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FRICTION STIR WELDING FOR DIFFERENT METALS ALLOYS: REVIEW

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ABSTRACT

Friction stir welding (FSW) is a relatively modern process which is considered a suitable permanent join method for different industrial applications such as aerospace and automotive. Moreover, friction stir welding is preferred in contrast with other welding methods due to its ability to join similar and dissimilar metals with high efficiency. The current study presents a review for new researches taking in the consideration FSW process variables like welding speed, tool rotational speed and pin geometry for different metals alloys in addition to failure modes occurred in these alloys.

Keywords: *Friction stir welding, tool rotational velocity, welding velocity, failure modes, aluminum alloys.*

1.INTRODUCTION

After years of scientific research with various welding alloys, the welding institute (United Kingdom) presented friction stir welding (FSW) for the first time in 1991. [1-3]. FSW has been carried out in a number of industries for the past two decades, including aerospace, maritime, industrial, and railway applications. FSW is a highly efficient and reliable metal joining process where the metals are under thermal conditions. Major changes occurred in the metallurgical structure of the metals depend on the temperature and materials properties. FSW has many advantages like reduce the consumption of power, no filler material and good welding quality. FSW can be also used for metals that cannot be welded with the other welding methods [4]. However, FSW has many disadvantages such as welding speed is relatively slow, the equipment is expensive and huge, great tool wear [5].

FSW welds parts by causing a spinning tool to perforate within the joint and travel down the length of the joint. FSW is divided into three stages, each one of them can be represented by a period of time during which the work piece and welding tool move in relation to one another. The rotating tool displaced in a vertical direction into the joint line in the first step. Following this, a dwell period existed, during which the rotating tool is held in steady situation but nevertheless still rotating. Because of material plastic deformation and frictional work, mechanical interaction produces heat due to the difference of velocity among the work piece and the rotating tool. This heat is moved to the material and subsequently increase the temperature and make the material softening. FSW can be done by pushing the work piece or the tool along the joint line relative to each other [6]. Figure.1 shows the FSW Process.

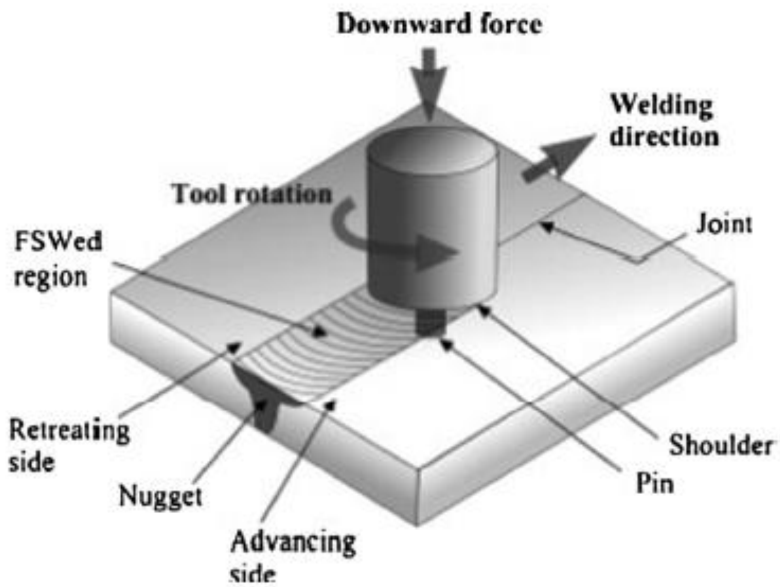

Figure.1 illustrates FSW process [7].

2-FSW VARIABLES

The parameters of FSW can be categorized as [8]

1- Tooling parameters such as shoulder diameter, pin and shoulder materials, thread pitch, pin diameter and pin length.
2- Machine variables like plunge force spindle speed and welding speed.
3- Other parameters such as work piece material and work piece size.

3-LITERATURE REVIEW

A numerous of research papers have been published on friction stir welding for different metals alloys. A brief review of some selected references on this topic is presented**.**

Hassan Abd El-Hafez and Abla El-Megharbel presented FSW for AA2024-T365 and AA5083-H111 aluminum alloys. Different welding parameters used such as weld velocities (16, 40 and 80) mm/min, tool pin shapes (square, triangular and stepped) as shown in figure.2 and tool rotational velocity

(900,1120 and 1400) rpm and in order to study the mechanical characteristics for the joint. Moreover, different locations were investigated as extra parameter. Hardness and tensile test achieved to evaluated the mechanical characteristics. It could be concluded that the various welding parameters had significant effect on mechanical characteristics of the welds [9].

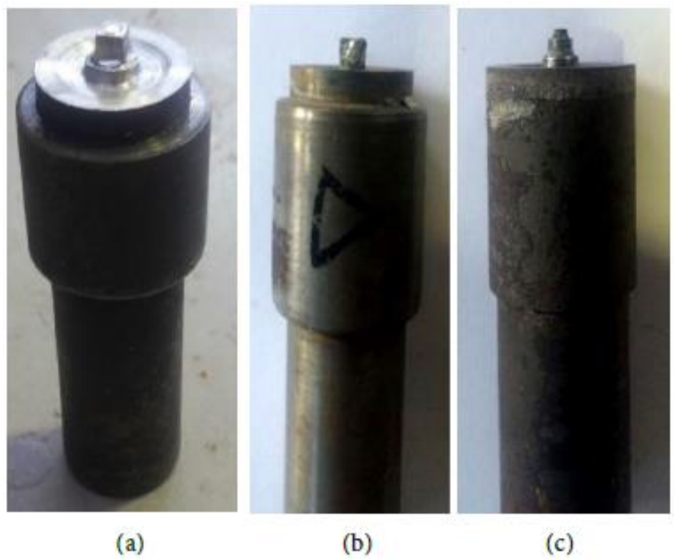

Figure 2. FSW tools shapes. (a) Square;(b) Triangular; (c) Stepped.[8]

T Vuherer et al. studied the fatigue behavior for aluminum alloy AA-2024. FSW process done by using vertical milling machine with steady speed of tool 750rpm with three various welding speeds which were 73, 116 and 150 mm/min. The experiments showed that the welding variables effect on the mechanical characteristics of AA-2024 alloy [10].

R Vaira Vignesh et al. simulated the FSW by using finite elements modeling for aluminum alloy AA6061-T6. By using the finite elements, the thermal history of welding process and maximum temperature could be predicted. Different welding parameters were applied in this modeling like pin diameter of the tool, shoulder diameter, welding velocity and tool rotational velocity. The main conclusion was that the maximum temperature is inversely preoperational with welding speed and directly with shoulder diameter and tool rotational speed while the maximum temperature was not affected by the pin diameter [11].

Jianli Liang and Zhenhua Zhao. Used Q235 steel with a thickness of 4mm and a tool fabricated of YG8 Cemented carbide, mechanism of the tool and failure modes during welding were investigated. Oxidation, mechanical wear, the convex and concave ring region on the shoulder, and brittle fracturing of the pin were all major modes of failure for the tool. Friction temperature of the tool for a long time was the main cause of failure and subsequently caused in partial diffusion of the CO phase. The hard-brittle phase Co6W6C and free carbon at the crystal boundary weakened the solid solution strengthening of the Co phase to tungsten carbide, reducing wear resistance and hardness. Figure. 3 illustrates the microstructure of the tool [12].

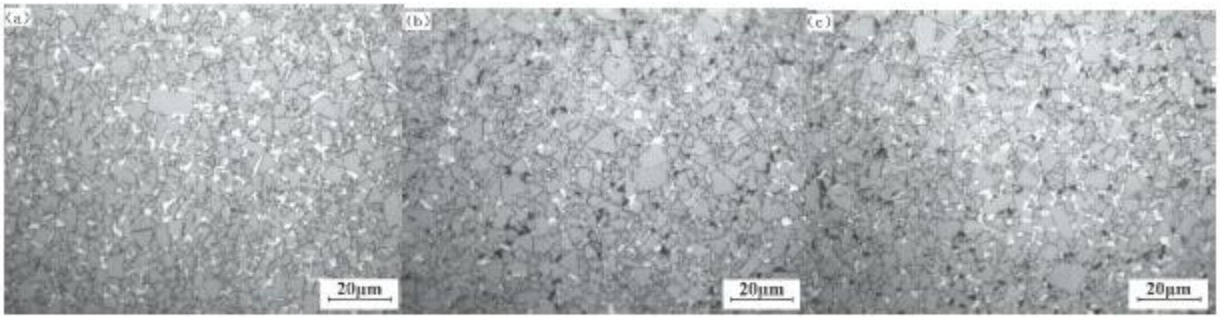

Figure 3. Tool microstructure (a. before welding; b. shoulder microstructure after failure; c.pin microstructure after failure) [11].

L. Commin et al. evaluated the temperature during FSW and residual stresses for AZ31 Mg alloy. Relationship between mechanical properties and microstructure with welding parameters, heat and plastic deformation was studied. It was found that the decreasing of welding speed or increasing the tool rotation velocity and increasing diameter of the shoulder could increase the heat generation [13].

T Küçükömeroğlu et al. investigated hardness, microstructure and tensile characteristics of FSW for DP 600 steel plates. The steel plate with thickness 1.5 mm was welded by a tungsten carbide stirring tool with 14 mm shoulder diameter and a conical pin with a diameter of 5 mm and a length of 1.25 mm (angle=30°). The tool rotational speed were 170 mm.min-1 and 1600 rpm.Authors found that the hardness increased up to 400 HV. The reduction in the elongation was about 55% [14].

D. Devaiah et al. FSW was used to connect 5 mm thickness AA6061 T6 and AA5083-H321 aluminum alloys applying a tool pin shape with taper cylindrical threaded and shoulder scrolling. Four separate welding velocities (40, 63, 80, 100) mm/min were employed to link weld the aluminum alloys at a steady tool rotational velocity of 1120 rpm. Good mechanical properties and characteristics were gotten at welding velocity of 80 mm/min. formation of plastic flow region effected by welding velocity [15].

Hamid Reza Ghazvinloo and Nasim Shadfar. Investigated the effect of the tool rotational velocity and tool travel velocity on the quality of FSW joints in Al-6%Si aluminum alloy. Different tool travel used (50, 75, and 125) mm/min with tool rotation velocity of 800, 1000, and 1200 rpm. the lateral flash defect happened in welding joints. The more lateral flash defect occurred at lowest tool travel speed and lowest tool rotational velocity. The incomplete root penetration defect was noticed in all welding condition. The tunneling defect was observed only in tool rotation velocity of 1000 rpm and travel velocity of 75 mm/min. Figure.4 illustrates lateral flash defect while figure. 5 illustrates the tunneling defect [16].

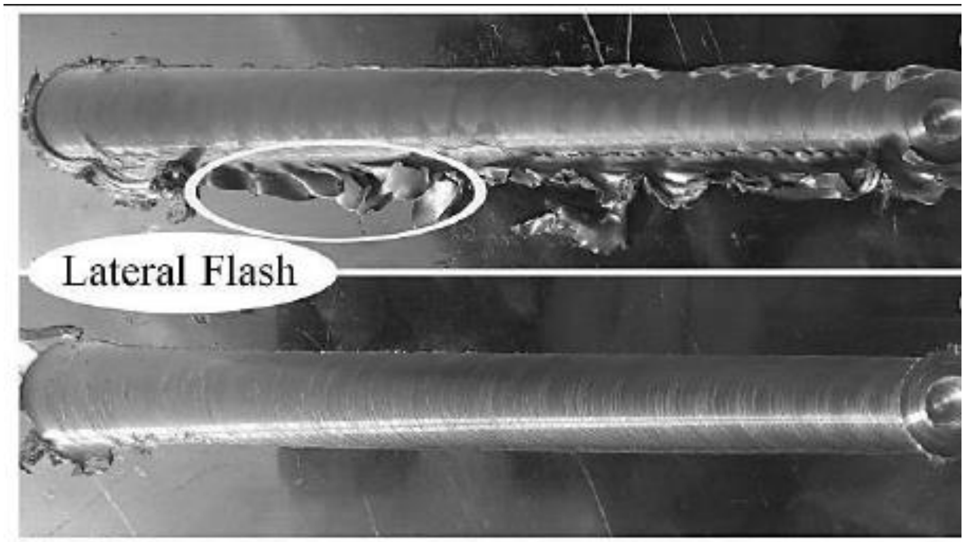

Figure .4 Lateral flash defect[16].

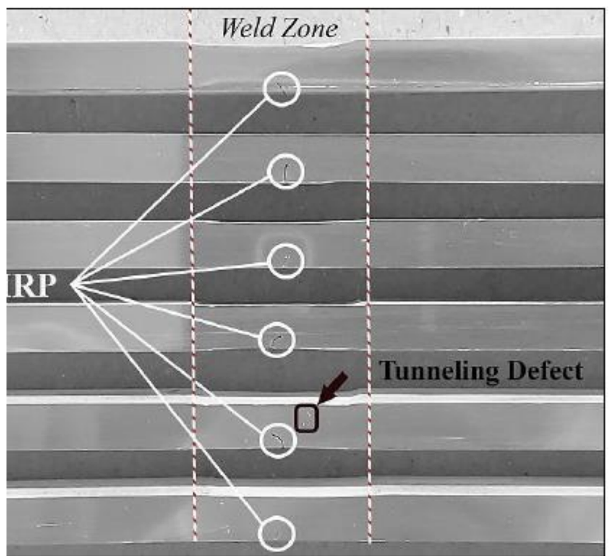

Figure. 5 Tunneling Defect [16].

Amir Ghiasvand et al. conducted the effect of pin offset, location of dissimilar alloys and tool offset on the heat distribution and maximum temperature of FSW of AA5086 and AA6061 alloys. It could be concluded that the most effect parameter on the maximum temperature was pin offset [17].

S. Dharani Kumar and S. Sendhil Kumar. The mechanical characteristics of butt weld joints made of aluminum alloys AA6063 with AA5083 were discussed. Various tool rotational velocity used which were (600, 800, 1000) rpm. It could be observed that the brittle fracture occurred in FSW. The maximum hardness was occurred at rotational velocity of 1000 rpm. By increasing tool rotational velocity, the impact and flexural strength decreased, while tensile strength increased. Figure.6 illustrates hardness difference for FSW [18].

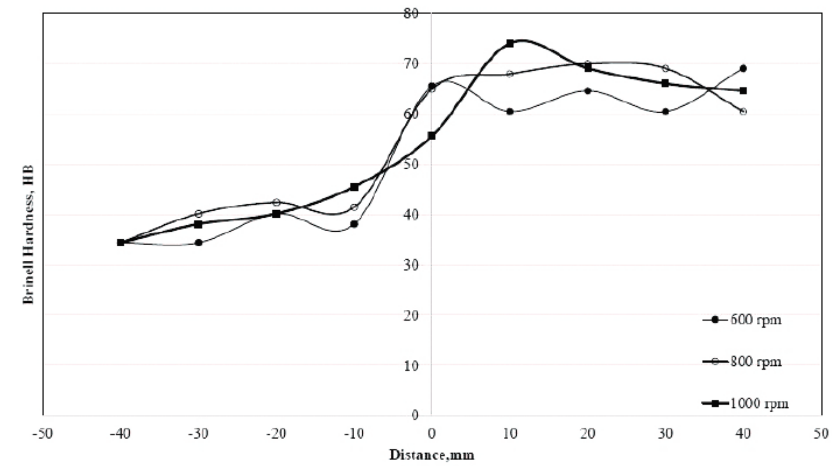

Figure.6 illustrates hardness difference for FSW [18].

N.F.M. Selamat et al. Used welding parameters, transverse speed 100 mm/min and tool speed 1000 rpm for dissimilar joints (AA5083-AA6061) and similar joints (AA5083-AA5083).The microstructure investigation showed the development of " onion ring "structure in nugget zone while distorted and wavy patterns observed in dissimilar joint. The tensile strength of dissimilar similar joint was 19% and 22% less in contrast with base metal of Al5083 and Al6061 [19].

Yuhua CHEN et al. Welding was performed using pure copper sheets with a thickness of 5mm and dissimilar magnesium alloy AZ31. Nugget zone has a vortex-like pattern and a lamella structure. In the nugget region, CuMg2 intermetallic compounds were discovered. The welding region had a higher hardness than the base materials. In the center of the stir field, the highest value of hardness can be found. Hardness levels near the Mg edge of the weld were higher in contrast with those on the Cu edge. The joint's tensile strength was 86 MPa, and it fractured brittlely. [20].

Bo Du et al. Studied FSW for 8-mm-thick 2219-T87 aluminum alloy in order to assess hardness distribution, microstructure, mechanical properties and fracture behavior for the welding. The major conclusions were that the mechanical characteristics and welding formation effected by welding force and geometry size of plate hole. Elongation of FPW joint could reach 8% and The ultimate tensile strength was 336.3MPa. Dimples differentiate the tensile fracture morphology of the FPW joint. [21].

Huseyin Tarik Serindag and Binnur Goren Kiral. Investigated Experimentally and numerically FSW for AZ31 Mg-alloy plates under translational velocities of (80,100,120,140) mm/min and rotation velocity of 1200 rpm. Mechanical characteristics were determined by used hardness and tensile test. Because of the reduced translational speed during FSW, heat generation increased and grain structure was refined. To measure stress distribution and temperature, ANSYS software was used in a numerical simulation. [22].

Pradeep Johnson and N.Muruganb. Used FSW to connect 3 mm thick AISI 321 stainless steel at axial force of 13 kN ,tool rotational velocity of 55 mm/min and tool tilt angle of 1.5 degrees. The results showed that the weld joints at 500 rpm and 700 rpm stronger approximately 88% and 93% in contrast with the base metal as well as hardness[23].

Muhamad Tehyo et al. Conducted influence of FSW variables on mechanical structure and microstructure of dissimilar aluminum alloy sheets between Semi-Solid Metal (SSM) 356-T6 and AA6061-T651 under six welding velocities (20, 50, 80, 120, 160, 200) mm/min and two various tool rotation velocities (1,750 and 2,000 rpm). Due to the tool rotation velocity was increased, tensile elongation increased as well. When the tool rotation velocity was reduced, the overall tensile strength decreased.. Table. Listed the fracture location. [24].

Table.1 Fracture location and mechanical characteristics of weld joint [24].

Tool rotation speed (rpm)	Welding speed (mm/min)	Tensile properties at room temperature		
		Tensile strength (MPa)	Elongation (%)	Fracture location
1,750	20	193.5	5.071	TMAZ of SSM356-T6
	50	196.3	4.952	TMAZ of SSM356-T6
	80	192.8	5.289	TMAZ of SSM356-T6
	120	189.6	3.609	TMAZ of SSM356-T6
	160	181.1	2.389	TMAZ of AA6061-T651
	200	180.7	2.007	
2,000	20	202.1	4.006	SZ
	50	205.8	5.036	TMAZ of AA6061-T651
	80	206.3	5.519	TMAZ of SSM356-T6
	120	197.2	4.563	TMAZ of SSM356-T6
	160	198.7	4.748	SZ
	200	194.7	3.224	SZ

Egoitz Aldanondo et al. conducted the influence of FSW variables and tool geometry for AA2099-T83 with AA2060-T8E30 aluminum alloy. The rotation velocity was (800,1200)rpm and welding velocity (250,800) mm/min. It could be inferred that tool geometry and welding variables had an effect on FSW defect features such as hook and cold lap defects [25].

D. Jayabalakrishnana and M. Balasubramanian. Applied FSW for thin sheets of AA 6061 and steel with new joint shape. The welding process carried out by using a tool without prop. In order to evaluate the welding efficiency, the tensile test carried out. Moreover, macro and micro metallographic investigations achieved. It could be concluded that the deformation aluminum alloy into steel because of stirring effect [26].

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A Boșneag et al. achieved the experimental tests for three dissimilar aluminum alloys AA7075 AA 2024 and AA6061 with various FSW variables. FSW speed was 70 mm/min while the rotational speed (600, 1400)rpm. The results showed that the roughness value was directly proportional with rotational speed [27].

C. Meran et al. Investigated FSW ability for AISI 304 austenitic stainless steels while the tool fabricated of a tungsten-based alloy. FSW achieved by using 11 kW vertical milling machine. Rotational speed was 1000rpm while travel speed was between 40 to 100 mm/min. The hardness of welding specimen was close to hardness of base materials[28].

4-CONCULSIONS

This work presented a review for modern papers in FSW for different similar and dissimilar metals alloys. Most of the researchers done their experimental and numerical simulation on various aluminum alloys with two or three welding process parameters and analyzed heat treatment, failure modes and welding quality while less number of researchers worked on other metals. It could be concluded that welding variables have a great influence on the mechanical and metallurgical behavior of joint. In contrast with other welding methods, the tensile strength, hardness and fatigue were improved. For future studies, it is recommended to focus on friction stir welding with new generation of high strength steel which is widely used in automotive industry and taking into consideration more welding process parameters and study the influence of these variables on the underwater friction stir welding.

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