrate before the adhesion operation is carried out.

The first step in the preparation of surfaces will be to eliminate paint or clear coats that may have been applied to the zone to be joined. Traces of oil, grease or any other dirt should be eliminated with a degreaser suitable for the adhesive that is to be used.

Acetone, trichloroethylene and perchloroethylene may be considered suitable, but alcohol, petrol or clear coat solvents should not be used.

SURFACE TREATMENTS
CLEANING AND DEGREASING • Scrubbing • Immersion
MECHANICAL TREATMENTS • Sanding • Brushing • Grit blasting
PHYSICAL TREATMENTS • Blow-torching • Plasma
CHEMICAL TREATMENTS • Application of adherence promotors and primers

Table 16 – Surface treatments

Nonetheless, adhesives manufacturers usually have a range of cleaning products for the different surfaces, which are compatible with their adhesives, and it is advisable to use these, since as well as cleaning, they will activate the surfaces for the bonding.

Certain materials, before being cleaned with solvent, need surface activation with mechanical means (sanding, nickel scouring, grit blasting, etc.).

Cleaning will be carried out with cellulose paper soaked in the cleanser; the zone should always be rubbed in the same direction, and the paper should be changed frequently. Rubbing in circles will only lead to a redistribution of the dirt.

The use of cleaning rags is not recommended, since they are likely to be reused and there is therefore a risk of using dirty ones, which will not lead to effective cleaning.

Most manufacturers recommend specific primers for each type of material to be joined. Primers have three basic functions:

- They work as a chemical inhibition barrier, which will prevent the treated surfaces losing the conditions that have been achieved; for instance, they impede a surface oxidation in the case of metals.
- They will help the adhesive to work not just through surface adhesion, but also create a chemical interface between the substrate and the adhesive, which improves the adhesion.
- They act as a protector in the case of bonding transparent materials to avoid the ultraviolet radiation of sunlight making certain adhesives deteriorate.

The application of primers will be performed with a paintbrush or a swab, and these should not be reused for different types of primer applications.

The drying times recommended by the manufacturers must always be respected, both for cleansers and for primers.

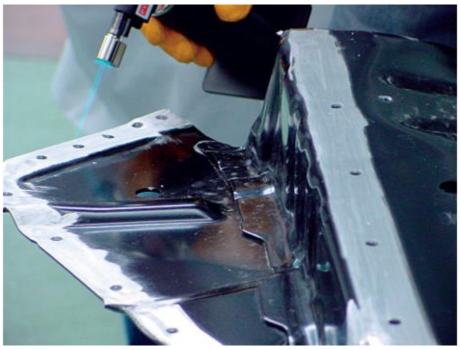



Figure 92 and 93 - Specific equipment for blow-torching & Blow torching the joint. Source: CESVIMAP

There are cases where the manufacturer may recommend blow torching the zone, in order to increase the final adherence of the product, as may be for aluminium and plastic deriving from polyolefins (>PP<, >PE< and their alloys). There are specific kits on the market for this type of treatment, composed of a small gas blowtorch.

When working with a direct flame, any risk of combustion must be removed beforehand.

Choice and preparation of adhesive

There are a host of adhesives and formulations on the market, with different properties and characteristics, without there being a universal adhesive for all types of application.

In order to choose the right adhesive, consideration should be given to factors such as:

- Types of substrates to be joined, given that the adherence of the adhesives depends on the substrate.
- Surface finish of the parts to be joined.
- Types of products, solvents, oils or other contaminants that may be in contact with the join.
- Maximum and minimum temperatures that the joint will endure, and if these temperatures will be constant or intermittent. This factor is particularly relevant in joints with materials with different thermal coefficients, such as metal-plastics; in this case an adhesive should be applied which is elastic enough to allow a good distribution of the stresses which those temperatures will cause.

- The rigidity of the joint and of the elements to be joined will partly condition the rigidity of the adhesive used. The elasticity of the adhesive will adapt to the elasticity of the substrate, and rigid adhesives should not be used to join flexible elements.
- Size and type of demand that may have to be endured.
- Special requirements, such as thermal or electrical insulation, corrosion prevention, etc.
- If the joint is to be spot-welded through the adhesive.

In any case, in order to make a good choice, the specifications set out by the adhesive manufacturer must be followed.

When using monocomponent adhesives, these are provided ready for use, with no prior preparation needed. They can be applied directly or with an extrusion, manual or pneumatic gun.

However, if using bicomponent adhesives, they must be uniformly mixed and, in the proportions, indicated by the manufacturer, prior to their application. This mixing can be performed in two ways, automatically or manually.

Automatic mixing

Most bicomponent adhesives are sold in double cartridges of different capacities, and with the mixture proportion given in the design of the cartridge itself. The diameters of each chamber have the same ratio as the proportion of mix in volume of each compound (1:1, 2:1, 4:1...).

Figure 94 - Proportion of products. Source: CESVIMAP

For application, a specific extrusion gun is used, and a tube or nozzle. This nozzle has a spiral inside, which mixes them together, as the products run along the spiral during application. All the same, it is advisable to throw away the initial part of the product that is released to ensure a homogeneous mixture.

Manual mixing

Manual mixing can be carried out directly, either with a spatula, or in a receptacle, depending on the viscosity of the products. In both cases, both spatulas and receptacles must be completely clean, avoiding contact of the mixing spatula with the rest of the adhesives that have not yet been cured. The correct dosage of the products must be observed, along with a homogeneous mixing.

In both cases, it is important that, once the mixing has been performed, the application time is limited, since the curing reaction begins immediately.

Application of the adhesive

The adhesive must be in intimate contact with the surfaces to be joined. It is applied at room temperature, since high temperatures lower the time of use and low temperatures weaken the adhesive's strength.

The main aspects to be taken into account in the application of an adhesive are the thickness of the adhesive and the shape and dimensions of the bead.

Regardless of the application system, one matter to be kept very much in mind is the thickness of the adhesive coat. The strength of a joint can deteriorate if the bond line is too thick.

The highest strength structural joints are obtained with thinner bond line; however, for some filler applications of flexible adhesives (non-structural) thicker bond lines are desired.

- The greater the quantity of adhesive, the greater the likelihood that air bubbles will appear or foreign bodies which may weaken the join.
- The force needed to deform a thin film is greater than that needed for a greater thickness.
- The internal tensions arising in the joining process are related to the thickness of the film applied.
- The more the thickness increases, the greater the probability that the adhesive seeps or crystallises.

Therefore, it is advisable to achieve thinner bond lines, but still ensure that the quantity of adhesive is enough to completely cover the surface of the substrate and to compensate for any shape irregularities.

For informational purposes, the maximum bond line application thickness according to the adhesives families are:

- Cyanoacrylates: up to 0.25 mm.
- Epoxy: up to 3.0 mm.
- Polyurethanes: up to 8 mm.

These thicknesses are guidelines and will be dependent on the specific formulation of each adhesive, meaning that in order to find out the exact data, the technical specification sheet of the adhesive must be consulted.

In certain types of applications, the final thickness of the adhesive is established by the use of small separator blocks which, placed in the joint, will prevent the substrates from coming too close together.

Similarly, some adhesives contain glass beads that act to separate the substrate materials and generate a specific bond line thickness. Adhesives with glass beads are suitable for use with blind rivets, but not with resistance spot welding.

The shape of the bead we apply will depend on the type of join to be performed. In the case of window bonding with polyurethane adhesives, it will be a triangular bead, and the nozzle will be given the corresponding shape.

When it is a matter of sticking bodywork panels together, a bead will be applied in the shape of a half straw, and with a diameter of about 6 mm.

Depending on how the adhesive is administered and what its objective is, it may be applied by extrusion, with a brush or with a spatula.

- **Application by extrusion**: when the adhesive is prepared in cartridges or bags, it will be applied by extrusion, using the most suitable gun and nozzle.
- **Manually operated guns** are better for intermittent or one-off applications; pneumatic guns permit a continual application and a constant flow.
- **Brush application**: the brush enables liquid or very low viscosity adhesives to be sprinkled over a wide surface with a thin thickness. It is very important to clean the brushes after each application. For this, it is preferable to use hard brushes, such as nylon ones.
- **Spatula application**: the spatula is the best option for dense or thick and pasty adhesives; in order to obtain higher thicknesses.
- In many cases, the use of a brush or a spatula is complementary to application by extrusion, serving to spread the adhesive over the entire zone of the bare metal.

Once the adhesive has been applied and the part correctly placed, intimate contact all along the joint must be ensured. For this, pressure will be exerted, spread uniformly over the whole surface, with special care in the case of glass bonding.

There are different methods of applying pressure, according to the accessibility of the zone:

- **Self-blocking clamps**: These will be used in those cases where it is possible to put them in place, such as with tabs, part edges, etc. Various clamps are placed along the joint, with an approximate distance of 10 centimetres between each of them.
- In those cases where the use of clamps is not possible, such as in the cutting lines of saving sections, other methods will be turned to.
- **Fasteners**: this consists of welding washers onto the bodywork part closest to the joint and of threading fasteners through them, with a sloped geometry so that, when they are inserted, the foot sits resting on the joint, exerting the pressure needed.
- **Washers**: cut in half and welded in the shape of a bridge along the joint.
- Special devices: attached with adhesive or electromagnetic suction pads.

When the parts are made of polyester, self-tapping screws are normally used, attached to the parts and to the following flanging strap. When the adhesive has dried, it is removed and the hollow is filled with resin.

Adhesive curing

The reticulation or curing of the adhesive is to be understood as the group of processes that take place from the moment when the mixture is produced and the application of the adhesive until it has cured completely.

The speed of curing will depend on:

- The proportion of the mixture, the curing being quicker the greater the proportion of curing agents there are.

- The speed of drying will also depend on the room temperature; temperatures above 20º C will accelerate the curing of the adhesive. Some manufacturers will consider the application of infrared equipment heat or in the paintwork booth to shorten drying times. However, in these cases, the manufacturers` recommendations should be kept in mind since incorrect heating can deteriorate the adhesive, and result in a loss of strength in the joint.
- In the case of monocomponent polyurethanes, drying is carried out by moisture absorption, meaning that the drying time will be inversely proportional to the relative moisture present in the surrounding environment.

Within the curing process, three stages can be distinguished:

- Handling time: the time that elapses between the adhesive application and the start of the formation of a skin, when such viscosity is achieved that no further manoeuvre is possible. This is the time the technician has to handle joining: presentation and adjustment of the part
- Solidifying time for handling or mixture lifetime: the time that elapses from the start of the curing until the moment when the adhesive has acquired sufficient solidity to be able to continue with the work process.
- Curing time: the time that elapses between the start of the curing process and the moment of its conclusion, when the maximum values of mechanical strength are reached.

In practice, these times are often incompatible since, on the one hand, it is advisable that the solidity time until the handling time or curing time be as short as possible in order to carry on with the work on the vehicle. However, on the other hand, the handling time must be, to a certain extent, ample, in order to be able to carry out proper positioning and adjustment of the part, above all when it is a matter of large panels.

Durability of the adhesive

The deterioration and durability of bonded joints is conditioned by temperature, environmental conditions and the mechanical loads they have to withstand.

To obtain strength during its life in service in a bonded joint, the joint must maintain a significant proportion of its load capacity for long periods, withstand the environmental conditions during its life in service and guarantee durability for a specific application.

The factors that can affect the durability of a join in service conditions are:

- Static and dynamic loads
- Environmental agents (temperature, rain, moisture, saline environment...),
- UV exposure
- Water
- Organic solvents
- Detergents
- Fuels and lubricants

One of the most common causes of failures in adhesive joins is lack of knowledge of the force to which the assembly will be subjected.

The behaviour is very different if it is subjected to a combination of different combined effects such as dynamic loads plus saline water and sharp changes of temperature, etc. Of all the environmental agents, water is the substance that generates the most problems in the durability of adhesive joints. It is also the most common medium to which the joint finds itself subjected. By hydrating the metal, oxide is created on the surface leading to the failure of the joint. It alters the properties of the adhesive irreversibly by means of hydrolysis and generates cracks or craters in it, attacking the adhesive/substrate interface by a process of displacement and displacing the adhesive, inducing tensions due to adhesive swelling.

Creep is the permanent deformation according to the time that a material suffers when it is subjected to a constant load; this has to do with time, temperature and humidity. The mechanical effects of the adhesives are affected by great sensitivity to climate conditions, sensitivity to creep in certain conditions, the characteristics of the adhesive (porosity, fissures, lack of homogeneity, deficient curing) environmental conditions (temperature, moisture, etc.), geometry of the joint (distribution of tensions) etc.

2.2.6 Adhesive product data and safety sheets

The product data and safety sheets constitute the detailed information about the various properties of the product, handling instructions, properties, etc. It is important to be familiar with them when working a specific adhesive and pursuing the reduction of work and environmental risks.

The data sheets on safety give advice about safety, precautions and risk of the product.

(Continue on the next page)

LOCTITE

Technical Data Sheet

LOCTITE® HY 4090™

July 2017

PRODUCT DESCRIPTION

LOCTITE® HY 4090™ provides the following product characteristics:

Technology	Cyanoacrylate / Epoxy Hybrid
Chemical Type (Part A)	Cyanoacrylate
Chemical Type (Part B)	Epoxy
Appearance (Comp. A)	Transparent colorless to straw colored liquid[LMS]
Appearance (Comp. B)	Off-white to light yellow gel[LMS]
Appearance (Mixture)	Off-white to light yellow gel
Components	Two components - requires mixing
Mix Ratio, by volume - Part A: Part B	1 : 1
Viscosity	High
Cure	Room temperature cure after mixing
Application	Bonding

LOCTITE® HY 4090™ is a two component, general purpose adhesive which provides a very fast fixture at room temperature. It is designed to bond a variety of substrates including metals, most plastics and rubbers. LOCTITE® HY 4090™ provides good temperature and moisture resistance which also makes it suitable for applications in high temperature/humidity environments. The thixotropic nature makes it suitable for applications where good gap filling properties on rough and poorly fitting surfaces are required.

TYPICAL PROPERTIES OF UNCURED MATERIAL

Part A:

Specific Gravity, g/cm³	1.01
Viscosity, Cone & Plate, mPa·s (cP):	
Temperature: 25 °C	4,000 to 7,000[LMS]
Flash Point - See SDS	

Part B:

Specific Gravity, g/cm³	1.06
Viscosity, Cone & Plate, mPa·s (cP):	
Temperature: 25 °C	25,000 to 40,000[LMS]
Flash Point - See SDS	

TYPICAL CURING PERFORMANCE

Curing is initiated on mixing the Part A and Part B components. Handling strength is achieved rapidly; full strength is achieved over time.

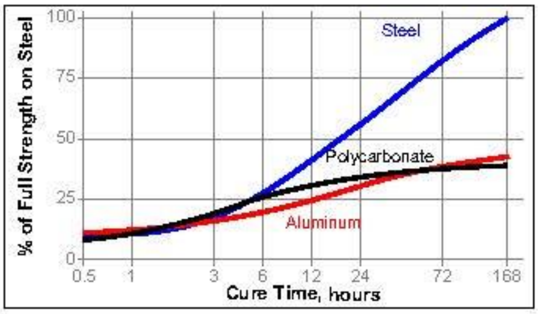
Fixture Time

Fixture time is defined as the time to develop a shear strength of 0.1 N/mm².

Fixture Time @ 25°C, seconds <180[LMS]

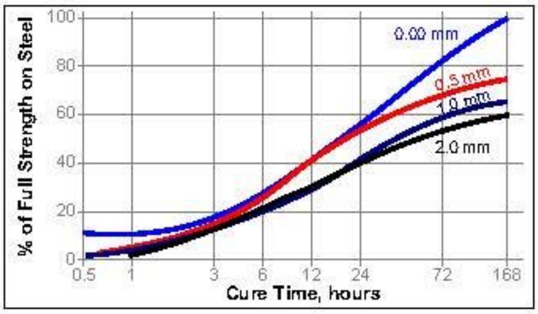
Cure Speed vs. Substrate

The rate of cure will depend on the substrate used. The graph below shows the shear strength developed with time on steel lap shears compared to different materials and tested according to ISO 4587.



Cure Speed vs. Bond Gap

The rate of cure will depend on the bondline gap. The following graph shows the shear strength developed with time on grit blasted mild steel lap shears at different controlled gaps and tested according to ISO 4587.



Cure Speed vs. Temperature

The rate of cure will depend on the ambient temperature. The graph below shows the shear strength developed with time at different temperatures on grit blasted mild steel lap shears and tested according to ISO 4587.

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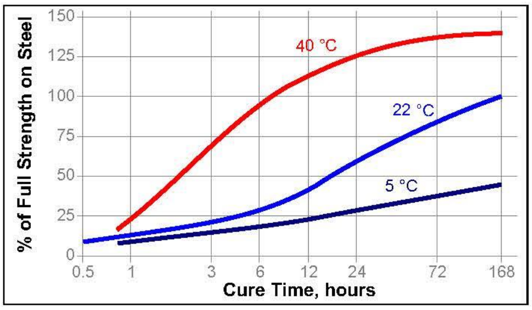
Figure 95 – Technical Data Sheet. Source: LOCTITE



TYPICAL PROPERTIES OF CURED MATERIAL

Cured for 1 week @ 22 °C

Physical Properties:

Glass Transition Temperature, ISO 11359-2, °C		88
Coefficient of Thermal Expansion, ISO 11359-2 K^{-1}:		
Below Tg (88°C)		71×10^{-06}
Above Tg (88°C)		175×10^{-06}
Shore Hardness, ISO 868, Durometer D		65 to 69
Tensile Strength, at break, ISO 527-3	N/mm²	7.1
	(psi)	(1,025)
Tensile Modulus, ISO 527-3	N/mm²	565
	(psi)	(81,800)
Elongation, at break, ISO 527-3, %		3.6

TYPICAL PERFORMANCE OF CURED MATERIAL

Adhesive Properties

Cured for 168 hours @ 22 °C

Shear Strength, Lap Shear Strength, ISO 4587:

Steel (grit blasted)	N/mm²	17
	(psi)	(2,420)
Aluminum	N/mm²	7.6
	(psi)	(1,100)
Aluminum (etched)	N/mm²	13
	(psi)	(1,900)
Zinc dichromate	N/mm²	9.1
	(psi)	(1,320)
Stainless steel	N/mm²	15
	(psi)	(2,120)
ABS	N/mm²	5.2
	(psi)	(750)
Phenolic	N/mm²	3.2
	(psi)	(460)
Polycarbonate	N/mm²	6.9
	(psi)	(1,000)
Nitrile	N/mm²	0.7
	(psi)	(100)
Wood (Oak)	N/mm²	4.8
	(psi)	(700)
Epoxy	N/mm²	9.1
	(psi)	(1,320)
Polyethylene	N/mm²	0.5
	(psi)	(72)
Polypropylene	N/mm²	0.6
	(psi)	(87)

TYPICAL ENVIRONMENTAL RESISTANCE

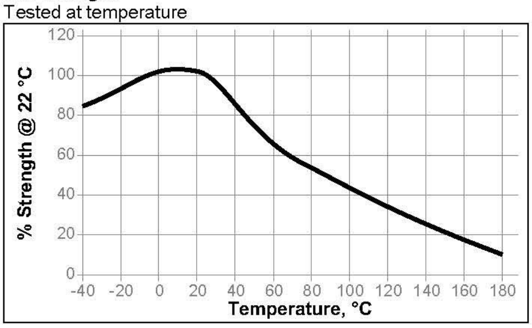
Cured for 1 week @ 22 °C

Lap Shear Strength, ISO 4587:

Steel (grit blasted)

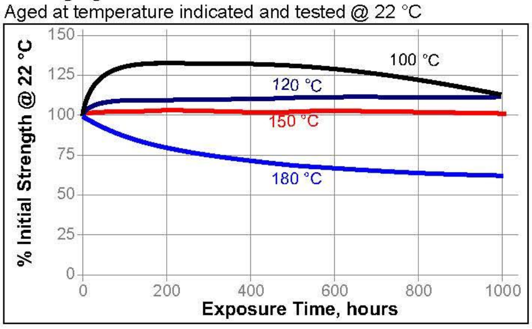
Hot Strength

Tested at temperature



Heat Aging

Aged at temperature indicated and tested @ 22 °C



Chemical/Solvent Resistance

Aged under conditions indicated and tested @ 22 °C.

		% of initial strength		
Environment	**°C**	**100 h**	**500 h**	**1000 h**
Water	22	90	75	70
Water	60	80	55	55
Motor oil	40	120	130	130
Unleaded gasoline	22	95	100	105
Ethanol	22	85	90	90
Isopropanol	22	100	100	95
Water/glycol 50/50	87	50	5	5
98% RH	40	85	70	70
95% RH	65	95	85	65

Lap Shear Strength, ISO 4587:

Polycarbonate

		% of initial strength		
Environment	**°C**	**100 h**	**500 h**	**1000 h**
98% RH	40	100	90	80

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Figure 96 – Technical Data Sheet. Source: LOCTITE

Lap Shear Strength, ISO 4587:
Aluminum

		% of initial strength		
Environment	**°C**	**100 h**	**300 h**	**500 h**
95% RH	65	100	95	85

GENERAL INFORMATION

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Safety Data Sheet (SDS).

Where aqueous washing systems are used to clean the surfaces before bonding, it is important to check for compatibility of the washing solution with the adhesive. In some cases these aqueous washes can affect the cure and performance of the adhesive.

Directions for use:

1. Bond areas should be clean and free from grease. Clean all surfaces with a Loctite® cleaning solvent and allow to dry.
2. To use, Part A and Part B must be blended. Product can be applied directly from dual cartridge by dispensing through the mixer head supplied.
3. **50g Dual Cartridge:** Stand dual cartridge upright for 1 minute. Keeping the cartridge in an upright position, insert it into the application gun, remove cap and expel a small amount of adhesive to be sure both sides are flowing evenly and freely. Attach the mixing nozzle.
4. **400g Dual Cartridge:** Stand dual cartridge upright for 1 minute. Remove the cartridge cap and locking ring, attach the mixing nozzle and secure with the locking ring. Load cartridge into the application gun so that the yellow label on cartridge is visible above the nozzle. Holding the application gun at a 45° angle, with the nozzle tip pointing upwards, begin dispensing the adhesive until the product reaches the nozzle tip.
   NOTE: A pneumatic application gun is required to apply the product from the 400g dual cartridge at a maximum dispense pressure of 2 bar.
5. Dispense and discard a bead as long and as wide as the mixing nozzle, to ensure sufficient mixing.
6. Apply the mixed adhesive to one of the bond surfaces to be joined. Parts should be assembled immediately after the mixed adhesive has been applied.
7. Bonds should be held fixed or clamped until adhesive has fixtured.
8. Keep assembled parts from moving during cure. The bond should be allowed to develop full strength before subjecting to any service load.

Loctite Material Specification^LMS

LMS dated May 27, 2013 (Part A) and LMS dated June 10, 2013 (Part B). Test reports for each batch are available for the indicated properties. LMS test reports include selected QC test parameters considered appropriate to specifications for customer use. Additionally, comprehensive controls are in place to assure product quality and consistency. Special customer specification requirements may be coordinated through Henkel Loctite Quality.

Storage

Store product in the unopened container in a dry location. Storage information may be indicated on the product container labeling.

Optimal Storage: 2°C to 21°C. Storage below 2°C or greater than 21°C can adversely affect product properties. Material removed from containers may be contaminated during use. Do not return product to the original container. Henkel Corporation cannot assume responsibility for product which has been contaminated or stored under conditions other than those previously indicated. If additional information is required, please contact your local Technical Service Center or Customer Service Representative.

Conversions

(°C x 1.8) + 32 = °F
kV/mm x 25.4 = V/mil
mm / 25.4 = inches
µm / 25.4 = mil
N x 0.225 = lb
N/mm x 5.71 = lb/in
N/mm² x 145 = psi
MPa x 145 = psi
N·m x 8.851 = lb·in
N·m x 0.738 = lb·ft
N·mm x 0.142 = oz·in
mPa·s = cP

Figure 97 – Technical Data Sheet. Source: LOCTITE

applications and results. We strongly recommend that you carry out your own prior trials to confirm such suitability of our product.
Any liability in respect of the information in the Technical Data Sheet or any other written or oral recommendation(s) regarding the concerned product is excluded, except if otherwise explicitly agreed and except in relation to death or personal injury caused by our negligence and any liability under any applicable mandatory product liability law.

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Figure 98 – Technical Data Sheet. Source: LOCTITE

2.3 MECHANICAL FASTENERS IN CAR BODY REPAIR

In OEM production lines many aluminium components are joined by the combination of adhesives with mechanical fixing elements. The most common element used in primary vehicle manufacture is the self-piercing rivet (SPR). However, adhesives are also employed in combination with flow drilling screws, conventional thread forming screws, blind rivets, tacking elements and many more. These element types are used to join together an array of aluminium sheet, extrusions and castings as well as numerous dissimilar materials joining applications.

However, for car body repair, the use of elements such as self-piercing rivets and flow drilling screws requires very specific equipment and technical knowledge. For each material combination a very specific rivet, die and set of parameters must be employed, only the vehicle manufacturer has access to these specific parameters for each joint and possess all relevant equipment and tooling to apply the joint correctly. Consequently, only OEM's themselves employ these technologies for repair of aluminium components.

The most common and universally applicable method to repair element joints in an aluminium body structure is blind riveting. In general, when replacing a panel, the original element (usually a self-piercing rivet) is drilled out using a slightly oversized drill, then a new panel is applied and a blind rivet is set into the remaining hole to perform the repair. The blind riveting process is easy to apply manually and works very well in combination with adhesive to fix aluminium components in place.

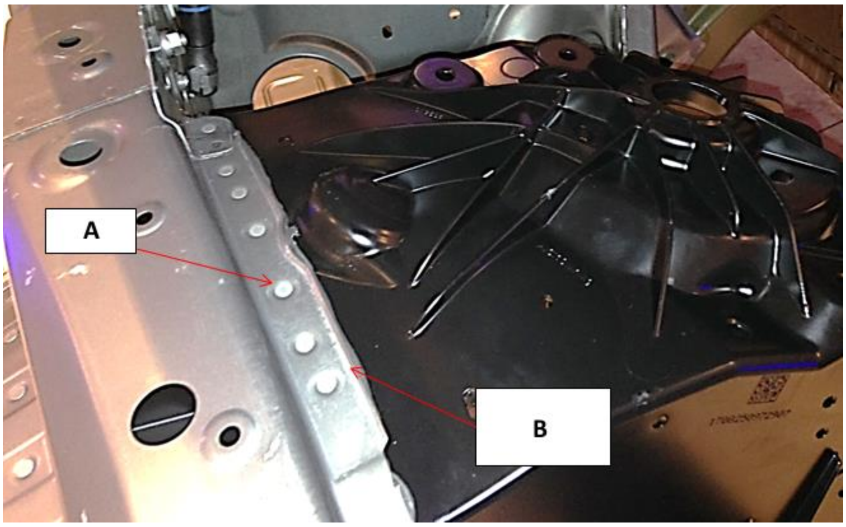


Figure 99 - SPR and structural adhesive in a car body: A. SPR, B. Structural Adhesive. Source: TWI

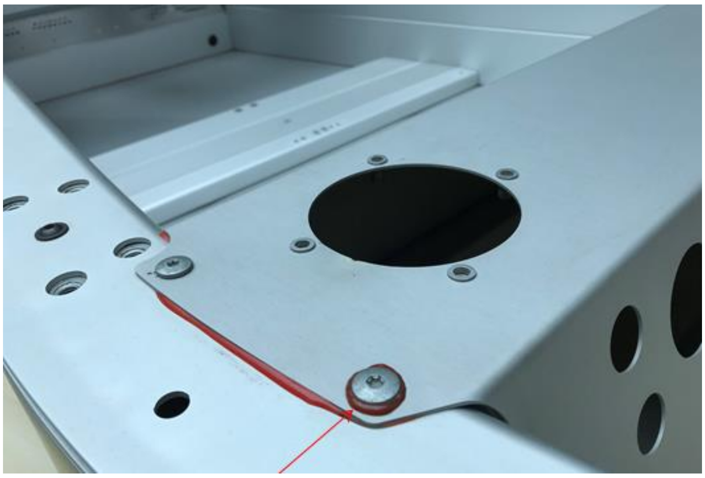


Figure 100 - Flow drill screws and adhesives in a car body. Source: TWI

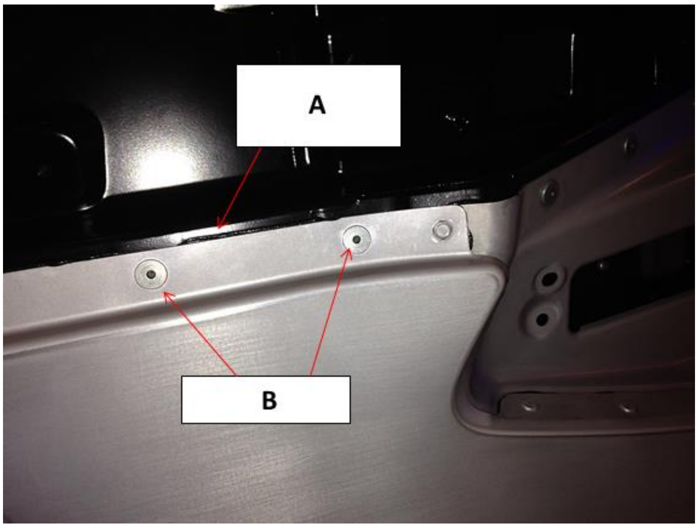


Figure 101 - A. Structural adhesive, B. Blind rivets. Source: TWI

Some of the most common mechanical fasteners used in the automotive industry are the following:

- **Thread Fasteners**: these detachable joints require a mating thread and are classified as; a bolt, if a nut is used (internally threaded component), in which case a clearance hole is required; a screw, on the other hand, resorts to an internally threaded hole. When used for aluminium, these fasteners are usually made of coated carbon steel. The tightening torque should be applied adequately so that the corresponding preload force prevents sliding between the components.
- **Self-tapping Screws**: these fasteners form their own thread as they are screwed into pre-drilled core holes. Therefore, the screw head must be harder than the mating material. The high tightening torque and the positive fit prevents spontaneous loosening of the screw.
- **Hole and Thread Forming Screws**: similar to the previous, but without pre-drilling. If preheating is not conducted, then the screw must have such geometry that a high contact pressure is applied, leading to the necessary plastic deformation. Otherwise, a flow forming process takes place where a tapered punch rotating at high speed is forced down, heating the metal sheet.
- **Press-in Nuts and Bolts**: threaded inserts that are pressed into a pre-punched hole in a sheet metal by applying a steady squeezing force. Used when the part to be screwed is thinner than the thread pitch of the tapping screw. Create wear-free screw connections capable of withstanding high loads in thin walled components from metallic materials. These fasteners are torque-proof, wear-resistant and capable of withstanding high loads.
- **Blind Rivet Nuts and Bolts**: thread-bearing insert fasteners that offer a versatile solution for high-strength fastening when wall thickness is too small, the material is too soft to support tapped threads or when disassembly is required.

Rivets are economical permanent mechanical fasteners, where the parts to be joined are clamped together using a rivet. Several types of rivets exist, but the most common in the automotive industry are highlighted below.

- **Blind Rivet:** the joining component is inserted and closed from one side only using pre-drilled holes. Commonly used in the automotive industry, in general it consists of two components, a smooth, cylindrical rivet and a solid rod mandrel with a head, which runs through the hollow rivet shaft. While the shaft of the mandrel is discarded after setting, the mandrel head usually remains permanently attached.

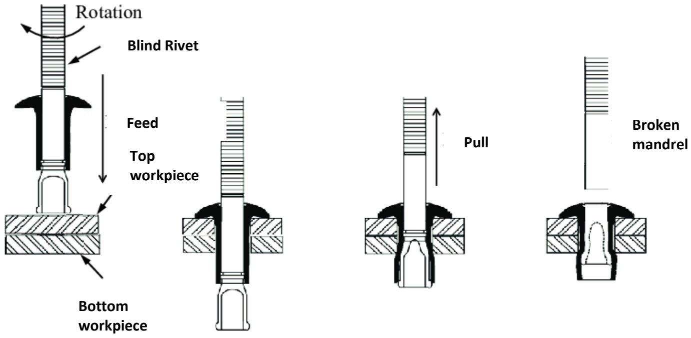


Figure 102 - Blind Rivet Installation Source: https://manufacturingscience.asmedigitalcollection.asme.org/article.aspx?articleid=2630454

- **Self-piercing Rivet:** a high-speed, single-step, combined cutting-riveting procedure. Two-sided access to the work piece is necessary. In half-hollow riveting, a semi-tubular rivet is driven through the top material layers, by a punch or a die. While driven into the die-side sheet, it is plastically formed and forced to penetrate laterally into this sheet by the special shape of the die. Thus, forming a durable joint, where the lower layer acts as a mechanical interlock.

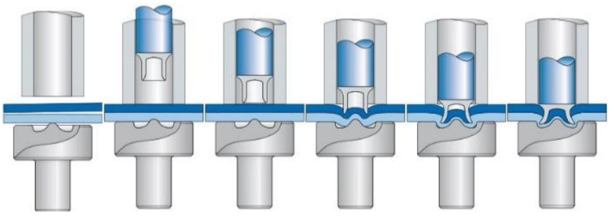


Figure 103 - Self-pierce Rivet Installation. Source: http://www.weltderfertigung.de/archiv/jahrgang-2011/ausgabe-maerz-2011/4-generation-verbindet-in-der-4-dimension.php

Blind riveting is a non-threaded mechanical fastening technique, particularly used when access to the joint is only available from one side or when the materials to be joined are not weldable. The rivet is placed in a pre-drilled hole and is generally of a tubular form with a head on one side, and a headed mandrel through it. As the mandrel is pulled back, it causes the tail of the rivet to flare against the reverse side of the sheets, providing the mechanical interlock between the original and the newly formed head. As the load on the mandrel increases, it breaks at a notch just behind the head, inside the rivet (closing off the hollow rivet), although with some types, the mandrel is pulled through entirely (leaving an opening). The fastener design and exact mode of operation are generally proprietary.

Figure 104 - The stages of blind riveting. Source: TWI

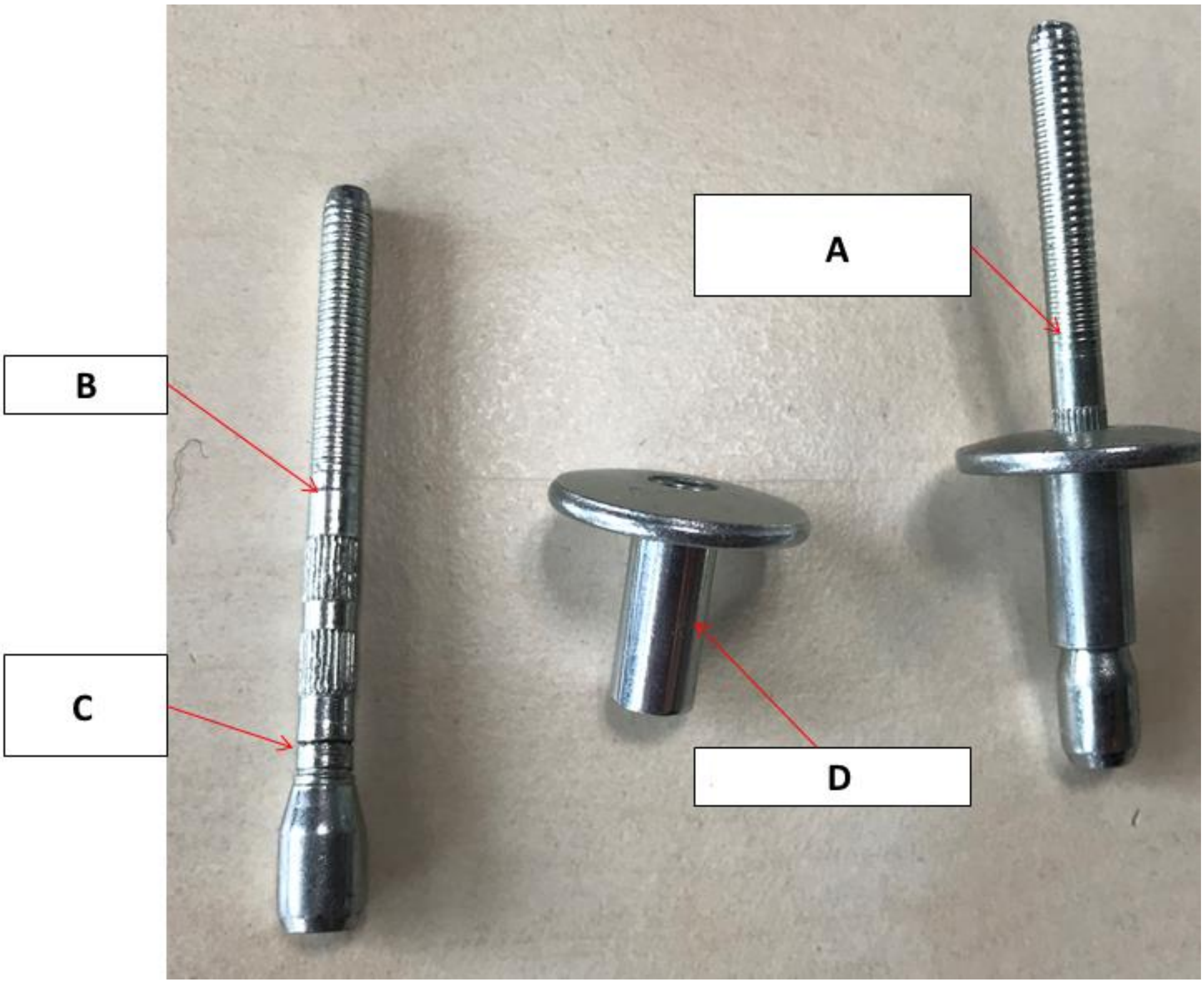


Figure 105 - The components of a blind rivet. A. Assembled blind rivet, B. Mandrel, C. Snap off point, D. Blind rivet body. Source: TWi

Figure 106 - Blind rivets set in a 3-sheet material stack and a rivet cross section. Source: TWI

There are numerous quality requirements for blind riveting, importantly the correct rivet must be selected for the sheet thickness and hole diameter into which it is to be applied. A correctly selected and set rivet will have a mandrel break off point located within the rivet head, not deep inside the rivet or above the head. The rivet should close the sheets of material together and the head should fit down flush onto the upper sheet of material.

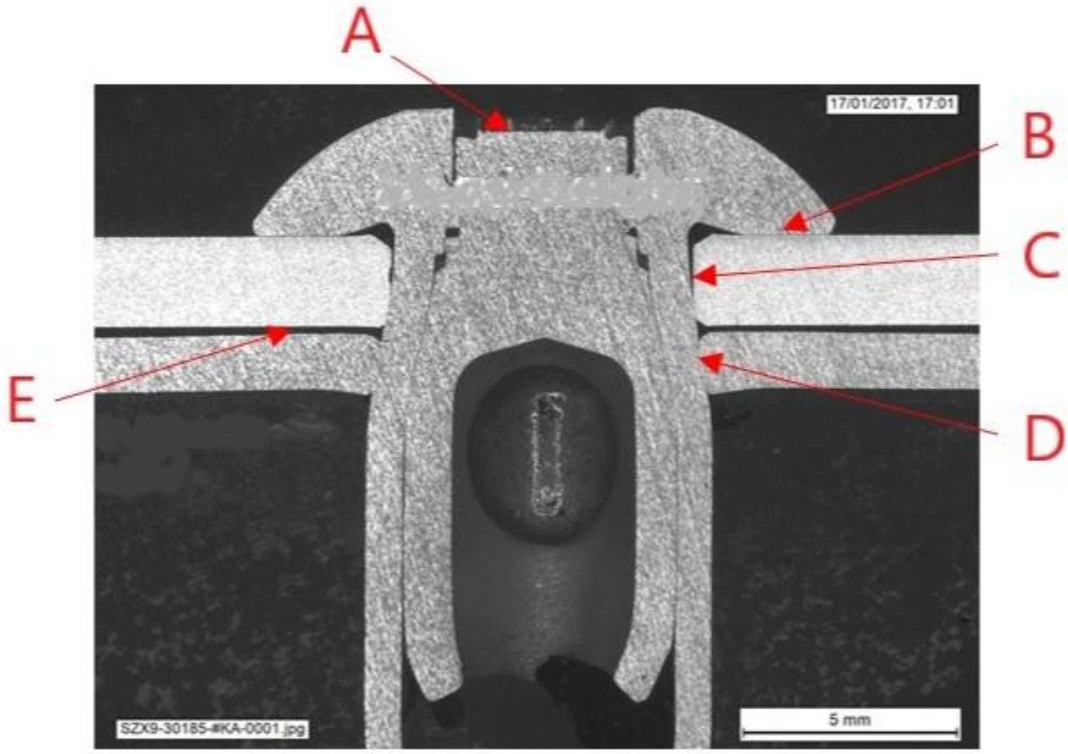


Figure 107 - Cross section of a blind rivet showing the required quality factors. A. Mandrel fracture in rivet hear required, B. Rivet head flush to sheet, C. Gap between rivet head and upper sheet preferably closed, D. Flush fit of rivet tail to lower sheet, E. Gaps between sheets should be closed. Source: TWI

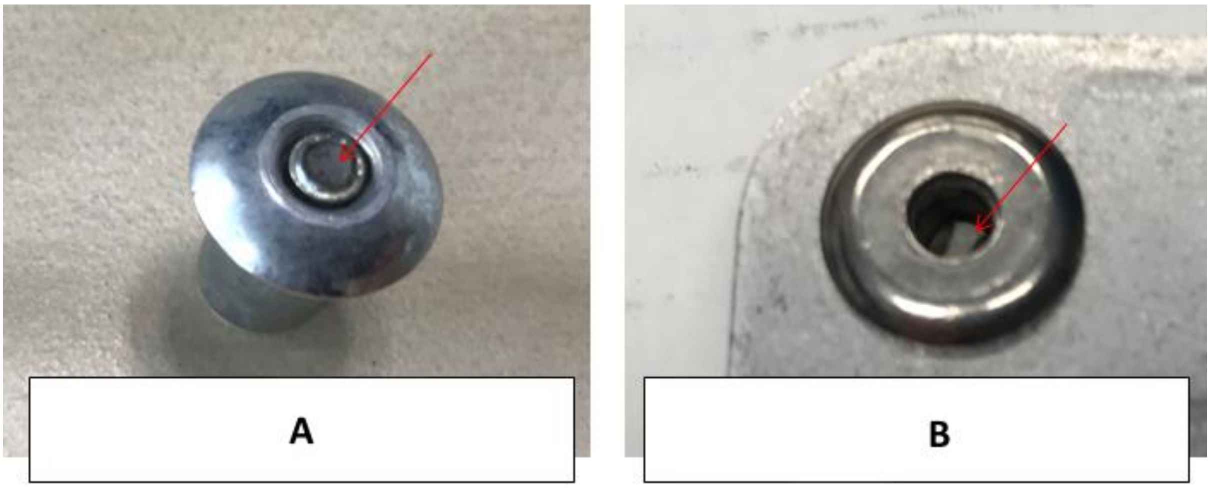


Figure 108 -Examples of correct mandrel snap off in the rivet head and incorrect mandrel snap of deep inside the rivet body A. Mandrel snap off in rivet head – correct, B. Mandrel snap off deep inside rivet – incorrect. Source: TWI

Blind rivets are available in many different shapes and sizes as they are used for many differing applications in the automotive, aerospace and general manufacturing sectors.

The different geometries control the rivets behaviour:

- Rivets with a large head can be used in oversized holes (useful for repair purposes) and provide greater mechanical strength to the joint.
- Long rivets can be used to join thicker material stack ups.
- Rivets with wide mandrels are used in larger holes and have a higher break off force, which translates to greater closing forces on the joint.

Blind rivets are also available in a range of different materials. Most commonly the rivets are made from carbon steel with a coating of zinc, but aluminium and stainless steel rivets are also available.

Selection of the appropriate rivet for a joint is critical. The total sheet stack thickness must be within the rivet's gripping range, the rivet must be suited to the hole size into which it is to be inserted. Each specific rivet type and material also has a specification for its closing force (to clamp the sheets together) and its shear and tensile strengths. These closing forces and joint strengths must be suitable for the component into which the rivet is being set. An example of the rivet specification and performance data given by a manufacturer is given in the table below.

Figure 109 - A variety of blind rivet geometries with varied; head sizes, rivet body lengths, mandrel and body diameters and folding points within the rivet body. Source: TWI

Example of rivet specifications and performance data, as typically supplied by blind rivet manufacturers (note the data is an example and not from any actual product):

Rivet material: Carbon steel, zinc coated				**Rivet head shape: Dome**	
Required hole diameter, mm	Rivet body diameter x length, mm	Grip range, mm	Rivet code	Rivet shear strength, N	Rivet tensile strength, N
5.1	5 x 8	2.0 – 4.0	XXXX	3100	4400
5.1	5 x 10	4.0 – 6.0	XXXX	3100	4400
5.1	5 x 12	6.0 – 8.0	XXXX	3100	4400
5.1	5 x 14	8.0 – 9.5	XXXX	3100	4400
6.1	6 x 10	2.5 – 4.5	XXXX	4400	6000
6.1	6 x 12	4.5 – 6.5	XXXX	4400	6000
6.1	6 x 14	6.5 – 8.5	XXXX	4400	6000
6.5	6.4 x 12	3.0 – 6.0	XXXX	4900	6800
6.5	6.4 x 16	6.0 – 9.0	XXXX	4900	6800
6.5	6.4 x 18	9.0 – 11.0	XXXX	4900	6800

Table 17 – Rivet Specification and performance data

It is important that not only the correct rivet is selected for the sheet stack thickness and hole diameter, but also that the holes in the component are correctly lined up.

Misaligned holes effectively reduce the area into which the rivet can expand and can result in bad joint quality or in the worst case no joint at all.

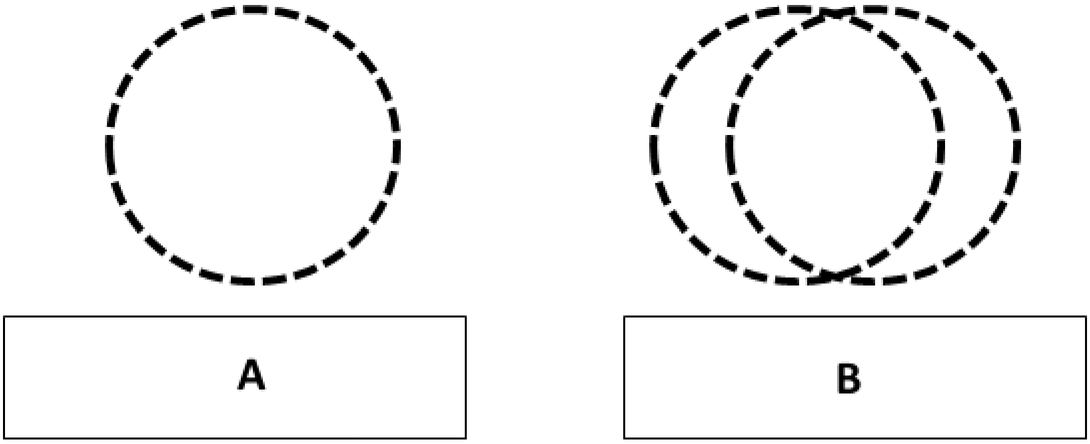


Figure 110 -Importance of correct hole alignment for rivet setting. A. Sheet holes well aligned = good rivet quality, B. Sheet holes misaligned = poor rivet quality. Source: TWI

When drilling out a self-piercing rivet (SPR) to perform a repair with a blind rivet, it is easier to drill from the back face of the rivet (rivet toe), drilling the hard steel rivet head is more challenging. Typically, a self-piercing rivet has a body diameter of 5.0 mm and it can be drilled out with a 6.5 mm diameter drill, leaving a hole suitable to set a blind rivet with a body diameter of 6.4 mm. Regularly in both production and repair scenarios, it is very difficult to exactly align the holes in both (or in some cases three) sheets of material. For this reason, it is common practice to produce holes that are slightly oversized in the upper sheet of material, which allows for components to be fitted together more easily. However, it is critical that the rivet head is larger than the upper sheet hole to ensure that a good joint is formed.

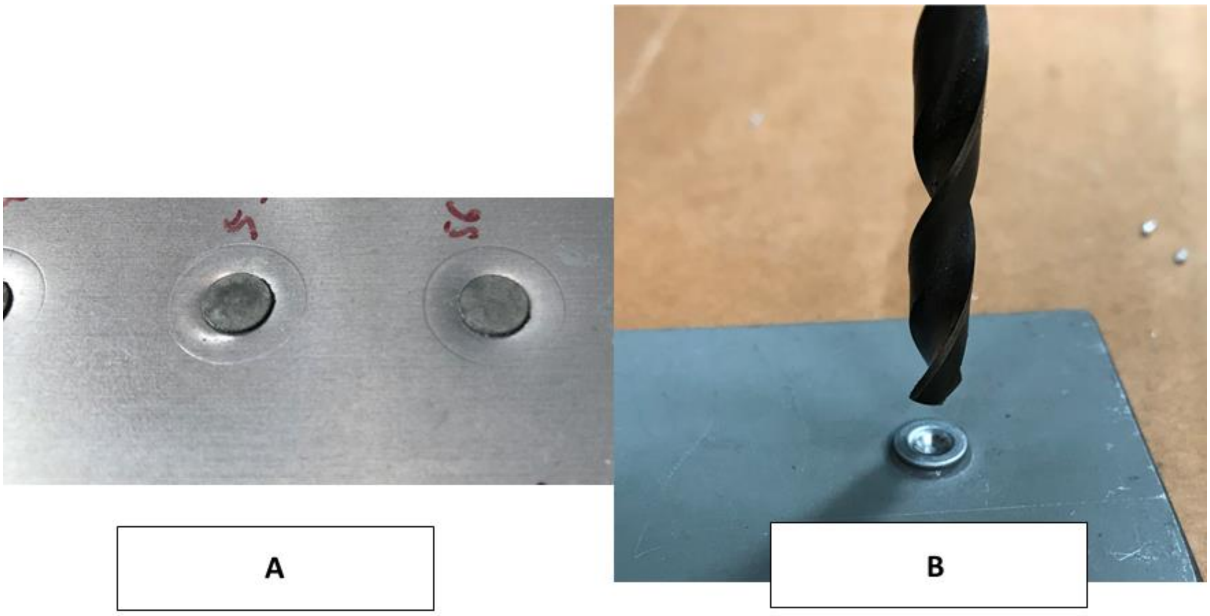


Figure 111 - Drilling out an SPR from the back face (rivet toe), where access allows. A. Rivet head - more difficult to drill through, B. Rivet toe – easier to drill through. Source: TWI

When setting a blind rivet, the specific operating instructions for the tool are supplied by the tool manufacturer. These instructions should always be followed.

Several types of blind riveting tool are available, ranging from manual tools, where a hand operated mechanism sets the rivet, to battery powered and pneumatic systems.

- In each case, the correct nozzle for each rivet type (mandrel diameter) must be installed.
- Then the rivet is fed in manually to the nozzle.
- Then the riveting tool and rivet are inserted into the hole, taking care to keep the tool perpendicular to the sheet metal surface.
- Downward pressure is applied.
- Then the rivet is set by operating the tools trigger or manual mechanism.

Figure 112 - Examples of blind riveting tools. Source: TWI

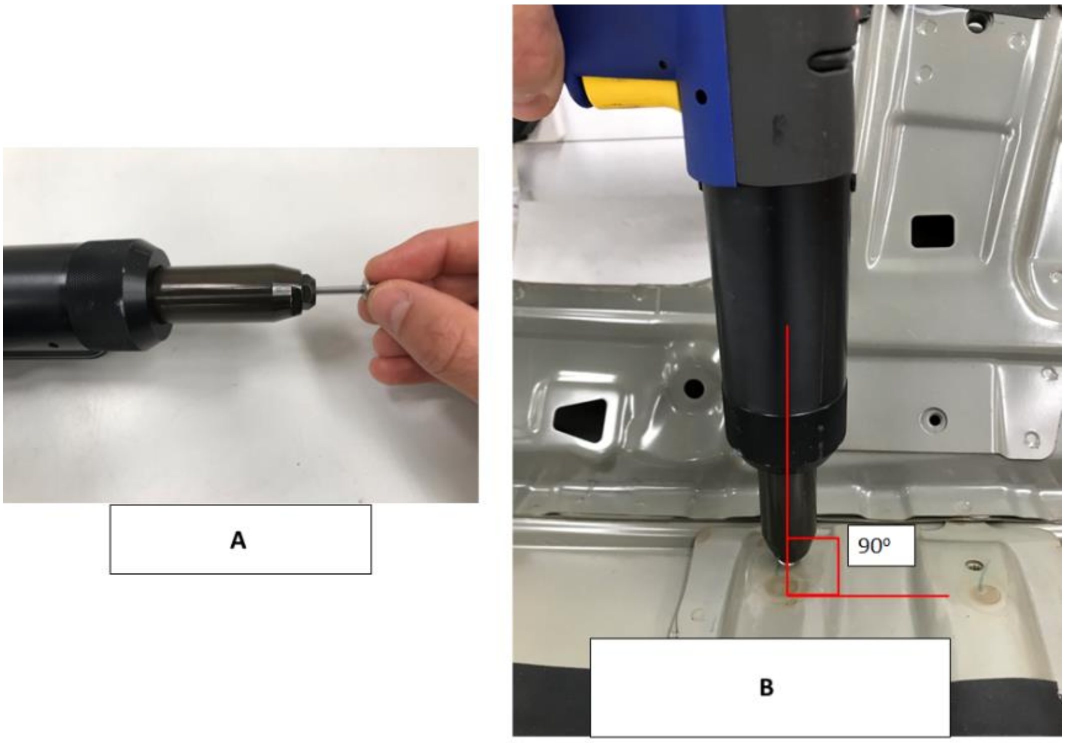


Figure 113 - Inserting a rivet into the nozzle and setting a blind rivet perpendicular to the metal surface. A. Inserting the rivet into the nozzle, B. Setting the rivet into the hole, with the tool perpendicular to the metal surface. Source: TWi

When performing repairs of aluminium components with blind rivets and adhesives, the following items are of importance:

- Drill out any remaining rivets, screws and fasteners from the joining area.
- To prepare the spare part and place it on the vehicle body, carrying out the corresponding adjustments in order then to perform drill holes where the blind rivets will be put into place.
- To prepare the surfaces of all the tabs where the adhesive must be applied in order to guarantee adhesion.
- To apply the adhesive bead all along the join tabs. It is worth ensuring that a continual bead of adhesive surrounds the orifices of the rivets.
- The adhesive application must be sufficient to cover all surfaces but not excessive resulting in adhesive expulsion and contamination of other parts of the car body.
- The panel is made available and adjusted, fixing it with self-blocking clamps.
- Ensure all holes line up between the upper and lower sheet surfaces and wipe away excessive adhesive from the holes.
- When setting a blind rivet, the tool suppliers' guidelines and procedures should be followed.
- The correct nozzle for the rivet type should be installed on the tool. The rivet is fed into the nozzle of the tool.
- The tool and rivet should be placed into the hole, the tool must be perpendicular to the sheet surface to ensure the rivet is set properly.
- Down force should be applied.
- The rivet tool trigger is pressed (or mechanism operated on a manual tool), the mandrel snaps off and the rivet is set.
- The blind rivets will help to keep the joint immobile while the adhesive curing takes place.
- Eliminate the traces of adhesives that may have overflowed from the joint and clean the tools and rivet utensils of possible product contaminations.

3rd Practical training

Blind Rivet Aluminium-Aluminium Joints Through an Adhesive, Using a Flat Coupon Test Piece

(2 hours)

Figure 114 - Blind rivet. Source: TWI

Figure 115 - Structural adhesive. Source: TWI

Item	Description
A	150 mm (6.0 inches)
B	75 mm (3.0 inches)
C	37.5 mm (1.4 inches)
D	75 mm (3.0 inches)
E	30 mm (1.1 inches)
F	Blind rivets

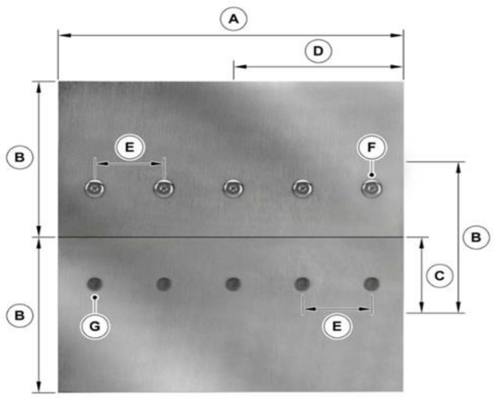


Table 18 – Descriptions. Figure 116 - Test piece. Source: TWI

Figure 117 -Self-blocking clamps. Source: TWI

Figure 118 -G clamp. Source: TWI

Figure 119 - Drill and drill bit. Source: TWI

Figure 120 - Blind riveting tools. Source: TWI

Consumables
✓ Structural adhesive KIT
✓ 4 aluminium sheets of 100 x 70 mm (thickness from 1.0 – 3.0 mm)
✓ Surface cleaner recommended by the structural adhesive manufacturer
✓ Disposable paper to clean surfaces
✓ Masking tape or sheet metal worker's tape
Tools
✓ Adhesive application gun
✓ Drill
✓ 6.5 mm drill bit and 7.5 mm drill bit
✓ Blind riveting tool
✓ Drill
✓ Blind rivets 6.4 mm diameter body, suitable grip range for the sheet stack thickness (minimum of 10 blind rivets needed)
✓ Self-blocking clamps
✓ G clamps
Health and Safety
Use: work clothes, rubber or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will normally be necessary, as well as the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used to dry the skin, and not cloth towels.
Proper ventilation of the place of work is advisable.
Follow working procedures for drilling.
Follow safe working procedures for blind rivet application, use operators' instructions for operation of the riveting tool.

Work process

Prepare the test piece

Perform the test piece according to the plan as indicated.

Drilling the holes

1. Position the aluminium sheets as shown in the diagram, with the correct 35 mm overlap,
2. Clamp the aluminium sheets to a suitable work bench or drilling table,
3. Ensure there is an open area or block of wood under the area to be drilled,
4. Drill the holes in 3 sheets with a 6.5 mm drill bit,
5. Drill the holes in 1 sheet with a 7.5 mm drill bit.

Safety specifications of the structural adhesive

Read the safety specifications of the product and note the safety kit that the person applying the product must wear.

Product technical specifications sheet

Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.

Check the product's expiry date

Check the product's expiry date and dispose of it if is past the date.

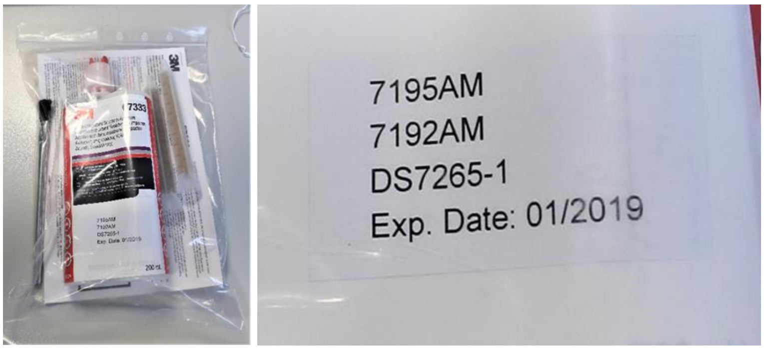


Figure 121 – Expiration Date. Source: CESVIMAP

Test bead

A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.

Pre-treatment - Preparation of the substrate

The surfaces to be joined should be cleaned in advance with a good degreasing agent, in particular the one recommended in the manufacturer's specifications, in order to eliminate any trace of oil, grease or of dirt. Low degree alcohols, petrol or paint solvents should never be used as degreasing agents.

The strongest joins are obtained after subjecting the surfaces, already degreased, to mechanical abrasion treatments or to chemical stripping treatments. A mechanical abrasion treatment would involve a new degreasing process after this treatment.
Application of the adhesive
The mix of resin and hardener must be applied directly or with a spatula on the dry and pre-treated surfaces.
A coat of adhesive with a thickness of 1 mm on each surface to be joined, will provide the maximum mechanical strength for the join. The surfaces to be joined must be positioned in a fixed and definitive position once the adhesive has been applied.
Put two pressure clamps in place, one on each side of the joint, during the whole drying process.
Setting the blind rivets - Part A 6.5 mm holes in upper and lower sheet
1. Ensure the holes are correctly lined up in the test pieces (upper and lower holes are 6.5mm diameter), 2. Wipe away any excess adhesive that flows out of the holes, 3. Follow the rivet tool manufacturers operation procedures, 4. Insert a rivet into the tool, 5. Place the tool and rivet into the hole, ensure the tool is perpendicular, 6. Apply down force, 7. The rivet tool trigger is pressed (or mechanism operated on a manual tool), the mandrel snaps off and the rivet is set, 8. Check the rivet tail has properly clamped the lower sheet, check the rivet head is flush to the upper sheet, check the mandrel has snapped off in the right position within the rivet head.
Setting the blind rivets, 7.5 mm hole in the upper sheet, 6.5 mm hole in the lower sheet
1. Ensure the holes are correctly lined up in the test pieces (lower holes are 6.5 mm diameter; upper holes are 7.5 mm diameter), 2. Wipe away any excess adhesive that flows out of the holes, 3. Follow the rivet tool manufacturers operation procedures, 4. Insert a rivet into the tool, 5. Place the tool and rivet into the hole, ensure the tool is perpendicular, 6. Apply down force, 7. The rivet tool trigger is pressed (or mechanism operated on a manual tool), the mandrel snaps off and the rivet is set, 8. Check the rivet tail has properly clamped the lower sheet, check the rivet head is flush to the upper sheet, check the mandrel has snapped off in the right position within the rivet head.
Tool maintenance
All the tools can be cleaned with hot water and soap before the adhesive residue has cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

2.4 HYBRID JOINING IN ADHESIVE BONDING

2.4.1. Adhesive bonding and Resistance Spot Welding

The adhesive-welding joining technique combines the use of adhesives with resistance spot welding and it is typically referred to as weld-bonding.

The effectiveness of the joint is much higher than when it is established by any of the systems individually. A combined joint improves the distribution of the stresses and the possibility of minimising fatigue problems, as well as allowing the adhesive to be fixed in place until it cures.

The two techniques most frequently used are adhesive - spot welding, commonly referred to as weld-bonding and adhesive – riveting, commonly referred to as riv-bonding; the first is more common in steel vehicle bodies and the second in aluminium bodies.

Many components in a steel vehicle are spot welded through an adhesive in the OEM's original production line. Most epoxy adhesives and sealants used in car body applications are spot weldable. The usual order of process in the car body assembly line is:

- Initial panel placement.
- Application of adhesive from dispensing system.
- Placement of second (and sometimes third) panel.
- Spot weld applied.

The electrode force when spot welding through an adhesive must be sufficient to displace the adhesive under the electrode, in car body welding plants, forces greater than 2kN (2000N or 200kg) are used. The adhesive formulation flows out of the area under the electrode and allows the current to pass.

The passage of current melts the steel and locally burns any remaining residues of the adhesive. Fumes released from burned epoxy can be toxic, so extraction systems may be used.

In general, little alteration to the spot welding program is required for welding through an epoxy adhesive. However, if difficulties are faced in achieving an adequate quality spot weld through an adhesive, the following actions can be taken:

- Increase the welding force: This helps to squeeze out the adhesive allowing the welding current to flow as normal between the steel sheets.
- Increase the squeeze time: This allows a little more time to squeeze out the adhesive prior to welding (weld time).
- Increase the weld time: A longer weld time allows a gentler rate of weld growth, which can be more stable than rapid growth in a short time.
- Reduce the welding current: If splashing or expulsion is a problem when welding through an adhesive, then the use of a lower current (often in combination with increased force and increased weld time) can stabilise the weld growth without overheating.
- Use a pre pulse current: Some welding equipment has the possibility to program a 'pre pulse' current, which is a low current initial pulse, this can be used to heat and soften the plates of material and warm the adhesive to help it flow out of the joint area before the main welding current pulse is applied.

It is very important to note that adhesives containing glass beads are not suitable for spot welding.

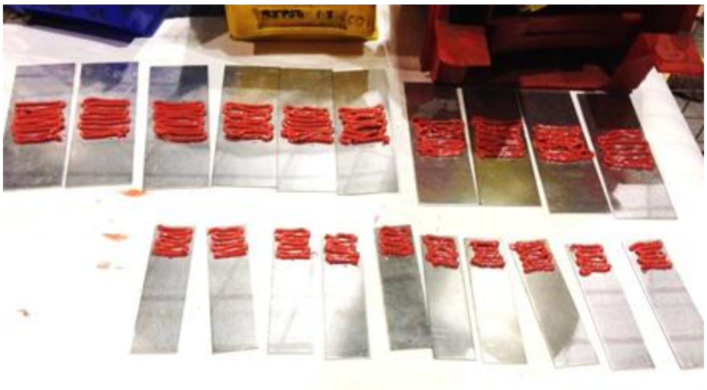


Figure 122- Preparation of small specimens for spot weld-bonding, parameter development trials. Source: TWI

When spot welding through an adhesive, the following items are of importance:

- Check if, with the electrodes available on the welding machine, it is possible to reach the area of the vehicle to be welded and can easily access the flanges at a perpendicular angle.
- A sufficient quantity of the adhesive is applied on the tabs to be joined, spreading it, if necessary, with the aid of a spatula. The adhesive application must be sufficient to cover all surfaces. Excessive adhesive application will result in adhesive expulsion and contamination of other parts of the car body.
- The panel is made available and adjusted, setting it in place with self-blocking clamps.
- With the aid of a spatula, remove any excess adhesive which may have overflowed out of the joint area.
- After this, the weld is carried out within the handling time of the adhesive. It is very important that the adhesive does not begin to cure prior to welding, as this will mean that a successful weld cannot be made.
- If the welding equipment has a preheating function capability, the application of a short low current heating pulse prior to the main welding pulse can help displace adhesive allowing a better quality weld to be made.

    - It is important the adhesive does not contaminate the electrode tip as this will result in surface burning and overheating of the weld.

Operator Name: Date: Welding machine: Standards / procedures followed: Vehicle / component:					Material 1: Material 2: Material 3:	
Electrode details Water cooling Test piece dimensions: Weld pitch: Adhesive used: Adhesive expiry date:					Squeeze time: Weld time: Hold time: Electrode force / pressure: Transformer tap:	
Weld number	Current (kA or heat %)	Weld diameter d1 (mm)	Weld diameter d2 (mm)	Average diameter d1+d2/2 (mm)	Weld splash (expulsion)	Comments observations

Table 19- Example spot welding data sheet

2.4.3 Quality Control

Process to ensure quality control and join inspection (non-destructive tests such as visual inspection)

There are a variety of possible faults in adhesive joins, cracks, fissures, discontinuities, etc., due mainly to errors occurring during surface pre-treatment. Once the joint has been designed and the adhesive has been applied, there are various control methods to check the final quality, such as ultrasound, x-rays, acoustic signal, thermal or infrared and thermographic inspection, seal quality, etc. Visual inspection is the technique most used in bodywork bonding processes.

In the repair of automobile bodies where adhesive is involved, a check must be made of the bonded area to see if:

a. The adhesive properly covers all the surfaces to be joined without leaving any surface free of adhesive.

b. The curing of the adhesive has been correctly applied

In order to ensure that these two parameters are correct the following checks must be verified and undertaken:

1. After conducting an adhesive bond in combination with riveting or resistance spot welding, a check must be made, to ensure that the adhesive overflows all along the adhesive joined area.
    a. A vehicle manufacturer will indicate in the repair shop manual for the vehicle that surplus or overflowing adhesive should be removed from the joint with the recommended consumables. Despite this warning, it is very important for the adhesive to overflow all along the join, as this will be a sign that the adhesive has reached all the surfaces to be joined. Correct dosing during adhesive application is important.
2. Curing test bead
    a. Before applying the adhesive on the surfaces to be joined, it is important to carry out a curing test bead that meets the following characteristics and performance procedure:
    b. Once the structural adhesive cartridge has been prepared, and the components of the adhesive have been pushed out through the cartridge nozzle, the mixing nozzle is set in place, and a curing test bead on a disposable substrate is produced. The test bead should be approximately 300 mm in length. It must be placed on a disposable substrate, and left to dry in conditions similar to those of the real repair. In other words, if the joint is left to air dry, the test bead is left to air dry, and if the joint is dried by forcing drying by means of heat, the test bead should be placed in the vehicle and subjected to the same conditions of curing by temperature as the vehicle.

c. Once dried and cured, the bodywork repair technician will be able to observe the colour of the bead (see the indications of the adhesives manufacturer) and carry out a touch test to ensure that the product has dried and is firm.

Work procedures

The work processes regularly used in bodywork repair are: replacement of bonded windows, replacement of the metallic bodywork parts, plastics repairs, bonding of small parts, etc.

Replacement of bodywork metallic parts

In the repair of accident-damaged vehicles, it is very common to replace one or more of the components making up the vehicle body. These operations involve, on certain occasions, laborious work and significant manipulations of zones of the bodywork, excessively disproportionate in relation to the size of the damage needing to be repaired.

Replacement of the bodywork by partial sections are operations that are performed by all the automobile manufacturers; by performing these it is possible to preserve the original performance of the vehicle to the maximum, maintaining, as far as possible, the joints created during manufacture.

Among the main properties of adhesive bond are their suitability to join dissimilar materials, since these joints do not alter or deform fine sheets of metals, as is the case with welding. They also seal the joints and distribute out the forces uniformly. The replacement of a roof in most cases has only one alternative, by means of adhesive.

When it is a matter of sticking one part to another the parts need to receive prior treatment, in order to boost adherence.

First of all, any paintwork, waxes or adhesives residue that there may be must be eliminated.

Figure 123 – Sanding. Source: CESVISMAP

Next, the surfaces to be joined are sanded, using P80 or P100 grain, only where necessary; on the parts which have original zinc coating this is not necessary because they have good adherence.

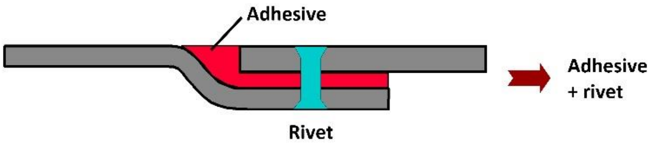


Figure 124 –Hybrid overlapped join. Source: CESVIMAP

The design of the joint depends on the geometry of the part; in bodywork the most common joint is the overlapped joint, which can be performed with a manual overlapping device or a pneumatic one.

Once sanded, the surface is degreased with specific solvents or acetone.

Figure 125 – Degreasing. Source: CESVISMAP

Surface treatments to be undertaken will depend on the adhesive manufacturer's instructions; when primer application is recommended, a fine coat is applied on the bodywork and on the replacement part, in cases where cleaning is not enough.

Figure 126 – Surface Treatment application. Source: CESVISMAP

New replacement parts do not need to be treated, since the glue sticks to the surface perfectly; the surface just needs to be cleaned, and, if the adhesive manufacturer recommends it, apply the primer.

Figure 127 – Application. Source: CESVISMAP

Application must be performed with an adhesive bead of 3.5 mm in order to spread it over the entire joint with a spatula or brush to guarantee the anti-corrosive protection, fixing the pieces in a maximum length of time of 30 minutes (or open time specificied on the adhesive data sheet). If the glue flows through the join all along its length, this means that enough glue has been used, and the surplus must be removed in any case.

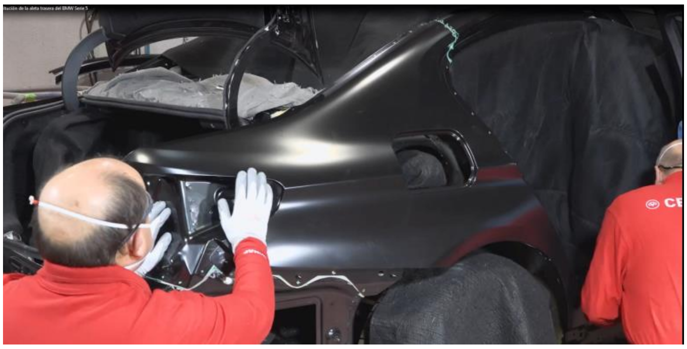


Figure 128 –Clamping. Source: CESVISMAP

The part must be clamped immobilised until the adhesive hardens completely; in the zone of an overlap joint, screws and bolts are used, pressure clamps are used to enable the placement of blind rivets.

Figures 129, 130 and 131 – Application. Source: CESVISMAP

In the wheel arch, the tab is folded before the adhesive hardens

Figure 132 – Folding. Source: CESVISMAP

The curing time of the adhesive varies between 8 / 12 hours, according to the manufacturer and to the ambient temperature, and the process can be speed up by means of the application of heat. Once the adhesive is dry, the joint is sanded, eliminating surplus adhesive, and where necessary a finishing putty is applied.

Figure 133 – Sanding. Source: CESVISMAP

The final sanding leaves the bodywork ready for the painting of the vehicle.

Figure 134 – After sanding. After painting. Source: CESVISMAP

Removal of bonded joins

The general method consists of cutting through the glue with blades or by means of spatulas. Some adhesives soften with the application of heat, making the above-mentioned operation easier because the joint becomes less strong.

2.4.4 Health and safety, and environmental safety

The main risks that an operator may encounter in the application of adhesives is due, basically, to contaminants of a chemical type, related directly to the products used.

These may appear in the form of gases and vapours or in the form of liquids, and their main paths of entry into the human body are the respiratory tracts and through the skin.

Certain products used as curing agents for epoxy resins contain aliphatic amines, which cause irritation to the skin, eyes and respiratory tracts, and can even cause asthma.

Polyurethanes are composed, in a large proportion, of isocyanates, which cause mucous sensitivity and, to a lesser degree, cutaneous irritation and skin sensitivity.

The volatility of certain isocyanates increases with the reaction of polymerisation.

- Apply the products in premises fitted with good ventilation.
- Do not perform repairs close to flames or incandescent bodies, since certain products are inflammable.
- Do not smoke during applications.
- Avoid bringing the products into contact with skin or eyes; to avoid this, safety goggles and suitable gloves will be used.
- The respiratory tracts will have to be protected from the inhalation of vapours or gases, using masks suitable for each use.

The measures for protection and for safety to be used in the replacement of vehicle glass are:

- The risk of cuts with glass or with the tools must be prevented by the use of work gloves.
- The treatment of waste must meet the regulation established in each country and follow the recommendations of the adhesive manufacturer.

Adhesive joint quality control

The quality of adhesive joints is established by regulations (EN-UNE, ASTM, ISO and internal regulations of the adhesives manufacturers). These regulations are documented agreements; they contain technical specifications that are used as rules to create lines of action, definition of characteristics, to ensure that the joint is fit for purpose, and standardised.

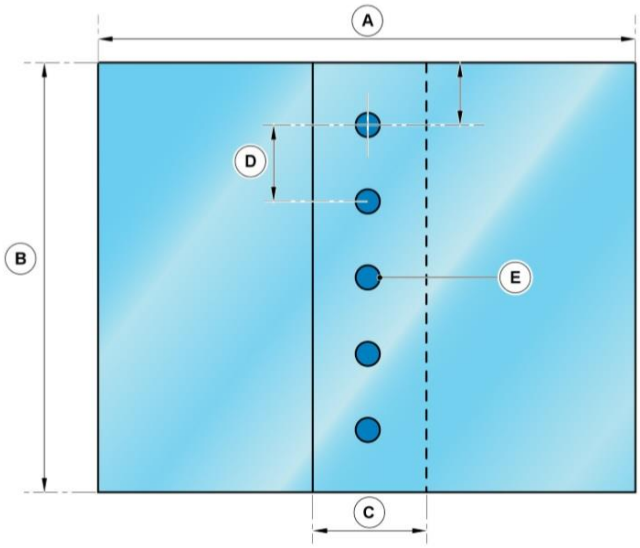
These regulations carry out mechanical trials in order to obtain data for the design, to compare or optimise joints, geometry of the joint, surface treatment, curing, processing, formulation of the adhesives, etc. To measure the mode of loading: peeling, shearing, etc., the form of the loading: impact, creep, fatigue, etc., conditions of service: temperature, moisture, etc.

4th Practical Training

HYBRID STEEL STEEL Joins: RESISTANCE SPOT WELDING + STRUCTURAL ADHESIVE. On test piece.

(3 hours)

Figure 135 - Structural adhesive. Source: CESVIMAP



Item	Description	Item	Description
A	Overall length - 115mm (4.5 inches)	B	Width – 180mm (7.0 inches)
C	Overlap - 35mm (1.3 inches)	D	Pitch - 30mm (1.1 inches)
E	Resistance spot weld		

Figure 136 - Test piece. Source: CESVIMAP

Figure 137 - Self-blocking clamps. Source: CESVIMAP

Consumables
✓ Structural adhesive kit.
✓ 2 mild steel flanges of 75 x 180 x 0.9 mm.
✓ Surface cleanser recommended by the structural adhesive manufacturer.
✓ Disposable paper to clean surfaces.
✓ Masking tape or sheet metal worker's tape.
Tools
✓ Adhesive application gun.
✓ Self-blocking clamps.
✓ Resistance spot welding machine.

Health and Safety
✓ Use: work clothes, rubber or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will be necessary. Likewise the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used, and not cloth towels, to dry the skin.
Proper ventilation of the place of work is advisable.
Work process
Prepare the test piece
Perform the test piece according to the plan as indicated.
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet
Read the technical specifications of the structural adhesive and note the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.

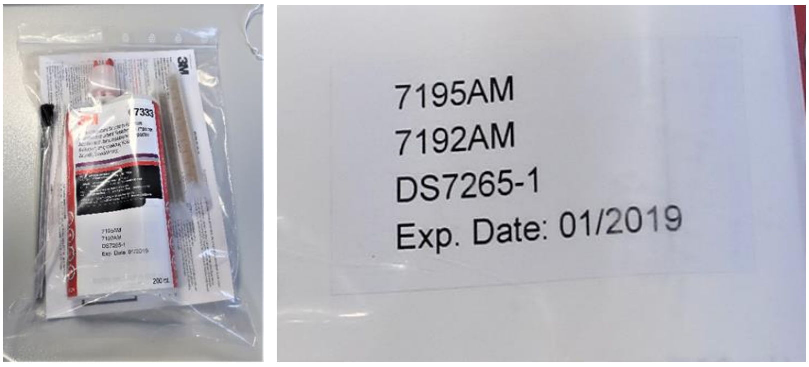


Figure 138 – Expiration Date. Source: CESVIMAP

Test bead
A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.
Pre-treatment - Preparation of the substrate
The surfaces to be joined should be cleaned in advance with a good degreasing agent, in particular the one recommended in the manufacturer's specifications, in order to eliminate any trace of oil, grease or of dirt. Low degree alcohols, petrol or paint solvents should never be used as degreasing agents.
The strongest joins are obtained after subjecting the surfaces, already degreased, to mechanical abrasion treatments or to chemical stripping treatments. A mechanical abrasion treatment would involve a new degreasing process after this treatment.
Application of the adhesive
The mix of resin and hardener must be applied directly or with a spatula on the dry, pre-treated surfaces.
A coat of adhesive with a thickness of 1 mm on each surface to be joined, will provide the maximum mechanical strength for the join. The surfaces to be joined must be positioned in a fixed and definitive position once the adhesive has been applied.
Put two pressure clamps in place, one on each side of the join, during the whole drying process.
Performing the resistance spot weld
Following the measurements of the test piece, perform the resistance spot weld

Tools maintenance
All the tools can be cleaned with hot water and soap before the adhesive remains have cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

5th Practical Training

HYBRID Aluminium-Aluminium Joins: STRUCTURAL ADHESIVE + RIVETING (SELF PIERCING - PIN BREAKAGE) On test piece.

(2 hours)

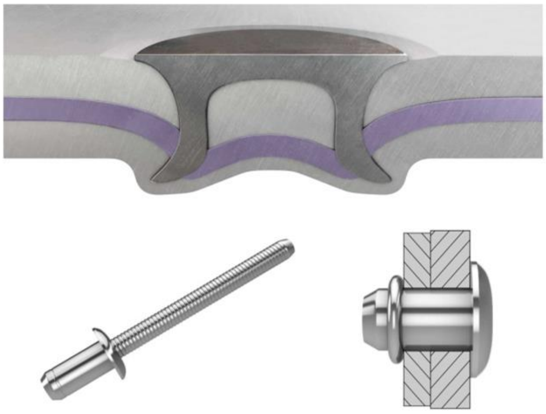
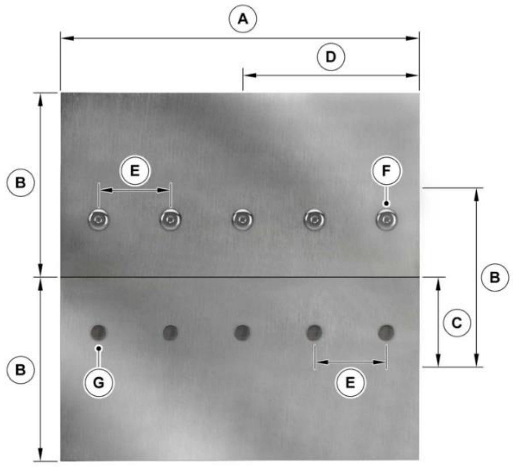


Figure 139 - Blind rivet and pin breakage. Source: CESVIMAP

Figure 140 - Structural adhesive. Source: CESVIMAP



Item	Description
A	150mm (6.0 inches)
B	75mm (3.0 inches)
C	37.5mm (1.4 inches)
D	75mm (3.0 inches)
E	30mm (1.1 inches)
F	Breakstem Fasteners
G	Self Piercing Rivets (SPR)

Figure 141 and Table 20 - Test piece. Source: CESVIMAP

Figure 142 - Self-blocking clamps. Source: CESVIMAP

Figure 143 - Riveting devices for snap-off pin rivets. Source: CESVIMAP

Figure 144 - Self-piercing rivet device. Source: CESVIMAP

Consumables
✓ Structural adhesive KIT.
✓ 3 aluminium flanges of 100 x 75 x 1 mm.
✓ Surface cleaned recommended by the structural adhesive manufacturer.
✓ Disposable paper to clean surfaces.
✓ Masking tape or sheet metal worker's tape.
Tools
✓ Adhesive application gun.
✓ Drill and 6.5 mm bit.
✓ Self-piercing rivet machine. Rivets.
✓ Rivet machines for snap-off pin riveting. 6 mm diameter rivets.
✓ Self-blocking clamps.
Health and Safety
✓ Use: work clothes, rubber or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will normally be necessary. Likewise the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used, and not cloth towels, to dry the skin.
Proper ventilation of the place of work is advisable.
Work process
Prepare the test piece
Perform the test piece according to the plan as indicated.
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet
Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.

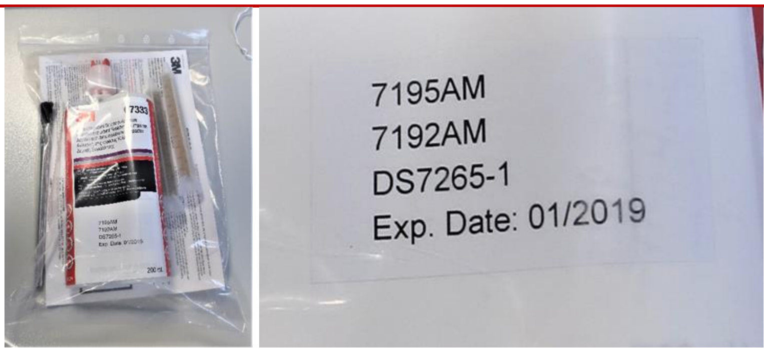


Figure 145 – Expiration date. Source: CESVIMAP

Test bead

A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.

Pre-treatment - Preparation of the substrate

The surfaces to be joined should be cleaned in advance with a good degreasing agent, in particular the one recommended in the manufacturer's specifications, in order to eliminate any trace of oil, grease or of dirt. Low degree alcohols, petrol or paint solvents should never be used as degreasing agents.

The strongest joins are obtained after subjecting the surfaces, already degreased, to mechanical abrasion treatments or to chemical stripping treatments. A mechanical abrasion treatment would involve a new degreasing process after this treatment.

Application of the adhesive

The mix of resin and hardener must be applied directly or with a spatula on the dry and pre-treated surfaces.

A coat of adhesive with a thickness of 1 mm on each surface to be joined, will provide the maximum mechanical strength for the join. The surfaces to be joined must be positioned in a fixed and definitive position once the adhesive has been applied.
Put two pressure clamps in place, one on each side of the join, during the whole drying process.
Performing the riveting with snap-off pin rivets.
Perform the riveting according to the plan of the test piece.
Performing the self-piercing riveting
Perform the riveting according to the plan of the test piece.
Tools maintenance
All the tools can be cleaned with hot water and soap before the adhesive residue has cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

6th Practical Training

Replacement of an aesthetic element of an aluminium vehicle body - roof (Substrate: aluminium - aluminium) by means of structural adhesive and riveting.

(6 hours)

Figure 146 - EXAMPLE: aluminium roof. Source: CESVIMAP

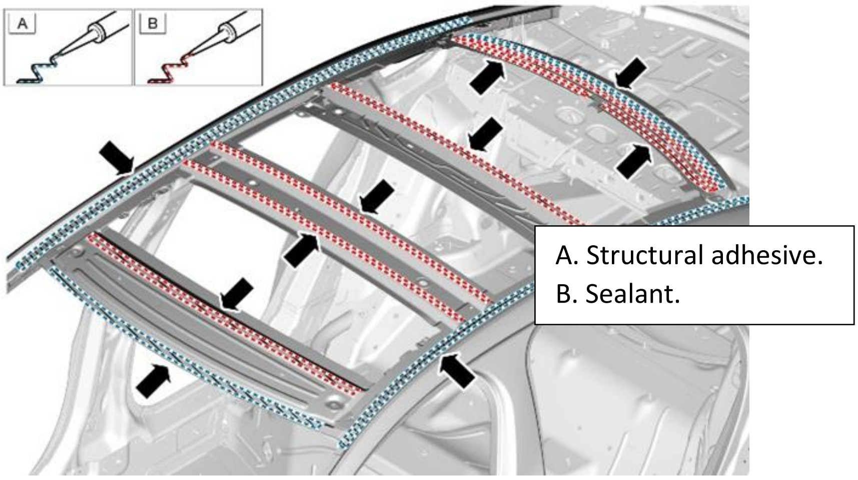


Figure 147 - Zones of adhesive application in the roof join. Source: CESVIMAP

Main consumables
Aluminium vehicle body
Replacement roof of the previous vehicle body
Health and Safety.
✓ Use: work clothes, rubber gloves or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will normally be necessary. Likewise the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used, and not cloth towels, to dry the skin.
Proper ventilation of the place of work is advisable.
Work process
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet
Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.
Test bead

A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.
Repair shop manual - roof replacement procedure
Read the repair shop manual which indicates the procedure for replacement of the aluminium roof in an aluminium vehicle body, and obtain the following information:
• Obtain information about the utensils and tools needed to carry out the process.
• Obtain the consumables needed to carry out the process.
Repair shop - Carry out the replacement procedure as indicated
Follow the replacement procedure for the aluminium roof in an aluminium vehicle body step by step.
Tools maintenance
All the tools can be cleaned with hot water and soap before the adhesive remains have cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

7th Practical Training

Replacement of an aesthetic element of an aluminium vehicle body - REAR WING (Substrate: aluminium - aluminium) by means of structural adhesive, riveting.

(9 hours)

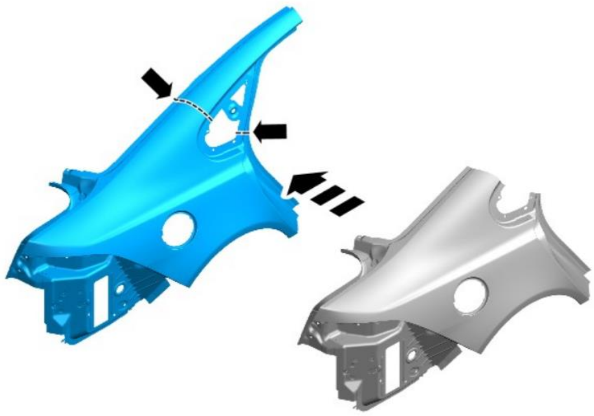


Figure 148 - EXAMPLE: aluminium rear wing. Source: CESVIMAP

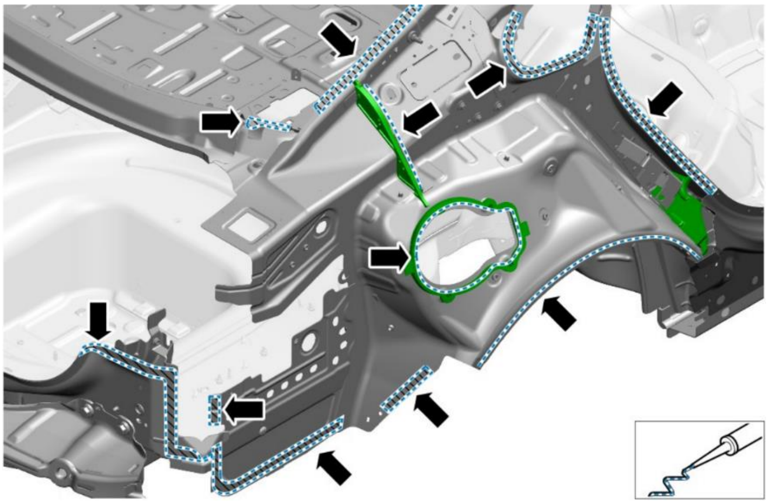


Figure 149 - Zones of adhesive application in the join. Source: CESVIMAP

Main consumables
Aluminium vehicle body
Replacement of the rear wing on the previous vehicle body
Health and Safety
Use: work clothes, rubber gloves or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will normally be necessary. Likewise the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used, and not cloth towels, to dry the skin.
Proper ventilation of the place of work is advisable.
Work process
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet
Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.
Test bead
A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be

approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.
Repair shop manual - Rear wing replacement procedure
Read the repair shop manual which indicates the procedure for replacement of the rear wing in an aluminium vehicle body, and obtain the following information:
Obtain information about the utensils and tools needed to carry out the process.
Obtain the consumables needed to carry out the process.
Repair shop - Carry out the replacement procedure as indicated
Follow the replacement procedure for the aluminium rear wing in an aluminium vehicle body step by step.
Tools maintenance
All the tools can be cleaned with hot water and soap before the adhesive remains have cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

8th Practical Training

Replacement of a STRUCTURAL element of an aluminium vehicle body - B-PILLAR REINFORCEMENT (Substrate: aluminium - aluminium) by means of structural adhesive, riveting.

(5 hours)

Figure 150 - EXAMPLE: -B- pillar reinforcement . Source: CESVIMAP

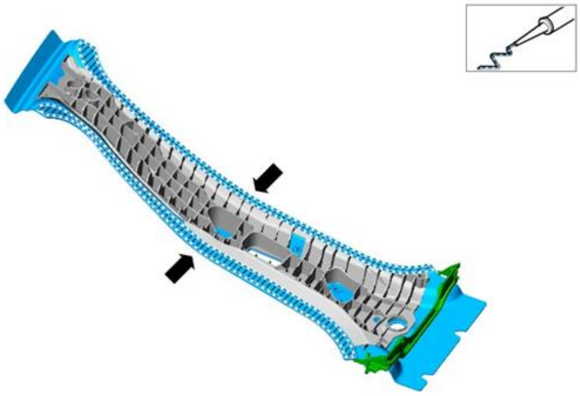


Figure 151 - Zones of adhesive application in the join. Source: CESVIMAP

Main consumables	
Aluminium vehicle body.	
Replacement B-pillar reinforcement corresponding to the previous vehicle body.	
Health and Safety	
Use: work clothes, rubber gloves or impermeable plastic gloves, goggles.	
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.	
The use of rubber or impermeable plastic gloves will normally be necessary. Likewise the use of protection for the eyes.	
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.	
Disposable paper should be used, and not cloth towels, to dry the skin.	
Proper ventilation of the place of work is advisable.	
Work process	
Safety specifications of the structural adhesive	

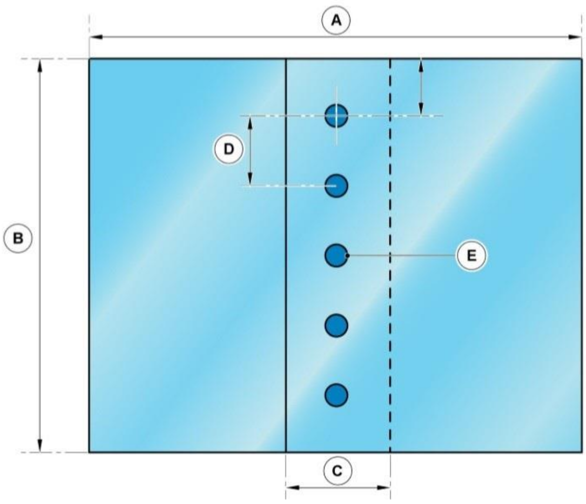
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet
Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.
Test bead
A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.
Repair shop manual - Rear wing replacement procedure
Read the repair shop manual which indicates the procedure for replacement of the rear wing in an aluminium vehicle body, and obtain the following information:
Obtain information about the utensils and tools needed to carry out the process.
Obtain the consumables needed to carry out the process.
Repair shop - Carry out the replacement procedure as indicated
Follow the replacement procedure for the aluminium B-pillar reinforcement in an aluminium vehicle body step by step.
Tools maintenance
All the tools can be cleaned with hot water and soap before the adhesive remains have cured. The elimination of adhesive residue, once cured, is difficult and takes

time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

9th Practical Training

Resistance Spot Welding Of Steel To Steel Through An Adhesive On Test Pieces (3hours)

Your practical training will involve performing resistance spot welds on two overlapping steel plates (Figure 128). The material shall be two times steel plates of single sheet thickness 0.6 – 1.5 mm, the plates may be uncoated or zinc coated. A weldable epoxy adhesive will be applied between the plates and spot welding trials will be performed through the adhesive.



Item	Description	Item	Description
A	Overall length – 120mm (4.5 inches)	B	Width – 180mm (7.0 inches)
C	Overlap – 20mm (1.3 inches)	D	Pitch – 30 mm (1.1 inches)
E	Resistance spot weld		

Figure 152 and table 21 - Test piece. Source: CESVIMAP

Figure 153 - Structural adhesive. Source: CESVIMAP

Figure 154 - Mole grips / Self-blocking clamps. Source: CESVIMAP

Figure 155 - Pliers and grips. Source: CESVIMAP

Figure 156 - Vernier calliper. Source: CESVIMAP

Consumables
Structural adhesive kit.
10 steel sheets of 70 x 180 x 0.9 mm.
Surface cleanser recommended by the structural adhesive manufacturer.
Disposable paper to clean surfaces.
Masking tape or sheet metal worker's tape.
Tools
✓ Adhesive application gun.
✓ Self-blocking clamps.
✓ Resistance spot welding machine.
✓ Pliers or grips.
✓ Vernier calliper.
Health and Safety
Use: work clothes, rubber or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will be necessary, as well as the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used, and not cloth towels, to dry the skin.
Proper ventilation of the place of work is advisable.
Work process
Prepare the test piece
Perform the test piece according to the plan as indicated.
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.
Product technical specifications sheet

Read the technical specifications of the structural adhesive and note the application procedure and the times for handling and drying.
Check the product's expiry date
Check the product's expiry date and dispose of it if is past the date.

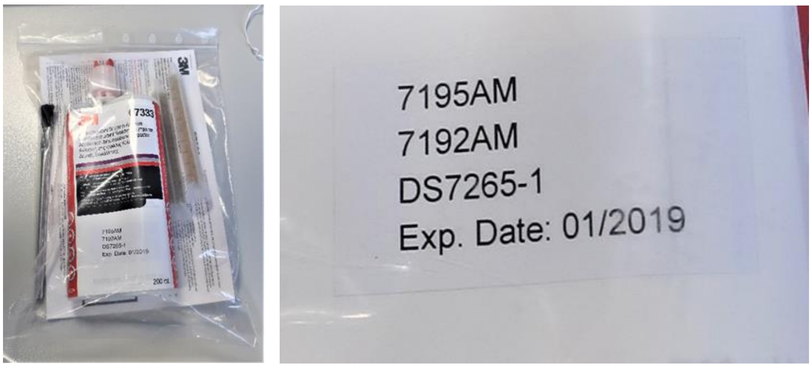


Figure 157 – Expiration date. Source: CESVIMAP

Test bead
A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.
Pre-treatment - Preparation of the substrate
The surfaces to be joined should be cleaned in advance with a good degreasing agent, in particular the one recommended in the manufacturer's specifications, in order to eliminate any trace of oil, grease or dirt. Low degree alcohols, petrol or paint solvents should never be used as degreasing agents.
The strongest joins are obtained after subjecting the surfaces, already degreased, to mechanical abrasion treatments or to chemical stripping treatments. A mechanical abrasion treatment would involve a new degreasing process after this treatment.
Preparing the plates and clamping
Position the plates in a configuration where one overlaps the other with a flange width of 35mm, as shown in the figure. Clamp the plates in position at both edges with the self-blocking clamps.
Application of the adhesive
The mix of resin and hardener must be applied directly or with a spatula on the dry, pre-treated surfaces.

A coat of adhesive with a thickness of 1 mm on each surface to be joined, will provide the maximum mechanical strength for the join. The surfaces to be joined must be positioned in a fixed and definitive position once the adhesive has been applied.
Put two pressure clamps in place, one on each side of the join, during the whole drying process.
Setting up the resistance spot welding program
Following the measurements of the test piece, perform the resistance spot weld. Select welding parameters according to an instruction or standard, initially select a low current value or heat percentage. Position the test piece between the electrodes and make the first weld. If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat percentage) by approximately 10% of the initial value.
Performing the spot welding test (Part A)
Record all parameters on a test sheet, as shown below: 1. Position the test piece between the electrodes and make the first weld (The distance (pitch) between subsequent welds must be 30 mm). 2. If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat %) by approximately 50% of the initial value. 3. If a weld is made without the occurrence of splash, increase current in small steps (either 0.2kA or + 2.5% heat). 4. Continue increasing current in small steps and welding on test pieces until splash occurs. 5. At the end of the test, hold one side of the test piece in a clamp and tear the other side open using pliers or grips. 6. Measure the spot weld size with a Vernier calliper, as shown in the figure. 7. Record the largest and smallest diameter of the weld area and calculate the average; record the data on the data sheet. 8. Check to see if the minimum weld size requirement could be met at a stable welding condition before splash (liquid metal expulsion occurred). 9. At the end of welding, check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary, repair the electrode surface with a tip dressing tool, or replace the electrode with a new one.
Repeating the spot welding test (Part B- Increased force and weld time)
In Part A, a spot welding process window was defined for a fixed set of parameters. In Part B, the spot welding parameters will be varied by selecting a weld time 200% of the time used in part A and a weld force (pressure) 200% of the force used in part A.
1. Position the test piece between the electrodes and make the first weld (The distance (pitch) between subsequent welds must be 30 mm). 2. If a weld splash occurs (liquid metal expulsion) reduce the welding current (or heat percentage) by approximately 50% of the initial value. 3. If a weld is made without the occurrence of splash, increase current in small steps (either 0.2kA or + 2.5% heat). 4. Continue increasing current in small steps and welding on test pieces until splash

occurs.

5. At the end of the test, hold one side of the test piece in a clamp and tear the other side open using pliers or grips.
6. Measure the spot weld size with a Vernier calliper, as shown in the figure.
7. Record the largest and smallest diameter of the weld area and calculate the average; record the data on the data sheet.
8. Check to see if the minimum weld size requirement could be met at a stable welding condition before splash (liquid metal expulsion occurred).
9. Compare the results to the Part A test to see the influence of increased weld time and force on the process.
10. At the end of welding, check the electrode condition for contamination by adhesive (or excessive wear as a result of the zinc coating, if coated steel was used). If necessary, repair the electrode surface with a tip dressing tool, or replace the electrode with a new one.

Tools maintenance

All the tools can be cleaned with hot water and soap before the adhesive remains have cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.

10th Practical Training

Blind Rivet Aluminium-Aluminium Joints Through an Adhesive, Using a Flat Coupon Test Piece

(2 hours)

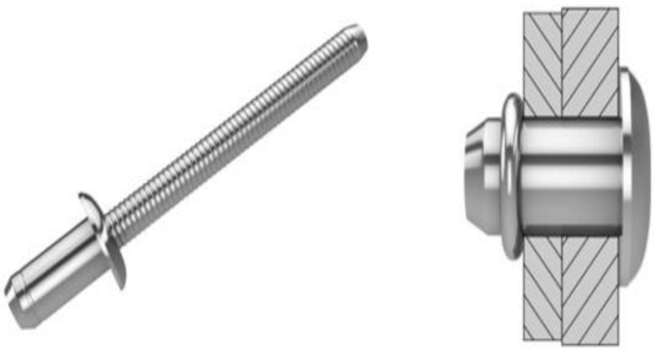


Figure 158 - Blind rivet . Source: CESVIMAP

Figure 159 -Structural adhesive. Source: CESVIMAP

Item	Description
A	150 mm (6.0 inches)
B	75 mm (3.0 inches)
C	37.5 mm (1.4 inches)
D	75 mm (3.0 inches)
E	30 mm (1.1 inches)
F	Blind rivets

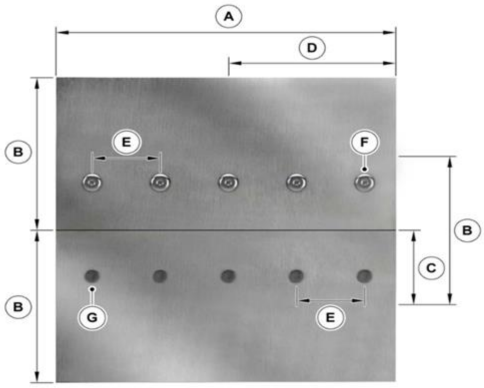


Figure 160 and Table 22 -Test piece. Source: CESVIMAP

Figure 161 -Self-blocking clamps. Source: CESVIMAP

Figure 162 -G clamp. Source: TWI

Figures 163 and 164 - Drill and drill bit. Source: TWI

Figure 165 - Blind riveting tools. Source: TWI

Consumables
✓ Structural adhesive KIT
✓ 4 aluminium sheets of 100 x 70 mm (thickness from 1.0 – 3.0 mm)
✓ Surface cleaner recommended by the structural adhesive manufacturer
✓ Disposable paper to clean surfaces
✓ Masking tape or sheet metal worker's tape
Tools
✓ Adhesive application gun
✓ Drill
✓ 6.5 mm drill bit and 7.5 mm drill bit
✓ Blind riveting tool
✓ Drill
✓ Blind rivets 6.4 mm diameter body, suitable grip range for the sheet stack thickness (minimum of 10 blind rivets needed)
✓ Self-blocking clamps
✓ G clamps
Health and Safety
Use: work clothes, rubber or impermeable plastic gloves, goggles.
Measures must be taken to prevent materials which are not cured from coming into contact with skin, since people with especially sensitive skins may be affected.
The use of rubber or impermeable plastic gloves will normally be necessary, as well as the use of protection for the eyes.
The skin must be cleaned with warm water and soap at the end of each period of work. Avoid the use of solvents on the skin.
Disposable paper should be used to dry the skin, and not cloth towels.
Proper ventilation of the place of work is advisable.
Follow working procedures for drilling.
Follow safe working procedures for blind rivet application, use operators' instructions for operation of the riveting tool.
Work process
Prepare the test piece
Perform the test piece according to the plan as indicated.
Drilling the holes
6. Position the aluminium sheets as shown in the diagram, with the correct 35 mm overlap, 7. Clamp the aluminium sheets to a suitable work bench or drilling table, 8. Ensure there is an open area or block of wood under the area to be drilled, 9. Drill the holes in 3 sheets with a 6.5 mm drill bit, 10. Drill the holes in 1 sheet with a 7.5 mm drill bit.
Safety specifications of the structural adhesive
Read the safety specifications of the product and note the safety kit that the person applying the product must wear.

Product technical specifications sheet

Read the technical specifications of the structural adhesive and note down the application procedure and the times for handling and drying.

Check the product's expiry date

Check the product's expiry date and dispose of it if is past the date.

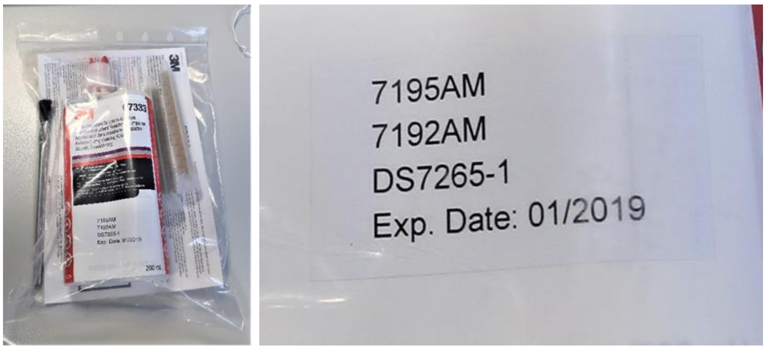


Figure 166 -Expiration date. Source: CESVIMAP

Test bead

A test bead should be performed once the product has been properly prepared according to the manufacturer's instructions for use. The test bead should be approximately 300 mm in length. This must be set in place on a disposable substrate and left to dry in conditions similar to those of the real repair. Once the drying cycle indicated has been completed (15 minutes at a temperature of 80°C or at room temperature for 24 hours), the bodywork technician will be able to observe the colour of the bead and carry out a touch test to ensure that the product has dried and is firm.

Pre-treatment - Preparation of the substrate

The surfaces to be joined should be cleaned in advance with a good degreasing agent, in particular the one recommended in the manufacturer's specifications, in order to eliminate any trace of oil, grease or of dirt. Low degree alcohols, petrol or paint solvents should never be used as degreasing agents.

The strongest joins are obtained after subjecting the surfaces, already degreased, to mechanical abrasion treatments or to chemical stripping treatments. A mechanical abrasion treatment would involve a new degreasing process after this treatment.

Application of the adhesive

The mix of resin and hardener must be applied directly or with a spatula on the dry and pre-treated surfaces.

A coat of adhesive with a thickness of 1 mm on each surface to be joined, will provide the maximum mechanical strength for the join. The surfaces to be joined must be positioned in a fixed and definitive position once the adhesive has been applied.

Put two pressure clamps in place, one on each side of the joint, during the whole drying process.

Setting the blind rivets - Part A 6.5 mm holes in upper and lower sheet
9. Ensure the holes are correctly lined up in the test pieces (upper and lower holes are 6.5mm diameter), 10. Wipe away any excess adhesive that flows out of the holes, 11. Follow the rivet tool manufacturers operation procedures, 12. Insert a rivet into the tool, 13. Place the tool and rivet into the hole, ensure the tool is perpendicular, 14. Apply down force, 15. The rivet tool trigger is pressed (or mechanism operated on a manual tool), the mandrel snaps off and the rivet is set, 16. Check the rivet tail has properly clamped the lower sheet, check the rivet head is flush to the upper sheet, check the mandrel has snapped off in the right position within the rivet head.
Setting the blind rivets, 7.5 mm hole in the upper sheet, 6.5 mm hole in the lower sheet
9. Ensure the holes are correctly lined up in the test pieces (lower holes are 6.5 mm diameter; upper holes are 7.5 mm diameter), 10. Wipe away any excess adhesive that flows out of the holes, 11. Follow the rivet tool manufacturers operation procedures, 12. Insert a rivet into the tool, 13. Place the tool and rivet into the hole, ensure the tool is perpendicular, 14. Apply down force, 15. The rivet tool trigger is pressed (or mechanism operated on a manual tool), the mandrel snaps off and the rivet is set, 16. Check the rivet tail has properly clamped the lower sheet, check the rivet head is flush to the upper sheet, check the mandrel has snapped off in the right position within the rivet head.
Tool maintenance
All the tools can be cleaned with hot water and soap before the adhesive residue has cured. The elimination of adhesive residue, once cured, is difficult and takes time. If solvents such as acetone are used for the cleaning, the necessary protective measures must be taken and contact with eyes and skin must be avoided.