A Review on Submerged Friction Stir Welding of Light Weight Alloys

M.Sucharitha\textsuperscript{1*}, B. Ravi Sankar\textsuperscript{2}, P.Umamaheswarrao\textsuperscript{2}

\textsuperscript{1}Department of Mechanical Engineering, BIHER, Chennai, 60073, Tamilnadu, India.

\textsuperscript{2} Department of Mechanical Engineering, Bapatla Engineering College, Bapatla,522101, AP, India

E-Mail: saisuchi2002@gmail.com

Abstract

Friction stir welding gained wide acceptance in many industries owing to its capability of joining lightweight materials, the subsequent development to Friction stir welding (FSW) was to submerge workpiece in liquids during welding termed as submerged friction stir welding (SFSW) resulted in improving mechanical properties. However, joint efficiency was much dependent on the process parameters. Hence, the present work aimed to consolidate the research works available in underwater friction stir welding (UFSW) primarily focusing on effect of process parameters on weld joint.

1. Introduction

Friction stir welding (FSW) is invented by The Welding Institute (TWI), U.K. in 1991 [1, 2]. It's a solid state welding process which leads welding without filler material. This welding is merely for light weight alloys where it is not possible to do the fusion welding and to regulate the welding temperatures [3]. The friction developed in between the tool and work piece thanks to rubbing, the surface on the metal get plasticized and therefore the bonding will happen. The applications found from FSW are automotives, aerospace and ship manufacturing [4-6]. From soft alloys to harder metals and for poly ethylene [7] sheets this SFSW produces good results than the friction stir welding and traditional welding. Utilization of SFSW leads to good welded grades and improves the mechanical properties. SFSW is one among the advanced technique to regulate the temperatures developed while welding and may avoid various welding defects like hot cracks, shrinkage etc. [8].
In SFSW, the rotating tool and base metal are immersed in a liquid medium, in order that when the friction is developing in between the tool and work piece the temperature will increase and thermal cycles were developed, it results the plastic deformation and may controlled by the surrounded cooling medium and maintain the temperature distribution throughout the length of the weld [9]. It produces different fine grain structures and improves the weld efficiency also mechanical properties.

2. Literature Review

H.J.Ilu et al. [10] has focused on homogeneity of 2219-T6 high strength aluminum alloy under water friction stir welded plates, divided into three layers and concluded that all the three layers had good tensile strength because of cooling effect on welding region for the soft material. Zhang et al. (2011) [11] evaluated the microstructure as the coarsening of the grains reduced compare than normal FSW because of controlling the thermal cycles by cooling effect, so that the precipitation is reduced in the weld region. When compared to normal FSW the heat distribution is narrowed at near the joint because the boiling temperature occurred at the thermal joint and the surrounding sides having less temperature. The heat flux is generated at the surface of joint, and then the mechanical properties will be improved [12]. Thermal cycles at the joint soften the surface of the material results the poor mechanical properties. The optimal welding parameters can control the temperature near the joint in under water friction stir welding [13]. As the speed increases the hardness will be increased due to the dislocation density and voids also increases with increasing the speed. To improve the tensile strength and grain structure the optimal welding parameters are required [14]. At stir zone and heat affected zone the material should not drag by pinhole because of low viscous flow of the material on the surface of the joint [15]. The size of the stir zone decreases as the tool rotational speed decreases [16].

Fratini et al. [17] concentrated on heat treatable aluminum alloys as 7075 to improve the FSW welded joints. Because of the external cooling medium the fracture area has been reduced in UFSW compared to air FSW by narrowing the thermal cycles at HAZ and TMAZ. They evaluated the microstructure as equiaxed grains have taken place by fracture determination at loci. Nelson et al. [18] observed that 7075 alloy is having more heat sensitivity compared to 2219 and low quench sensitivity. The ultimate tensile strength has lowered for reduced quench sensitivity materials in either hot or cold water medium. The mechanical properties are based on the temperature developed in FSW process and precipitation occurred on the surface of the joint. The cooling medium reduces the surrounding thermal flow and results the minimized fracture [19]. The nugget size decreases with increase in the welding speed [20].
Sabari et al. (2015) investigated and concluded that in normal FSW, the tool traverse speed vary from 25-40 mm/min and at the same conditions in UFSW the speed vary from 20-30 mm/min it results fault less joint because proper plasticization took place due to sufficient heat development and produced maximum tensile strength as well as efficiency improved one fourth of the normal FSW. The welded joint which is made at tool traverse speed of 30 mm/min has exhibited good performance, because of lower hardness [21]. When compared to normal FSW, in UFSW the size of the TMAZ and heat affected zone sizes had reduced because of cooling minimizes the size of the precipitates. So, the tensile strength was increased [22].

Kishta et al. (2014) Marine-grade 5083 aluminum alloy samples were friction stir welded in normal and submerged weld joints. The effects of different process parameters on the temperature void friction, and mechanical properties of the welded sample were investigated. Compared to air FSW, underwater FSW required higher rotational speed to produce high thermal capacity of water compared to submerging the sample in water also caused a reduction in the cooling rate. Compared to the parent material, the void area friction decreased significantly in the stirred material in the SFSW sample. The estimated void area fraction in the stir zone of the SFSW sample was almost one third of that in the parent material. The tensile strength of the underwater FSW sample was very close to that of the parent material. The elongation of the SFSW sample increased to approximately twice the elongation of the parent material [23].

Ratinasuriyan et al. (2017) performed investigation on SFSW and NFSW of 6061-T6 aluminum alloys. Results indicated that the position of the XRD peak shifts to a lower angle in SFSW compared to normal FSW. The value of SFS welds (water head of 20 mm) increasing by 12.88 % comparing to the NFSW due to the higher compressive force in the welded material during SFSW process. SFS welded sample at the water head of 20 mm exhibits higher micro hardness compared to the submerged FSW of water head 10 mm and normal FSW samples. This result is due to the increase in space lattice parameter values. Also, micro hardness value is directly proportional to the residual stress value.

The grain size of SFSW samples is smaller compared to the normal FSW samples and also the grain size is indirectly proportional to the lattice parameter and residual stress values. The significant variation is observed in displacing, lattice parameter and residual stress in SFSW as because of change in water medium leads to produce the higher cooling rate. In normal and submerged FSW, no significant variation is observed in d-spacing, lattice parameter and residual stress for a variation in rotational speed. The reason for this is that temperature variation is not much with respect to the various rotational speeds. Both the rotational speed and water head have significant influence on micro hardness since both parameters contributes for the formation of fine grain size in the welded samples [24].
Wahid et al. (2018) concentrated on 6082-T6 Aluminum alloy of a factorial-based study was successfully used to establish a relationship between the tensile strength of the welded joints and the process parameters. Among the significant parameters identified, the second-order term of rotational speed was the most influential. The optimum value of lastingness of the welded samples was 241MPa, which is like 0.79 times the lastingness of the bottom material. In comparison to welds made in FSW at these optimum conditions, a tenth increase in lastingness was realized. The low peak temperature and fewer thermal gradients thanks to water cooling limit the coarsening and dissolution of strengthening precipitates. This could be the rationale for the strength improvement within the optimal UFSW joint as compared to the traditional FSW joint. The distribution of temperature during UFSW showed similar variation with distance far away from the weld center both on AS and RS. The utmost temperature measured during UFSW was 119°C on the AS closest to the weld center. Moreover, the temperature on AS was found to be higher as compared to RS, because the AS experiences a greater deformation than RS in FSW. The precipitates are fragmented into a smaller size in SZ thanks to intensive heat and severe plastic deformation. Grain coarsening and dissolution of precipitates was observed in TMAZ and HAZ. Finely populated dimples with no voids were observed, which shows defect-free joint with a traditional fracture.

Senthil kumar et al. (2016) conducted experimentation on the submerged FSW of AA 6063-O alloy and optimized process parameters using TOPSIS. The optimum process parameters are rotational speed of 1200 rpm, welding speed of 120 mm/min and the tapered tool pin profile. It was found that the welding speed, the rotational speed and the tool pin profile contributes 37%, 30% and 28% respectively. Due to the warmth treatment at the weld zone, normal FSW joints have finer grains compared to the bottom metal. Therefore, mechanical properties at the weld zone are improved. Also, the submerged FSW causes further improvement due to cooling. The typical grain size, hardness value at both the traditional FSW and submerged FSW joints were compared. The typical grain size reduces from 8.35 µm to 3.45 µm and also the hardness value increases from 48.85 Hv to 61.54 Hv.

Ghetiya et al. [27] developed a mathematical model was to predict the welded AA2014-T14 aluminum alloy. The welding speed has predominant effect on the tensile strength. The developed relationships are often wont to predict the lastingness in immersed FSW of AA2014-T14 aluminum alloy joints within the range of parameters. Detailed microstructural analysis of weld joint was administered to understand reason for strength improvement in immersed FSW. It’s going to flow from to formation of fine grains in NZ and microstructure improvement at TMAZ. Intense heat and severe plastic deformation followed by water cooling were liable for fine grain formation. Fracture feature of welded joint obtained at optimal weld condition was studied. Joint was fractured at advancing side and at the interface between NZ and TMAZ. Fracture pattern shows varying size and fine dimple with some void which indicates the brittle fracture at the interface between NZ and TMAZ [28].
Wang Kauiet al. (2012) concentrated that ECAP pressed 2017 Al alloy with average grain size of ~0.4 μm is underwater friction stir welded at a rotational rate of 950 r/min and a travel speed of 60 mm/min. Sound joint without obvious defect is produced by underwater FSW UFG microstructure is retained in the FSW nugget by employing external water cooling, and the size of the recrystallized grain is ~0.7 μm. Compared with the UFG based material, the underwater FSW joint exhibits softening along the cross-section, and the HAZ has the lowest hardness value owing to the coarsening of the strengthening precipitates [29].

Ammar Mofid et al. [30] has explored friction-stir and submerged friction-stir welds of AA5083/Mg AZ31 were produced in air, underwater, and under liquid nitrogen. The temperature profile, microstructure, and hardness were evaluated. The temperature profile showed a decrease of 319 K (46 C) and 326 K (53 C) from a maximum of 708 K (435 C) within the case of air-welded specimen to a maximum of 662 K (389 C) and 655 K (382 C) for welds made underwater and nitrogen. Maximum DT was realized for the coldest sample, that is, the weld initiated at 233 K (40 C) under nitrogen. The stir zone of air-welded specimen displayed massive intermetallic compound formation within the stir zone due to constitutional liquation. The stir zone of underwater welded and under nitrogen welded specimens showed a way smoother interface and fewer intermixing. Thanks to a decrease within the peak temperature, the formation of intermetallic compounds was suppressed significantly and grain growth wasn't noticeable within the dynamically recrystallized Mg alloy within the stir region. High hardness values were observed within the stir zone of the air-welded specimen suggesting the probability for the precipitation of brittle intermetallic compounds. In underwater and nitrogen weld specimens, these high hardness values weren't observed [30].

Kulwant Singh et al. [31], & Unnikrishnan et.al. [32] concluded that the tool geometry and weld parameters have taken an important place to improve the joint efficiency because the width of the stir zone will give the fine grain structure. So, that the joint will have good mechanical properties. Kouadri et al. [33] evaluated that the residual stresses developed in friction stir welding of magnesium alloy (AZ31B). The fraction volume slowly lowers than base metal at stir zone because of equiaxed grain structure. Dhanapal et al. [34] investigated on corrosion behavior of AZ61A and found that chloride ions were aggressive on Mg alloys then formed as oxides, it increases the hydrogen ions then result as the corrosion time increased. Senthil raja et al. (2015) has worked on optimization of welding parameters of AZ91D. They found that the contribution of tool rotational speed 44%, welding speed 36% and axial force 17% to improve the tensile strength of the joint [35]. Jaiganesh et al. [36] focused on AZ80A and suggested that cylindrical taper pin profile gave good joint because of sound yield strength and improved mechanical properties.
Sevvel et al. [35] investigated and found the changes being produced in the macrostructural characterization and mechanical properties of the AZ31B Mg alloy by using three different tool pin profiles at the optimized process parameter values including tool rotational speed of 750 rpm, 0.5mm/min feed rate and axial force of 3KN during the FSW. Results concluded that taper cylindrical pin profiled tool exhibited improved & better mechanical properties in comparison with the opposite two pin profiles under FSW parameters of optimized values. Also the related yield strength value is almost 54.5% of its base metal and therefore the percentage of elongation being 5.45%.

Ratinasuriyan et al. [36] carried out investigations of SFSW/SFSP, concluded that in SFSW/SFSP, mainly two process parameters rotational speed, welding speed are identified more influence to grain refinement and strength improvement. In SFSW/SFSP or FSW/FSP, mainly three distinct zones are identified stirred nugget zone (NZ), thermo-mechanically affected zone (TMAZ), and heat-affected zone (HAZ) supported microstructural characterization of grains and precipitates. Maximum temperature of underwater joint is less than the traditional joint also because the time spent for the processing the fabric is low. SFSP is an improved method to FSP for the creation of ultra-fine grained bulk samples. SFSW has achieved more lastingness compared to the traditional FSW and SFSP has achieved better of elongation compared to the traditional FSP. Failure features on the traditional FSP and SFSP for grain growth and cavities coalescence during super plastic deformation [36].

3. Literature Gaps

The above literature review shows very scanty research had published on the investigations of SFSW. Submerged Friction Stir Welding required the further research to pay more attention in this field with different light weight alloys by using different fluid mediums and various optimization techniques.

4. Conclusions

In this paper work related to friction stir welding (FSW and SFSW) of aluminum alloys and magnesium alloys were reported. Scanty work has been done on SFSW of magnesium alloys as well as the researchers may pay more attention with different liquid mediums. The following conclusions are drawn from this study

- Cylindrical taper pin profile furnished good joint efficiency because of sound yield strength and improved mechanical properties.
- Rotational speed, welding speed had more influence on grain refinement and strength improvement.
- The grain size of SFSW samples is smaller compared to the normal FSW samples and also the grain size is indirectly proportional to the lattice parameter and residual stress values.
Both the rotational speed and water head have significant influence on micro hardness since both parameters contributes for the formation of fine grain size in the welded samples.

The cooling medium reduces the surrounding thermal flow and results the minimized fracture.

5. References

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