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A Review on The Friction Stir Process Using Aluminium Alloys

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Abstract

Friction stir process (FSP) is a similar solid state welding technique as friction stir welding (FSW). In FSW a non consumable rotating tool with a specially designed pin and shoulder is plunged into the interface between two plates to be joined and traversed along the line of joint. Localized heating is produced by the friction between the rotating tool and the work piece to raise the local temperature of the material to the range where it can be plastically deformed easily. FSP is a local thermo mechanical metal working process that changes the local properties without influencing the properties of the bulk material. The main aim of this study to review the friction stir welding (FSW) and friction stir process (FSP) of aluminum alloys with a focus on the analysis of the resulting microstructure, mechanical testing and the tools employed for processing the metals and also present an insight into future research in this area of study.

Keywords: *Friction stir process , aluminium alloys, microstructure, grain refinement.*

Introduction
The focus of researchers is mainly in developing fast and simple thermo-mechanical process in manufacturing area for worldwide industrial applications.

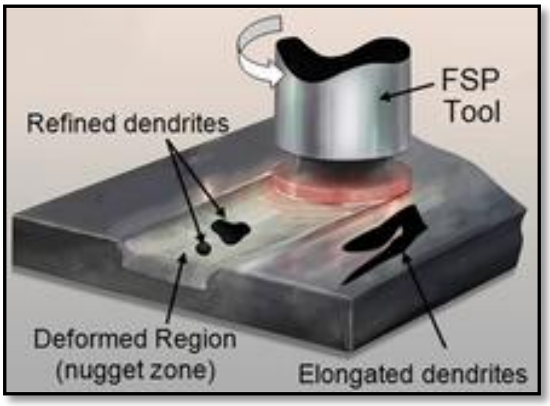

Figure 1: Schematic of friction stir process.

Friction stir process (FSP) is a similar solid state processing technique as friction stir welding (FSW) which was invented by the welding institute (TWI) for welding and processing the metal and plastics that eliminates casting defects and refines microstructures, thereby improving strength and ductility, increasing resistance to corrosion, wear and fatigue, enhancing formability, and improving other mechanical properties.

FSP uses, a non consumable tool comprising a shoulder and pin same as used in FSW, which rubs against the work material and produces enormous friction heat. The heat, combined with deformation

Figure 2: Schematic view of FSW Tool.

by the stirring action of the tool pin and pressure due to tool shoulder, produces a defect free, recrystallized, fine-grained microstructure. The main process parameters are (a) tool geometry, (b) welding speed and (c) tool revolutions. Typical friction stir process in its cross-section consists of the following three main zones (a) Nugget, stirred zone, (b) thermo-mechanically affected zone(TMAZ) and (c) heat affected zone (HAZ).

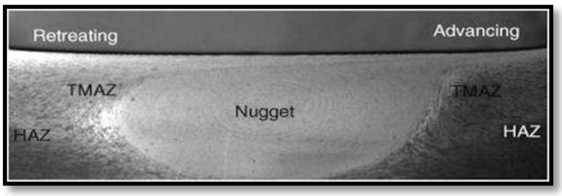

Figure 3: Illustration of different microstructural zones in the transverse cross section of a friction stir processed material.

The three zones pose distinct mechanical properties and nugget and TMAZ. The weld is not symmetrical due to the rotational movement of the tool, thus moving material from advancing side to retreating side.

Studies on Friction Stir Process In Aluminium Alloys.

The development of experimental work on the friction stir process of aluminium materials with a different methodology, tool geometry and process parameter optimization will provide a good insight on their possible industrial application to enhance industrial development. Ying chum Chen et.al. [1] performed the FSW of 2219-O and 2219 -T6 aluminum and the effects of the base material conditions on the FSW characteristics was investigated. They observed that the base material condition has a significant effect on weld morphologies, weld defects and mechanical properties of joints. In the 2219-O welds, no discernible interface exists between the stir zone (SZ) and the thermo-mechanically affected zone (TMAZ) and weld defects are liable to form in the lower part of the weld. In the 2219-T6 welds, there is visible interface between the (SZ) and the (TMAZ) and a weld nugget with an “onion ring”- like morphology clearly exists. Furthermore they observed that the defects are liable to form in the upper part of the weld and the strength efficiency of 2219-O joint is 100 % while that of 2219-T6 joint is only up to 82% and in addition, the two types of joint have different fracture location characteristics. Hua-Bin Chen et. al [2] conducted FSW of 5456 aluminium alloy and the outer factors on the FSW typical defects, formation of defects which are generated with the changes of the tool tilt angle , material condition, and the mechanical properties of the joint are also analyzed and discussed by using optical microscopy (OM),energy dispersive X ray spectroscopy (EPS) and scanning electron microscopy (SEM),and they observed that the tool angle has an essential influence on the heat input into the material and the position of the defects in the weld. Furthermore investigated that the generation of the kissing bond characterization of the single lap pattern occurs in the nugget zone due to the low tilt angle, which corresponds to the causes leading to the reduction of tensile strength, while conducting tensile tests. ZHANG Hong et. al [3] developed a two dimensional model of the FSW process by using elastic-visco plastic constitutive relationship and the return mapping algorithm, they investigated that the stress and deformation of the material around the pin and the effect of the viscosity coefficient on material behavior and stress distribution is also analyzed. They demonstrated that the distribution of equivalent plastic strain looks like “onion ring” is equal to the forward movement of the rotating tool in one rotation and the increase of viscosity of the equivalent plastic strain. Furthermore they observed that the influence range of the rotating tool can be decreased with the decrease of the viscosity coefficient. and also the radial stress and the circumferential stress in front of the pin are greater than those behind the pin. And in addition the material flow on the retreating side is faster than that on the advancing side.

T. Minton , D. J. Mynors [4] observed that a conventional manual milling machine is capable of performing FSW and producing reasonable welds using a relatively stout tool to join 6.3 mm and 4.3 mm thick 6082-T6 aluminium sheets when joining 6.3 mm thick 6082-T6 aluminium, and lesser quality welds were produced joining 6.3 mm thick 6082-T6 aluminium by a designed single generic tool for the 6.3 and by a truncated tool for the 4.6 mm sheet. Also it was observed that the temperature of the materials being welded and the backing plate were much greater than during the 6.3 mm trails. L. Fratini , G. Buffa, R. Shivpuri, [5] investigated the possibility to improve the mechanical properties of friction stir welded blanks of aluminium alloy with different thickness. They have been performed both experiments and a FE analyses are developed for a few case studies with different thickness ratios between the blanks. In particular, geometrical parameters, namely shoulder geometry and the two nuting angles, are critical factors in obtaining sound joints with nugget integrity, and the first nuting angles are strongly required in order to get effective process conditions allowing the proper bonding of the blanks to be welded. They observed that the joints obtained with such process conditions show good mechanical resistance at varying thickness ratios senseless. A.Murphy, W.McCune, et.al, [6] observed that welding induced residual stresses have a significant influence, and that collapse behavior is less sensitive to advanced process effects and process effect magnitudes than panel initial buckling behavior, while utilizing experimentally validated finite element modeling methods.

A. K. Lakshminarayan, et. al , [7] observed that the tool rotational speed has 41% contribution, traverse speed has 33% contribution and axial force has 21% contribution to tensile strength of welded joints, when conducting FSW of RDE-40 aluminium alloy Additionally they confirmed that the optimum value of process parameters such as rotational speed, traverse speed and axial force are 1400rpm,45rpm and 6 KN respectively. R.M.Leal, A.Loureiro, [8] investigated the effect of overlapping friction stir welding passes on the soundness and the changes in the microstructure and mechanical properties of welds in 3mm thick plates of 5083-O and 6063-T6 aluminium alloys and observed that the subsequent overlapping passes produced a modest increase in hardness and strength in both alloys as well as the elimination of tunnel defects in welds in 5083-O alloy. Hsin –Wei Lee , Truan [9] observed that the homogeneous grain refinement is acquired with one pass friction stir process, and the tensile flow curve feature, work hardening rate and an increase in tensile ductility are correlated with the variations of textural feature, while friction stirring of extruded AZ31 alloys. LIU Hui-Jie , ZHANG Hui – Jie, [10] conducted both the offset method friction stir repair welding and symmetrical method friction stir repair welding on 2219 aluminium alloy plate of 7.5 mm in thickness and observed that the groove defect can be removed by friction stir repair welding, and the offset repair welding process is superior to the symmetrical repair welding process. A good quality repair joint can be obtained by the offset repair welding process, and the repair joint is fractured near the interface between the weld nugget zone and thermo mechanically affected zone during the tensile test and the large dimples occur on the fracture feature is plastic. Shigeki Hirasawa, et. al, [11] investigated the effect of tool geometry on the plastic flow and material mixing during friction stir spot welding (FSSW) with different pin geometries using the particle method approach. They observed that a triangular pin with a concave shoulder is the preferred tool geometry from the current study that results in high strength spot welds. And in addition the material flow,and thereby the resultant hook formation, is quantified using numerical methods and is expressed as standard deviation of the particle movement. S.Jana, R.S.Mishra ,J.A.Baumann, et. al, [12] evaluated the effects of process parameters and friction stir processing (FSP) run configurations on the stability of microstructure at elevated temperatures, while friction stir processing of Al-7 Si-0.6 Mg alloy using a combination of tool rotation rates and tool traverse speeds, and observed that all single pass runs showed some extent of abnormal grain growth (ACG) whereas multi-pass runs were more resistant to ACG, Additionally, higher tool rotation rate are beneficial for controlling ACG.

S.Mukherjee , A.K.Ghosh ,[13] observed that the deformation field around the pin of an FSP tool by inserting a ductile foil in between two plates and a whirlpool of rotating material around the FSP pin tool. Furthermore observed a sinusoidal variation of shear strain - rate is observed along the pin - work piece interface with the maximum occurring close to the advancing side and the minimum occurring close to the retreating side. Olivier Lorrain , Veronique Favier, [14] performed FSW welds using 4mm thick aluminium alloy 7020-T6 rolled plates and two tools with different pin profiles made of high carbon steel they observed that the material flow using classical threaded tools and material is deposited in the advancing side in the upper part of the weld and in the retreating side in the lower part of the weld and a rotating layer appears around the tool. Also observed that the product of the plunge force and the rotational speed was found to affect the size of the shoulder dominated zone and this effect is reduced using the cylindrical tapered pin with flats.

L.Fratinl, G.Buffa, et. al, [15] observed that the use of an in process surface cooling treatment during FSW could have a significant potential beneficial effect on the overall mechanical performance of the joints, while welding AA7075-T6 aluminium blanks. Such an effect was found to be most effective when it was able to inhibit the metallurgical and mechanical phenomena that limit joint resistance in the HAZ / TMAZ areas, i.e grain growth and precipitate solubilisation. L.Kathikeyan , et. al, [16] conducted the FSP using Cast A319 grade aluminium alloy employing different tool rotational and feeds. They observed that both tool traverse and tool rotational speeds influence the microstructure and mechanical properties significantly. At certain combination of tool rotational and tool feeds, sound micro-structures, practically devoid of processing defects Further more observed that the ductility, hardness and yield strength of FS processed specimens are increased .

L.Dubourg, et. al [17] observed that (i) the increase of travel speed or decrease of the rotational speed caused a reduction of the hooking size.(ii) Double pass welds by over lapping the advancing sides improved significantly the weld quality by overriding the hooking defect.(iii) Change of the rotational direction from clockwise inhibited the top plate thinning defect. Furthermore observed that (iv) the tensile strength of FSW joints approached that of the base material but with a significant reduction in the fatigue life, (v) the probe plunge and removal locations served as the crack nucleation sites in specimen (vi) double pass welds with overlapping advancing sides showed outstanding fatigue life and very good tensile properties. S.Rajakumar, et. al [18] developed empirical relationships by response surface methodology (RSM) to estimate the average grain size and tensile strength of friction welded AA 6061-T6 aluminium alloy joints incorporating FSW tool and process parameters and established a linear regression equation between grain size and tensile strength of the weld nugget of FSW joints. S.Rajakumar, C.Muralidharan, et. al [19] evaluated friction stir spot welded Al alloy 6061-T4 sheet using a conventional pin (CP) tool and off-center feature (OC) tool. They observed that the tool rotation speed and plunge depth profoundly influenced lap-shear separation loads. And in addition investigated that no direct relationship between micro hardness and separation modes, and the HAZ was the softest region.

W.Yuan, et. al, [20] in this study, researchers were fabricated channels in Al6061-T6 alloy using FSC and the polar plots of the net resultant force acting on the pin during friction stir channeling were developed and analyzed and they observed that the position of net force acting on the tool aids in predicting the occurrence of channels in the nugget. Yoshiaki Morisada, Hidetoshi Fuji, [21] observed that the tool layer without defects are formed by the laser cladding with the optimized process conditions. The sound SPC 5 layer is obtained by the laser power of over 600w.The solidification structure of the cladding layer is refined by the laser cladding at lower laser power. Furthermore observed that the size and shape of the carbide particles are controlled by the process conditions of the laser cladding and the FSP. The nano structured tool steel layer formed by the laser and the FSP under the optimized conditions had a micro hardness of -900HV which was higher than that of conventional tool steels. Hassen BOUZAIE et. al, [22] undertaken an experimental study of aluminium alloy 2017 using the identified models based on least square method and response surface method and the contribution of FSW independent factors on the hardening parameters, and observed that the rotational speed and welding feed rate are the factors have greater influence on hardening parameters, following by diameter ratio that has no influence on the hardening coefficient.

M.Salehi, et. al [23] conducted the L16 Taguchi orthogonal designed experiments of FSP on AA6061/ SiC nano composites and observed that the rotational speed is the most influential parameter than traverse speed, tool penetration depth and pin profile.Furthermore observed that the ultimate tensile strength (UTS) for threaded pin is larger than that for square pin. Also, the higher the rotational speed and lower the transverse speed, the higher the UTS. Rajneesh KUMAR , et. al **,** [24**]** observed that the tool speed, welding speed, tool shoulder diameter and probe diameter are critical process parameters affecting axial force and heat input, while conducting FSW welds of AA5083 specimens. Axial thrust (Z-force) is most affected by welding speed, pin diameter and interaction of tool diameter and rotational speed. And in addition heat input in FSW is affected by welding speed, tool diameter and rotational speed and their all possible two level inter actions. Chatanya Sharma, et.al [25] investigated the effect of in-process cooling on the microstructure and mechanical properties of the weld joints using Al-Zn-Mg alloy AA7039 by means of optical microscopy, tensile and micro hardness tests. They observed that the in-process cooling decreased the size of heat affected zone (HAZs) and thermo-mechanically affected zones (TMAZs) and also reduced the size of aluminium grains in weld nugget zone (WNZ), TMAZs and HAZs. Furthermore observed that the hardness of the HAZ was higher than WNZ and TMAZ of the joints developed with in-process cooling while reverse trend was observed for normal joints.

Conclusion

Friction stir process is a solid state technique to refine the grains and to modify the microstructure of metal and alloy plates. The processing of aluminium plates using FSP has been reviewed to open a way for journey to the researchers in order to utilize the significance of this technique with the aim of achieving optimized process parameters for expanding the industrial applications. In earlier research major concentrations rendered by the researchers to join the aluminum metals of high strength and low defects and only the less concentration is made in the area of designing tool geometry, and the optimization the process parameters for friction stir process. In this summary the review of the friction stir welding (FSW) and friction stir process(FSP) of aluminum alloys has been successfully conducted. This research will provide a comprehensive vision for current research and also provide the current status of the research on friction stir process. Furthermore, new studies on FSP in aluminum alloys with respect to the process optimization, analysis of the microstructure, mechanical characterization and the design of FSP tools to produce a refined microstructure still needs to be developed.

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