Feasibility Study on the use of Adhesive Fixation in Conjunction with Friction Stir Welding

Uwe Reisgen[1], Alexander Schiebahn[1], Marc Essers[1], Andreas Naumov[1]
[1]Welding and Joining Institute (ISF),
RWTH Aachen University,
Pontstrasse 49,
52062 Aachen, Germany

Mohamed Harraz[2]
[2]Faculty of Engineering and Materials Science,
German University in Cairo,
New Cairo, Egypt

***Abstract*— A robust clamping and fixation process during friction stir welding is often a complicated and time-consuming procedure, but very essential for a successful welding process. The limited accessibility in mechanical clamping, particularly in the fixation of complicated and three-dimensional structures, adds more constraints and causes problems. Moreover, friction stir welding of thin metal sheets is extremely difficult due to the lack of stiffness, and thus needs tight fixation close to the weld zones, which is difficult to achieve using mechanical clamping. As an alternative to mechanical clamping, adhesive technology can be used to reduce the effort and time consumption of mechanical fixation. The approach presented in this paper provides significant applications advantages in that complex geometries and thin overlapping aluminium sheets AA5754 up to 0.5 mm thick can be easily, timely and conveniently friction stir welded without the need for complicated mechanical fixing. This study has rendered the adhesive technology as a proven reliable fixation method, thus offering prospects for broader applications in the friction stir welding technology.**

Keywords: friction stir welding, adhesive bonding, hybrid welding, aluminium.

I. INTRODUCTION

High forces that occur during friction stir welding (FSW) process require a reliable clamping and fixation of the parts to be joined together. In general, the mechanical clamping of the parts to be joined in FSW is made in the form of hold-down structures, collets, etc. Depending on the design and geometry of the parts to be joined, the time required for a reliable fixation and weld preparation is mostly immense compared to the welding process itself. Simple part geometries are usually easily friction stir welded, but as for complex structures, reasonable effort is given to the mechanical fixing of the components. To improve the economical potentials and competitiveness of FSW over other welding processes, it is among other requirements, necessary to reduce the considerable time and effort consumed in clamping and fixing process, and especially when welding three-dimensional structures. One of the possible approaches is to consider the use of special adhesives for the fixation process. For this reason feasibility study for using adhesive fixing technology in conjunction with friction stir welding is conducted at the Institute for Welding and Joining Technology (ISF) at the RWTH Aachen University.

The basic idea of this hybrid technical application is to combine the advantages of two joining methods together. In this application the adhesive used in the FSW process not only could achieve the advantage of minimising clamping effort but could also protect the weld area from climate influence, and therefore a subsequent sealing of the weld would not be needed. Furthermore, the joining of very thin plates by FSW using the conventional mechanical clamping technology is difficult to implement. Due to their lower stiffness, the FSW of thinner sheets often causes warping and severe burr during the welding process and requires clamping as close as possible to welding zone. Here the conventional mechanical clamping is irrational, because of collision reasons, a minimum distance between the clamping tools and the friction stir welding should be perceived. Currently the limit of plate thickness to be joined by friction stir welding with conventional clamping technique is about 0.8 mm [1]. Using an adhesive fixation technology can reduce the limit to 0.5 mm, since the mechanical constraint in the mating zone region can be eliminated and thus the fixing of the sheets is possible right up to the area of the weld zone. The course of this contribution is therefore to further analyse and present the potentials for adhesive fixation technology to the friction stir welding of thin and complicated geometries. The procedure shown below has been developed at the Welding and Joining Institute in Aachen (ISF). In this regards, Figure. 1 shows a schematic representation of the three possible fixation modes in conjunction with friction stir welding [2].

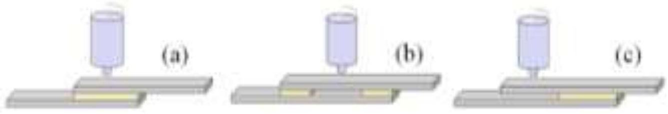

Figure 1. Three modes of arrangements of adhesive material between the overlapping sheets

(a) FSW through the adhesive, (b) FSW in-between both-sided adhesive, (c) FSW on single-sided adhesive

II. MATERIALS AND PROCEDURE

A. *Experimental setup:*

The FSW experimental studies on adhesive-fixed plates are carried out on a path-controlled CNC milling machine. The material used for the aluminium sheets is a wrought aluminium alloy AA5754. For experimental purposes, the standard aluminium sheets are tailored with a hydraulic shearing machine with the dimension 160 x 500 mm, while the overlapping length was initially set to 60 mm. In the later course of the investigation, the overlap length is adjusted to minimum necessary requirement with respect to the adhesion force needed for the fixation and assembly process. Sheet thicknesses of 0.5 mm and 1.5 mm were examined with the following sheet overlapping combinations:

- Sheet thickness 1.5 mm with 1.5 mm
- Sheet thickness 0.5 mm with 1.5 mm

As for the friction stir welding tool, which is made of alloy tool steel X38CrMoV51, a shoulder with an outer diameter of 8 mm and a welding tapered probe (pin) of diameter 3 mm were used. The welding pin is fixed by two fittings coaxially with the shoulder in such a way to allow easy adjustment of the pin protrusion from the shoulder portion. A typical conventional mechanical clamping fixture that is used at ISF in the form of a hold-down construction as shown in Figure 2 has a 20 mm width of available processing area after clamping.

Figure 2. Conventional mechanical clamping with a hold-down construction

For fixations of overlapping sheets using adhesive technology the mechanical hold-down construction can be omitted altogether and is replaced by simple steel U-profiles (Figure 3) placed at a parallel distance of 110 mm from each other, only to prevent slipping of the sheets on the machine table.

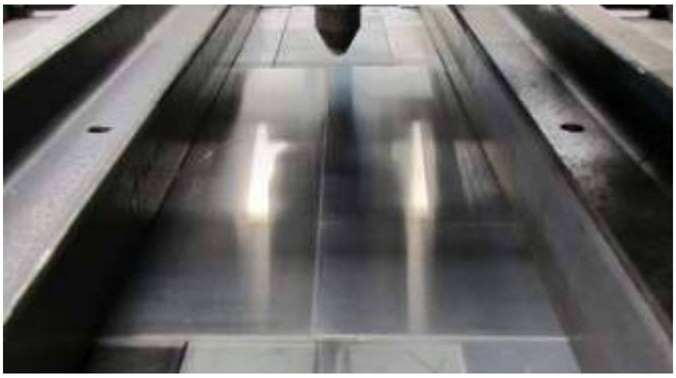

Figure 3. Simplified mechanical clamping with steel U-profiles for alternative adhesive fixation

B. *Adhesive selection:*

For the technical fixing application in friction stir welding an adhesive bonding material is required to be carefully selected to fulfil the requirements. On one hand it has to be easily and timely convenient to do the job and on the other hand provide a high initial bonding integrity and strength. These requirements essentially correspond to pressure-sensitive adhesives, which are composed of highly viscous polymers and are characterized by a permanent tack. In general, adhesives contain ingredients that have a high tackiness, such as resins and plasticizers. Applied pressure is necessary in order to achieve sufficient wet-out onto the substrate surface to provide adequate adhesion [3]. Once the components are joined with such adhesives, a mutual displacement of joined surfaces is no longer possible after the pressing procedure. Different types of adhesion tapes can be used such as double coated tapes as well as transfer tapes, but in both cases the adhesive must be a highly viscous medium, which can be displaced under high pressure to allow for the penetration of the welding probe through the adhesive layer [4]. In the framework of this particular investigation, a high performance double coated tape 9088 and an adhesive transfer tape F9460PC are used. Both tapes are based on a modified acrylic adhesive with a total tape thickness of 0.21 mm and 0.05 mm in the double coated tape and the transfer tape respectively. Both tapes were selected because of their proven high adhesion strength and excellent long term holding power in fixing application [5].

In addition to the adhesion strength required for the fixation application of the FSW process, the adhesive must have an adequate short-term temperature resistance, since in the vicinity of the joint zone temperatures can occur, which may critically affect the adhesion strength. The short-term temperature resistance depending on the adhesive type however ranges from 150 to 300 °C.

C. Experimental design:

The FSW experiments combined with adhesive fixation technology are conducted based on a parametric study that has relatively shown the best results concerning weld strength and weld shape appearance. The major welding process parameters such as tilt angle (α), pin distance to the backing plate (pd), heel plunge depth (hpd), rotation speed (n) and feed rate (f) are shown in Table I.

Table 1

Friction stir welding test parameters

Sheet Combination	α [°]	pd [mm]	hpd [mm]	n [RPM]	f [mm/min]
1.5 mm + 1.5 mm	2	1	0.30 to 0.65	2500 to 3000	300 to 500
0.5 mm + 1.5 mm	2	0.7 to 1	0.15 to 0.45	2500 to 3000	300 to 500

The FSW investigations were conducted using the two types of adhesive tapes, with respect to the three different modes of arrangements shown in Figure 1. The adhesive tape width and spacing arrangements according to the fixation application vary for each combination. The objective was to get as close as possible to the weld line with the minimum necessary adhesive to do the job. The width of the adhesive stripes varied from 5 to 30 mm with an increment value of 5 mm. The adhesive stripes are applied by hand to a previously degreased 500 x160 mm sheets that are fixed in the overlapping position together with an overlapping distance of 60 mm.

Assessing the quality of the welded joint and appropriate fixation of the joining partners is based partly on purely optical characteristics such as the weld shape appearance and the evolution of other defects such as weld distortion and fissure in the overlapping joint area. On the other hand, destructive testing methods such as lap-shear tensile tests were conducted and compared to pure tensile tests that are performed on samples of the relevant sheet material to have a complete evaluation of the joint strength. The size of the lap-shear tensile specimen is shown in Figure 4.

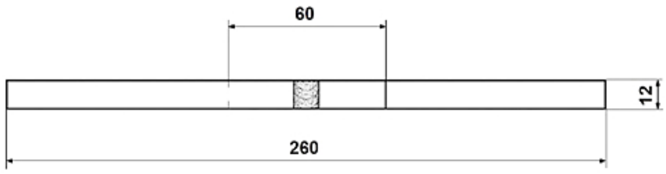

Figure 4. Specimen sample for lap-shear tensile test

III. RESULTS AND DISCUSSION

In order to compare the effect of FSW with and without the adhesive fixation technology, first welds are performed on a pair of plates 1.5 mm thick, which are clamped only by two U-profiles as shown in Figure 3 but without the use of any adhesives. As shown in Figure 5, due to the lack of fixation during the FSW, a clear gap of up to 4 millimetres is formed in the area of overlap of the pair of plates. In the case of using of adhesive fixation close to the weld zone and with the same experimental conditions, the previously observed gap formation induced distortion, can be avoided.

Figure 5. Gap formation in the welded plates due to inadequate fixation in the overlap region.

Depending on the type and arrangement of the adhesive used, strips width ranging from 5 up to 30 mm were used in order to achieve satisfactory welding results. The proximity of the adhesive strips to the weld line up to a distance of 5 or 6 mm has proven to achieve good results. At shorter distances to the weld line, the welding is associated with a loss of strength with respect to conventionally produced welds. Apparently, the glue or adhesive material in this case acts detrimental to the process sequence; however there is no confirmation that a residue of the adhesive material interfere in the immediate joining zones, so this point is not further investigated. In addition, the temperature distribution in the vicinity of the joint zone shows no significant effect on the adhesion strength. Previous studies on FSW of aluminium alloys have shown that most of the heat generated is at the surface, which is intuitively propagated away through the aluminium structure [6]. In this case, the heat generated during FSW has no detrimental influence on the adhesion fixation in the vicinity of the weld joint. A possible adhesive-related thermal insulation during the course of the process can thus be excluded. Table II shows detailed investigation results that are recorded using the two different types of adhesive tapes. When applying the adhesive transfer tape, all arrangements lead to a good overall result. Only the strength at a central (through) arrangement, which is in the range of 75 to 85% of the strength of the base material, is usually somewhat smaller than for the lateral (single- and both-sided) adhesive placement. The use of double-sided adhesive tape leads in comparison to the "transfer tape samples" in both single-sided and double-sided adhesive with a similar arrangement to good overall result. The central (through) arrangement was observed to result in a light burr on the surface, and a drop in the overall strength when compared to that of the base metal. This can be attributed to firstly the non-viscous carrier layer of the tape and on the other hand due to the approximately four times bigger adhesive tape thickness that substantially must be displaced from the joint zone during the FSW process, and thus leads to some instabilities. Investigations have also shown that any further increase in the adhesive width beyond the necessary fixing application leadsto no additional increase in the strength.

Table 2

Investigations results for using adhesive fixation tapes in conjunction with FSW of 1.5 + 1.5 mm sheets

Adhesive arrangement between the overlap sheets 1.5 + 1.5 mm	Transfer adhesive tape F9460PC		
	Recommended tape width [mm]	Recommended distance to weld line [mm]	Strength with respect to base metal [%]
(a) Through	15	-	75 to 85
(b) Both-sided	5	5	85 to 95
(c) Single-sided	5	5	85 to 95
Adhesive arrangement between the overlap sheets 1.5 + 1.5 mm	**Double coated tape 9088**		
	Recommended tape width [mm]	Recommended distance to weld line [mm]	Strength with respect to base metal [%]
(a) Through	15	-	75 to 85
(b) Both-sided	5	5	85 to 95
(c) Single-sided	5	5	85 to 95

Table 3

Investigations results for using adhesive fixation tapes in conjunction with FSW of 1.5 + 0.5 mm sheets

Adhesive arrangement between the overlap sheets 0.5 + 1.5 mm	Transfer adhesive tape F9460PC		
	Recommended tape width [mm]	Recommended distance to weld line [mm]	Strength with respect to base metal [%]
(a) Through	30	-	70 to 100
(b) Both-sided	10 / 5	5	95 to 100
(c) Single-sided	10	5	95 to 100
Adhesive arrangement between the overlap sheets 0.5 + 1.5 mm	**Double coated tape 9088**		
	Recommended tape width [mm]	Recommended distance to weld line [mm]	Strength with respect to base metal [%]
(a) Through	-	-	no weld
(b) Both-sided	15 / 10	6	95 to 100
(c) Single-sided	20	6	95 to 100

The FSW of ultra-thin aluminium sheet 0.5 mm to 1.5 mm or more aluminium sheet using a conventional clamping is almost impossible, because the 0.5 mm thick sheet metal overhead tends to be in the course of the intervention tool arrears, lump and warping are typical formed defects. As a result, provided a stable welding parameters, the process is usually accompanied by a strong burr formation and tearing of the upper thin sheet. This may be due to the fact that the fixation is not close enough to the joint zone, a reduction in the fixing rigidity assist the FSW tool to displace the sheet with the lower stiffness sheet leading to tearing in the thin sheet. An appropriate adhesive fixation however can provide a solution for joining 0.5 mm thin sheet to 1.5 mm thick sheet without the formation of tearing and warping in the thin sheet. This was confirmed by appropriate investigations in the course of which very satisfactory welding results were obtained. Figure 6 shows weld with a length of about 230 mm, in which the sheets have been previously fixed with a 10 mm wide transfer adhesive strip, which was positioned 5 mm in parallel distance to the joining line. Here the joint measured lap shear tensile strength corresponds approximately to that of the base material, and is characterized by an attractive surface shape.

Figure 6. A typical thin sample joined by FSW with conjunction with adhesive fixing technique

With the two examined tape types, both welds with single as well as double-sided adhesive fixation show that tensile shear strengths of 95 to 100% of the strength of the base material can be achieved. Welds by the central (through) adhesive arrangement are not recommended here because of the high strength of the fluctuations and unstable process history. Similar to the previous investigation, an increase in the adhesive width beyond the necessary fixing application leads to no additional increase in the strength. Table III shows detailed investigation results that are recorded using the two different types of adhesive tapes.

A further application of adhesive technique in conjunction with FSW is particularly evident in the fixation of three-dimensional structures. Figure 7 shows this example where a 0.5 mm thick and 240 mm long angle plate is shown which is fixed during the welding process via adhesive fixation only on the lower parts to be joined (3 mm thick plate material). As shown in the figure mechanical clamping of the angle plate is entirely omitted and the position and width of the applied adhesive strip is indicated by two marks on the left of the seam. The example shows how simple three-dimensional structures can be fixed quickly and easily by means of adhesive application only. The problem of limited accessibility, especially present in mechanical fixing elements is therefore eliminated.

Figure 7. A thin angle plate friction stir welded to thicker plate without the need of mechanical fixation

CONCLUSION

The feasibility study on the use of adhesive techniques for fixation with conjunction with friction stir welding demonstrated that the adhesive can fulfill wide range of fixing applications and is even superior to conventional mechanical clamping with regards to the proximity to the weld zone areas. In all investigated metal (sheet) combinations welds of high strength can be produced with strength values equal to that of the base material. An increase in the range of area where the adhesive is applied beyond the required range does not necessarily correspond to a further gain in strength. In the case of combination plate thickness 0.5 mm + 1.5 mm, it is however necessary to have a sufficient fixation in joint zone vicinity, in order to overcome the very low stiffness of the 0.5 mm thick sheet metal, and to ensure a general weldability in the first place under the given experimental conditions. Due to the good results that have been achieved based on using adhesive fixation with the sheet combinations of 0.5 mm + 1.5 mm, it is quite conceivable that even metal thicknesses that are less than 0.5 mm can be welded using friction stir welding process. As was demonstrated at the end of the investigation the possibility of easily friction stir welding an angle plate, other three-dimensional structures can be fixed quickly and easily solely using adhesive without the need for complicated and expensive fixtures. The possibility of joining very thin aluminium sheets as well as the possibility of simply fixing complicated and three-dimensional structure for welding, open up new scopes and potentials for the applications of friction stirs welding process.

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REFERENCES

[1] S. Sattari, H. Bisadi, M. Sajed, Mechanical Properties and Temperature Distributions of Thin Friction Stir Welded Sheets of AA5083, Internat. J. of Mechanics and Applications 2012, 2(1): 1-6.

[2] RWTH Aachen, Method for material bonding by means of friction welding using an adhesive, patent application, WO 2010/130271 A1.

[3] Kinloch, A. J. Adhesion and adhesives, 1987 (Chapman and Hall, London).

[4] I.. Krieger, and L-H. Lee, Lieng-Huang (Eds.), “Flow Properties of Adhesives”, Adhesive Bonding, Plenum Publishing, 1991, pp. 31-45.

[5] Habenicht, G.: Kleben – erfolgreich und fehlerfrei. 5. Aufl. Wiesbaden: Vieweg + Teubner, 2008, pp. 50-52.

[6] H Schmidt, J Hattel and J Wert, 2004, An analytical model for the heat generation in friction stir welding, Modelling Simul. Mater. Sci. Eng. 12, 143–157.