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Effects of Process Parameters that affect the microstructure of Aluminium Alloy: A Review

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Abstract-**The aim of the current study to investigate the effect of process parameters that affect the microstructure of aluminium alloy. As the current concerns for energy efficiency and fuel economy is increasing in the transportation industries. The industries are seeking forward to weight reduction of the automobile components. The fusion welding of these alloys is difficult because cracks and defects are formed in the melting and solidification phases of fusion welding. Friction stir welding is a solid-state welding which eliminate the defect formation during the aluminium alloy welding. Friction stir welding (FSW) is a novel green manufacturing technique due to its energy efficiency and environmental friendliness. This solid state joining process involves a rotating tool consisting of a shoulder and/or a probe. The shoulder applies a downward pressure to the work piece surface, constrains the plasticised material around the probe, generates heat through the friction and causes plastic deformation in a relatively thin layer under the bottom surface of the shoulder. The rotating probe mainly drags along, plasticises, and mixes the adjacent material in the stir zone, creating a joint without fusion.Aluminium alloys, such as the 2xxx, 5xxx, 6xxx and 7xxx alloy series are the most commonly utilised materials in composite fabrication. Addition of various reinforcements such as fly ash, TiC, SiC, Al2O3, TiO2, B4C etc. In recent years, Al based composite materials have gained significance in aerospace, automotive and structural applications due to their enhanced mechanical properties and good stability at high temperature. This review paper is an attempt to describe the effect of process parameters that affect the microstructure of aluminium alloy. In this paperdiscussedabout the axial force, rotational speed and welding speed of FSW of aluminium alloy.**

Key words: Friction stir welding (FSW), hardness, axial force (AF), rotational speed (S)

I. Introduction

Friction stir welding (FSW) is an innovative welding process usually known as a solid state welding process. This opens up whole new areas in welding technology. It is particularly appropriate for the welding of high strength alloys which are extensively used in the aircraft industry. Mechanical fastening has long been favoured to join aerospace structures because high strength aluminium alloys are difficult to join by conventional fusion welding techniques. Its main characteristic is to join material without reaching the fusion temperature. It enables to weld almost all types of aluminium alloys, even the one classified as non-wieldable by fusion welding due to thermal cracking and poor solidification microstructure in the fusion zone.Aluminium has aninclusive range of applications; it is used from packing foil for the food industry to aerospace and shipbuilding industries [1]. The main advantages of the aluminium and its alloys are high strength-to-weight ratio and good corrosion resistance [2]. It is a non-ferrous material and is highly sensitive to the heat and temperature. It is not possible to use all types of manufacturing processes for aluminium. Mostly the aluminium alloys are hard through precipitation hardening [3] and hence the fusion welding cannot be applied to them because the high heat generated during these processes causes loss of some of its properties and leaves it unable to serve the intended functions. In 1991, a new technology in welding processes was invented by The Welding Institute (TWI) [4] and it was named as Friction Stir Welding (FSW). The basic concept of FSW is simple. A rotating tool with a specially designed probe (pin) and shoulder is inserted into the abutting edges of the sheets or plates to be joined and traversed along the joint line [3-5]as schematically shown in Figer1. The material is softened by frictional heating, and the forging pressure from the shoulder reconsolidates the material behind the tool. Friction stir processing (FSP) is a variant of FSW that involves traversing of the friction stir tool through the material in the absence of a joint inter face.

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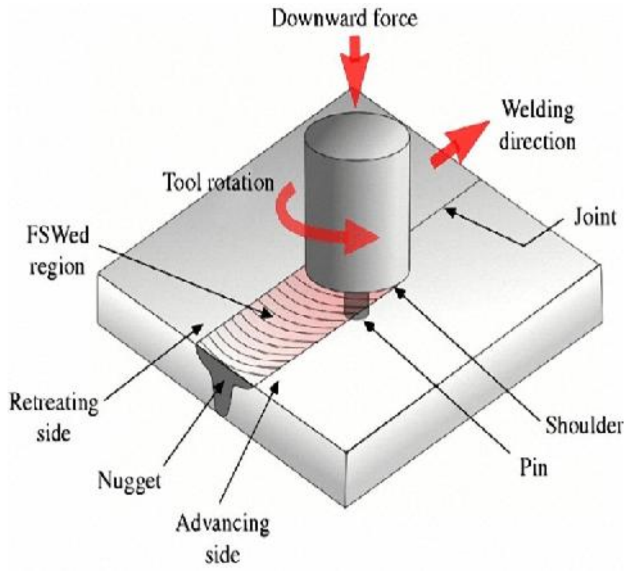

Fig1: friction stir welding

The main roles of the FSW process toolsare to heat the work piece [5], induce material flow and constrain the heated metal beneath the tool shoulder. Heating is created by the friction of the rotating tool shoulder and probe with the work piece and by the undecorated plastic deformation of the metal in the work piece. The ordinary heating softens the material around the probe. The tool rotation and translation cause the movement of the material from the front to the back of the probe. The tool shoulder also restricts the metal flow under the bottom shoulder surface. Because of the various geometrical features of the tools, the material movement around the probe can be extremely complex and significantly different from one tool to the other. In this study, some critical issues related to the FSW process tools (shoulders and probes) are briefly mentioned. The important parameters to be considered for achieving a good quality defect-free weld joint in FSW are tool rotational speed, welding speed, axial force, pin profile, tool tilt angle, shoulder diameter and pin diameter [6] [7]. If these parameters are not properly selected and maintained, the defects such as voids, hooks, onion ring and tunnel defects may arise. The incorrect speed range, welding speed and axial force may even lead to the damage of the tool. The cross-sectional area of an FSW weld joint is characterized by the different zones such as Heat Affected Zone (HAZ), Thermo-Mechanically Affected ZoneTMAZ) and Weld Nugget Zone (WNZ). Also, there are Advancing Side (AS) and Retreating Side (RS), which are the two sides relative to the weld centre line. The rotational motion and linear motion of tool pin are in the same direction in AS and they are opposite in direction in the RS. The Fig. 2 shows the different weld zones in FSW.

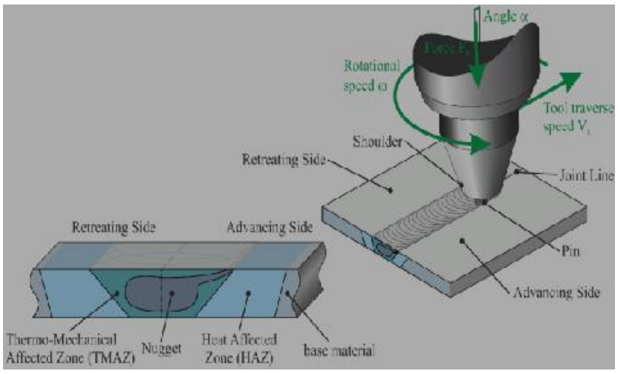

Fig2:Weld zones in friction stir welding

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II. DIFFERENT AREAINMICROSTRUCTURE

A. Heat affected zone (HAZ)

This area is only affected by the thermal cycle, but plastic deformation does not occur Mahoney et al [20] have characterized HAZ in heat treatable aluminum alloys, that materials should experience a temperature of more than 250°C in HAZ. The heat affected zone maintains a grain structure similar to that of base metals. In any case, the application of temperatures above 250^0C will have an important effect on the structure of sediments. The reports of Azimzadegan et al [21] says that if the input heat to the HAZ is low, or the ratio of the rotational speeds to the progressive speed is low, the boundary between the sediments and the matrix in this zone becomes almost rough. Figure 3 shows the effect of high and low ratios of the rotational speeds to the progressive speed on the HAZ microstructure.

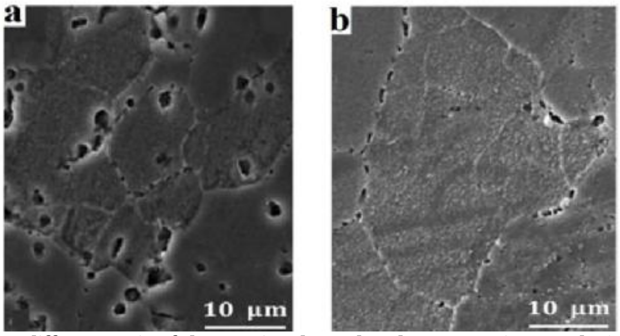

Fig 3: SEM image of HAZ with two different ratio of the rotational speed to the progressive speed: a)rotational speed 1300rpm and progressive speed 40 mm/min, b)Rotational speed 1000 rpm progressive speed 80 mm/min.[21]

B. The thermo mechanical affected zone (TMAZ)

The unique feature of the FSW process is creation of an area between the weld region and the base metal called the area affected by mechanical operations. This area experiences the plastic deformation and heat together. Highly deformed structure with more elongated grains of the base metal under upward flow pattern around the weld zone is one of the TMAZ features. [8], [16], [17],[18] This region such as weld zone is not subjected to plastic deformation, so recrystallization, due to lack of plastic strain, does not occur. However, in a few cases have been reported that in this area dynamic recrystallization phenomenon is partially occurs. [17],[19] Figure 4(a) shows the severe distortion of grains in TMAZ. The grains have high density of dislocations that are accompanied by an extensive lattice of fine grains in TMAZ (Figure 4(b)). Based on the results of Feng and his colleague's studies. Sedimentary particles of the second phase often grow in the grains or in the grain boundaries of TMAZ due to the heat generated by the FSW process (Figure 4(c)).

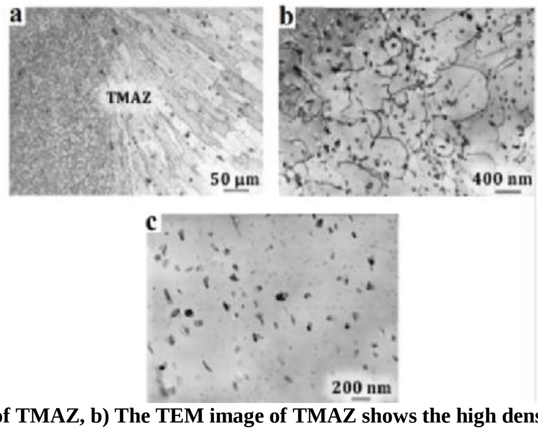

Fig 4: a) Optical microscope image of TMAZ, b) The TEM image of TMAZ shows the high density of dislocations, c) TEM image of the sedimentary particle growth in TMAZ[14]

C. Welding zone

The material in the welding zone is exposed to heat and severe deformation. The maximum temperature in the FSW process occurs in this zone. Depending on the welding variables, the maximum temperature about 6061 alloy and 7075 alloy respectively is 400°C and 480°C. [9], [11]Due to the high deformation and relatively high temperature, a dynamic recrystallization is performed in the welding zone, which modifies the microstructure of this region that result in creating a grain size structure between 2 and 10 micrometers.[10],[12]As a result of the FSW process, the welding zone is seen as airing structure, such as onion rings (Figure 5). [13],[14] The cooling rate in the welding zone makes only stable phases grow and prevents making additional phases. Another point is that in this region the crystallization process changes from homogeneous to non-homogeneous state, which occurs due to accidental crystallization of sediments on dislocations. [12],[15]

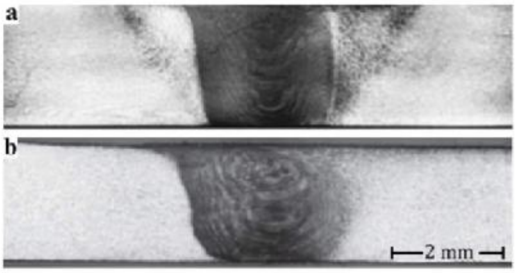

Fig 5: a) 2024-T351 alloys welding zone affected from welding with rotational speed of 1200 rpm and forward speed of 300 mm/min. [13] b) 7075-T6 alloy's welding zone affected from welding with rotation speed of 1200 rpm and traverse speed of 10 mm/min. [14]

III. PROCESS PARAMETERSTHAT AFFECTTHE MICROSTRUCTUTRE

A. Rotational speed

Rotational speed is a important parameter. which plays a crucial character on the material flow and heat generation thereby controlling the microstructures and mechanical properties of joint [22],[23] Thus, control of rotational speed during welding has become a critical matter for sound weld. As the tool rotation speed increases, the possibility of mixing the deformed materials in the weld zone will increase, which is considered a positive variable. If thepin rotational speed increases the speed of the shoulder also increases too, which will cause more heat in the jointing area, because about 95% of the total heat generated by the shoulder. Also, with increasing rotation speed, the amount of generated heat is increased and the size of the pieces taken from the material entering the matrix is increased. This reduces the strength of weld metal. On the other hand, increasing the rotation speed causes porosity at the welding surface, which lead an imperfection in the weld metal. At low rotation speeds, the thickness of the intermetallic structure will be reduced. However due to the decrease in the rotation and its passing through a minimum state speed, due to a decrease in friction energy, a proper connection will not be made. [24]The results of Kundu et al [25] showed that high tool rotational speed produce smooth welding as compared to low tool rotational speed. Schneider et al [26] showed that the rotational speed has a noteworthy effect on the shape of weld zone and joint strength. Moshwan et al [27] showed the if the rotational speed be 3000 rpm, then all welds between AA 5052–O plates will be sound welded joints with smooth surface appearances. Also, Thangarasu et al [28] showed that higher rotational speed provided homogenous distribution of Tic particles in the AA6082 matrix while lower rotational speed caused poor distribution of TiCparticles in the surface composite.

B. Welding speed

Forward motion of the tool assists the movement of the plasticised material under the tool shoulder from advancing side to the back of the immersed pin. Apart from that, effective heat input to the material to be joined depends on the weld speed. High weld speed drastically reduces the effective heat supply during welding [29]. Reduction in heat supply reduces the process peak temperature and results insufficient material flow around the tool pin in stir zone. Insufficient material flow leads to tunnel defect in stir zone. Selection of higher welding speed increases torque in the tool and develops excess stress in tool pin [30]. As tool pin is completely immersed in the material the excess stress on tool pin results tool pin breakage. Decrease in weld speed not only leads to the excess heat supple but also increases production time. The action of heating and stirring of material in stir zone leads to grain refinement in stir zone. Recrystallization of material in stir zone is affected by the increase in tool rotational speed and decrease in welding speed. Refined grains in weldment ensure better weld quality. Tool rotation and traversing speed must be selected to ensure efficient welding. Lower rotational speed combined with higher traversing speed results in colder weld whereas, higher rotational speed along with lower traversing speed results in hotter weld. Being easily controllable weld parameters many researches (Table 4) has been done to optimise the tool rotational speed with respect to the tool feed rate.

Material	Analysed parameter levels		Optimum outcome value		Reference
	Tool traverse speed(rpm)	Tool rotational speed(mm/min)	Tool traverse speed(rpm)	Tool rotational speed(mm/min)	
AA1050	800 to1600	100to300	1200	100	[31]
AA2024-T3	800to1600	35to140	1200	35	[32]
AA2024-T4	560to1800	11to45	900	35	[33]
AA2024-T6	1100to1900	10to75	1500	40	[34]
AA4047	500to1100	45to55	1100	54	[35]

Table 1. Optimum process parameters

C. Axial force

Vertical force exerted to the work piece through the tool is one among the easily controllable parameter. Proper selection of vertical force ensures quality weld even if there are tolerable thickness variations in the materials to be joined. As vertical force is one among the key factor on frictional heat generation during the process, higher vertical force enables high speed welding [39]. Plunge depth is the depth of penetration of shoulder surface in the work piece. Plunge depth increases heat generation as well as it controls the forging of flow material in the stir zone [40]. Axial force can be increased through increasing plunge depth which results higher heat generation. Higher plunge depth affects grain growth in stir zone and affects ductile strength of the joint [41]. Lower plunge depth reduces vertical force which in turn reduces heat supply and leads to improper material flow around the tool. Therefore, appropriate plunge depth is important for producing good-quality joints by ensuring adequate forging pressure required to consolidate flowing material properly as well as full penetration of the tool inside BM.

IV. Conclusion

The FSW process which is a solid state welding method is the best process to welding of different alloys of aluminum with an outstanding quality. In the FSW process three different areas including stir zone (SZ). Thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) are created. The main factors of this process are tool geometry rotational speed, traverse speed, axial force and welding speed and tilt angle which affect the microstructure and mechanical properties. It is clear that, the departure of traverse speed and rotation speed in the FSW welding process is not accurate. Thus, for each metal, there is a window about traverse speed and rotational speed so as to creating sound weld. Also, mechanical properties of the weld are mostly related to the rotational speed, because the rotational speed plays a critical role on the material flow and heat generation. Although, tool design and the type of alloy have direct effect on the morphology and structure of grains and sediments. It should be mentioned that the position of dissimilar sheets has effect on the mechanical properties of the final weld. For any aluminium alloy the set of process parameters cannot be fixed as constant and it can only be defined as an optimum range based primarily on the geometry of the joint, construction of the work piece restraint system and design of the FSW machine.

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