International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Enhancements in mechanical properties of dissimilar materials using friction stir welding (FSW) - A review

R.S Mishra, Shivani Jha

Department of Mechanical Engineering, Delhi Technological University Delhi, India

Abstract

The various light weighted material which reduces the overall weight of a component, increases the mechanical properties like tensile strength, hardness, fatigue strength etc. plays a important role in the emerging world of technology. New developments in friction stir welding contributes to the major acceptance in the research field. Among the various metals, the research is focused on the aluminum metal matrix composite which replaces the conventional welding of iron and steel. Moreover, the joining of dissimilar metals aluminum and other alloys is a need of the physical world. In the present paper the main emphasis is on the enhancement of mechanical properties in the FSW of the dissimilar aluminum joints.

Keywords: Mechanical Properties Enhancement, FSW, Dissimilar metals, Green Technology

1. Introduction

To meet the ever demanding requirement of industry in joining of various materials welding technology now a day comes into rescue to resolves the demand. As when compared to other joining techniques such as adhesive and mechanical fasteners welding again comes on top. The basic requirement of any joint is to achieve satisfactory physical, mechanical and tribological properties which are ideally superior to the base materials. Development regarding improvement in joint quality has been addressed worldwide by various researchers [1]. Although, various welding technique leads to formation of defects such as cracks, voids, and inter-metallic compounds in the joints. Thus, a better welding process needs to be employed so as to decrease or eliminate these persisting problems by employing joining technique which is either in a solid state or it is in a semi solid state. Friction stir welding (FSW) is one of such contemporary solid state joining process which makes a high strength joint by transforming the metal into a plastic state at a certain temperature necessarily below the melting point, and then under high forging pressure the mechanically stirs of two metals form a high-strength welded joint [2–5]. However, keeping in mind the recent industrial requirement of light weight metals or composites there are still many challenges that has to be addressed for joining of such metals or composites.

1.1 Aluminum alloys

Many aluminum alloys are strong by virtue of precipitation hardening through natural or artificial ageing from the solution–treated condition. The heat associated with welding changes the microstructure of the material. The effect of welding is to cause a drop in hardness from HV_{max} towards HV_{min} as the peak temperature experienced increases. This is because precipitates will coarsen and reduce in number density in regions remote from the heat source, and will re–enter solution when the peak temperature is sufficiently high. Some re–precipitation may occur during the cooling part of the thermal cycle, resulting in a hardness value beyond HV. The ultimate result is the continuous line with a minimum in hardness somewhere in the heat–affected zone, due to the competing effects of dissolution and re–precipitation. But in contrast to age hardenable AA 6082, where a minimum hardness occurs in the HAZ, FSW of non-hardenable AA 5082 results in uniform hardness across the weld. This general scenario may be complicated by the effects of deformation in FSW as described for the specific example of AA 2219. AA 2219 is a copper precipitation–strengthened alloy containing about 6.3 wt% Cu, which because of its strength and

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
https://doi.org/10.36037/IJREI.2020.4306

toughness at low temperatures, is used for containing liquified gases for rockets of various kinds. It is frequently supplied in the T87 condition, meaning that it has been solution treated, cold–worked (10% reduction in rolling) and artificially aged. It can be welded using arc processes but this results in a reduction in the cross–weld strength because the proof strength of the fusion zone decreases to about 140 MPa compared with the 370 MPa of the plate. The former can be increased to between 220–275 MP a using pulsed or pulsed electron beam welding techniques because this promotes finer grains in the fusion zone . Friction stir welding does not seem to have an advantage over arc welding with respect to the strength of the fusion zone. It was observed that that the TMAZ is somewhat softer than the fusion zone because the latter dynamically recrystallizes into a fine grain structure. It is the coarsening of the Al_2Cu precipitates in the TMAZ that is partly responsible for its softening. Some transmission electron micrographs across the weld; these show clearly the huge changes due to the heat from the process. The formation of coarse precipitates at the grain boundaries, and their associated precipitate–free zones, are common detrimental features in the microstructure. Aluminum being one of the light weight material which is most commonly used in industry needs severe attention as welding of dissimilar aluminum alloys is difficult. Fusion processes of such material can result in significant loss of strength in the joint due to the intense heat generation because of thermally activated softening mechanisms. Dissimilarity in welding can be viewed in various aspects and can be categorized accordingly such as similar base metals but different thicknesses or shape, welding of similar metals with different alloy compositions, welding of dissimilar metals with some compatibility on the phase diagram as in the case of aluminium and copper, welding of incompatible dissimilar metals, such as between magnesium and steel, welding of metal and ceramic which are considered to form metallic bonds between each other. Keeping in mind the need of energy efficiency, environmental friendliness, and versatile technology for joining of dissimilar metals FSW is considered to be the most significant development in recent decades. This process offers a number of advantages over conventional joining processes. The few of them includes (a) absence of expensive consumables such as a cover gas or flux; (b) ease of automation of the machinery involved; (c) low distortion of the work-piece; and (d) good mechanical properties of the resultant joint [12].The fact that FSW welds in precipitation hardened alloys lead to a weak zone is not surprising given that the majority of strengthening in most strong alloys comes from precipitates. There is some evidence that manipulation of pin profiles and FSW parameters may help improve slightly, the hardness in the central region or indeed, in the HAZ . Theoretical work has also been done to see if cryogenic cooling after the tool pass can help retain alloying elements in solution after the peak temperature is experienced, so that the alloy can then naturally age and not develop the coarsened microstructures typical of slow cooling from the peak temperature. However, computations indicate that the advantage in so doing is likely to be minimal. It was observed that the grain size increases with increase in peak temperature caused by increase in rotational speed. Here grain size is related to peak temperature by assuming static grain-growth of dynamically recrystallized grains, during the cooling of the thermal cycle .The precipitate free zones form near the grain boundaries because grain boundaries act as sinks for nearby dislocations, reducing nucleation sites for precipitates and also as precipitation sites, effectively reducing the solute content around them. As grain size increase, assuming constant width of PFZs, their volume fraction decreases with increase peak temperature .Not all alloys of aluminum are precipitation hardened. In the 2000 series alloys, the strength depends more on grain size (d), which has been expressed in terms of the Zener-Holloman parameter

$$\log d = a + b \log Z$$

Where a and b are empirical constants based on data from extrusion experiments and the hardness is then related to d using a form typical of the Hall–Petch type equation:
$HV = HV_0 + c/\sqrt{d}$ where c is a constant . In the cast Al–Si alloys, friction stir welding breaks up the large silicon particles in the nugget and the TMAZ, Fig. 26; as a consequence, the fracture is located in the base plate during cross-weld tensile tests because in this case, it is the coarse silicon particles which control failure. FSW can also heal casting defects such as porosity. Corrosion studies indicate that the weld zones produced by friction stir welding have comparable environmentally assisted cracking susceptibility as the unaffected parent.

1.2 Magnesium alloys

Magnesium alloys, normally produced by casting, may find significant applications in the automotive and aerospace industries with rapid growth particularly in die–cast vehicle components because of their better mass–equivalent properties. They are used for light–weight parts which operate at high speeds. The motivation for using FSW for magnesium alloys is that arc welding results in large volumes of non–toxic fumes. On the other hand, solid-state FSW does not result in solute loss by evaporation or segregation during solidification, resulting in homogeneous distribution of solutes in the weld.
Also, many magnesium alloys in the cast condition contain porosity which can be healed during FSW. The hardness and strength can be retained after friction stir welding. There is no significant precipitation hardening in the alloy studied (AZ31, ≃Mg–3Al–1Zn wt% wrought) and the net variation in hardness over the entire joint was within the range 45–65 HV, with the lower value corresponding to the base plate. In the same system, a higher starting hardness of70 HV leads to a substantially lower hardness in the nugget (50–60 HV); the variations in hardness appear to be consistent with measured variations in grain size in accordance with the form of the Hall–Petch relationship . The grains in both the nugget and TMAZ tend to be in a recrystallized form, and tend to be finer when the net heat input is smaller (for example at higher welding speeds). In Mg–Zr alloys with Zr–containing particles, FSW leads to a considerable refinement of the grain structure and sound welds can be produced in thin sheets over a wide range of welding conditions for sheets thicker than about 3 mm, the welds contained defects associated with an inability to supply sufficient heat during welding. There are, however, contradictory results showing

successful welds in 6 mm thick Mg–Zn–Y–Zr plates so it is unlikely that these results are generic to magnesium alloys.

1.3 Copper alloys

Copper which has much higher thermal diffusivity than steel cannot easily be welded by conventional fusion welding techniques. Heat input required for copper is much higher than conventional. FSW because of the greater dissipation of heat through the work–piece. Recently, FSW has been successfully used to weld 50 mm thick copper canisters for containment of nuclear waste. FSW in copper alloys have all the typical zones found in other materials: the nugget, TMAZ, HAZ and base structure. The nugget has equiaxed recrystallised small grains and its hardness may be higher or lower than than the base material depending on the grain-size of the base metal. When 4 mm thick copper plates with average grain size of 210 μm were welded at high rpm (1250) and low welding speed (1.01 mm/s), nugget had lower hardness (60–90 HV), compared to base metal.(105–110 HV). Even though grain size decreased from 210 to 100 μm, hardness decreased slightly due to reduction in dislocation density relative to base metal. Similar decrease in dislocation density in the nugget zone compared to parent metal has been observed for AA 7075 and AA 6061.

On the other hand, when 2 mm thick copper plates with average grain size of 30 μm were welded at 1000 rpm and 0.5 mm/s low welding speed, nugget (128–136 HV) was harder than the base metal (106–111 HV) due to reduction in average grain size to 11 μm . Flores et al. have also shown that as-cast AA 7073 showed that weld nugget was harder than base metal while the 50 % cold-rolled alloy showed reduced hardness in the nugget.

1.4 Titanium alloys

By far the most dominant of titanium alloys is Ti–6Al–4V, which in its commercial condition has a mixed microstructure consisting of hexagonal–close packed α and body–centred cubic β phases, which is the stable phase at high temperatures. This alloy, which accounts for about half of all the titanium that is produced, is popular because of its strength (1100 MPa), creep resistance at 300◦C, fatigue resistance and cutability. Friction stir welding must clearly disrupt the base microstructure both through the thermal and deformation components of the process, but the consequences of this on performance during fabrication and service need investigation. General investigations on fatigue performance indicate that the crack growth rate in the HAZ can be higher or lower than the base material depending on specimen geometry, microstructure and residual stress levels. Several Experiments have also been conducted by several investigators, on a fully β–titanium alloy in thin sheet form, primarily to prove that the crystallographic texture observed corresponds to one generated by shear deformation, consistent with similar observations in aluminium alloys. Pure titanium in its hexagonal close–packed α–form is interesting because there is also a tendency for deformation by mechanical twinning during friction stir welding. The nugget region of an FSW joint is found to contain a large density of dislocations and mechanical twins, with transmission microscopy showing an elongated fine–structure, but the overall grain shape seem to remain equiaxed on the scale of optical microscopy. It is speculated that recrystallisation must have occurred during welding but was followed by a small amount of plastic deformation. The HAZ simply revealed grain growth, a consequential lower hardness, and hence was the location of fracture in cross–weld tests. There was no clearly defined TMAZ as is typical in aluminium FS–welds.

1.5 Steels

The friction–stir welding of steels has not progressed as rapidly as for aluminium for important reasons. First, the material from which the tool is made has to survive much more strenuous conditions because of the strength of steel. Second, there are also numerous ways in which steel can be satisfactorily and reliably welded.

Third, the consequences of phase transformations accompanying FSW have not been studied in sufficient depth. Finally, the variety of steels available is much larger than for any other alloy system, requiring considerable experiments to optimize the weld for a required set of properties. Early optimism that FSW will become a commercially attractive method for the fabrication of ships, pipes, trucks, railway wagons and hot plate has not yet come to fruition.

That the application of FSW to steels is premature is emphasized by the fact that with few exceptions, only elementary mechanical properties have been characterized; most reports are limited to simple bend, tensile and hardness tests. For serious structural applications of the type proposed above it would be necessary to assess fracture toughness and other complex properties in greater depth. There are indications that elongation suffers following FSW. A typical temperature profile behind a friction–stir weld on steel. The maximum temperature reached is less than 1200ºC and the time _t8−5 taken to cool over the range 800–500◦C is about 11 sec .Therefore, the metallurgical transformations expected on the basis of cooling rates alone are not expected to be remarkably different from ordinary welds.

Various researches show that the yield and ultimate tensile strengths has been improved up to 100% as compared to the base parent metal of the joints. In the FSW, the materials do not go into molten state and then it does not solidify. This is why aluminum which is practically difficult to be welded using fusion joining techniques is weldable in this case. Also, the joint achieved in FSW of such aluminum metal are defect free [2, 5, 6–10]. FSW not only finds its application in case of soft materials but it can be employed in variety of harder and dissimilar materials. A vast majority of research has been carried out of material ranging from low to intermediate melting points, i.e. Mg-alloys and Cu-alloys and its process efficiency has been determined. Furthermore, tests have also been done on high strength structural materials with high melting points, i.e. Fe, Ti and Ni alloys, dissimilar alloys, metal matrix composites, polymers, etc. [11-13]. Metal matrix composites (MMCs) due to their excellent mechanical, physical and tribological properties are of great interest in recent decades. They possess characteristics such as lightweight, high strength, high stiffness, wear resistance, and creep resistance, high electrical and thermal conductivity [7]. Friction stir welding offers ease of handling, precise external process control and high levels of repeatability thus creating very homogeneous welds. FSW need not any preparation of the sample and pollution created during the welding process is also very less.

Sahlot et al.[14] investigated the dissimilar lap joint of CuCrZr alloy and 316L stainless steel using friction stir welding. The thickness of the CuCrZr alloy is 6mm and 316L stainless steel is 3mm.Along the weld cross section, the higher load bearing ability was achieved throughout the joint due to the strong mechanical interlocking feature as well as indicating the good mechanical bonding between Cu and Fe. As the formation of pronounced hooking occurs at the Cu/ steel alloy interface, the mechanical interlocking property can be enhanced. To enhance the weld strength, the FSW parameters such as improving material flow, heat transfer, traverse speed, rotation speed and tool geometry can be optimized.

Moradi et al [15] examined the texture evolution and microstructure of friction stir welded dissimilar AA2024 and AA6061 alloys. The AA2024 were adjusted on advancing side as well as AA6061 on the retreating side on the bed of the machine. The thickness of both the sheets are 6mm. The fine equiaxed grain structure is observed in the stirred zone on the retreating and the advancing sides both in contingency of the static as well as dynamic recrystallisation. Due to the difference of the temperature on the retreating side and advancing side and initial size of precipitates, the higher volume of fraction of precipitates appears on the retreating side in the stirred zone. On the advancing side, there is less overall texture intensity on the contrary the texture intensity is increased on the retreating side stack up against with initial sheets. The initial elements completely eliminated on the both sides. Moreover, some strong shear textures observed owing to severe shear deformation during the FSW.

Infante et al.[16] studied the fatigue behaviour of dissimilar joints using FSW. The investigation is performed within Lightrain project and the objective is to improve the life cycle value of the passenger railway car. In the study, the two samples are taken. First is AA6082-T6 and AA5754-H111, and AA6082-T6 the thickness of the alloys is same i.e. 2 mm. The Lap joint specimens is tested on a constant amplitude loading in accordance with a stress ratio R=0.1. The tested specimen of fatigue analysis results in the comprehensive metallographic characterization of the welded zone. Moreover, the fatigue test results also show the hardness distribution at the welded zone. The base metal AA5754 and AA6082 have the higher fatigue strength than the similar and dissimilar joints as there is a hook defect in the weld joint. Improvement in fatigue performance is observed at lower applies stress ranges, the fatigue performance results in the dissimilar AA6082 and AA5754 FSW weld specimens shows a shallower S-n curve as compared with the AA6082-AA6082 FSW weld specimens .

Zandsalami et al. [17] analyzed the mechanical properties of the dissimilar 6061 aluminum alloy and 430 stainless steel. The thickness of the base metals taken as 5mm. The microstructure of the joints is examined by the Energy dispersive X-ray, Scanning electron microscopes and optical microscopy. Moreover, mechanical properties is evaluated by tensile and microhardness test. The best microstructure is obtained at a rotational speed of 900 r/min, tool offset of zero and a traverse speed of 120 mm/min. The most significant factor is tool offset in accordance with the weld quality. A composite structure has been shown in the stir zone of the weld joint which consist of the dispatched steel particles presented in aluminium.

The best joint quality is obtained at an offset of zero, includes the serrated nature as well as the mechanical locking of the dissimilar weld joint. At the values above and below the zero offsets, the formation of weld defects such as voids and microcracks decreased the tensile strength of the weld joint.

Ahmed et al. [18] investigated the similar and dissimilar friction stir welding of AA7075 and AA5083. The type of joint is the butt joint. The friction stir welding is done at a rotational speed of 300 rpm and several traverse welding speed of 50, 100, 150 and 200 mm/min. With the use of electron backscattered technique, the crystallographic textures and microstructures are observed. The tensile and microhardness test is done to examine the mechanical properties. As the welding speed increases from 50 mm/min to 200 mm/min, results into a reduced grain from 6μm to 2μm size of similar AA7075 as well as in case of AA5083 from 9μm to 3μm. In case of dissimilar welding, there is no significant with the average grain size of 4μm in the two cases of welding speed of 50mm/min and 200 mm/min. In the Nugget zone, the crystallographic texture reflects simple shear texture irrespective of the effect of the welding speed in similar and dissimilar weld joints. In the similar weld joints, the hardness profile reflects the typical behaviour with the reduction in hardness in nugget zone of AA7075. In the nugget joint of similar AA5083 weld joints, there is a increase in the hardness number. In the dissimilar weld joint, it is observed that there is a smooth transition in the hardness among the two hardness alloys. The experiments showed that the ultimate tensile strength examined the values in between the 245MPa and 267 MPa with efficiency of joint ranges from 77% and 87% in accordance with the strength AA5083BM. The dissimilar weld joint shows a brittle and ductile fractographic features such as grain boundary cleavage, facets decohesion and dimples.

Mehta et al. [19] analyzed the conventional and cool assisted FSW of AA6061 and AZ31B alloys. The thickness of 6mm is used for the base materials. This process of welding joint is analyzed by visual inspection, scanning electron micrographs, optical macro plus microscopy, energy dispersive X-ray spectroscopy, X-ray diffractions, microhardness indentation and tensile testing. In the nugget zone, it is observed the presence of onion rings comprises of various phases as Mg in an aluminum matrix and Al in Mg matrix. Moreover, there are intermetallic compounds such as $Al_{l3}Mg_2$ and $Al_{12}Mg_{17.}$ A diffusion layer has been observed on the aluminum side. Moreover, there is no presence of diffusion layer on the Mg side. The tensile strength is improved by cool assisted welding process as there is decrement in the intermetallic compounds along the weld bead. There is a highest hardness peak are analyzed in the nugget zone when the welding is done by conventional method.

Celik and Cakir [20] investigated the mechanical and microstructural properties of Al-Cu butt joint by the friction stir welding. The parameters are taken at different tool traverse speed (20, 30, 50 mm/min) and tool rotational speed ranging from 630 rpm, 1330 rpm and 2440 rpm with four various tool position (0, 1, 1.5, 2 mm). The microstructure are observed by the optical microscope and SEM with EDS. X-Ray diffraction is to determine the intermetallic phases that is presented in weld zone. Along the side of Fine Cu particles, high tensile strength is observed.

Husain Mehdi et al. [21-24], investigated the effect of friction stir processing on TIG-welded joints with different fillers were used to improve the mechanical properties of TIG-welded joints, the FSP tool pin rotates on an already welded joint by TIG welding to lower the welding load and improve the weld quality by adjusting the processing parameters of friction stir processing. After analyzing the mechanical properties of TIG + FSP-welded joint, computational fluid dynamics-based numerical model was developed to predict the temperature distribution and material flow during TIG + FSP of dissimilar aluminum alloys AA6061 and AA7075 by ANSYS fluent software.

Ghaffarpour et al. [25] investigated the microstructure and mechanical properties of dissimilar aluminum sheets I.e. 5083-H12 and 6061-T6 welded by friction stir welding. The optimization of FSW parameters by DOE and RSM techniques. A very little difference is observed between the measured and predicted strength of the components. Dissimilar weld joint alloys 5083-H12 and 6061-T6 has the lower hardness than that of both BMs of material in the stir zone. In case of dissimilar alloys, HAZ shows the lower hardness in comparison with other zones of welding. The HAZ of AA6061-T6 is observed with minimum hardness. The outcomes of tensile test as well as hardness test are same with results of LDH tests. By enhancing the rotational speed results in decrement in hardness in stir zone.

Rec et al [26] analyzed the effect of process parameters upon the mechanical properties and microstructures of dissimilar weldments AA7075-T651 and AA5083-H111 alloys. The various parameters (tool pin design, tool rotational speed and configuration of joined alloys) are taken. According to the study, there is influence of alloy placement and tool rotational speed on the formation of weld. In accordance with the configuration, the AA5083-H111 alloy is on the advancing side and the AA7075-T651 is on the retreating side. Moreover, higher mixing of both materials is obtained at high rotational speeds. Despite of this, more welding defects such as voids, porosity and wormholes were observed in the stir zone of the weld joint. There is increase in tool rotational speed results into the decrement of the mechanical properties irrespective of the configuration and pin design. The higher weld efficiency and tensile strength is achieved by the use of triflate pin. There is no effect of configuration on the mechanical properties. The best defect free weld is obtained when triflate pin with the configuration (AA5083 is on the advancing side and AA7075 is on the retreating side) with a tool rotational speed of 280 rpm.

Mehta et al [27] obtained the effect of tilt angle on the microstructural and mechanical properties of dissimilar FSW of as electrolytic tough pitch copper and aluminum 6061-T651.

In this experiment, the tool tilt angle ranges from 0° to 4° with the regular interval of 1°. Moreover, the various parameters such as welding speed, workpiece material position, tool pin offset and tool rotational speed are kept constant. The various examinations such as macrostructure analysis, scanning electron macroscopy, macro hardness test, tensile test and energy dispersive x-ray spectrographic test to investigate the weld joint properties. The results of various tests are show that the defect free weld at the tilt angles of 2°, 3°, 4°.The highest tensile strength and macro hardness is obtained at 4° in the nugget zone. At the copper side, thermo mechanically affected zone confirmed the weakest zone.

Ratnam et al [28] optimize to enhance the mechanical properties of dissimilar AA2024 and AA6061 alloys of 6mm by FSW. The chosen three levels are welding speed, tool rotational speed and tool tilt angle. The orthogonal array is taken as L27 and the results are obtained by Taguchi's ANOVA. For the tensile strength, the most significant factor is tool rotational speed and the least is welding speed. The best tensile strength is obtained at welding speed 11mm/min, tool rotational speed 1340 rpm and tool tilt angel of 2°. In accordance with the hardness, the most and least significant factor are tool rotational speed and welding speed respectively. At the welding speed of 11 mm/min, tool rotational speed of 2000 rpm and tool tilt angle of 3°, the optimum hardness is achieved. A defect free weld joint is achieved by twin-pin tool.

Husain Mehdi et al. [29-31], In tungsten inert gas welding (TIG), micro-cracks, porosity, coarse grain structure and high residual stress distribution were found due to persisting thermal conditions. The TIG welded joint is processed using friction stir processing with input process parameters to avoid these defects. The tensile test results shows that the hybrid TIG + FSP welded joint had higher tensile strength than TIG welded joint with filler ER4043, whereas the increment in the micro-hardness of TIG + FSP welded joint was observed. The grain size also decreases when tool pin rotates on TIG welding with different processing parameters. It was found that the maximum tensile stress, % elongation and micro-hardness at nugget zone for TIG + FSP welded joint.

Pourali et al [32] analyzed effect of welding parameters on the formation of intermetallic compounds in aluminum and steel FSW. Due to the major difference in steels and aluminum, there is formation of thick brittle intermetallic compounds at the weld joint. The dissimilar material thickness is taken as 2mm and Al1100 and St 37 low carbon steel were lap welded by FSW. The welding parameters were carried are rotational speeds (315 and 400 rpm) and welding speeds (50 and 63 mm/min). According to the EDS analysis, a thick layer of Fe-rich IMCs is obtained in weld joint interfaces up to 93µm as it does not show any effect on the joint strength .Moreover, welding defects such as voids results in the detrimental condition in the weld strength. Lower welding time as well as lower welding speed results in fine mechanical fixing and increase heat input is obtained with the high rotational speeds which confirms the good mechanical mixing and metallurgical bond. At the high rotational speed and lower welding speed, the tensile strength is optimized. At the welding speed of 50mm/min and tool rotational speed of 400 rpm results in the maximum shear tensile load is 1925 N. Among the all tensile specimens, the failure happens in the Al-side nugget zones.

Rogriduez et al [33] investigated the micro structural and mechanical properties of AA6061 and AA7050 aluminum alloys. Except the rotational speeds, the other parameters are kept constant. As the tool rotational speed was varied, the microstructure shows the presence of bands of mixed and unmixed elements that represents the extent of material mixing.

Increase in the tool rotational speed results in the enhancing the material intermixing as well as joint strength. From the scanning electron microscopy, it is evident that failure occurs in the stir zone at low tool rotational speed owing to improper material intermixing.

2. Conclusions

This paper contributes the review towards the recent research in friction stir welding of dissimilar welding for enhancing the mechanical properties of materials. The following conclusions were drawn:

- By increasing the welding speed, the mechanical properties such as tensile strength increases
- By increasing tool rotational speed the welding, the mechanical properties like tensile strength decreases.
- The best defect free weld is obtained when triflute pin with the configuration (AA5083 is on the advancing side and AA7075 is on the retreating side) with a tool rotational speed of 280 rpm.
- The results of various tests are show that the defect free weld at the tilt angles of 2°, 3°, 4°.The highest tensile strength and macro hardness is obtained at 4° in the nugget zone.
- The tensile strength is improved by cool assisted welding process as there is decrement in the inter-metallic compounds along the weld bead.
- The best microstructure and joint quality is achieved at tool offset zero. The defect such as voids, micro cracks arises which decreases the tensile strength of the weld joint.

References

[1] Shah, L. H., Othman, N. H., & Gerlich, A. (2018, April 3). Review of research progress on aluminum–magnesium dissimilar friction stir welding. Science and Technology of Welding and Joining. Taylor and Francis Ltd.

[2] Kumar, N., Yuan, W., & Mishra, R. S. R. S. (2015). Friction Stir Welding of Dissimilar Alloys and Materials. Friction Stir Welding of Dissimilar Alloys and Materials (pp. 1–126). Elsevier Inc.

[3] Jamshidi Aval, H. (2015). Microstructure and residual stress distributions in friction stir welding of dissimilar aluminum alloys. Materials and Design, 87, 405–413.

[4] Aydin, H., Bayram, A., Uğuz, A., & Akay, K. S. (2009). Tensile properties of friction stir welded joints of 2024 aluminum alloys in different heat-treated-state. Materials and Design, 30(6), 2211–2221.

[5] Wang, B., Lei, B. B., Zhu, J. X., Feng, Q., Wang, L., & Wu, D. (2015). EBSD study on microstructure and texture of friction stir welded AA5052-O and AA6061-T6 dissimilar joint. Materials and Design, 87, 593–599.

[6] Guo, J. F., Gougeon, P., & Chen, X. G. (2012). Characterization of welded joints produced by FSW in AA 1100-B 4C metal matrix composites. Science and Technology of Welding and Joining, 17(2), 85–91.

[7] Salih, O. S., Ou, H., Sun, W., & McCartney, D. G. (2015). A review of friction stir welding of aluminum matrix composites. Materials and Design, 86, 61–71.

[8] Venkateswarlu, D., Nageswara rao, P., Mahapatra, M. M., Harsha, S. P., & Mandal, N. R. (2015). Processing and Optimization of Dissimilar Friction Stir Welding of AA 2219 and AA 7039 Alloys. Journal of Materials Engineering and Performance, 24(12), 4809–4824.

[9] Hu, Z. L., Wang, X. S., & Yuan, S. J. (2012). Quantitative investigation of the tensile plastic deformation characteristic and microstructure for friction stir welded 2024 aluminum alloy. Materials Characterization, 73, 114–123.

[10] Guo, J., Gougeon, P., & Chen, X. G. (2012). Microstructure evolution and mechanical properties of dissimilar friction stir welded joints between AA1100-B 4C MMC and AA6063 alloy. Materials Science and Engineering A, 553, 149–156.

[11] Padhy, G. K., Wu, C. S., & Gao, S. (2015, November 1). Auxiliary energy assisted friction stir welding – Status review. Science and Technology of Welding and Joining. Maney Publishing.

[12] Dialami, N., Chiumenti, M., Cervera, M., & Agelet de Saracibar, C. (2017). Challenges in Thermo-mechanical Analysis of Friction Stir Welding Processes. Archives of Computational Methods in Engineering, 24(1), 189–225.

[13] Peel, M., Steuwer, A., Preuss, M., & Withers, P. J. (2003). Microstructure, mechanical properties and residual stresses as a function of welding speed in aluminum AA5083 friction stir welds. Acta Materialia, 51(16), 4791–4801

[14] Sahlot, P., Nene, S. S., Frank, M., Mishra, R. S., & Arora, A. (2018). Towards attaining dissimilar lap joint of CuCrZr alloy and 316L stainless steel using friction stir welding. Science and Technology of Welding and Joining, 23(8), 715–720.

[15] Moradi, M. M., Jamshidi Aval, H., Jamaati, R., Amirkhanlou, S., & Ji, S. (2018). Microstructure and texture evolution of friction stir welded dissimilar aluminum alloys: AA2024 and AA6061. Journal of Manufacturing Processes, 32, 1–10

[16] Infante, V., Braga, D. F. O., Duarte, F., Moreira, P. M. G., De Freitas, M., & De Castro, P. M. S. T. (2016). Study of the fatigue behaviour of dissimilar aluminum joints produced by friction stir welding. In International Journal of Fatigue (Vol. 82, pp. 310–316). Elsevier Ltd.

[17] Zandsalimi, S., Heidarzadeh, A., & Saeid, T. (2019). Dissimilar friction-stir welding of 430 stainless steel and 6061 aluminum alloy: Microstructure and mechanical properties of the joints. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 233(9), 1791–1801.

[18] Ahmed, M. M. Z., Ataya, S., El-Sayed Seleman, M. M., Ammar, H. R., & Ahmed, E. (2017). Friction stir welding of similar and dissimilar AA7075 and AA5083. Journal of Materials Processing Technology, 242, 77–91.

[19] Mehta, K. P., Carlone, P., Astarita, A., Scherillo, F., Rubino, F., & Vora, P. (2019). Conventional and cooling assisted friction stir welding of AA6061 and AZ31B alloys. Materials Science and Engineering A, 759, 252–261.

[20] Celik, S., & Cakir, R. (2016). Effect of friction stir welding parameters on the mechanical and microstructure properties of the Al-Cu butt joint. Metals, 6(6).

[21] Husain Mehdi, R.S. Mishra, Influence of Friction Stir Processing on Weld Temperature Distribution and Mechanical Properties of TIG-Welded Joint of AA6061 and AA7075. Transactions of the Indian Institute of Metals, (2020). https://doi.org/10.1007/s12666-020-01994-w.

[22] Husain Mehdi, R.S. Mishra, Effect of friction stir processing on mechanical properties and heat transfer of TIG welded joint of AA6061 and AA7075, Defense Technology (2020), https://doi.org/10.1016/j.dt.2020.04.014.

[23] Husain Mehdi, R.S. Mishra, Investigation of mechanical properties and heat transfer of welded joint of AA6061 and AA7075 using TIG+FSP welding approach, Journal of Advanced Joining Processes Volume 1, 2020, https://doi.org/10.1016/j.jajp.2020.100003.

[24] Husain Mehdi, R.S. Mishra (2019), Analysis of Material Flow and Heat Transfer in Reverse Dual Rotation Friction Stir Welding: A Review, International Journal of Steel Structure, vol-19, issue 2, pp 422-434.

[25] Ghaffarpour, M., Kolahgar, S., Dariani, B. M., & Dehghani, K. (2013). Evaluation of dissimilar welds of 5083-H12 and 6061-T6 produced by friction stir welding. Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science, 44(8), 3697–3707.

[26] Kalemba-Rec, I., Kopyściański, M., Miara, D., & Krasnowski, K. (2018). Effect of process parameters on mechanical properties of friction stir welded dissimilar 7075-T651 and 5083-H111 aluminum alloys. International Journal of Advanced Manufacturing Technology, 97(5–8), 2767–2779.

[27] Mehta, K. P., & Badheka, V. J. (2016). Effects of tilt angle on the properties of dissimilar friction stir welding copper to aluminum. Materials and Manufacturing Processes, 31(3), 255–263.

[28] Ratnam, C., Sudheer Kumar, B., & Sunil Ratna Kumar, K. (2018). Optimization of friction stir welding parameters to improve the mechanical properties of dissimilar AA2024 and AA6061 aluminium alloys. International Journal of Mechanical and Production Engineering Research and Development, 8(6), 937–944.

[29] Husain Mehdi, R.S Mishra (2016), Mechanical Properties and Microstructure Studies in Friction Stir Welding (FSW) Joints of Dissimilar Alloy A Review, Journal of Achievements of Materials and Manufacturing Engineering vol-77, issue 1, pp 31-40.

[30] Husain Mehdi, R.S.Mishra (2019), Study of the influence of friction stir processing on tungsten inert gas welding of different aluminum alloy, SN Applied Sciences, 1 (7) 712. https://doi.org/10.1007/s42452-019-0712-0.

[31] Husain Mehdi , R.S. Mishra (2020), Effect of Friction Stir Processing on Microstructure and Mechanical Properties of TIG Welded Joint of AA6061 and AA7075, Metallography, Microstructure, and Analysis (Springer), https://doi.org/10.1007/s13632-020-00640-7

[32] Pourali, M., Abdollah-zadeh, A., Saeid, T., & Kargar, F. (2017). Influence of welding parameters on intermetallic compounds formation in dissimilar steel/aluminum friction stir welds. Journal Of Alloys And Compounds, 715, 1-8.

[33] Rodriguez, R. I., Jordon, J. B., Allison, P. G., Rushing, T., & Garcia, L. (2015). Microstructure and mechanical properties of dissimilar friction stir welding of 6061-to-7050 aluminum alloys. Materials and Design, 83, 60–65.

Cite this article as: R.S. Mishra, Shivani Jha, Enhancements in mechanical properties of dissimilar materials using friction stir welding (FSW) - A review, International Journal of Research in Engineering and Innovation Vol-4, Issue-3 (2020), 154-160. *https://doi.org/10.36037/IJREI.2020.4306*.