WELDING OR ADHESIVE BONDING — IS THIS A QUESTION FOR THE FUTURE?

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Modern light-weight structures are composed of most different materials. The joining of these materials with and among one another requires the application of different joining techniques with the focus on welding and adhesive bonding. In this paper, the advantages of both methods are discussed and possibilities for the combined application of welding and bonding techniques are presented. 5 Figures.

Keywords: *laser beam welding, plasma soldering, friction stir welding, adhesive bonding, steels, aluminium alloys, automotive car body, advantages of methods*

The joining technology is an interdisciplinary technology which allows the combination of parts which have most different geometries and which are consisting of a wide variety of materials towards complex structures and products.

Riveting has been the dominating joining technology of the 19th century. Numerous impressive structures serve as demonstration, for example, the Eiffel tower with more than 2.5 mln rivets. In the course of the 20th century, riveted structures were increasingly replaced by welded structures. The production of welded structures is, on the one hand, economically more efficient and the structures have, on the other hand, a higher strength. Besides welding, the adhesive bonding technology is, nowadays, increasingly used for many applications.

A major advantage of welding compared with adhesive bonding is its advance of several decades in research and industrial application. The welding technology is for many joining tasks still the called-for method.

Particularly for thick-walled welded structures which are joined on butt joint, T-joint or cruciform joint, the application of the welding technique is unrivalled. In this field, also methods which are assumed to be out-of-date, such as electro-slag welding, can be applied with a high efficiency. Figure 1 depicts an impressive example.

For the manufacturing of a large press, a steel sheet structure has been chosen instead of a cast structure. The steel sheet structure was manufactured with particularly lesser quantities of material and was, thus, much more cost-favourable. However, this type of structure required to join the large-format steel plates with one another. Each plate had a thickness of several centimetres. As a standard welding technology for this task, multiple-pass submerged arc welding has been applied with a production duration of three up to four weeks just for the weld. The application of electro-slag welding allowed a reduction of the welding time down to 14 h, compare Figure 1.

In working with modern designs it is often not possible to apply just one welding method. They are often characterized by the use of many different materials such as different steel grades,

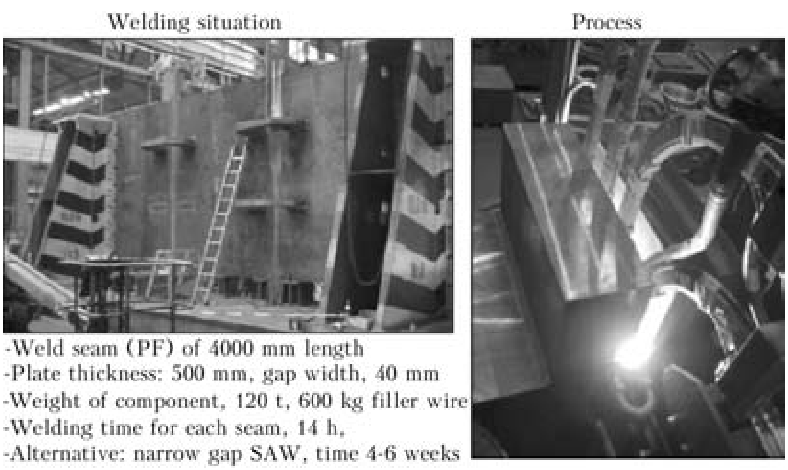

Figure 1. Electro slag welding of large components for presses

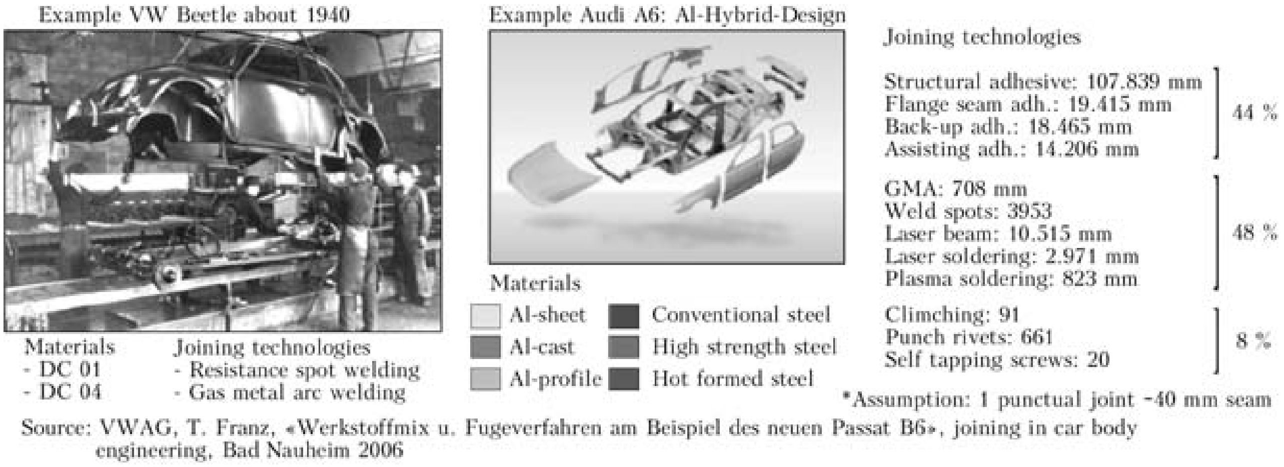

Figure 2. Conventional steel design (*left*) and modern aluminium-steel-hybrid design (*right*)

aluminium or fibre reinforced plastic. This applies in particular to light-weight structures. The production of these applications requires the control over the entire band width of industrially available joining methods in order to identify and qualify the best solution for a specific design under specific production boundary conditions.

The complexity of this task can be clarified by the example of automotive car body design. In the following text this example is used to discuss the question which technology will prevail in the near future: adhesive bonding or welding technology.

Requirements of modern light-weight structures to the joining technique, using the example of the vehicle body construction. In the beginning of the automobile large-scale production, complex structures such as the car body have been joined using a few simple welding methods. Figure 2 (*left*) shows the example of the car body of a VW beetle from the fourties of the last century. The car body has almost exclusively been made using resistance spot welding, supplemented by gas metal arc welding to a small degree. This is, nowadays, unthinkable. Besides increased demands made to corrosion protection, strength and production speed, also the application of most different materials for a car body is, here, particularly responsible.

In the nineties of the last century, aluminium car bodies were to an increasing level introduced to the market and, as a consequence, also aluminium-steel hybrid design structures. Besides this, also pure steel bodies are, nowadays, in principle material mixed constructions. Other than in the car body of the VW beetle where mainly two steel sorts, DC 01 and to a certain degree also DC 04, have been used, modern steel car bodies are made of many different steels, such as deep-drawing steels, high and highest-strength steels and hot-formed steels. Besides this, also fibre-reinforced plastic materials are increasingly gaining in importance in the field of automotive car body construction.

From the perspective of joining, the following important challenges result:

• Joining of materials which are difficult to weld, e.g. highest-strength steels with a defined micro-structur.

• Joining of multi material-mixed compounds, e.g. steel-aluminium, steel-CFK.

• Joining of complex geometries, e.g. combination of plates, profiles, sandwich.

These requirements can no longer be fulfilled with only one joining method. For the production of modern car bodies, therefore numerous joining methods are applied. Besides the established methods resistance spot welding and arc welding, also «younger» welding methods such as laser beam welding, mechanical joining techniques such as clinch riveting and riveting also also adhesive bonding are applied, compare Figure 2 (*right*).

Adhesive bonding vs. welding. Propelled by the request to apply also materials which are difficult to weld or even multi material compounds, research about alternative joining techniques has been promoted. The focus is, on the one hand, on the mechanical joining techniques and, on the other hand, on adhesive bonding. Both technologies are capable of low-heat joining of most different materials with one another.

Compared to the mechanical joining methods, adhesive bonding has several process-related advantages. Adhesive bonding allows the production of optically excellent, leakproof joints with a good corrosion protection and a favourable load transmission using a big joining area. In order to use the advantages also under the high requirements of automotive serial production, several generations of adhesive developments had been required. The most important developments comprise:

• The washout resistance - modern car body adhesives are, also in the non-cured state, not washed out in the paint bath of the cataphoretic immersion priming.

• The oil tolerance - modern car body adhesives are capable to develop good adhesion also on oiled sheets. The expenditure for surface preparation is thus drastically reduced.

• The crash resistance - modern car body adhesives do not suffer brittle failure despite high stiffness and strength. Through the embedding of elastic domains into the stiff matrix, the stress-strain diagram of the adhesives has, in the beginning, a high elastic modulus and transforms in the crash case on a high load level into a deformation plateau.

Due to these developments, the application of adhesive bonding technology in vehicle car body production has, meanwhile, become a standard. The adhesive bonding technology is, thus, directly competing with the welding technology. When working with materials or material mixed compounds which are difficult to weld, the advantages of adhesive bonding will become obvious, also for laypersons. But also pure metal joints are, to an increasing degree, adhesively bonded.

As far as structural tasks are concerned, adhesive bonding is preferentially applied together with spot welding. Attention must be paid to the fact that the main loads are transmitted from the adhesive layer. From the point of mechanics, the weld spots are, above all, minimising the peel load which is unfavourable for adhesively bonded joints. The main reason for the application of spot welding is to guarantee a sufficient handling strength and stiffness of the car body during the production process for the period between adhesive application and adhesive curing.

Having the many advantages of adhesive bonding in mind, the question arises where the welding technology is superior to adhesive bonding. It applies to the joining of metal materials: Adhesive bonding requires a certain expanse in order to transmit the necessary forces. The strength of polymer adhesives is by at least one order of magnitude lower than the strength of metal materials. Especially in the case of only small flange widths or if plate geometries are not to be joined overlapping but on butt joint, the application of welding technology is recommendable. Welding allows, moreover, joining under high thermal load, a robust manufacturing process under rough conditions and the application of established repair concepts.

Furthermore recent developments in the field of welding meet the demands for low expenditure for devices, high productivity and lowest-possible influencing of the base material by a defined heat input. The latter is explained especially from the request to weld also light-weight materials, such as high-strength steels, aluminium or even mixed compounds with good joining properties.

In the field of arc welding, increasingly controlled short-arc processes are applied. Those processes are capable of a defined heat input and allow thus even the joining of aluminium and steel. In the field of laser technology, solid-state lasers which allow high production speed with, at the same time, excellent beam qualities, are applied to an increasing degree. Remote welding processes where the laser beam is deflected via a scanner system with extreme speed, allow meanwhile to achieve welding speeds of up to 20 m/min almost without downtime. For the joining of heat-susceptible materials which lose their good properties permanently through fusion welding, meanwhile joining technologies are used which are capable of working below the fusion temperature, for example ultra-sonic welding or friction stir welding.

Figure 2 makes clear that welding technologies, to a certain degree also mechanical joining methods and also the adhesive bonding technology all have their place with good cause. If sufficient flange areas are provided and especially if materials which are difficult to weld and material compounds are to be joined, the increasing degree of application of adhesive bonding is anticipated.

Since the advantages of both methods are well complementing one another, it is an interesting question whether, in future, better combination possibilities may be found for both technologies. A good example for a successful implementation of this idea is the above-mentioned resistance spot welding adhesive bonding.

Adhesive bonding + welding. In resistance spot weld adhesive bonding, welding and adhesive bonding are combined within one joining zone. While the adhesive bonding guarantees high strength values, stiffness and a good corrosion protection, the resistance spot welding provides above all for the minimising of the peel load and for a high initial strength immediately after the joining process.

The ISF Welding and Joining Institute at RWTH Aachen University (ISF) is working intensely on the development of further possibili-

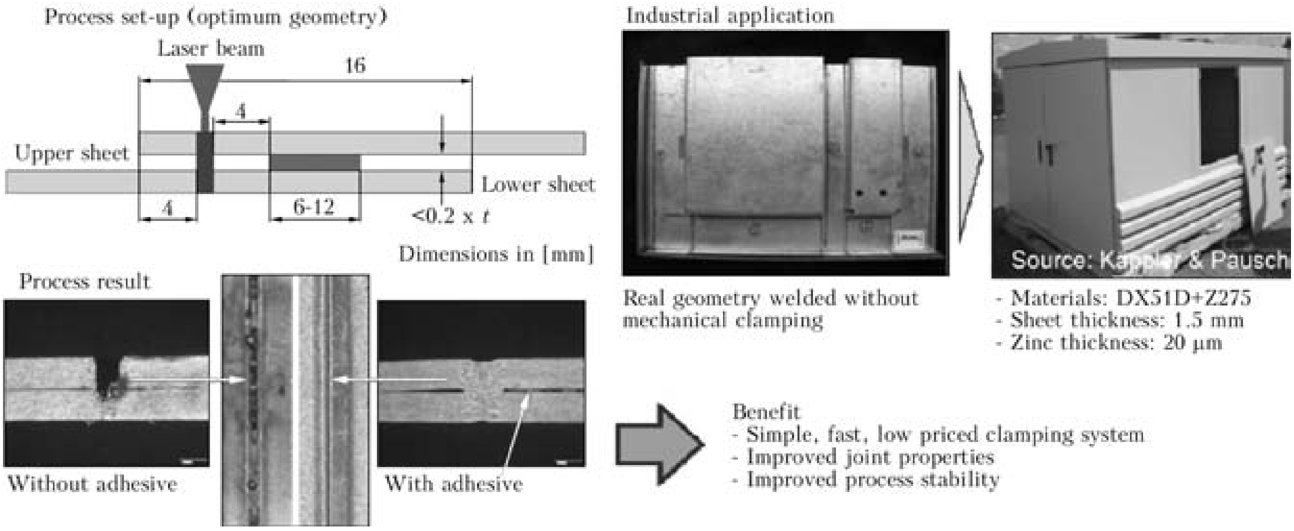

Figure 3. Laser beam welding combined with adhesive bonding

ties for combining welding and adhesive bonding. Thus, among others, the combination of laser beam welding and adhesive bonding and also the combination of friction stir welding and adhesive bonding have been developed and investigated. Both methods will be presented in the following.

Laser beam welding + adhesive bonding. Laser beam welding allows the production of high-quality welded seams with a small heat affected zone at high production speeds. Besides the high investment costs for an industry-standard laser including safety devices, the required clamping devices for a specific joining task represent a substantial cost factor.

In cooperation with the TU Braunschweig together with partners from industry, the ISF has combined the processes laser beam welding with adhesive bonding. While in spot weld adhesive bonding, the bonded seam carries the main load and the weld spots serve mainly for the fixation, it is, here, the opposite. The used adhesives are pressure-sensitive adhesives. These allow the immediate fixation without requiring additional mechanical devices. Since it is not possible to weld straight through the adhesive layer, the advantage of easy and inexpensive clamping comes with larger flange widths, because a certain minimum distance between adhesion and welding must be maintained, compare Figure 3.

Besides the fixation, there are also technical advantages as far as the welding process itself is concerned. During the welding of galvanised sheets with overlap joint, the degassing zinc layer often results in pores in the weld if the sheets are pressed firmly together. To avoid this problem a gap has to be provided between the plates which is so small that the reliable running of the welding process is ensured and which is, on the other hand, so large that the zinc layer is still capable to degas reliably. Gap measures of 0.2 × plate thickness have proven to be recommendable. The clamping of plates with a defined gap measure is extremely complex and requires expensive preparation in terms of clamping devices. Here, the combined process offers the ideal preconditions since, via the adhesive layer thickness, it is be possible to comfortably set the degassing gap without any additional expenditure. Accordingly, very good weld qualities are achieved. The advantages of the degassing gap and of the reduced expenditure for clamping are, especially in the joining of galvanised sheets for small-scale production, outweighing the disadvantages of the larger flange widths and the expenditure for the additional application of the adhesive bonding technology. It has, thus been possible to industrially implement this technology already during the first research project which has been dealing with this subject.

Friction stir welding + adhesive bonding. Based on the successful implementation, the idea has been transferred to friction stir welding. In friction stir welding, tools with a pin and a tool shoulder are used. These tools are set into rotation, subsequently the pin is dipping into the workpiece until the tool shoulder is reaming over the workpiece surface. Via the mechanical rotation and the developing frictional heat, the material is stirred with one another below melting temperature and firmly bonded. Process-related, very high forces are developing which, normally, require clamping devices close to the joining point with high forces. Otherwise, there is the risk of plate warping, Figure 4 (*right*).

The application of the combined process allows to weld almost completely without mechanical clamping technology. It is from a technical point of view, moreover, possible to join thinner

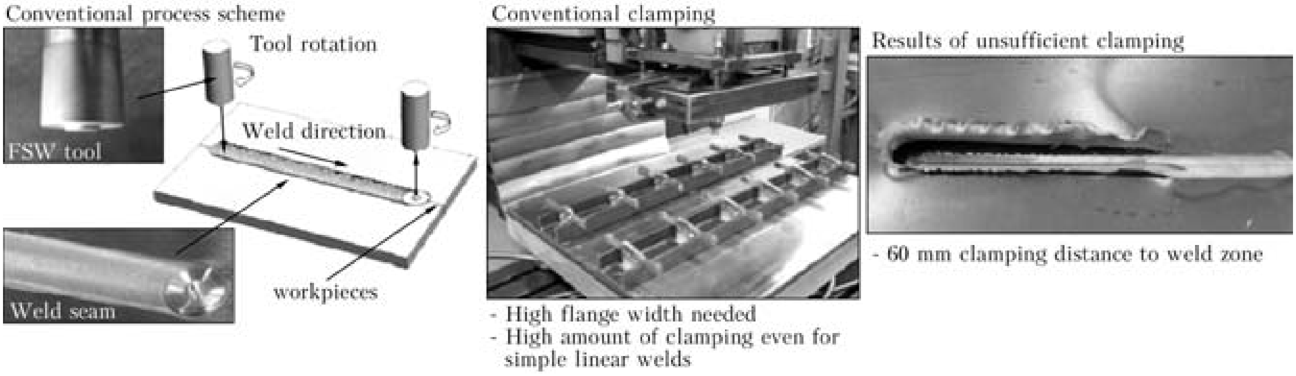

Figure 4. Conventional friction stir welding

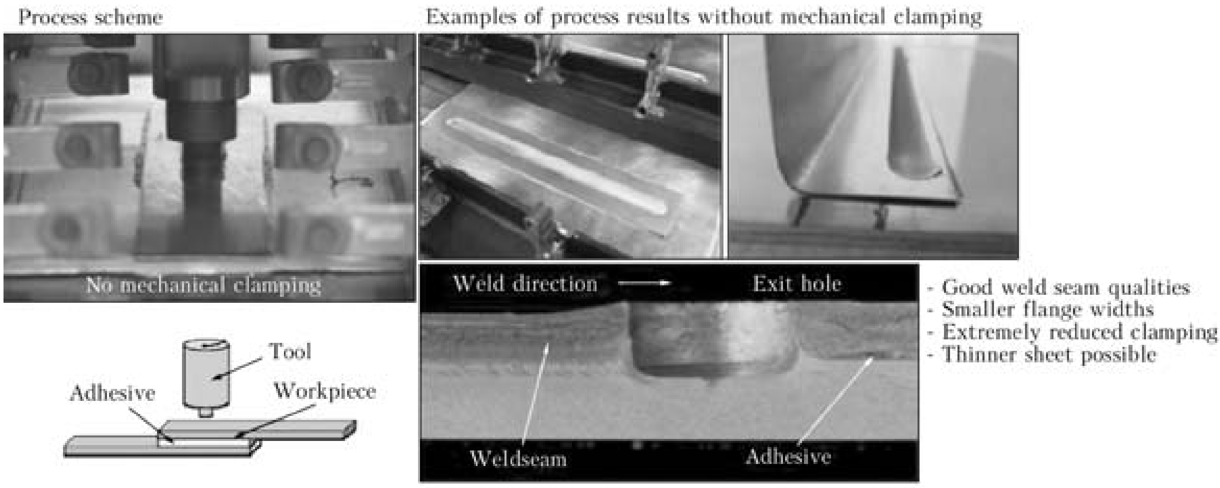

Figure 5. Friction stir welding combined with adhesive bonding

plates due to the lateral load transmission. It is even possible to weld directly through the adhesive layer. The applied pressure-sensitive adhesives are, at that, pushed out and high-quality welded seams are developing, Figure 5. The strength values of the base material are almost achieved. Further advantages, such as reduced cranny corrosion are to be expected and are subject to current research work.

Conclusion

Using the example of automotive car body manufacturing, the application fields of the technologies of adhesive bonding and of welding have been discussed. The application of the welding technology is preferentially used for metal joints, particularly if only small flange widths are available, plates are to be butt-jointed, high application temperatures are prevailing or if immediate strength under demanding production conditions is required. If sufficient adhesive surface is available, the adhesive bonding technology, on the other hand, allows the low-heat joining of most different materials with excellent mechanical properties. It is thus possible to join steels, aluminium alloys and fibre-reinforced plastic materials with most different properties without loss of strength in the base material. The application of the adhesive bonding technology is due to the increasing application of multi material mixed compounds currently also strongly on the rise.

Hybrid technologies which combine the advantages of both methods in one joining zone are particularly advantageous. Besides the already established resistant spot weld adhesive bonding, the ISF Welding and Joining Institute at the RWTH Aachen University has been developing also other process combinations. The combination of adhesive bonding with laser beam welding as well as with friction stir welding was presented. Both of them offer, besides technical advantages, a considerable economical potential through the minimisation of the required clamping technique.

It can already be stated today, that the combined approach between adhesive bonding and welding holds great potentials for future developments.

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