

EAA Aluminium Automotive Manual – Joining

5. Electric resistance welding

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5. Electric resistance welding

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5.0 Introduction

Electric resistance welding refers to a group of thermo-electric welding processes such as spot and seam welding. The weld is made by conducting a strong current through the metal to heat up and finally melt the metal at a localized point, predetermined by the design of the electrodes and/or the work piece to be welded. A force is always applied before, during and after the application of current to confine the contact area at the weld interfaces and, in some applications, to forge the work pieces.

The general heat generation formula for resistance welding is:

$$\text{Heat} = I^2 \times R \times t,$$

where I is the weld current through the work pieces, R is the electrical resistance of the work pieces and t is the weld time. The weld current and duration of current are controlled by the resistance welding power supply. The resistance of the work pieces is a function of many different factors, i.e. the electrical resistance of the work pieces and electrodes, the geometry of the work pieces, the surface conditions of both work pieces and electrodes, the electrode geometry, the electrode pressing force (i.e. the force used to hold the materials together), etc.

When the electrical current passes through the metal, heat is preferentially generated at the connecting or "faying" surfaces of the parts to be joined. When the welding temperature is reached, the parts are welded in spots at their contact points between the electrodes by the electrode force. In general, resistance welding methods are efficient (very short process time), require no consumables, are clean and environmentally friendly, but their application is limited to relatively thin materials and the equipment cost can be high.

Aluminium and its alloys have high thermal and electrical conductivity compared with steel and, as the process depends on resistance heating, they require much higher welding currents.

There are three basic types of resistance welding bonds:

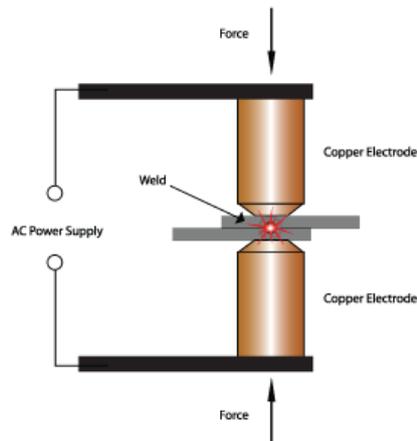
- In a **solid state bond** (also called a thermo-compression bond), dissimilar materials are joined using a very short heating time, high weld energy and high force. There is little melting and minimum thermal impact on both materials, i.e. the materials are more or less bond while still in the "solid state". The joint typically exhibits good shear and tensile strength, but poor peel strength.
- In a **fusion bond**, either similar or dissimilar materials, both materials are locally heated to the melting point. The subsequent cooling (and combination of the two materials) forms a weld nugget. Typically, high weld energies at either short or long weld times, depending on physical characteristics, are used to produce fusion bonds. The bonded materials usually exhibit excellent tensile, peel and shear strengths.
- In a **reflow braze bond**, resistance heating of a low temperature brazing material is used to join either dissimilar materials or widely varying thick/thin material combinations. The brazing material must wet each part and possess a lower melting point than both work pieces. The resultant bond has definite interfaces with minimum grain growth. Typically the process requires a longer heating time at low weld energy. The resultant bond exhibits excellent tensile strength, but poor peel and shear strength.

In the following, the fusion bond approach will be considered in more details. Solid state resistance welding and resistance brazing are only relevant for very specific types of joints between aluminium and other materials.

5.1 Resistance spot welding

Resistance spot welding is a resistance welding process that utilizes the heat obtained by the resistance to the flow of electric current to the work pieces through electrodes that concentrate current and pressure at the weld area. The generated heat is used to melt and

solidify a nugget at the faying surfaces of a joint. The resistance spot welding process is characterized by a very fast welding operation which is readily adapted to automation.



Schematic of resistance spot welding process

The work pieces are overlapped and held together under pressure exerted by two shaped copper electrodes. The applied force presses the sheet surfaces into intimate contact. A large current is then passed through electrodes and work pieces for a very short time. The electrode faces concentrate the welding current into a small spot. Governed by Joule's law, heating is caused due to the bulk resistance of the work pieces and the contact resistances, which are determined by the surface condition of the work pieces (surface roughness, cleanliness, surface oxides and, if applicable, surface coatings). Welding times vary depending on the type of material, its thickness, the electrode force and the diameter of the electrodes.

5.1.1 The resistance spot welding process

Spot welding involves three stages. At first, the electrodes are brought in contact with the surface of the metal and a slight pressure is applied. On a microscopic scale, the metal surface is quite rough, i.e. when the metals are forced together, some peaks will make contact. Where the contact pressure is sufficiently high, the oxide layer breaks, forming a limited number of metal-to-metal bridges. The weld schedule must include sufficient time to build electrode force to 95% of the intended weld force prior to initiating current.

Then a high current flows for a short time. As it passes through the bulk metal, the weld current is distributed over a large area. However, as it approaches the interface, the current is forced to flow through the metallic bridges, which increases the current density and generates enough heat to cause melting. As the first of these bridges melt and collapse, new peaks come into contact, forming new bridges and additional current paths. The resistance of the molten metal is higher than that of the new bridges so that the current flow transfers primarily from bridge-to-bridge. This process continues until the entire interface is molten. The amount of heat (energy) delivered to the spot depends on the resistance between the electrodes and the magnitude and duration of the current. The amount of energy must be chosen to match the properties and thickness of the materials to be joined and the type of the electrodes. Applying too little energy will not melt the metal or will make a poor weld. Applying too much energy will melt too much metal, eject molten material, and make a hole rather than a weld.

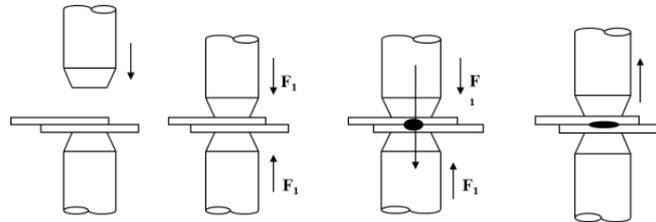
After the current is removed, the electrode force is maintained for a fraction of a second, while the weld rapidly cools. At the end of the cycle, solidification of the nugget is completed under the electrode force. Often the work piece is locally cooled via coolant holes in the centre of the electrodes. Typically, a circular nugget of diameter between 4 and 7 mm is produced. There is no protruding weld-bead on either side of the joint.

Since the resistance welding process relies on heating, some amount of heat affected zone (HAZ) is inevitable. In general, the goal in resistance welding is to minimize the HAZ. When the flow of current stops, part of the heat generated is lost to the surroundings by heat

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transfer through solids, heat lost from exposed surfaces by air-cooling, and radiation. Heat balance is a function of part material and geometry, electrode material and geometry, polarity, and the weld schedule. The goal of good resistance welding is to focus the heat generated close to the weld interface at the spot where the weld is desired.

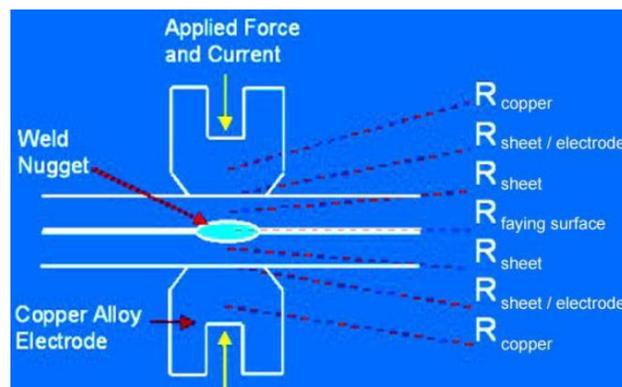
The applied pressure and the heat generation are localized by the form of the electrodes. The weld nugget size is usually defined by the electrode tip contact area, i.e. welding occurs without excessive heating of the remainder of the sheet



Typical steps in producing a resistance spot weld

(Source: EWI)

Modern welding equipment can accurately control the electrode force, the welding current and time. Thus any uncertainty in the resistance spot welding process comes from variability in the resistance term. For aluminium being such a good electrical conductor, the heat generated during spot welding is primarily obtained from the contact resistances at the faying surfaces and not from the bulk material resistance like in steel. The weld nugget will develop in the middle of the joint where the two oxide surfaces meet.



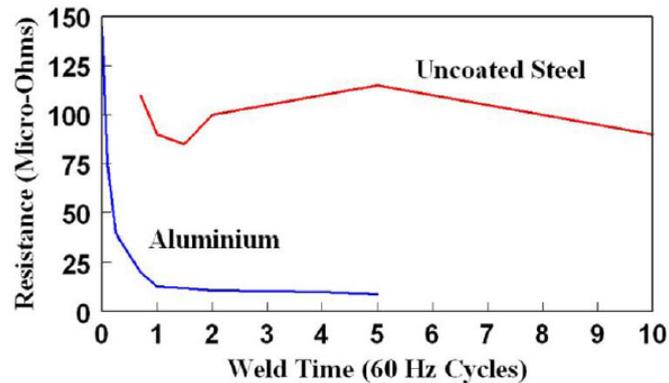
Total resistance is the sum of all resistances in the electrodes and work piece stack-up

Thus the key to successful resistance spot welding of aluminium is to guarantee reproducible and stable sheet surface characteristics. The surface contact resistance is determined by a combination of different materials-related factors:

- Surface topography
- Composition of oxide film (function of alloy type and processing route)
- Degree of any surface cleaning
- Type and amount of any chemical pre-treatments
- Type and amount of any residual lubricants, weld-through sealers or adhesives.

As a general rule, aluminium semi-finished products are spot weldable, but the inhomogeneous surface oxide leads to inconsistent weld performance and expulsion. Chemical or mechanical removal of the surface oxide film immediately before welding provides a consistent, but low surface resistance which, on the other hand, requires much higher welding currents that substantially increase electrode sticking. Some specially designed chemical surface treatments, often applied by the material supplier, provide a consistent, medium to high surface resistance and, thus good spot weldability can be ensured. Anodised surfaces or organic coatings (including dry lubricants) usually lead to very high resistance (sometimes even insulating) surface layers and are usually not spot weldable.

Optimised surface pre-treatments for spot welding generally include a cleaning step (mixed acid cleaning or electrolytic cleaning) followed by a conversion treatment (e.g. Alcoa 951 process, Ti or Ti/Zr fluoride treatment) or thin film anodizing in order to guarantee the required storage stability. But in the automotive industry, it is often also common practice to resistance weld lubricated aluminium sheet with no special surface treatments. Issues regarding inhomogeneous surface oxidation are addressed with improved mill controls, properly pre-lubricated aluminium materials and adapted transport and storage methods.



Resistance of aluminium and steel during spot welding

Characteristic for aluminium spot welding is a rapid fall of the electrical resistance in the beginning. Actually, the dynamic behaviour of the resistance value – which is determined by the breakdown of the contact resistances in the system – is more important than the initial (static) value. The weld current is initially concentrated by selective conduction through these fractured areas which explains the high initial contact resistance. Consequently, compared to steel, resistance spot welding of aluminium requires higher electrode forces. Higher force capability is also needed to control expulsion when welding thicker gauge aluminium materials.

In addition, in aluminium spot welding, short weld times are employed to generate the heat quickly and thus minimise the heat loss by conduction. Since the welding current must be two to three times higher than in case of steel and the welding time is only one third of the welding time of steel, the welding gun has to deliver high currents for very short times. This means the electric parameters (current and voltage) must be controlled more precisely in narrower time window.

5.1.2 Resistance spot welding equipment

The basic difference between the equipment required for aluminium spot welding compared to spot welding of steel is the force and current capability of the welding gun. An electrode force range of 0.2 to 4 kN and welding currents under 15 kA are usually sufficient for steel spot welding. For aluminium resistance spot welding, however, a force range of 0.2 to 8 kN and welding currents up to 40 kA are typically required.

A key element of an aluminium resistance spot welding system is therefore the power supply. Today, medium frequency direct current (MFDC) welding power supplies are mainly used. A particular benefit of MFDC power supplies is the flexibility to weld a variety of gauges and materials and the reduced size and mass of the welding transformer, enabling robot manipulation of the higher current guns needed for aluminium welding. This approach is further exploited by systems operating at even higher frequencies (up to 20kHz). More compact transformers offer particular benefit on long reach guns where the additional weight savings allow the use of a reduced robot size and also to reduce gun inertia.

But there are alternative power supplies that produce welds with the same quality as MFDC, i.e. single-phase alternate current (AC) and conventional direct current (DC) systems. These technologies offer a lower equipment cost, but will require larger robots and higher primary power. Typically, AC power supplies yield better electrode life performance compared to DC systems, but are less flexible whereas DC power supplies offer greater control of the short time welding pulse and thus improved weldability. Another possible power supply technology is the capacitor discharge (CD) method which is commonly used in the micro resistance

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welding industry, but could also provide advantages for aluminium resistance welding applications.

Polarity effects must be considered when using all power supply technologies. Nugget growth is offset slightly towards the positive electrode and this can be used to advantage when welding dissimilar thicknesses. In addition, the positive electrode is subjected to faster wear than the negative one. Also if any of the interfaces of a resistance weld is composed of dissimilar materials, that interface will heat or cool depending on the polarity of the applied potential. This effect is dominant only in the first few milliseconds of a weld, but significantly affects the weld quality and electrode wear. The effects of polarity can be minimized via the use of weld pulses of alternating polarity. Current stepping is an effective process control strategy that compensates for electrode growth and wear. There are also MFDC power supplies that can alternate polarity under development.

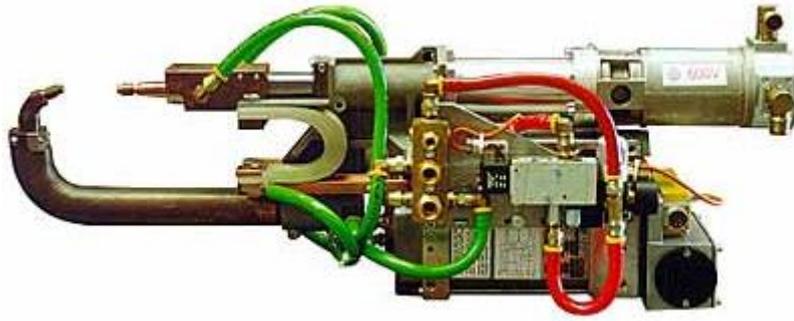


Resistance spot welding welding robot

(Source: T.J. Snow)

The other key elements used in the spot welding process are the tool holders and the electrodes. The tool holders provide the necessary electrode force and hold the electrodes firmly in place. They also support the (optional) water hoses which cool the electrodes during welding. Traditionally, pneumatic actuators have been employed in the automotive industry to apply the electrode clamping force. Today, electric servomotor actuators are usually installed. Unlike pneumatics, servo guns with force feedback control operate accurately at both low and high gun forces. They also offer the potential for faster cycle times by improved control of the electrode aperture and closing speed. Another interesting possibility is the ability to increase or decrease the electrode force during welding. Force stepping adds another degree of control since it maintains increased uniformity of the pressure – and ultimately current density distribution – across the welding interfaces. It may also reduce electrode erosion since it lowers the contact resistance at the electrode and sheet interfaces.

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Servo-controlled spot welding gun

(Source: ARO)

An MFDC servo gun specified for welding aluminium is fully capable of welding steel, therefore a production cell set-up for aluminium resistance spot welding offers the flexibility to also weld the full range of automotive steels (but not the other way round).



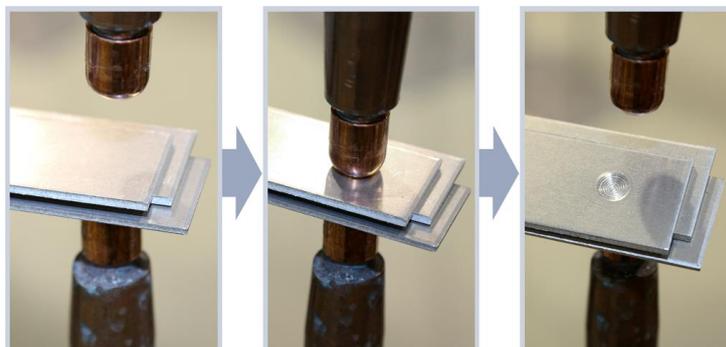
Manual resistance spot welder (left) and robot spot welding system (right)

(Source: Elektron/ Kuka Systems)

5.1.3 Electrodes and electrode maintenance

The copper electrodes used for aluminium resistance spot welding are designed in different shapes and sizes depending on the application. Radius style electrodes are used for high heat applications, electrodes with a truncated tip for high pressure, eccentric electrodes for welding corners, offset eccentric tips for reaching into corners and small spaces, and finally offset truncated for reaching into the work piece itself.

A new development for aluminium resistance spot welding is GM's patented multi-ring domed electrode. The new welding technique works on sheet, extruded and cast aluminium and enables stronger welds because the multi-ring domed electrode head disrupts the oxide on the aluminium surface.

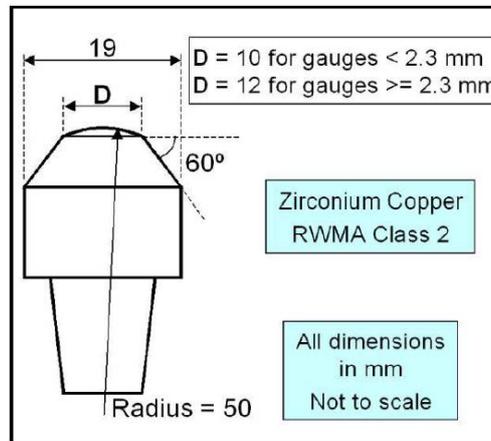


GM's proprietary multi-ring domed electrode head

(Source: GM)

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Recommended by the Resistance Welders Manufacturing Association are electrodes made from group A class 1 alloys. Group A class 1 alloys have the highest electrical conductivity. For the standard Al-Mg and Al-Mg-Si car body sheet alloys, electrodes A class 2 can be used too. Efficient cooling of the electrodes must be ensured; the coolant flow rate should be 5 - 10 litres per minute (more than in case of steel). It must be also noted that for aluminium welding, the electrode tip diameter and dome radius are bigger than for steel.



Schematic of an electrode for aluminium resistance spot welding

Newer studies showed that the face diameter D should be smaller than indicated in the figure above. It was found that for aluminium sheet thicknesses between 0.8 and 4.0 mm, a face diameter D between 5.0 and 10.0 mm promotes more uniform contact distribution at the electrode and interfacial surfaces, reduces undersized welds that occur intermittently and significantly increases electrode life.

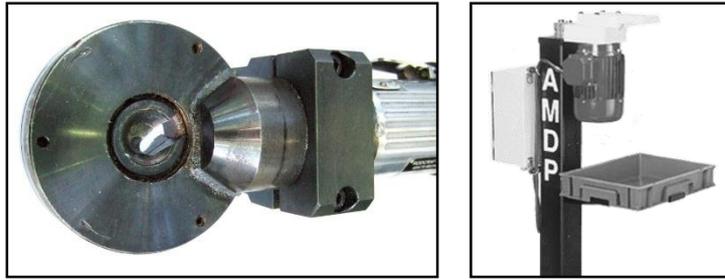
The main problem connected with resistance spot welding of aluminium and its alloys is the short life time of the electrodes. The rapid deterioration of the tip surface of the copper electrode is the result of the high pressure, the high temperature and in particular alloying processes during welding. The accumulation of aluminium on the electrode face causes increased resistance heating at the electrode-aluminium interface and therefore even more aluminium melts and sticks to the electrode. Once significant aluminium accumulation has occurred, deterioration of the weld consistency and quality is rapid. Unless some sort of electrode maintenance is employed, typically only between 300 and 3000 aluminium spot welds can be achieved on a set of electrodes before the weld quality drops below a minimum threshold.

Numerous process and material strategies to increase the electrode life performance have been proposed in the past. Most concepts focused on reducing electrode erosion through a variety of surface coatings and treatments. Such techniques can enhance spot welding performance, but are often difficult to implement and expensive.

More efficient proved to be the introduction of a regular electrode cleaning step, ideally before electrode wear contributes to poor weld quality. Dressing allows the user to restore a worn electrode to a desired geometry, thereby eliminating changes in electrode topography and diameter due to pitting and erosion. The actual type and frequency of electrode cleaning, process times and tool designs are dependent upon the overall cleaning strategy. The process takes up to several seconds and is typically completed during the part transfer operation.

In many automotive resistance spot welding lines, electrode dressing has been introduced to extend electrode life time and improve weld consistency both for steel and aluminium. A wide range of commercially available electrode dressing equipment has been developed; including hand-held dressers for manual guns and stand-mounted systems for robots.

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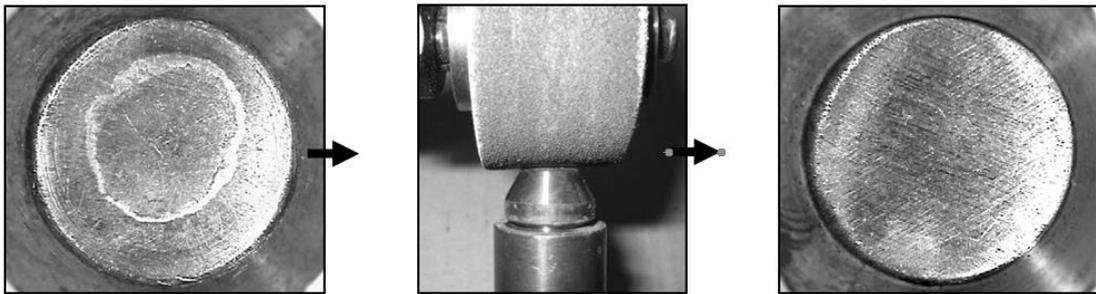


Hand-held dresser (left) and stand-mounted robot dresser with swarf tray (right)

(Source: University of Warwick)

A common feature of cutters designed for steel is the emphasis on reshaping the sides of the electrodes to remove mushrooming and thereby maintain welding current density. In aluminium resistance spot welding, mushrooming of the electrode does not occur and the main requirement of the cutter would be to take light cuts from the face to remove aluminium, oxides and pits. However, this is not the optimum solution because the required frequent electrode dressing may lead to substantial geometrical changes, i.e. the electrodes must be replaced early.

A more efficient solution for aluminium resistance spot welding proved to be the use of less aggressive electrode maintenance methods and to employ a dressing cutter only when the tip is badly damaged. The use of suitable abrasive wheels was found to be extremely effective at removing aluminium from the electrode face. An additional advantage is that the adaptable buffing wheels maintain the profile on domed electrodes.



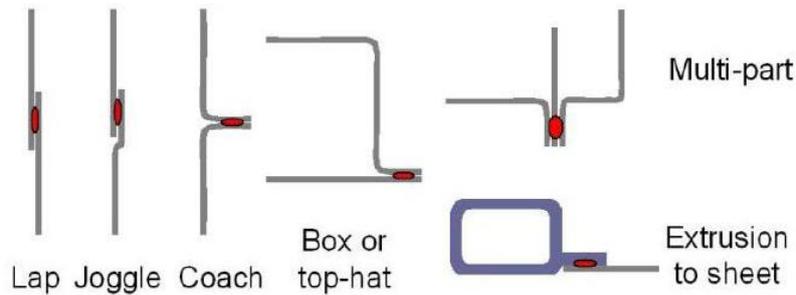
Ring of aluminium on electrode removed by a short buffing operation

(Source: University of Warwick)

Using a polishing wheel enables the electrodes to be buffed clean within the component cycle time, with only a minimal change in electrode geometry even after hundreds of buffing cycles. Restoration of the original electrode geometry is less necessary for aluminium than for steels since there is little mechanical deformation during electrode wear. The effect of periodic buffing after a relatively short number of spot welds is a significantly improved consistency of the aluminium resistance spot welding process, reduced process cost (less electrode replacement) and increased productivity (less down-time for electrode changes).

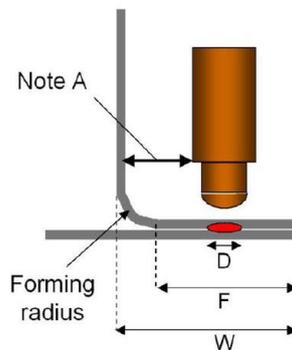
5.1.4 Joint configurations for resistance spot welding

The joint configurations suitable for aluminium are essentially the same as for steel. Resistance spot welding is most often configured in way that requires access to both sides of the joint, so welding to closed sections is not generally possible. There are some single-sided variants of the resistance spot welding process, but these are largely unproven for aluminium.



A selection of joint configurations suitable for resistance spot welding

Two or more components are overlapped in the region to be joined. Typically, this is along a weld flange specifically incorporated on the components for the purpose of accommodating the spot welds. In order to minimise the possibility of edge-welds and uncontrolled weld expulsion, weld flanges must have an adequate width to provide a flat portion that is wider than the anticipated weld nugget diameter. For dissimilar thickness joints, the flange thickness ratio should be less than 3:1.

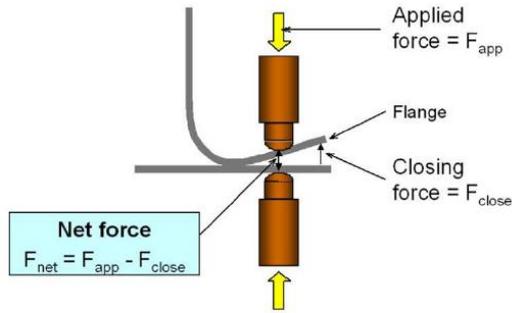


Typical flange for resistance spot welding

The recommended flange widths for aluminium are similar to those for steel. The weld flat dimension (F) must be several mm greater than the weld nugget diameter (D) and must include the usual tolerances for spot positioning and flange mismatches. The overall flange width (W) includes the allowance for the forming radius. Also, for reasons of accessibility, gun alignment and avoidance of current shunting, no part of the electrode (or its holder) is allowed to contact the corner radii or the up-flanged part of the component. Thus a certain distance (note A) must be kept to avoid any interference between electrode and work piece. Furthermore, nearby spot welds have a significant influence as they may offer lower resistance paths.

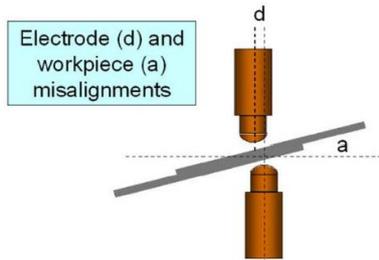
Production experience has shown that aluminium requires better part fit-up compared to steel. Poor sheet fit-up and off-angle electrode alignment affect the weld quality by overheating the joint, simultaneously promoting expulsion and small weld nugget sizes. Micro-movements at any of the surfaces (e.g. gun skidding, electrode rotation, or shear forces caused by asymmetric stack-ups or electrode geometries) must be minimised or avoided. An aluminium-specific problem are the high electrode forces which may cause deflection of inadequately designed gun arms, leading to misalignment and skidding (micro-movement).

Contact resistance is directly related to the force applied at the surfaces. Poorly fitting parts reduce the effective force to contain the growing weld nugget. Thus the components to be welded must be formed within tight tolerances to avoid the need to use the welding equipment to force the flanges together, i.e. the closing force required to move the parts back into intimate contact must be minimised.



Effect of poor part fit-up

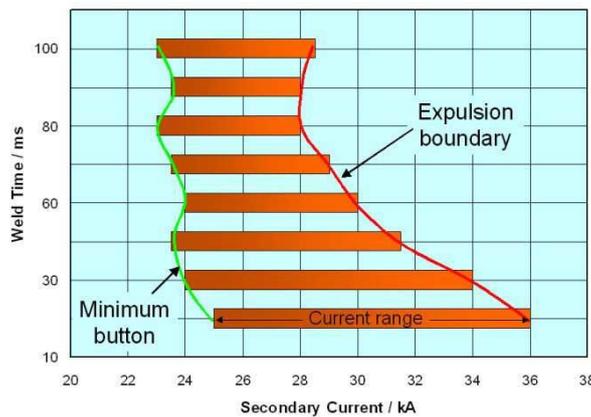
The electrodes must be kept as much as possible perpendicular to the sheet surfaces in order to maintain weld strength and to prevent cracking. Electrode designs with smaller radiuses on the face may improve weld quality under non-ideal fit-up conditions.



Misalignments cause changes in effective force and promote sliding at surfaces

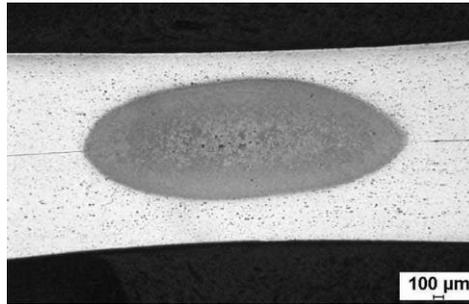
5.1.5 Resistance spot welding of aluminium alloys

For a given material combination and joining parameters (electrodes, joint configuration and electrode force), the weld lobe describes a region of acceptable welding parameters. The parameter axes are generally weld time and weld current while the electrode force is kept constant. The "lower" boundary is the parameter combination that produces a weld button of minimum acceptable dimensions. The "upper" boundary is defined by expulsion conditions. The area inside the lobe represents the "safe" welding window for new electrodes, i.e. it gives an idea of the parameter robustness.



Schematic of a typical weld lobe

The cross-section of an ideal aluminium spot weld shows good shape of the weld nugget, acceptable penetration, no cracks, and minimal porosity.

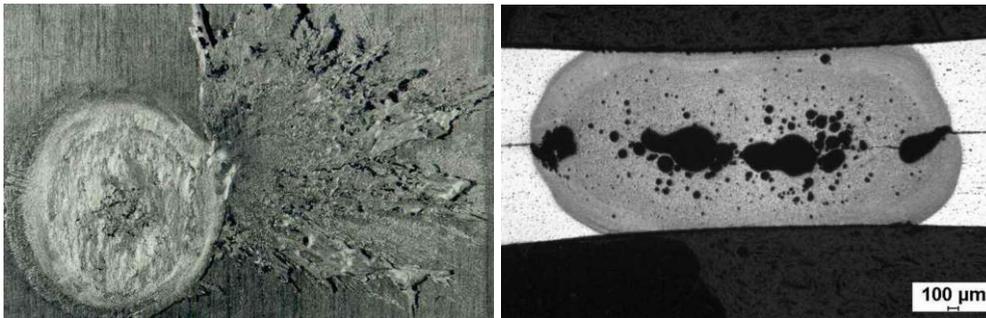


Ideal resistance spot weld between two aluminium sheets

The typical non-conformities of resistance spot welds are:

- cold welds or too small nuggets,
- too big nuggets (often leading to expulsion and deep indentations of the welding electrodes),
- cracks, porosity, pores, etc., inside the welding nugget.

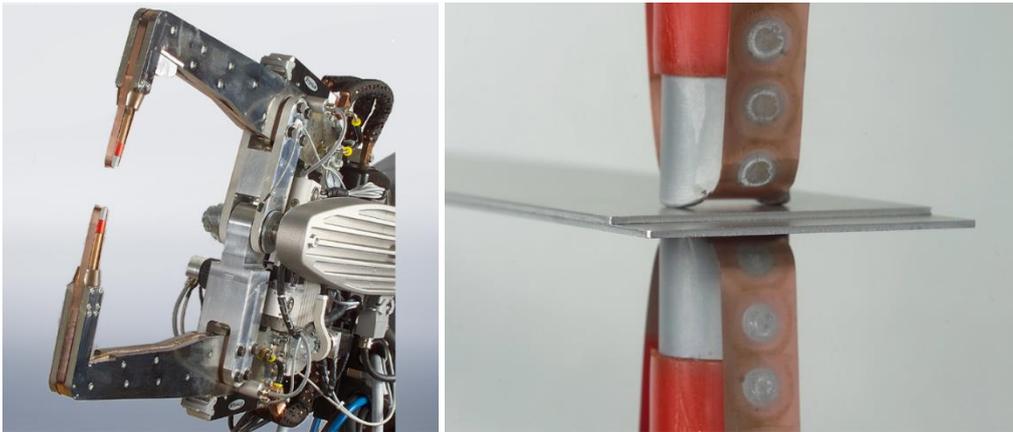
Expulsion (“weld splash”) is detrimental to weld quality and should be avoided. Some nugget porosity or cracking can occur, especially in sensitive alloy types. Small pores and other discontinuities located in the centre of the nugget do not significantly affect spot weld performance. However, if they are extensive or extend to the edge of the weld nugget where the influence of applied stresses is greater, unexpected and catastrophic failure through the weld nugget can occur when the structure is loaded.



Unacceptable welds: expulsion (left) and overheated weld with coarse defects (right)

5.2 Resistance spot welding with process tape

Resistance spot welding with an intermediate layer (process tape) is a further development of the conventional resistance spot welding process. The principle is based on a process tape running between the electrode and the work pieces, in the same rhythm as the spot-welding operation. Every time the “used” length of the process tape is moved out of the contact zone, i.e. exactly the same conditions are obtained for every weld spot. The presence of the intermediate layer enables - in combination with the servo-electric mechanical actuator and the powerful MFDC interactive process control - to form top-quality joints for different material combinations, even when there are different (and indeed only minimal) material thicknesses.

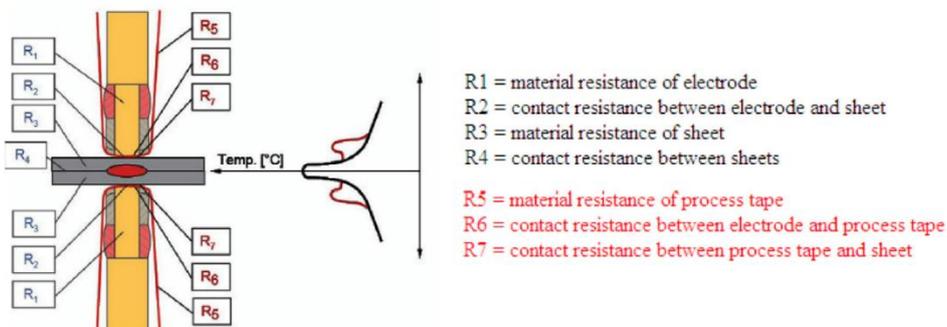


DeltaSpot® resistance spot welding process

(Source: Fronius)

Process tapes are available in a range of different alloys and coatings, with different electrical and thermal conductivities. The process tape performs several functions. It prevents direct contact between the electrode and the work piece, protecting the electrode from wear, contamination or other influences emanating from the surface of the work piece. Secondly, the constantly “new” electrode contact surface to the work piece prevents surface spatter and widens the process window. This results in an improved precision and reproducibility of the welding process, a consistent, high quality of the welding points and a significantly higher electrode service life.

Most important, however, is the possibility to directly and selectively influence the heat balance in the work piece. This is because the existing contact and material resistances are now augmented by the material and contact resistance of the process tape. When the current is switched on, the tape-related resistances generate additional heat which shields the joint against electrode cooling. The result is more heat in the work piece with lower electrical input power.



Principle of resistance spot welding with process tape

(Source: Fronius)

In the schematic representation shown above, the heat generation can be seen at the right side with (red curve) and without (black curve) the application of a process tape. By using process tapes made of different materials and with different coatings, the user can modify and optimise the overall heat balance and distribution of heat in the work pieces.

The process tape is a flexible tool for creating optimum conditions in each application. The same welding gun can be used to weld different sheet thicknesses, material combinations and multi-sheet joints simply by changing the process tape. Also the extra resistances allow to focus the added heat input onto the point being joined, reducing any shunt effects. Unwanted current transfer at other positions on the work piece hardly ever occurs. This is especially relevant for light-gauge sheets.

A difficult task for resistance spot welding is for example the realisation of a three-sheet joint including two thick sheets and one thin sheet. The welding point forms primarily in the area of the thicker sheet and does not cover the thin sheet sufficiently. The additional heat applied by

the process tape enables a targeted control of the welding point depth. Using a process tape with greater resistance, it is possible to compensate for the reduced amount of heat in the area of the thin sheet; the shape of the weld is symmetrical and shows increased volume in the area of the thinner sheet. Unlike in conventional spot welding where the weld-pool nearly always takes a nugget shape, the DeltaSpot® process creates a cylindrical weld shape if the boundary conditions allow. This is mainly due to the insulation against electrode cooling, and to the extra thermal input.



Spot weld joining three EN AW-5054 aluminium sheets (0.3 mm, 2.0 mm and 1.0 mm) produced using a coated process tape

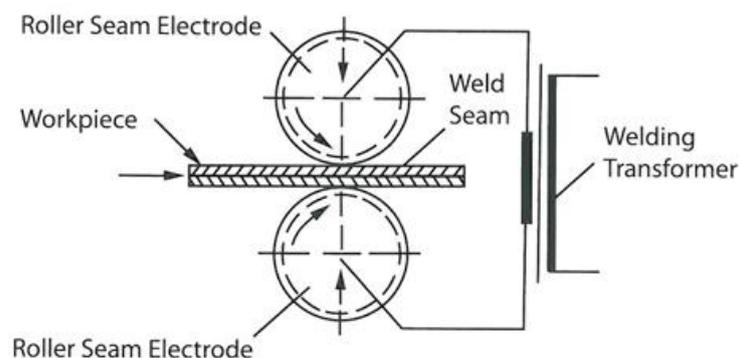
(Source: Fronius)

The standard electrode used in resistance spot welding has a convex shape. Due to the slightly elastic process tape, this results in an optimally shaped circular contact area. However, a concave electrode with a ring-shaped contact area can offer alternative advantages, i.e. producing a higher current density on the “ring” (compared to a flat electrode) which results in higher process reliability. Another benefit of spot welding with process tapes is that the surfaces of aluminium sheets are barely marked by any indentations at the weld spots.

5.3 Resistance seam welding

Resistance seam welding is a variation of the spot welding process where a series of overlapping weld nuggets are produced that form a continuous, leak-tight joint. In resistance seam welding, the spot welding electrode tips are replaced by a pair of driven copper wheels (typically ~200 mm in diameter) or one wheel acting against a stationary backing piece. Although it would be theoretically possible that a seam welder actually runs with a continuous flow of current, a pulsed welding current is generally used to form the individual spots.

The electrode force and welding current are transferred to the work pieces (strips, sheets, wires, sections) by means of roller or disk type electrode which also ensure feed motion transmission. The overlap area of the work pieces with its comparatively high electrical resistance is intensively heated by the current and the semi-molten overlap surfaces are pressed together by the welding pressure causing them to bond together after cooling.



Resistance seam welding process

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The size of the welding zone depends on the thickness of the individual parts and the electrode contact surface area. The pair of rollers makes contact with a small area of the work piece so that the current density required for the welding operation is achieved when the current passes through this zone. Because of the rotation of the roller electrodes, different points of the electrode are loaded with current. As a result, the thermal load and therefore wear of the electrode is smaller than with resistance spot welding. Most seam welding techniques use water cooling through the weld roller assembly due to the intense heat generated.



Resistance seam welding machine

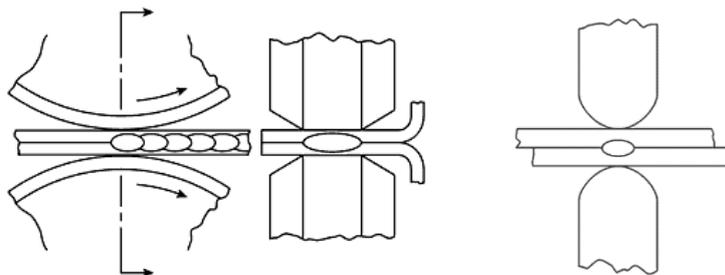
(Source: Sureweld)

The resistance seam welding process depends on three parameters:

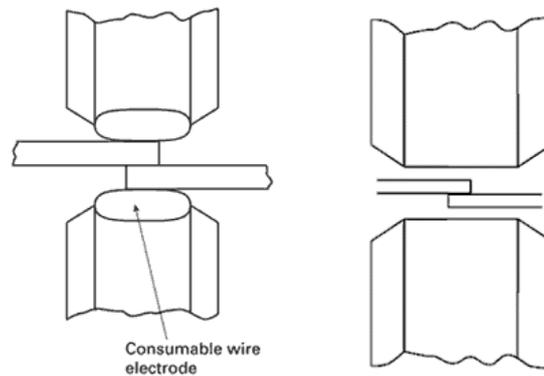
- Power supply and the weld control unit
- Welding wheel configuration
- Sheet configuration.

The current and the heat generation are localized by the peripheral shapes of the electrode wheels. The electrodes are not opened between spots. The electrode wheels apply a constant force to the work pieces and rotate at a controlled speed. The welding current is normally pulsed to give a series of discrete spots, but may be continuous for certain high speed applications where gaps could otherwise occur between individual spots. Seam welding equipment is normally fixed and the components being welded are manipulated between the wheels. The process may be easily automated.

There are a number of process variants for specific applications, e.g. wide wheel seam welding with a flat wheel contact area or narrow wheel seam welding where a round wheel contact shape is used.

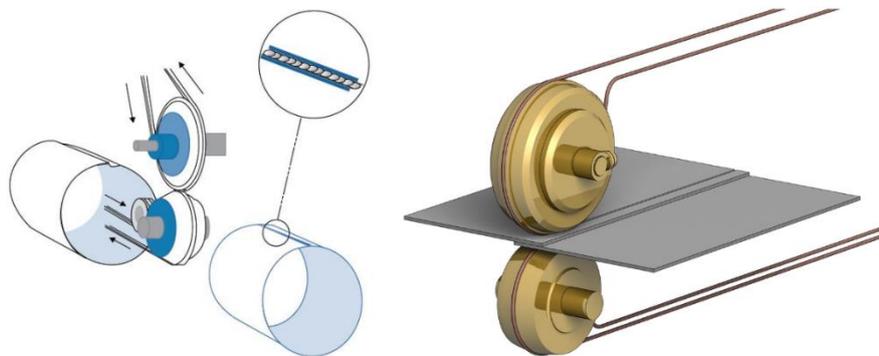


Wide (left) and narrow wheel seam (right)



Consumable wire (left) and mash seam welding (right)

Extensively used is also consumable wire seam welding where a properly shaped copper wire is fed between the wheels and materials to be joined in order to provide consistent clean contact. Another variant is mash seam welding where a narrow overlap of sheet edges is partly crushed together during welding.



Welding principle for pipes (left) and for flat products (right)

(Source: Soutec)

In consumable wire seam welding, the welding rolls assume the task of the electrode and the pressure tool. The copper wire is guided between the rolls and the work piece while simultaneously providing a constant high quality weld seam. The copper wire allows for minimal wear to the weld rolls. Welding spots are set closely by the rolls to allow for a continuous leak proof seam. The pulse frequency of the current determines the spot weld spacing. For tack or stitch welding, the spots are set further apart.

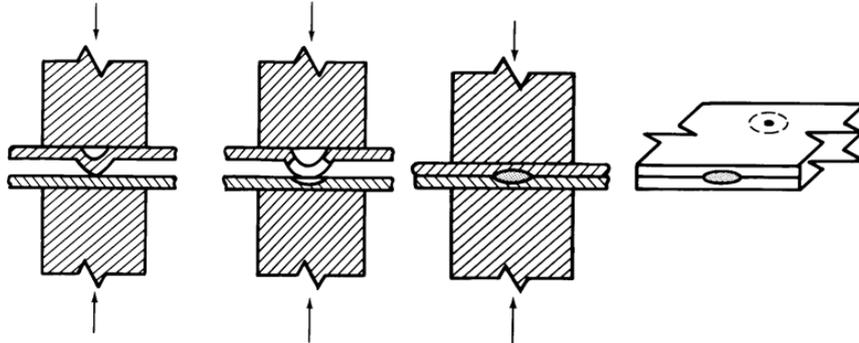
Roll seam welding enables high welding speeds compared with many other techniques, but can be limited by component shape and wheel access. The main issues concerning seam welding are in weld quality control and welding speeds. Factors such as material, control of pressing force and alignment of the electrodes are critical to achieve high speed, quality welding.

5.4 Projection welding

Another modification of the spot welding process is projection welding. In this process, the weld is localized by means of raised sections ("projections") on one or both of the work pieces to be joined. Current flow and thus heat generation is concentrated at the contact surfaces of the embossed, cold headed, or machined projections. They effectively localize the current, forcing the parts to heat predominately at the mating surfaces. This focuses heat at the mating surfaces of the pieces and minimizes bulk heating of the parts.

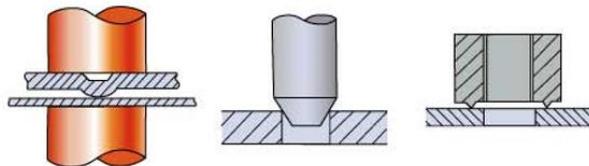
The concentration of the heat at the projections permits the welding of heavier sections or the closer spacing of welds. The projections can also serve as a means of positioning the work pieces. Projection welding is often used to weld studs, nuts and other screw machine parts to metal plate. It is also frequently used to join crossed wires and bars. Multiple projection welds can be arranged by suitable designing and jiggling.

The welding sequence is similar to that for resistance spot welding. The welding electrodes are used to apply both force and current across the configuration. The point of contact constricts current flow and – since it is a point of high resistance in the welding circuit – heating occurs preferentially at this point. Thus the material softens and the projection collapses under the force applied by the welding electrodes.



Process sequence of resistance projection welding

Projection welding allows for precision joining of parts with complex shapes, joining of challenging material combinations and simultaneous formation of multiple welds. While the projections usually collapse early in the weld cycle, the localized heating raises the material resistance locally and promotes further heating and finally weld development at the initial contact point. The process can be developed to produce a fusion type weld or a solid state weld depending of the application.



a. Embossed b. Stud-to-Plate c. Annular

Weld configurations used in resistance projection welding

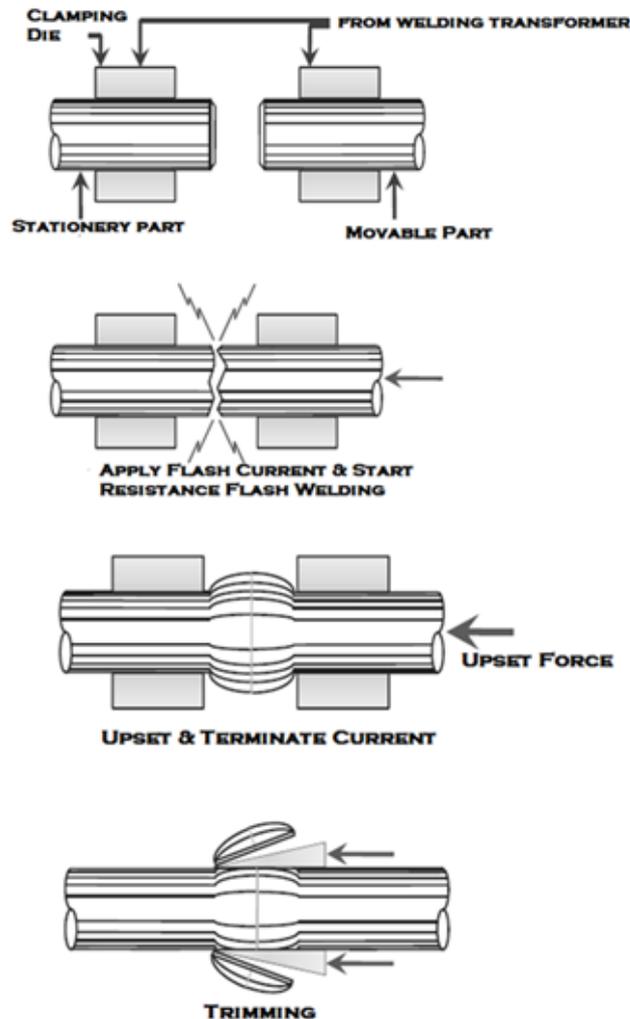
The most important process variable is the quality of the projections and the response of the cylinder as the projection collapses during welding. The welded metal must be strong enough to support the projection. Aluminium can be projection welded to a limited extent, but requires special projection geometries. Best results have been obtained for ring-shaped projections. However, the strength of most aluminium alloys is too low to allow the projections to survive under the forces applied by conventional projection welding equipment. Careful control of the applied welding forces is thus a necessity. Consequently, this technique is not much used for aluminium mainly because premature rapid collapse of the projections leads to unreliable joints.

5.5 Resistance butt welding (flash welding)

In the flash butt welding process, the ends of the piece to be welded are connected to the secondary circuit of a transformer. One piece is held firmly by a clamping device attached to a stationary platen; the other piece is clamped to a movable platen.

At the start of the process, the materials being joined are clamped rigidly in the dies and the parts are separated by a suitable air gap. Then the movable platen is advanced slowly. When the surfaces to be welded touch, the strong current passing through the local asperities starts to heat the edges (“flashing period”). The asperities start to melt, the molten bridges are broken and thrown off as flash particles. The objective of this step is to establish a suitable

temperature distribution in the work pieces to enable proper forging during the subsequent upset period of the cycle. When the metal behind the faying surfaces on either side is sufficiently heated to ensure adequate plasticity, the current is stopped immediately and the surfaces are rapidly squeezed together at a greater force ("upset period"). Oxides and other impurities are extruded out of the surfaces to be joined and satisfactory welding takes place.



Flash butt welding process sequence

Resistance butt welding is used to produce joints in long rods and tubes with similar cross sections, but due to its high electrical conductivity not suitable for aluminium.

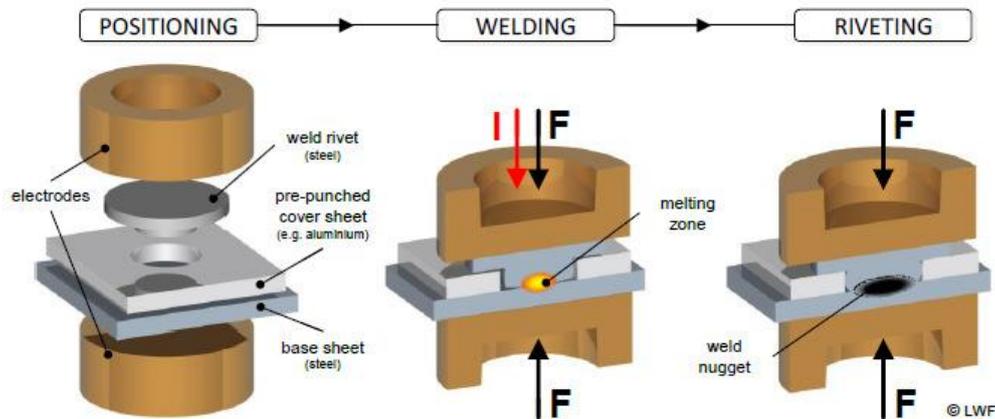
5.6 Resistance element welding

Resistance element welding is a further development of the conventional resistance spot welding process. It combines both thermal and mechanical joining principles by creating a metallic bond between an auxiliary joining element and the bottom plate, in combination with a force- and form-locking connection of the auxiliary joining element with the top plate.

In a first step, a hole is punched into the top (cover) sheet. Then the auxiliary element ("weld rivet") is inserted or positioned in the hole. One electrode is lowered onto the rivet and the other is positioned onto the bottom sheet. Pressure (F) and electric current (I) are applied simultaneously. The heat generated by the electrical resistance creates a weld nugget in the contact zone between the weld rivet and the base sheet and forms the connection.

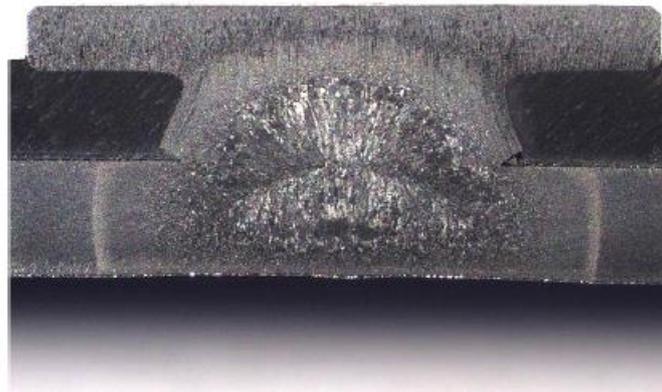
In the final phase, an increase of the electrode force leads to a deformation of the weld rivet in the axial direction and therefore to a tight force connection (surface pressure) between the rivet head and the cover sheet. A frictional connection is obtained at the contact between the rivet shaft and the cover sheet and between the rivet head and the cover sheet (surface

pressure). The individual process stages can be controlled by a variation of the parameter settings (weld time, current, force) generally used in state-of-the-art mid-frequency, servo-controlled spot welding equipment.



Resistance element welding process

(Source: LWF Paderborn)



Cross section of an aluminium (EN AW-6016, 1.5 mm) - steel (22MnB5, 2.0 mm) joint produced by resistance element welding

(Source: LWF Paderborn)

5.7 Resistance stud welding

Further stud welding technologies are covered in more detail under “3.3 Arc stud welding”. In the present context, only the contact welding variant is relevant.

Studs are primarily used for fastening applications. They are rapidly applied with portable equipment. Studs designed for resistance stud welding have a small tip extending from the base of the stud. This special tip provides precise weld time control for consistent, automatic welding. The stud tip is placed in contact with the base metal. Upon triggering, peak currents vaporize the tip, drawing a precisely timed arc. The arc melts the full diameter of the stud and the same area of the work piece. The stud is then forced into the molten metal, completing the process in a few milliseconds, with little or no reverse-side marking. In general, the capacitor-discharge method is applied to supply the arc power.

A specific application of this technique is found in aluminium dent removal equipment, i.e. the use of weld-on studs for pulling dents out of aluminium panels. The capacitor discharge technology delivers very brief, but high current density to break through surface oxide layer

without damaging the sheet metal below. Up to 6 mm diameter aluminium or titanium stud bolts can be welded onto clean, bare aluminium surfaces.



**Resistance stud welding system for dent pulling in aluminium panels
(Source: Elektron)**

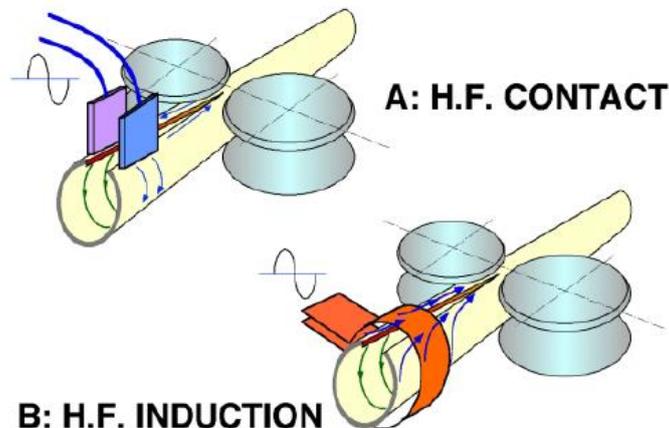
Conventional steel stud welders cannot be used for damaged aluminium body panels. The high heat dissipation of aluminium requires a power supply with a significantly higher current capacity.

5.8 High frequency welding

High frequency induction welding is primarily used to produce pipes or tubes from strip material. The rolled aluminium strip is fed into rolls which form the flat strip into a cylindrical shape. The faying edges are then brought together between squeeze (upsetting) rolls for welding. In addition, high frequency welding is nowadays increasingly integrated into roll forming lines to produce profiles with more complex, asymmetrical cross sections which may also include pre-punched holes, notches and other geometrical features.

There are two distinct types of high frequency welding:

- **Induction welding**, which uses an energized copper coil that is wrapped around the part without contacting it. As the material flows through the electromagnetic field created by the coil, current is induced into the material. The need to adjust, maintain, and replace contact electrodes is eliminated.
- **Contact welding**, which sends current flowing into the material through an electrode which touches the material.



High frequency welding techniques

(Source: EHE, Inc.)

High frequency welding is a form of electrical resistance welding. The high frequency current is concentrated on the edges of the strip and thus resistance heating will occur only in a

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narrow zone at the edges of the material. A voltage is applied (HF contact) or induced (HF induction) across the edges of the open tube just prior to the point of closure. This voltage causes a current to flow along the edges to the point where they meet, leading to rapid heating of the metal edges up to the welding temperature. The pressure applied by the upsetting rolls forces the heated metal edges into contact and thus forms the bond. The applied pressure also forces molten metal and any impurities out of the weld zone, i.e. the resulting joint shows rather a forged microstructure with a narrow heat-affected zone and therefore possesses very good mechanical properties.

The only real difference between high frequency contact and induction welding is that with contact welding, the voltage is applied directly to the strip edges by means of sliding contacts, whereas in the case of induction welding, the voltage is induced by the magnetic flux surrounding the coil. Both methods have their advantages and drawbacks, but in general, induction welding will produce smoother, more consistent welds and is therefore mainly used for aluminium welding.

When compared with other processes, high-frequency welding produces a high-quality butt seam at relatively high speeds. Consequently, production volumes need to be relatively high to justify the capital equipment cost.



HF welded aluminium tubes

(Source: Sapa)