

EAA Aluminium Automotive Manual - Joining

10. Hybrid joining techniques

Content:

10. Hybrid joining techniques

10.0 Introduction

10.1 Combination of adhesive bonding with mechanical joining

10.1.1 Hem flange bonding

10.1.2 Adhesive bonding in conjunction with mechanical point joints

10.1.2.1 Adhesive bonding and clinching

10.1.2.2 Adhesive bonding and self-piercing riveting

10.1.2.3 Adhesive bonding and blind riveting

10.1.2.4 Adhesive bonding combined with other mechanical fasteners

10.1.2.5 Adhesive bonding combined with solid state joining techniques

10.1.3 Adhesive injection fasteners

10.2 Combination of adhesive bonding with fusion welding

10.2.1 Adhesive bonding combined with resistance spot welding

10.2.2 Adhesive bonding combined with other fusion welding processes

10.3 Combinations of fusion welding techniques

10.3.1 Laser – arc welding processes

10.3.1.1 Laser - MIG welding

10.3.1.2 Laser - TIG welding

10.3.1.3 Laser - plasma arc welding

10.3.1.4 Laser – MIG tandem welding process

10.3.2 MIG plasma welding

10.4 Friction self-piercing riveting – a combination of two mechanical joining techniques

10.0 Introduction

In hybrid joining, two or more joining operations are carried out either simultaneously or sequentially, leading to enhanced properties of the joint due to a synergistic load bearing interaction under service conditions.

The most common type of a hybrid joint includes an adhesive in conjunction with a point joint such as for example a mechanical fastener (e.g. rivet or threaded device) or a spot weld. It is mainly used for joining sheet materials, but there are also applications involving extrusions and thin castings. The main advantages of combining a point joining method with an adhesive are:

- production of continuous, leak-tight joints
- in general improved strength (static and dynamic)
- increased joint stiffness
- improved peel and impact resistance (the point joint arrests crack growth in the adhesive bond).

An important advantage is also that the immediately effective spot-joint fixes the position of the components until adhesive curing takes place, i.e. the assembly process is significantly shortened and facilitated.

The adhesive is normally applied to the surfaces to be joined prior to assembly and fixing with point joints. The most widely used hybrid sheet joining methods are:

- adhesive bonding / hemming
- adhesive bonding / resistance spot welding ("WeldBonding")
- adhesive bonding / self-piercing rivets ("RivBonding")
- adhesive bonding / clinching
- adhesive bonding plus other mechanical fasteners (screws, tacks, ...).

The second important group of hybrid joining techniques involves the combination of two different fusion welding methods. This combination is mostly used in structural applications in order to join thicker sheet materials, extrusions and castings. The combination of two different welding processes allows to achieve an optimum in weld quality and welding speed by exploiting the advantages of individual processes. Although the term "hybrid welding" includes in principle any other combination of welding techniques (e.g. also plasma arc / MIG welding or plasma arc / laser welding), in practice, it is used to specifically describe the MIG augmented laser welding process.

Other possible combinations of joining methods are:

- mechanical joining / fusion welding
- mechanical joining / mechanical joining
- adhesive bonding / adhesive bonding

however, these combinations are much less important.

The combination of a mechanical and a fusion joining method in the form of a hybrid technology has little practical relevance, although the combination of some mechanical fixation techniques and the subsequent fusion welding process could well be considered as a sequential "hybrid joint".

The sequential use of two different mechanical joining methods can be observed in practice quite often. But only one example for the simultaneous use of two different mechanical joining methods has been found.

Also the combination of two different types of adhesive joining methods can be considered as a hybrid joining technique. As an example, combining pressure sensitive adhesive bonding with structural adhesives can offer advantages in terms of processing and load bearing capacity when high levels of both static and dynamic mechanical resistance are required.

Additionally, pressure sensitive adhesives can be combined with structural thermosetting adhesives (e.g. as a formulated blend), creating a thermo-curable, pressure sensitive bonding technology. The so-called structural bonding tapes exhibit pressure sensitive properties at ambient temperature, but can be cured to develop structural adhesive-like properties at temperatures above 140 °C. This material represents an adhesive hybrid system combining pressure sensitive and structural adhesives.

10.1 Combination of adhesive bonding with mechanical joining

The various aspects related to adhesive bonding are described in detail in the previous section (9. Adhesive bonding). Therefore only those aspects relevant for the specific hybrid joining technology are mentioned.

10.1.1 Hem flange bonding

Closure panels like doors, hoods, trunk lids or tailgates are usually made from an outer panel which is hemmed (or clinched) over an inner panel around its periphery. Whilst the hemming technique (described in section 8.1.1) produces a sufficiently strong mechanical bond, adhesives are today widely used in the flange to give improved strength, stiffness, crash performance and corrosion protection.

Hem flange bonding happens in the body shop of an assembly plant, i.e. before painting. The body panels are stamped and formed starting from rolled sheets, thus they may be covered with residues of various lubricants (rolling oils, pre-lubricants and/or drawing compounds). Aluminium surfaces are typically provided properly surface pre-treated for bonding (cleaned and pre-oiled or covered with a dry lubricant). However, in general, there is no cleaning step used in the stamping plant which removes the applied stamping lubricants.

The adhesive is applied using swirl, bead or fine jet nozzles. In order to avoid “zero gap” in the hem flange, most hem flange adhesives contain glass beads to ensure constant distance between the outer and inner panels. Then the inner panel is positioned and the outer panel is bent around the inner panel, forming the hem flange. The bead size is carefully controlled to fill the bond line, but not to squeeze out. Adhesives that escape the bond line would contaminate the equipment and cause cleanliness and maintenance issues in the assembly plant. Ideally, the excess adhesive would help seal the cut edge (where the bare metal is exposed), but equipment contamination issues are usually considered to be more critical.

A curing step may be introduced at this stage, such as induction curing. This can be a full cure or just enough to prevent any movement of inner to outer panel during subsequent processing. Depending on the applied adhesive, pre-gelling by induction heating holds the adhesive in place while improving resistance to wash-out of the adhesive.

However, in most cases, hem-flange bonded closure panels are not pre-cured. They are attached to the rest of the body-in-white and sent to the paint shop where the body-in-white is cleaned, primed (electro-deposition of a zinc phosphate film, complete with oven cure), and painted. Cure of the adhesive is completed in the paint ovens.

One of the reasons for using an adhesive in the hem flange is to reduce or eliminate the use of spot welds or mechanical point joints to hold the inner and outer panels together. Such point joints are sometimes noticeable on the outer panel, necessitating a finishing or polishing step prior to painting. Nevertheless, there are usually a few remaining spot joints which hold the panels together until the adhesive is cured, reducing the susceptibility of the adhesive to any peel loads.



Hem flange bonding

(Source: Fluidmetering)

Hem flange adhesives have to fulfill a wide range of requirements. They must not interfere with the integrity of the spot welds or mechanical point joints and may not escape during the joining process and get on the joining equipment. They must show improved wetting through lubricant films to ensure proper hem flange bonding on oily or draw-lubricated metals. Panel distortion during curing must be minimal, the adhesives should be tolerant to over-curing during lacquer baking and, last not least, must show good structural bond strength, excellent long-term durability and corrosion resistance. In practice, different types of one- or two-component adhesives are used.

10.1.2 Adhesive bonding in conjunction with mechanical point joints

Hybrid joints combining adhesive bonding with spot-joints with can generally be created in one of three ways:

- The “**fixing**” method, in which the adhesive is first applied to the parts being joined. Once the components have been joined together, a spot-joint is made to complete the process. This is followed by the hardening of the adhesive layer.
- The **injection** method where the parts are joined with a spot-joint before injecting the adhesive into the gap between the components. Capillary action causes the adhesive to spread throughout the joint. The adhesive layer then hardens.
- In the **sequential** method, the parts are joined after the adhesive has been applied. But the parts are spot-joined only when the adhesive has hardened.

Most industrial applications make use of the “fixing” method; the injection and the sequential variant are seldom chosen.

These types of hybrid joints are generally used for joining sheet materials and involve an adhesive in conjunction with a point joint such as a mechanical fastener, a clinched joint or a friction stir welded joint. The adhesive is applied to the surfaces to be joined prior to assembly and fixing with point joints. Similar results are achieved by combining resistance spot welding with adhesive bonding (see section 10.2.2).

The adhesives used in these hybrid bonds are predominantly liquid adhesives like single component hot curing or two-component room temperature curing toughened epoxy adhesives. However, combining pressure sensitive adhesive bonding with mechanical joining may also offer advantages in specific cases. The apparent advantages of pressure sensitive adhesives include quick-fix properties due to tack, easy roll-on dispensing and viscoelastic properties creating a high level of impact resistance and vibration dampening properties for pressure sensitive adhesive joints.

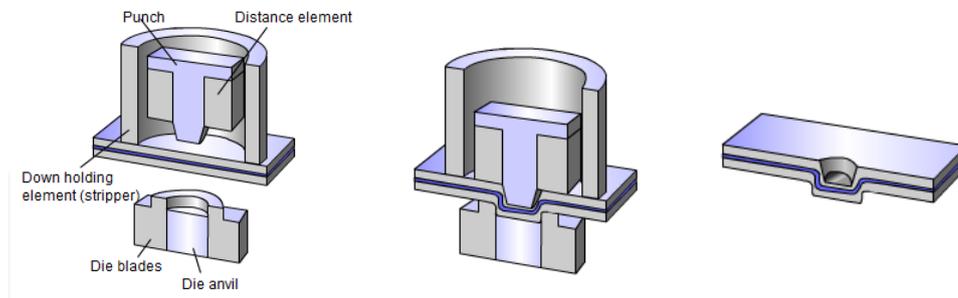
Hybrid joints using pressure sensitive adhesive tapes or structural bonding tapes with pressure sensitive properties in combination with mechanical joining exhibit superior

properties in terms of incipient tear and peel resistance. A negative interference can only be observed in case of clinching. A proper interlocking of the clinch punch is not achieved in the presence of the pressure sensitive adhesive tape.

The self-fix properties of the acrylic adhesive tapes greatly facilitate the overall hybrid joining process. As an example, the combination of acrylic pressure sensitive tape with self-piercing rivets leads to hybrid joints with an excellent peel resistance without the need of a thermal curing process. This practice is preferentially applied for mounting parts in final assembly (i.e. on the painted body).

10.1.2.1 Adhesive bonding and clinching

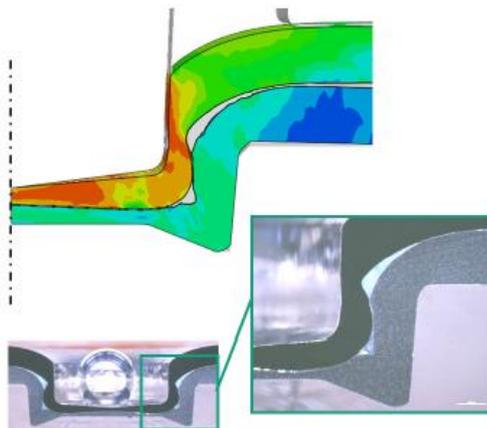
In this variant, the point joints are produced using the clinching technology (see section 8.1.2). Clinch-bonding has the advantage of being a cold joining process but, compared to other mechanical joining techniques, the only consumable is the adhesive. The adhesive is applied to one of the components being joined, and the two items are placed together. The components being joined are then subjected immediately to the clinching process, which causes some adhesive to ooze out of the joint. Once clinching has taken place, the joint is left to harden.



Clinch-bonding process

(Source: aluMATTER)

Proper control of the clinching operation is necessary. There is a risk that “pockets” are formed when the still liquid adhesive is squeezed out of the clinch point and the required clamping force cannot be achieved.



Formation of adhesive pockets in clinch-bonding

(Source: FhG Chemnitz)

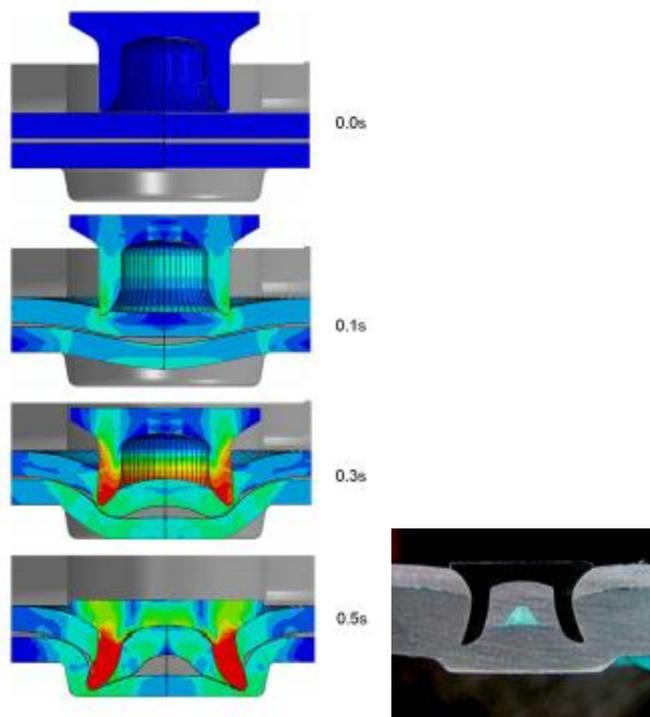
Clinch joints are not as strong as riveted or spot welded joints. Therefore clinch-bonding is used mainly for less demanding applications in the automotive industry, e.g. for joining steel to aluminium in areas where the structural loads are relatively small.

10.1.2.2 Adhesive bonding and self-piercing riveting

This combination developed to the predominant joining technology in the production of aluminium car body structures, in particular when using aluminium sheets. For details on the self-piercing riveting process, see section 8.2.2.3.

The adhesive is pre-applied to the faying surfaces, the joint is formed and the rivets are inserted. The adhesive is displaced by the self-piercing rivet and surrounds the resulting mechanical linkage. In an adhesive-intensive joint, the rivets serve as peel stops and thus compensate for the adhesive's inherent shortcoming in peel performance. In contrast, the adhesive excels in shear performance. The net result is a joint that shows significantly improved shear strength and peel performance and a much better fatigue life.

The result is a considerable potential to reduce the sheet thickness (and to save weight). Rivets produce point loads and stress concentrations. The material between the junction points transfers the load from one point to another, but does not participate in "joining" even though it is part of the "joint". With the addition of the adhesive, the material between junction points contributes to stress management all along the joint. Therefore, in structural applications, also less punctiform mechanical joints are required to transfer relatively high point-to-point loads. In addition, the reduced metal gauge may allow for higher fatigue life overall.



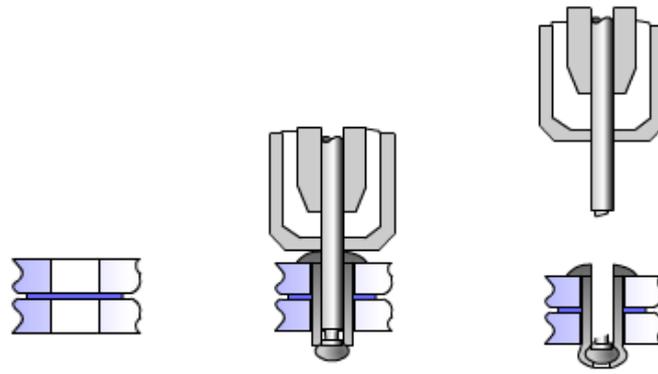
Formation of a self-piercing rivet / adhesively bonded joint

(Source: FhG Chemnitz / Boellhoff)

Proper control of the subsequent mechanical joining operation is required in order to ensure that the squeezing out of the adhesive does not lead to local imperfections. Of specific importance is the avoidance of open channels to the seam edges since these could lead to serious corrosion problems.

10.1.2.3 Adhesive bonding and blind riveting

In specific cases, also the combination of adhesive bonding with blind riveting (see section 8.2.2.2) may be useful. In this case, the adhesive is applied to one of the previously-drilled components. Then the items are joined, the joint is blind-riveted and the adhesive is left to harden. If a two-component adhesive system is used, it is important that the joint is finalised within the shelf-life of the product. Also this joining process causes some adhesive to ooze out of the joint.

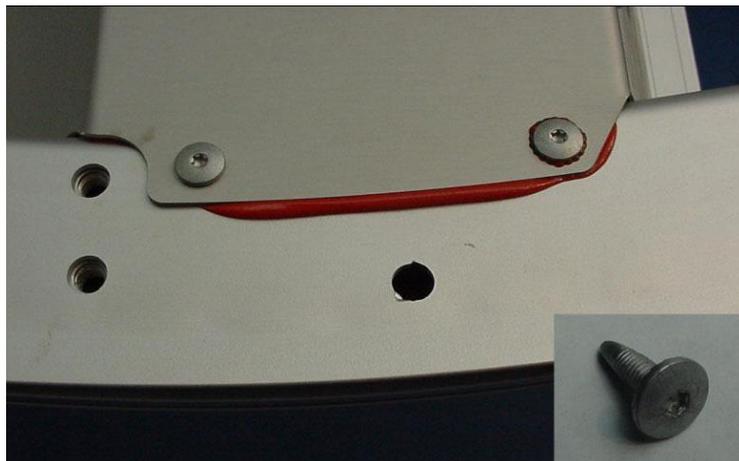


Adhesive bonding and blind riveting

(Source: aluMATTER)

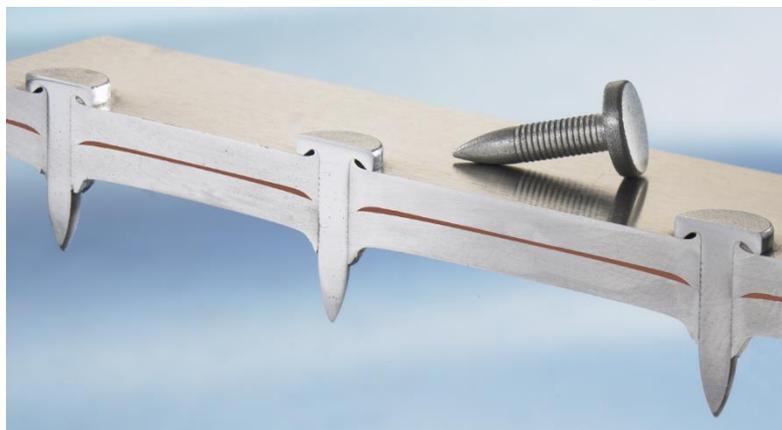
10.1.2.4 Adhesive bonding combined with other mechanical fasteners

In principle, all types of mechanical fasteners can be combined with adhesive bonding. Threaded fasteners (see section 8.2.1.2) were for example used in combination with structural adhesive bonding in the construction of the Lotus Elise. The screws hold the assembly together during cure of the adhesive, they clamp the parts together to give metal-to-metal contact and help to resist peel forces during impact.



Self-threaded drive screws hold the assembly together during adhesive cure

Another possibility for a preliminary fixation of the assembled structure is for example the tack high-speed joining technology (see section 8.2.2.6).



Aluminium-hybrid joint produced in RIVTAC® high-speed joining

(Source: Boellhoff)

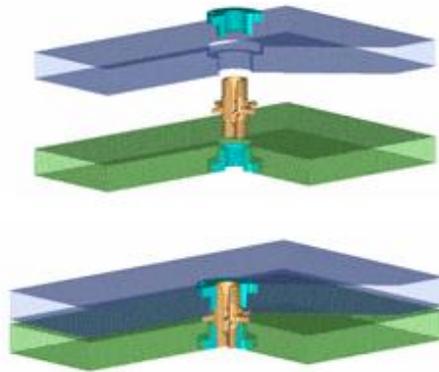
10.1.2.5 Adhesive bonding combined with solid state joining techniques

The combination of friction stir spot welding (see section 7.1.3) with adhesive bonding has been evaluated on an experimental basis. The adhesive does not only serve for bonding, but also seals the gap between the metal sheets to be joined. Positive effects of this hybrid joining method were observed in dissimilar Al/Mg welds. It seems that the adhesive suppressed the formation of large brittle intermetallic compounds during the welding process. However, no further applications are known.

Experimental tests have also been carried out combining adhesive bonding and ultrasonic welding (see section 7.3) using lap joints of EN AW-6022-T4 sheets. However no further developments were made in this case either.

10.1.3 Adhesive injection fasteners

Invented by TWI, AdhFAST® is a hybrid joining technology which differs from the methods described above in that the adhesive is introduced into the joint after the structure has been assembled using fasteners. The adhesive is injected into the joint through specially designed fasteners which incorporate a means of controlling the spacing between the top and bottom substrates. This gives greater control of bond-line thickness and, therefore, improved process reliability and joint quality, maximising the benefits of hybrid joint technology.



Computer simulated graphics showing cross sections of AdhFAST® in-situ and exploded views

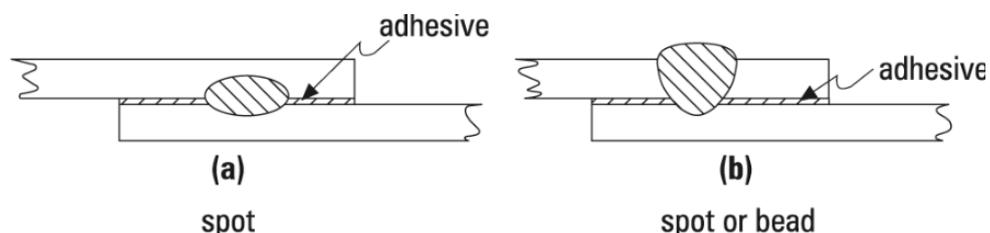
(Source: TWI)

The fastener design is very flexible and must only enable the three functions of retention, spacing and injection. Injection of the adhesive can be carried out manually or by an automated process. Again no automotive applications are known.

10.2 Combination of adhesive bonding with fusion welding

Only a few hybrid joining methods combine adhesive bonding with fusion welding. In principle, there are two possibilities to additionally join adhesively bonded sheets by a fusion welding process:

- a weld nugget can be placed between the two sheets
- a weld spot or bead can be made joining the upper to the lower sheet.



Fusion welding of adhesively bonded sheets

A necessary requirement is that the heat input by the applied fusion welding method is limited. Otherwise, the efficiency of the adhesive bond would be deteriorated too much. Consequently, only two fusion welding techniques are of specific interest: resistance spot welding (see section 5.1) and laser (spot or seam) welding (see section 4.1).

10.2.1 Adhesive bonding combined with resistance spot welding

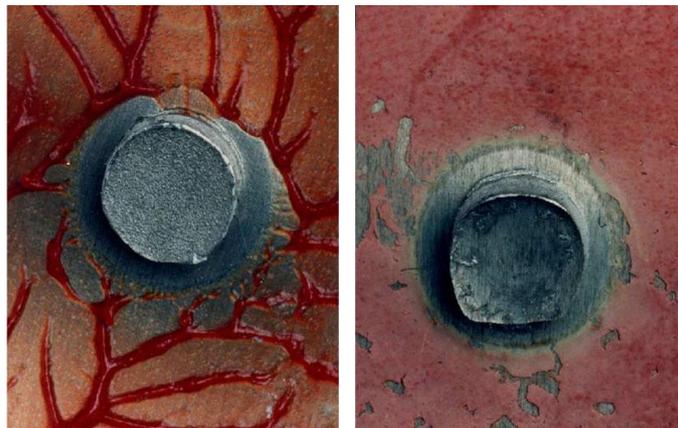
The combination of adhesive bonding and resistance spot welding (“WeldBonding”) allows designers to maximise the vehicle performance (e.g. body-in-white torsional rigidity, fatigue, weight reduction, etc.) while still maintaining the relative ease and speed of assembly.

It is one of the most common hybrid joining technologies used in the high volume automobile production (specifically for steel-intensive cars). The dominating joint configuration, which consists normally of overlapping sheets, is highly suited for both processes either singly or when combined. The weld-bonding process is generally fully automated and utilises robotic dispensing systems. Today, structural adhesives are used rather than low strength adhesives or sealants.

The adhesive is normally applied to one sheet in the area to be joined. After assembling the two elements, resistance spot welds are performed through the adhesive. Before the actual welding starts, the electrode force displaces the adhesive to obtain electrical contact between the sheets and the weld can be made in the normal way. The local heating generated during spot welding causes only a limited damage around the weld. The adhesive is finally cured to complete the assembly.

Heat curing paste type adhesives are normally used as these are stable and have a consistent viscosity at room temperature. Typically, such adhesives are cured in the lacquer baking ovens at up to 180°C for 30 minutes. Some adhesives are also available in tape form and incorporate a metal particle filler which allows initial electrical contact to be made for spot welding.

In automotive applications, adhesives and sealants are welded through in order to improve joint strength, load distribution, fatigue performance and joint sealing. Whereas for steel materials, no special difficulties are encountered, some development work was required for aluminium alloys. The surface condition (or prior surface treatment) of the aluminium sheets must be properly selected to ensure the long-time durability of the adhesive especially in difficult service conditions, but not to interfere with the spot welding process. It was found that a special, tightly controlled aluminium surface treatment step is necessary to achieve the required consistent surface quality which ensures long-term durability of adhesive bonds in hostile environments (e.g. in the presence of moisture, especially when under load), but nevertheless offers the required spot welding performance (where normally a low surface resistance is needed).



Examples of peeled weld-bonded aluminium joints: Peeled prior (left) and after (right) adhesive cure (note the clearance zone around the weld)

Good process control is required to ensure correct joint filling for the adhesive and to avoid weld quality problems. In the weld-bonding process, the work piece and tooling may be more susceptible to contamination as a result of adhesive being squeezed out of the joint. Also, health and safety issues linked to the use of adhesives need to be considered. Welding

through adhesives may create hazardous fume, thus suitable ventilation/fume extraction systems should be used.

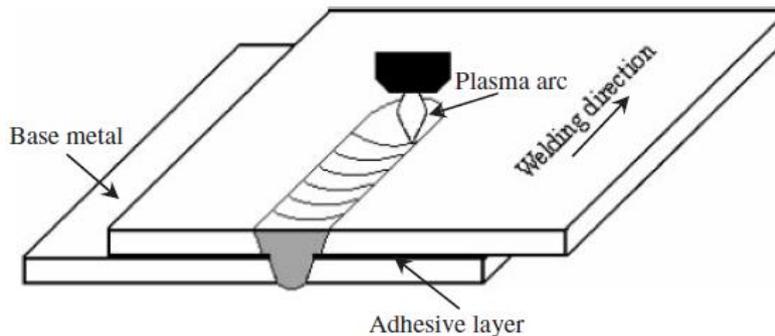
The success of the resistance spot welding step relies primarily on the force applied by electrodes to displace the adhesive before welding starts (during the “squeeze-time”). Thus, some specific recommendations be made:

- Spherical shaped electrodes will assist adhesive to flow from the weld site.
- Squeeze time must be long enough to allow adhesive to flow (typically ~1 sec).
- Temperature strongly affects adhesive viscosity. Too low temperatures (ambient or water-cooling temperatures) will make the adhesive hard to displace.
- A weld current profile that uses a pre-heat to warm the adhesive prior to welding can be an advantage.

10.2.2 Adhesive bonding combined with other fusion welding processes

Arc or beam welding can be used to produce welds spot or beads which join the upper to the lower sheet. Different weld-bonding hybrid processes have been evaluated with limited success.

As an example, the combination of a modified metal inert gas (MIG) spot welding process (see section 3.1.3.5) with adhesive bonding was examined. In another experiment, the “Plasma arc weld bonding” process, a combination of plasma arc welding (see 3.2.2) and adhesive bonding, was used to weld magnesium. It was found that the presence of the intermediate adhesive layer played an important role. However, the existence of the adhesive layer had not only advantages, but also some disadvantages. During fusion welding, the adhesive decomposes and produces a mass of decomposition products. The result is significant weld porosity and thus a decrease of the properties of the welded joint.

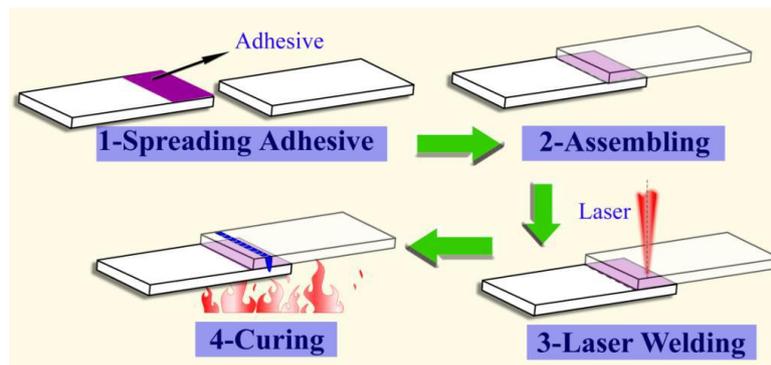


Plasma arc weld bonding process

(Source: L. Liu et al., Dalian University)

A further hybrid joining concept, called laser continuous weld bonding, was tested by joining the magnesium alloy AZ31B (upper sheet) to the aluminium alloy EN AW-6061 (lower sheet). The formation of brittle intermetallic phases in the fusion zone could be effectively reduced. It seems that the rising adhesive vapour hinders the downward movement of liquid magnesium. Hence, the weld is composed of a two-phase mixture with less intermetallic compounds and more solid solution.

The process consists of four stages: (1) spreading of the adhesive on the lower sheet surface; (2) applying pressure and assembling; (3) laser (spot or seam) welding and (4) adhesive curing.



Laser weld bonding process

(Source: Liu et al., Dalian University)

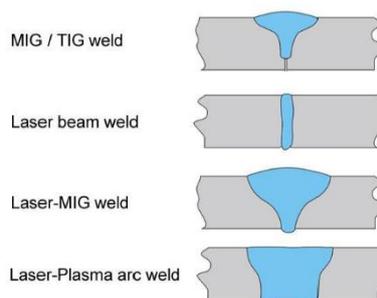
A hybrid assembly process which combines laser welding and adhesive bonding (“Laser weld bond”) to generate higher joint shear and peel strengths over conventional welding or adhesive bonding alone has also been evaluated in aircraft production. It has the ability to demonstrate significant manufacturing process simplification to produce very cost effective airframe structures and control surfaces. A variety of lasers, adhesives and substrates were tested. It was shown that the laser weld bond process is a viable joining alternative capable of producing joint strengths which exceed target rivet joint strength requirements.

However, the concepts combining adhesive bonding and arc or beam fusion processes described above are today not yet ready for practical application in the automotive industry. Further developments are necessary.

10.3 Combinations of fusion welding techniques

The term “Hybrid welding” is often used to describe the Laser-MIG welding process, but there are other combinations of fusion welding techniques used in practice (e.g. plasma arc and MIG welding).

The combination of two welding techniques allows the exploitation of the advantages and reduce as much as possible the negative factors of the individual techniques. It is, however, important to recognise that hybrid joining techniques need to be adapted to each specific application if maximum reliability is to be achieved. A good example is the influence on the weld profile.



Characteristic profiles of hybrid welds

10.3.1 Laser – arc welding processes

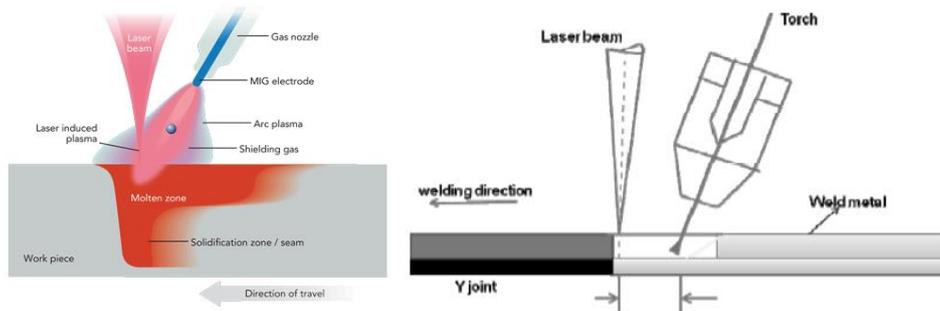
The combination of laser light and an electrical arc into a hybrid welding process has existed since the 1970s, but introduction into industrial applications took some time. Hybrid laser-arc welding is a joining process whereby arc welding and laser welding are carried out simultaneously, in the same weld pool and in the same welding operation.

Laser beam welding is described in detail in section 4.1. Since the laser is primarily used to ensure the deep penetration capability, power-intensive laser sources (CO₂, Nd:YAG, diode, fibre, etc.) are preferentially combined with any arc welding process (MIG welding, TIG welding, plasma welding). However, hybrid laser-MIG (often also referred to as GMA) welding

and laser-TIG (often referred to as GTA) welding are perhaps the most common combinations.

The hybrid process exhibits the individual advantages of both – laser beam and arc – welding processes when carried out separately. Deep penetration welds comparable with laser welds can be made, but at the same time, the tolerance to joint fit-up and the resulting weld profile are more comparable with arc welds. Furthermore, arc welding consumables (and gas mixtures) can be used, leading to a higher degree of control over weld quality and properties than with laser welding.

In hybrid welding, the laser beam is feeding heat to the weld metal in the top part of the seam, in addition to the heat from the arc, i.e. both welding processes act simultaneously in the same process zone. Depending on which arc or laser process is used, and depending on the process parameters, the processes will influence one another to a different extent and in different ways. Also the character of the overall process may be determined to a greater or lesser degree either by the laser or by the arc.



Laser and arc process operating in a single process zone (left) or in tandem (right)

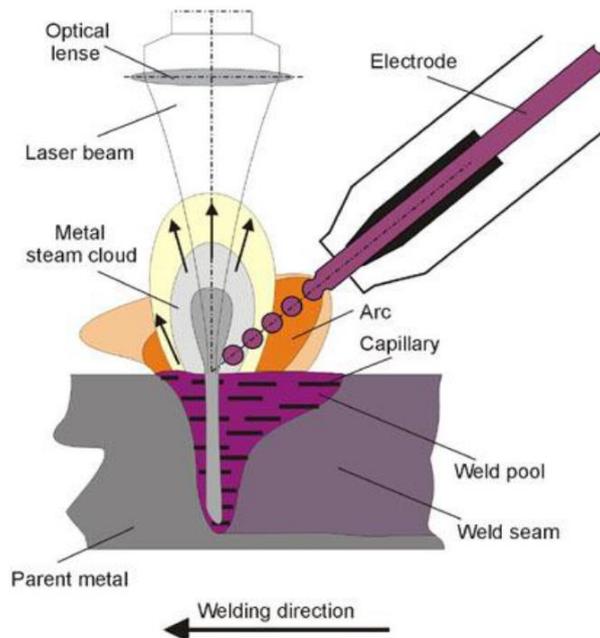
There is also the possibility a sequential configuration where two separate welding processes act in succession, but still in a joint weld pool. In this case, the greatest effect is achieved if the laser beam is used to produce the root pass, and MIG or TIG arc welding is used for filling the pass.

Where there are two separate weld pools, the subsequent thermal input from the arc means that the laser-beam welded area is given a post-weld heat treatment.

The biggest potential of laser-arc hybrid welding is seen in the addition of filler material. Thus the laser - MIG hybrid welding process is currently the most preferred laser-arc hybrid welding method. Using the MIG process (continuous or pulsed arc) as the arc process in laser hybrid welding, the gap bridging ability can be increased as the addition of filler metal is better controlled and filler metal volume can be higher than by using cold wire feeding together with the plasma or the TIG arc.

10.3.1.1 Laser - MIG welding

The laser and the MIG arc have a common process zone and weld pool. The process can be controlled in such a way that the MIG welding technique (see section 3.1.3) provides the appropriate amount of molten filler material to bridge the gap and to close the joint, while the laser delivers the high power densities needed to ensure the desired penetration depth and to enable higher welding speeds. Thus, the hybrid technique is faster than MIG welding alone, and the joined components are subject to less distortion.



Principle of the Laser - MIG welding process

As soon as the laser beam impinges on the material surface, it vaporises a spot on the surface. A vapour cavity is formed in the weld metal due to the escaping metal vapour, creating a deep and narrow heat-affected zone. The use of expensive laser energy is restricted almost exclusively to the deep-welding effect, which also permits thicker sheets to be joined. The remaining energy requirement is met by the cheaper MIG process, whose melting electrodes at the same time provide better gap-bridging capabilities. Since both processes focus their energy on the same processing zone, weld depth and speed are significantly improved compared to the individual processes. Depending on what ratio of the two power inputs is chosen, the character of the overall process may be determined to a greater or lesser degree either by the laser or by the arc process.

In hybrid welding, the arc torch has to be oriented with a flatter angle than in conventional arc welding because the laser beam may impinge the gas nozzle if the arc torch is too close to the laser beam.

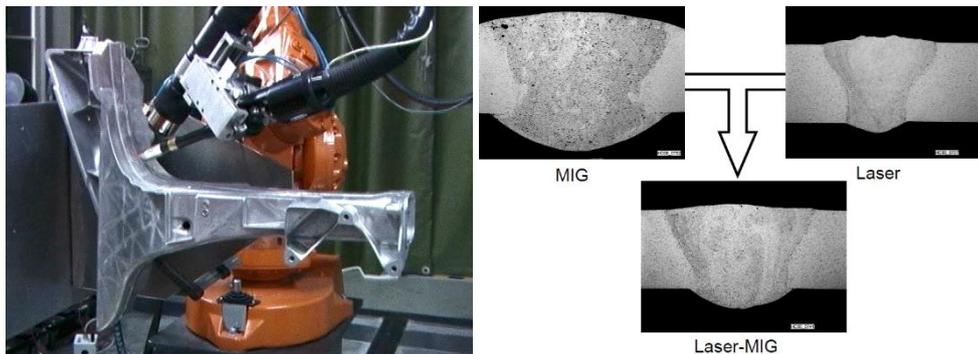
Laser – MIG hybrid welding is particularly suitable for applications that use industrial robots, as the potential offered by this high-performance process can only be exploited by automated applications. The heart of the hybrid welding system is a compact welding torch with an integral MIG system and laser optics. A robot holder gives the welding head the flexibility to access difficult-to-reach areas of the work piece. The filler wire can be placed in any position with respect to the laser beam, thus enabling the joining process to be adapted precisely to the wide variety of seam preparations, outputs, wire types, wire grades and joining tasks. A coated protective glass is required to protect the laser optics from welding spatter damage. In order to prevent weld-spatter from soiling the protective glass, a cross-jet is used to divert the spatter so that it can be vacuumed off through an exhaust-air duct. The work area remains free of contaminants and welding fumes.



Laser – MIG welding head

(Source: Fronius)

Both the weld penetration depth and the welding speed are greater in the combined process than when either of the processes is used on its own. The Laser – MIG hybrid welding process is suitable for a wide range of materials and thicknesses. It is specifically suitable to weld components where tolerances and preparation times make them unsuitable for laser welding. Another positive aspect is the relatively low heat input and the reduced amount of shielding gas required. On the one hand, high-strength materials exhibit hardly any loss of strength, while on the other hand, the low levels of thermal delay mean improved component precision.

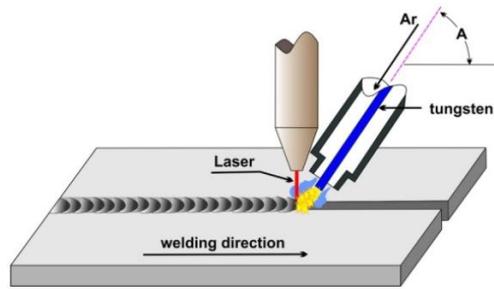


Laser – MIG hybrid welding of two vacuum high pressure die-cast aluminium half shells

Laser – MIG hybrid welding asks for lower tolerance requirements for edge preparation (low sensitivity for gap width variation) than laser welding, leads to an improved weld seam quality (less blowholes, porosity, undercuts, solidification cracks, better seam surface quality) than either laser or MIG welding and produces smoother thickness transitions and bead surfaces than by laser alone.

10.3.1.2 Laser - TIG welding

When the TIG arc technique (see section 3.2.1) is operated simultaneously with a laser beam, the absorption of the laser energy into the base material is enhanced in the heated region. Laser-TIG hybrid welding has proven to be a promising technique to weld thin steel sheets in a butt joint configuration. However there are no known practical application of this hybrid welding method with aluminium.

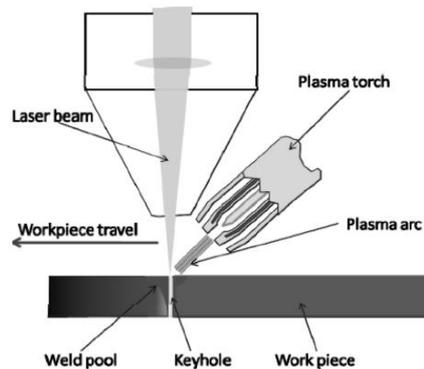


Principle of hybrid laser – TIG welding process

10.3.1.3 Laser - plasma arc welding

For laser - plasma hybrid welding, the laser beam and the plasma jet (see section 3.2.2) are brought together in the process region close to the work piece. The plasma torch is generally positioned at an angle of about 45° to the laser beam.

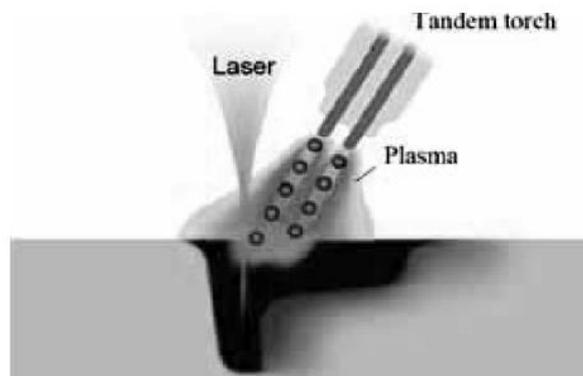
Plasma arc welding can be also used together with the laser beam process in such a way that the laser beam is surrounded by a concentric plasma arc. The heat of the plasma arc reduces the cooling rate of the weld zone and decreases the development of residual stresses. It is therefore possible to tailor the microstructure of the weld and the heat affected zone to a specific application.



Plasma arc augmented laser welding system

10.3.1.4 Laser – MIG tandem welding process

The combination of laser and MIG tandem welding (see section 2.1.3.4) is a logical development of hybrid laser – MIG welding. The laser beam is set at approx. 90° to the work piece and is used for welding the root. Both of the trailing arcs have a pushing tilt angle and are used to increase the ability to bridge root openings and increase weld throat thickness.



Laser – MIG tandem arc welding

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The process uses three different power outputs, thus the weld joint geometry, the preferred joint overfill and the welding speed can be selected by means of a suitable power output. The key advantage of combining the processes in this manner is the fact that as the filler metal melts off, it generates an arc pressure which does not act on the work piece, but is distributed across separate arc roots.



Laser – MIG tandem arc welding unit

(Source: Fronius)

An automated high-performance welding process is the combination of laser – MIG hybrid welding with MIG tandem welding. The combination of a laser beam with three arcs offers new possibilities to join heavy gauge metallic sheet materials: high welding speeds with good gap bridging and metallurgical characteristics.

The preceding laser - MIG hybrid process with one arc creates a very narrow heated zone with a great weld-depth to seam-width ratio. The following tandem welding process has considerably less concentrated energy and is characterised by a very high deposition rate.



Torch for laser – MIG hybrid plus MIG tandem welding

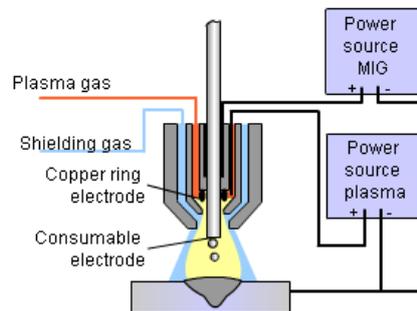
(Source: Fronius)

10.3.2 MIG plasma welding

MIG plasma welding is a high-performance welding process that was specifically developed for aluminium welding. The combination of MIG and plasma arc welding achieves an increase of the filler wire melting rate by adding the plasma arc and enables improved pre-heating of the work piece and filler wire, thereby avoiding cold shut defects at the weld start. However, it is unsuitable for manual welding due to the required large sized welding torches.

The process is a variation of MIG welding method in which the MIG arc is constricted with the help of a plasma gas. Unlike conventional MIG torches, a MIG plasma torch has a second, inner, water-cooled nozzle through which the plasma gas flows. The MIG electrode is placed in the centre and the ring electrode in which plasma arc is generated is placed in the circumference. The plasma gas, usually argon, is ionised by high-frequency pulses between the wire and the plasma arc and ignites the pilot arc, which then ionises the whole column of gas between the plasma arc and the work piece. As with MIG welding, the outer gas layer acts as a shield for the plasma arc to prevent the molten metal from reacting with ambient air.

The melting power of the MIG welding arc is increased by the addition of the plasma arc. Furthermore the plasma arc preheats the work piece and the wire, thus avoiding cold-shut (lack of fusion) defects at the start of the weld. The "hot" wire can be fed at a higher rate resulting in a higher melting performance. The higher heat input improves gap bridging, but may also lead to thermal distortion of the work piece. Thus the MIG plasma welding process is applied only in special cases (e.g. when welding aluminium components with large wall thicknesses).

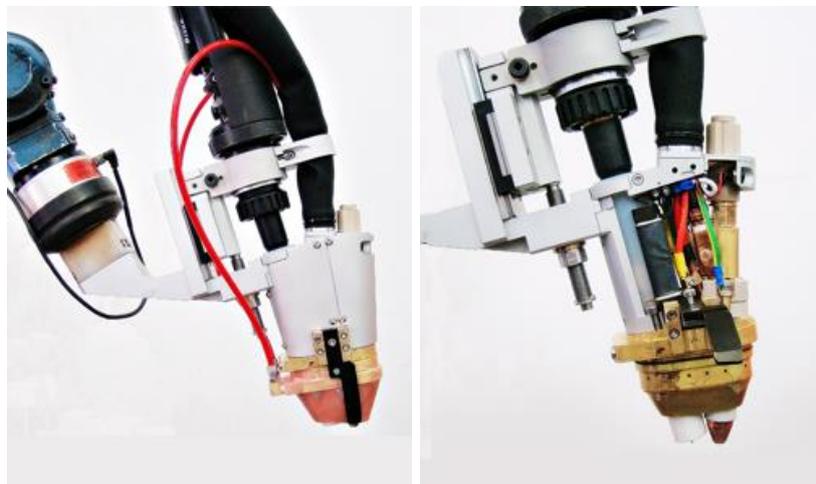


MIG plasma torch

(Source: aluMatter)

A slightly different arc configuration is used in the Super-MIG® technology. This hybrid welding technology combines the plasma arc and the gas metal arc technique into one operational welding system. It provides welding capabilities not available by each of the two welding technologies alone.

The equipment combines a plasma torch and a MIG torch in one processing torch. The axes of the non-consumable electrode (plasma arc) and the consumable electrode (MIG arc) are positioned in an acute angle facing the work piece. Thus the plasma arc at the leading position creates a keyhole and the following MIG arc operates typically in the conduction welding mode to fill the void created by the plasma arc. The net result is that the hybrid process relies on the plasma arc for deep penetration and high arc efficiency and metal deposition rate of the MIG process to finish the weld.

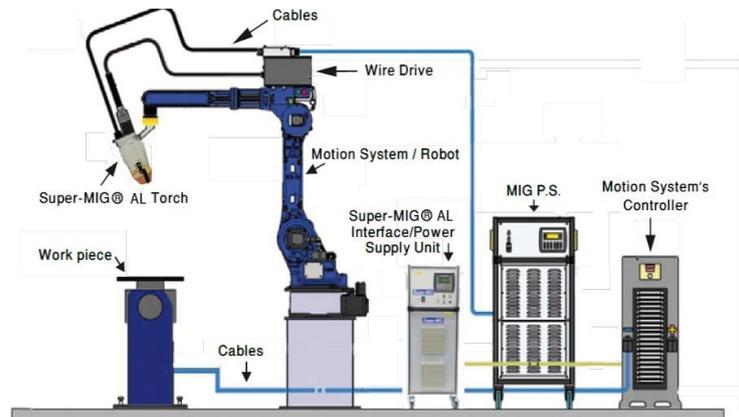


Super-MIG® processing torch

(Source: Plasma Laser Technologies)

THE ALUMINIUM AUTOMOTIVE MANUAL

The interaction between the plasma arc flow and the MIG arc promotes wire heating and current transfer at the anode spot (at the end of the MIG filler wire), where the molten weld metal droplets form and subsequently detach. The hybrid process uses a negative plasma arc electrode and a positive MIG electrode to achieve maximum processing speed and to operate in the spray transfer mode. The magnetic force causes deflection of the plasma arc toward the front of the weld pool, compensating for the plasma arc's natural tendency to trail behind the torch axis during high-speed welding. The resultant effect is an increase in plasma arc rigidity and stability, leading to increased penetration depth and welding speed when compared with conventional MIG technology.



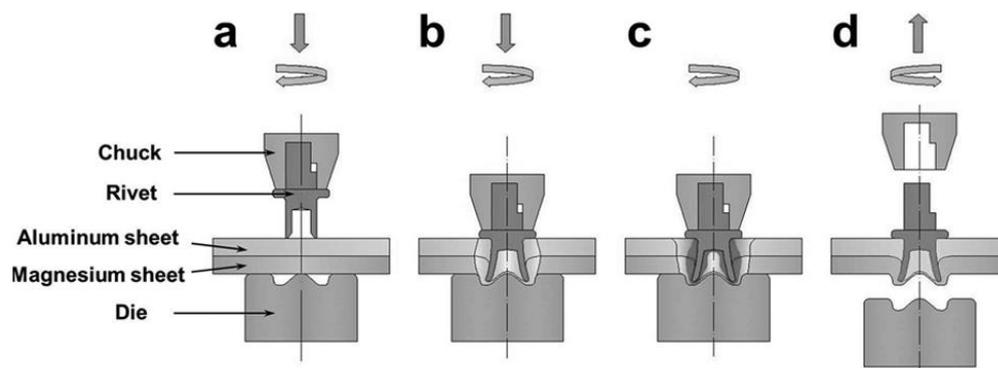
Super-MIG® aluminium welding system

(Source: Plasma Laser Technologies)

10.4 Friction self-piercing riveting – a combination of two mechanical joining techniques

Self-piercing riveting is currently the most popular mechanical joining technique for dissimilar materials and is widely used in joining all-aluminium and multi-material vehicle bodies. However, when riveting magnesium alloys, cracks always occur for its low ductility. A hybrid joining process named friction self-piercing riveting, which combines the mechanical joining mechanism of self-piercing riveting with the solid-state joining mechanism of friction stir spot welding was developed aiming at joining the low-ductility materials. In this process, the rivet rotates at high speed during the actual riveting process.

The effectiveness of the friction self-piercing riveting process was validated by riveting 1 mm thick EN AW-6061-T6 aluminium and 2 mm thick AZ31B magnesium sheet. The results showed that the riveting performance of magnesium alloys could be significantly improved and the joint strength could be greatly increased.



Friction self-piercing riveting process

(Source: YongBing Li et al., J. Manuf. Sci. Eng. 2013; 135(6))