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Research Paper

FRICTION STIR WELDING OF DISSIMILAR MATERIALS/ALLOYS: A REVIEW

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The friction Stir Welding is a process involving plastic deformation of the materials to be joined. This process does not involve the melting of the materials to be joined. This thing makes this process suitable for joining the different materials having different mechanical and chemical properties and different material structure. This review mainly providesfeasibility about the suitability of the FSW technique to join the various different materials/alloys.

Keywords: Friction Stir Welding, Plastic Deformation, Mechanical Properties, Alloys

INTRODUCTION

Combinations of soft alloys having the important applications in aerospace, automobile and shipbuilding industries. In all these applications it becomes necessary to get the higher performance of the welded joints. The main advantage of using dissimilar materials in welding structure is that, we can take the advantage of the properties of both the materials. Fiction Stir Welding can join easily the aluminum alloys and other materials which are soft than the tool used in the process because the tool which is hard than the materials to be joined, basically stir the material at the joint for producing heat by the friction and axial force make flow the material to weld. Hence the macroscopic melting of the material does not involve, the controls needed in fusion welding to avoid phenomena such as solidification and liquation cracking, porosity and loss of volatile solutes can be avoided. When we talking about the friction stir welding of the different materials, there are the numbers of factors which mainly influence on the welding and they are as follows:

i. The different deformation behaviors of the materials which are to be joined.

ii. Formation of detrimental intermettalic compounds.

iii. Differences in physical properties such as thermal conductivity.

iv. In two materials, which one should be at the advancing side and which one should be at the retreating side.

These factors can contribute to asymmetry in both heat generation and material flow,

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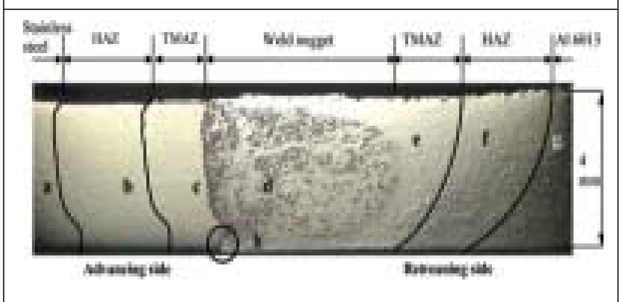
during Friction Stir Welding (Deb Roy and Bhadeshia, 2010). Hence these factors should be kept in mind before starting the welding. To deal with this the following review mainly provides the information about the joint configuration, mechanical properties, weld strength, joint efficiency etc. in joining of different materials/alloy by friction stir welding.

Kumbhar and Bhanumurthy (2012) carried out experiment in FSW to join aluminum alloys AA6061 and AA5052 at various combinations of tool rotation speeds and tool transverse speed. The transverse cross section of the weld was used for optical as well as electron microscopy observations. The microstructural studies were used to get an indication of the extent of material mixing both at the macro and micro scales. During experiments it was observed, that both materials exhibited similar texture despite the nonrigorous mixing of the materials in the nugget, at the interface region. Electron probe microanalysis was used to study the extent of interdiffusion of the alloying elements at the interface. Tensile testing of the specimen was also carried out which showed the good mechanical properties (Tensile properties of the friction stir welded AA5052-AA6061 were found better than the properties of the softest of the similar friction stir welded AA6061). It was seen that the interdiffusion of the alloying elements and development of similar orientations in the nugget could have contributed of the better tensile properties of the friction stir welded AA5052-AA6061 specimen.

Koilraj *et al.* (2012) studied friction stir welding of dissimilar aluminum alloys AA2219 to AA5083, on the basis of optimization of process parameters using Taguchi technique. In this FSW parameters were optimized w.r.t tensile strength of the joint and the optimum level of settings were found out. The optimum level of the rotational speed, transverse speed and D/d ratio (D-tool shoulder diameter, d-pin diameter) were 700rpm, 15mm/min and 3 respectively. The cylindrical threaded tool pin profile was found best among the other profiles. D/d ratio contributes 60% of the overall contribution. The joining of Al-Cu alloy AA2219-T87 and Al-Mg alloy AA5083H321 plate was also carried out by them using FSW technique.

Huseyin Uzun *et al.* (2005) joined dissimilar Al 6031-T4 alloy and X5CrNi18-10 stainless steel by using FSW. Microstructures, hardness and fatigue properties were investigated. Optical microscopy was used to characterize the microstructure of weld nugget, the HAZ, TMAZ and base material. Seven different zones of the microstructure in the welding were reported as follows: (1) parent stainless steel, (2) HAZ in the stainless steel at advancing side of weld, (3) TMAZ in the stainless steel at advancing side of weld, (4) weld nugget, (5) TMAZ in the Al alloy at retreating side of weld, (6) HAZ in the Al alloy at retreating side of weld and (7) parent Al alloy shown in Figure 1. A good correlation between the hardness

Figure 1: Macroscopic Overview of the Cross-Section of the Friction Stir Welded Al 6013-T4 Alloy to X5CrNi18-10 Stainless Steel



distribution and the welding zones were observed. Fatigue properties of Al 6013-T4/ X5CrNi18-10 stainless stel joints were found to be approximately 30% lower than that of Al 6013-T4 base metal.

Esther T Akinlabi *et al.* (2012) conducted statistical analysis on the weld data obtained from friction stir welding of aluminum and copper. The welds were produced by varying the process parameters, the rotational speed was varied between 600 to 1200 rpm and the welding speed varied between 50 and 300 mm/min. The Statistica (version 9.0) statistical analysis software package was used to generate the scatter and surface plots relative to the experimental results obtained from the tensile testing and the FSW data. Regression analysis was also done on the weld data. It was found that the downward vertical force has a significant effect on the Ultimate Tensile Strength of the weld and a strong relationship exist between the heat input into the welds and the measured electrical resistivity of the welds.

Firouzdor and Kou (2009) were investigated the effect of positions of Al and Mg with respect to the welding tool in friction stir welding of Al to Mg. It was found that the heat input and joint strength can be significantly affected by the positions of Al and Mg relative to the tool, and lap joint welding can be modified to double the joint strength. In this study 6061Al and AZ31Mg, the two most widely used Al and Mg alloys were selected.

Muhamad Tehyo *et al.* (2011) was investigated Friction stir welding of dissimilar joint between semi-solid metal SSM356 and AA 6061-T651 by computerized numerical control machine. Study was done under two different tool rotation speeds (1750 and 2000 rpm) and six welding speeds (20, 50, 80, 120, 160, and 200 mm/min). During study mainly it was found that, an increase in the welding speed appeared to lead to an increase in the tensile strength of the specimen. In fact, the tensile strength approached a maximum value close to the lesser of the parent base materials then decreased with increasing welding speed on the dissimilar friction stir welded specimens. Thus,neither a too low welding speed (below 80 mm/ min) nor a too high welding speed (beyond 80 mm/min) is desirable.

Masayuki Aonuma and Kazuhiro Nakata (2012) joined ZK60 magnesium alloy and titanium by friction stir welding. In this study the effect of alloying elements on the microstructure of the joint was examined. A commercial ZK60(Mg-Zn-Zr alloy) and titanium plates with 2 mm in thickness was butt joined by inserting the probe into the ZK60 plate and slightly offset into the titanium plate to ensure the direct contact between them. It was found that Zn and Zr of alloying elements of Mg-Zn-Zr alloy improved the tensile strength of titanium and magnesium joints by forming the thin reaction layer at the joint interface.

A. Scialpi *et al.* (2008) did mechanical analysis of ultra-thin friction stir welding joined sheets with dissimilar and similar materials. In this investigation, thin aluminum alloy 2024-T3 and 6082-T6 sheets, 0.8 mm thick welded in the rolling direction by µFSW (Friction Stir Welding for ultra thin sheets). Both similar and dissimilar joints was successfully produced and analyzed, and found that, these joints show excellent mechanical properties.

Hatsukade *et al*. (2007) developed an SQUIA-NDI technique for evaluation of friction stir welding between aluminum alloy A6063 and stainless steel SUS304 from the electric conductivities in board specimens bonded by FSW. HTS-SQUID gradiometer and current injection method was used to evaluate FSW between Al alloy and SUS. Locally changed currents in the FSW areas with different FSW conditions were measured and it was suggested that the conductivities in FSW areas are dramatically varied due to temperature heated by the friction between the tool and materials. The estimated change in the conductivities of FSW may be use to evaluate the presence of defect or deviated quality of friction stir welding from normal to standard specimen.

Saad Ahmed Khodir and Toshiya Shibayanagi (2008) focused their study on the microstructure and mechanical properties of dissimilar joints of 2024-T3 Al alloy to 7075-T6 Al alloy produced by friction stir welding. During the study, effects of welding speed and fixed location of base metals on microstructures, hardness distributions and tensile properties of welded joints were investigated.SEM-EDS analysis revealed that the stir zone contains a mixed structure and onion ring pattern with a periodic change of grain size as well as a heterogeneous distribution of alloying elements. Maximum tensile strength of the joint was achieved 423 MPa at the welding speed of 1.7mm/s when 2024 Al alloy plate was located on the advancing side.

Amancio-Filho *et al.* (2008) done preliminary study on the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminum alloys 2024-T351 and 6056-T4. In this, butt joints were obtained by varying process parameters, mainly the rotational speed (500-1200rpm) and the welding speed (150-400mm/min), while axial force and tool geometry kept constant. On the basis of macrographic analysis and microhardness testing, it was found that, sound joints can be obtained in the parameters range of rotational speed 800 rpm and welding speed 150 mm/min.

Duo Liu *et al.* (2011) investigated the microstructure and mechanical properties of friction stir weld joints of dissimilar Mg alloys AZ31 and AZ80. Different parameters were adopted and the effects of rotation speed and welding speed on the joint quality were discussed. It was found that the material with inferior plastic deformability (AZ80) should be set at the advancing side and the material with superior deformability (AZ31) should be set at the retreating side to get sound FSW joint of dissimilar Mg alloys.

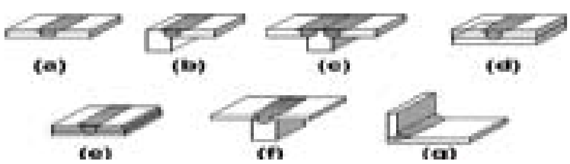
Cavaliere *et al.* (2006) studied mechanical and microstructural properties of dissimilar 2024 and 7075 aluminum sheets joined by friction stir welding. The two sheets, aligned with perpendicular rolling directions, have been successfully welded and the tensile testing was done at the room temperature in order to analyse the mechanical properties with respect to the parent material.

Elatharasan and Senthil Kumar (2012) were found the optimum range of process parameters for high quality FSW joints of dissimilar AA6061-T6 and AA7075-T6 by using RSM (Response Surface Methodology) technique. Optimum ultimate tensile strength, yield strength and displacement of dissimilar friction stir welded joints at 95% confidence level were found.

Moreira *et al.* (2009) was carried out a mechanical and metallurgical characterization of friction stir welded butt joints of aluminum alloy 6061-T6 with 6082-T6. Similar material butt joints were also made for the comparison with the dissimilar material butt joints, produced by FSW. Microstructure examination, microhardness, tensile and bending tests of joints were carried out. It was found that friction stir welded AA6082-T6 reveled lower yield and ultimate stress while the dissimilar joints showed intermediate properties. The dissimilar joints also displayed the intermediate properties in tensile tests. And in hardness profile the lowest values were obtained in the AA6082-T6 alloy plate side, where rupture occurred and in the nugget all type of joints present similar values.

Bo Li and YifuShen (2012) did a feasibility research on friction stir welding of a new typed lap-butt joint of dissimilar aluminum alloys as shown in Figure 2.

Figure 2: Joint Configurations for FSW: (a) Square Butt, (b) Square Butt, (c) Edge Butt, (d) T Butt Joint, (e) Multiple Lap Joint, (f) T Lap joint and (g) Fillet Joint



Aluminum alloys AA6063 and AA5052 were used. The lap-butt joint was successfully welded through the friction stir welding technique, using the designed tool of W93Cr4V with some geometric improvements. After the welding process parameters optimization experiments, the optimum work conditions and a process map were obtained.

Hansur Bang *et al.* (2012) studied Gas tungsten arc welding assisted hybrid friction stir welding (HFSW) of dissimilar materials Al6061-T6 aluminum alloy and STS304 stainless steel. The successful joint was achieved without any defect at the rotation speed 300 rpm by using a preheating GTAW heat source. Transverse tensile strength of approximately 93% of the aluminum alloy (Al6061) base metal tensile strength of FSW welds. HFSW that integrates GTAW preheating found advantageous to join dissimilar material as compared to conventional FSW.

Takehiko Watanabe *et al* (2006) obtained easily and successfully butt weld of an aluminum alloy plate to a steel plate by friction stir welding. The maximum tensile strength of the joint was about 86% of that of the aluminum alloybase material.

Fazel- Najafabadi *et al.* (2011) joined 304 stainless steel plate to CP-Ti (commercially pure titanium) by double shoulder tool employing friction stir welding technique. Sound lap joints were achieved using an advancing speed of 50 mm/min and rotation speeds in the range of 700-1100 rpm.

Chen and Nakata (2009) made lap joint of Al-Si alloy and pure titanium by friction stir welding. Microstructure and tensile properties of the joints were examined and it was found that the maximum failure load of joints reached 62% of Al-Si alloy base metal with the joints fractured at the interface.

JiahuDuyang *et al.* (2006) concentrated research on the temperature distribution and microstructural evaluation of friction stir welding of 6061 aluminum alloy (T6-temper condition) to copper and fount various results in regard of the better joint performance.

Ghosh *et al.* (2010) welded A356 and 6061 aluminum alloys by friction stir welding under tool rotation speed of 1000-1400 rpm and transversing speed of 80-240 mm/min keeping other parameters same. In the investigation it was found that the joint fabricated using lowest tool transversing and rotational speed, exhibits superior mechanical properties with respect to other.

On the basis of review present above, we can come through that, there is always present a possibility to join the different materials/alloys by friction stir welding. For the best joint results we have to concentrate our knowledge on the selection of appropriate welding parameters. DebRoy and Bhadeshia (2010) also has provided a review of friction stir welding of dissimilar alloys, in which they have resulted that a wide range of alloy systems including dissimilar aluminum alloys, aluminum/ magnesium and aluminum alloy/steel pairs can be welded with the help of friction stir welding.

CONCLUSION

This study is an attempt to show that, there is always present a feasibility to join the different materials/alloys with the help of friction stir welding. A number of papers are available on this issue which has cover all the points like joint configurations, microstructure investigations, mechanical properties, process parameters etc in regard of welding of dissimilar materials/alloys.

SCOPE OF FUTURE WORK

We have seen that, we can join dissimilar materials/alloys by FSW. But there is always present a need in everything to become more suitable and reliable in use. In this regard we can say that, we have to find more suitable tactics to join different materials/alloys economically by FSW, as we can get the best joint with good strength. Utilization of FSW and its scope of study and research of joining different materials/alloys should be increased in future because of the following points:

- Application of special coating materials or powder to get the high strength welds.
- To get the joint having good strength to weight ratio.
- To get the light weight structures used in aerospace and automobile applications.
- To join of aluminum to steel reliably and cost effectively.
- To join aluminum alloys and aluminum metal matrix composites.
- Selection of tool material and design of tool for the welding.

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