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Influence of Tool Geometry on Material Flow Pattern in Friction Stir Welding Process

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Abstract

Friction stir Welding (FSW) is a solid state processing method that eliminates casting defects and refine microstructures and improves strength and ductility, increases resistance to corrosion and fatigue, enhances formability. It produces fine grained microstructures and imparts super plasticity. It is a local thermo mechanical metal working process that transforms the local properties without changing the properties of the bulk material. In FSW friction is the major contributor for the heat generation tool rotational speed and traverse speed have significant effect on tensile strength of FSW.

The present work is to study the influence of tool geometry on material flow during friction stir welding in two dissimilar Aluminum Alloys. Various types of tool geometries are used for the process. Tool is made of H-13 tool steel. A fixture is designed for measuring the temperatures at various locations. A correlation between the temperature distribution and resulting material flow pattern is studied by analyzing the microstructural properties of the various locations using both optical microscope and Scanning Electron microscope(SEM).Tensile strength and micro hardness for different process parameters are recorded. The Microstructure analysis resulted in distinct lamellar bands and various degrees of intermixing that were correlated with different tool profiles. Tensile tests were conducted as per ASTM standards and, an increase in the tensile strength is observed with the increase in the number of the edges of the tool. Scanning Electron Microscope is used to inspect the fracture surfaces which suggested low mechanical strength and the failure through the stir zone is due to inadequate material intermixing. Conclusions are drawn to identify the effect of operating process parameters.

Keywords— FSW, solid state welding, mechanical properties, different pin profiles, FEM, SEM, EDX, Material flow pattern

1. INTRODUCTION

Friction Stir welding process has been a significant metal joining process since its invention by The Welding Institute(TWI) in 1991[1].Friction Stir welding process is a joining process which employs a tool which rotates and travels along the joining surfaces which are clamped together. The tool is non-consumable and many types of tool profiles are employed for the welding purpose. Tool geometry is defined by the diameter of the shoulder, diameter of the pin, shape of the pin and the pin length. The pin length is usually shorter then the thickness of the plates to be welded. The pin is penetrated into the work pieces and the tool rotates and transverses along the centreline. The interaction between the work piece and the tool results in friction generating heat which in turn creates plastic deformation and the flow of the work piece material takes place in plasticized state as the tool traverses forward [2].the process is illustrated in the Fig 1.The material flow in friction stir welding is complex in nature and mainly depends on the tool geometry, process parameters such as tool rotation speed, welding speed, tool tilt angle, axial force and properties of the material to be welded. The weld formation depends on the material flow behaviour of the materials to be welded. As friction stir welding is a fusion welding process the welding takes place due to the intermixing of the materials for which material flow is the primary criteria which happens in solid state due to the heat generated due to friction between tool and work piece.

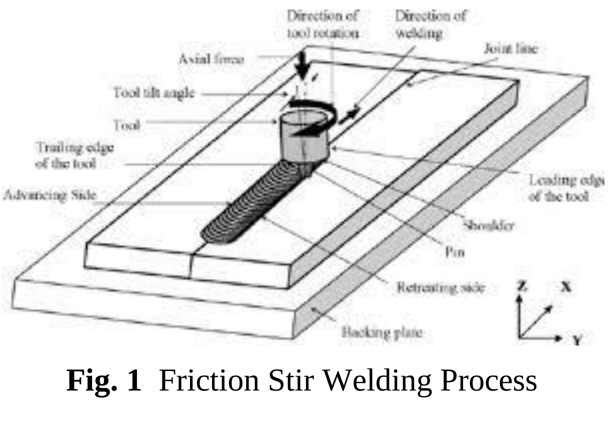

Fig. 1 Friction Stir Welding Process

Understanding of the material flow pattern and flow characteristics during the friction stir welding is very much essential for proper selection of the process parameters and the tool geometry [3].Few attempts are made by the researchers to describe the material flow characteristics. Material flow during the friction stir welding process is illustrated experimentally by employing marker insert technique which partially described the material flow in the weld zone [4].some attempts are made to describe the material flow using two-dimensional flow modelling around the tool pin [5-6].CFD was used by some researchers to describe the 3D model flow [7].Tool geometry plays an important role and influences material flow in friction stir welding process [8].The advantage of the friction stir welding process is that it reduces various metallurgical problems like porosity, spatter etc., and also it is an environmental friendly process. As friction stir welding is thermo mechanical process the weld zone is near the joint and is divided into different zones Base Metal zone(BMZ),Heat affected ZONE(HAZ) and thermo mechanically affected zone(TMAZ).BMZ has no microstructural changes, no plastic deformation occurs in the HAZ but due to the heat generated micro structural changes occur in HAZ..Drastic micro structural changes are observed in TMAZ [9-12]. The properties of the welded joint are mostly influenced by the temperatures due to the heat generated which is due to the friction between the tool and the work piece. The present work is to study the influence of tool geometry on material flow during friction stir WElding in two dissimilar Aluminium Alloys. Various types of tool geometries used for the process are triangular, square, pentagon and hexagon. The Tool is made of H-13 tool steel. Experiments are planned with different tool geometries. A fixture is designed for firmly clamping the work pieces with a provision of thermocouples for measuring the temperatures at various locations using thermocouples. Thermography is also employed using fluke thermal camera which records the temperature at various locations during the friction stir welding process. A correlation between the temperature distribution and resulting material flow pattern is studied by analysing the micro structural properties at the various locations using both optical microscope and Scanning Electron microscope (SEM). EDX studies are also carried out..

2. EXPERIMENTATION

Experiments are conducted on a modified milling machine with a fixture and arrangements for measuring temperatures due to heat generated during the process using thermocouples. K-type thermocouples are employed for the purpose. The welding process is carried out on 8mm thick plates having single plate size of 100mmX200mmX8mm.Friction stir welding is carried to join two dissimilar aluminium alloys AA 6061 and AA 6082. The properties of the materials are shown in the tables below

TABLE I

COMPOSITION OF AA 6061

Element	Al	Mg	Si	Cu	Cr
Amount (wt %)	Bal.	1.0	0.6	0.3	0.2

TABLE 2

COMPOSITION OF AA 6082

Element	Al	Mg	Si	Cu	Cr	Zn
Amount (wt %)	Bal.	0.87	0.9	0.08	0.09	0.03

The experiments are conducted at a constant tool rotational speed of 1400rpm and a welding speed of 20mm/min.Temparatures are recorded using thermography and analysed using fluke smart view thermal imaging software. The experimental setup with arrangement of thermocouples to measure temperatures is shown in the Fig 2.

.

Fig. 2. Friction Stir Welding Experimental Setup

A. Mechanism of Friction stir Welding Process

The friction stir welding process generally involves three stages plunging of the tool, tool traverse and retraction of the tool from the work piece. Initially the tool is plunged in to the work piece till the surface of the shoulder of the tool touches the surface of the work piece. Once the preheating time is elapsed the tool slowly traverses forward till the end of the work piece is reached and tool is retracted from the work piece leaving a hole at the end of the weld. All the three phases of the mechanism have physical significance as they influence the temperature distribution which in turn affects the material flow pattern and resulting microstructure.

B. Thermography

The temperature distributions during the friction stir welding process are the functions of the energy input from the tool, heat lost due to conduction to the backing plate and the preheating time of the work piece in the plunge stage. The success of the friction stir welding process larges depends on the highest temperature at the joint line of the workpiece.Insufficient temperature at the joint line results in the reduced material flow which in turn affects the traverse of the tool in the forward direction resulting in the weld defect formation and may also break the tool. If the temperature is too high the flow stress decreases resulting in the sticking of the material to the tool resulting in defect weld formation. and formation of coarse grain size. Generally a quality weld is characterised by its fine grain structure. Hence the analysis of the temperature along the weld line both in transverse and longitudinal directions is significant. Thermography helps in recording the thermal histories from the starting point of the weld to the end of the weld. As mentioned earlier Fluke infrared thermal camera is used to record temperatures due to the heat generated due to the friction between the tool and the work piece during the friction stir welding process using triangle, square, pentagon and hexagon shaped tool pin profiles. The advantage of the thermography is that the temperature histories can be recorded without physical contact using infrared sensors. The Thermal images are obtained using standard operating procedures of thermography and calibrated accordingly The specification of the infrared thermal imager is tabulated below

TABLE 3
SPECIFICATIONS OF THERMAL IMAGER

Emissivity	0.95
transmission	100%
Camera Model	Fluke Ti32
IR sensor Size	320x240
Camera Manufacturer	Fluke thermography
Calibration range	-10^{o}c to 600^{o}c

Thermocouples are also used to ensure the correctness of the analysis using thermography. Temperatures at various locations along the weld line at an interval of 35mm at points

A,B,C,D, and E at a distance of 35mm,70mm,105mm,140mm & 175mm from the initial point of the weld along the traverse direction of the tool are recorded and tabulated in TABLE 4. . Both the methods of recording of the thermal histories are correlated and found correct.. The Images obtained at point C are selected and analysed, and the corresponding temperature distribution profiles using fluke smart view thermal image software are given below.

TABLE 4

TEMPERATURES RECORDED USING THERMOCOUPLES AT DIFFERENT POINTS FOR DIFFERENT TOOL PROFILES

S.No.	Tool Geometry	A	B	C	D	E
1	Triangle	68	124	220	246	280
2	Square	97	146	272	282	296
3	Pentagon	98	210	320	328	364
4	Hexagon	112	226	420	436	454

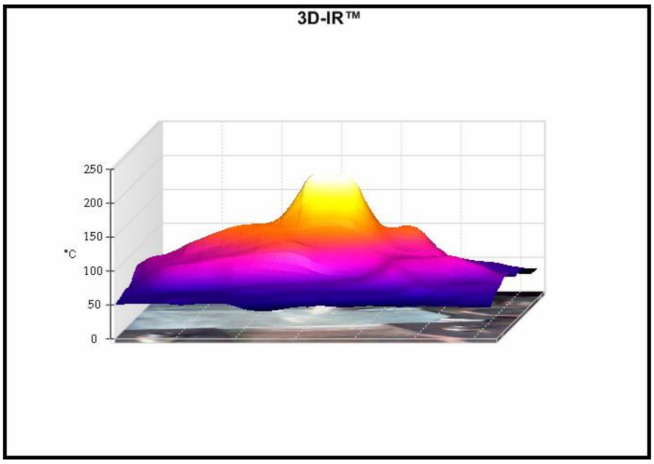

Fig. 3. Temperature Distribution during Friction Stir Welding Process using Triangle tool

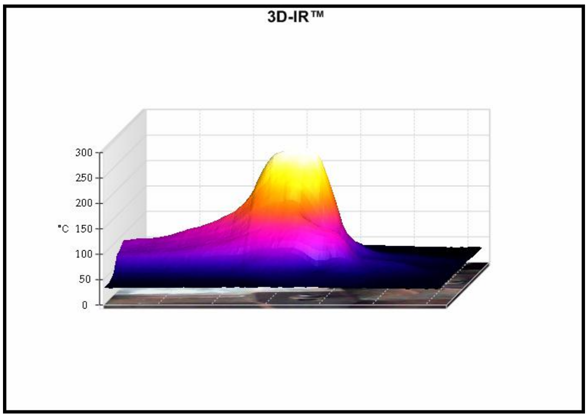

Fig. 4. Temperature Distribution during Friction Stir Welding Process using Square tool

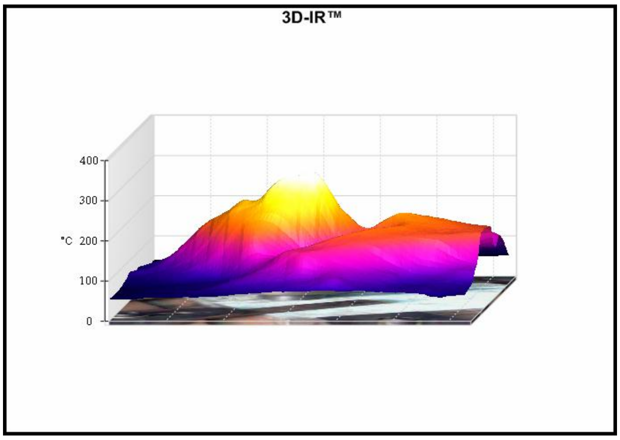

Fig. 5. Temperature Distribution during Friction Stir Welding Process using Pentagonal tool

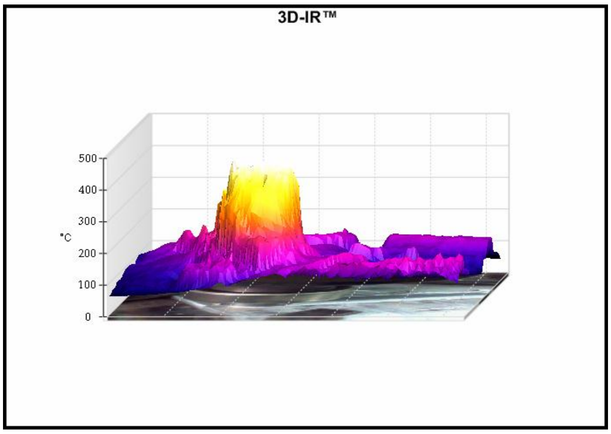

Fig. 6. Temperature Distribution during Friction Stir Welding Process using Hexagonal tool

The thermal histories are illustrated by the means of 3D plots generatd by the analysing the thermal images at point C using the thermal imaging sofrware fluke smartview and tabuluted below.

TABLE 5
TEMPARATURE DISTRIBUTION DURING FSW USING DIFFERENT TOOL PROFILES AT POINT C

S.No.	Tool Geometry	Max.Temp °C	MIn.Temp °C
1	Triangle	220.52	52.1
2	Square	297.41	71.4
3	Pentagon	319.30	102.4
4	Hexagon	452.24	108.3

C. Correlation between the thermal histories and Mechanical and micro structural properties of the weldments

The weldments obtained from the friction stir welding process using different tool profiles traigle,square ,pentagon and hexagon shaped tool profiles are subjected to mechanical and micstructural tests to corelate with thermal histories. For this purpose tensile tests are conducted on the specimans as per ASTM standards.For this purpose the specimans are sectioned longitudanally as per ASTM standards and tested on a universal testing machine and corresponding stress – strain curves are obtained. Similarly micrographs are obtained by means of optical and scanning electron micrography(SEM) to coorelate the materal flow pattern with the themal distribution.

Fig. 7. Tensile Specimens after Tensile Test

1. Specimen corresponding to Triangle Tool
2. Specimen corresponding to Square Tool

3. Specimen corresponding to Pentagonal tool

Fig. 8. Tensile Specimens after Tensile Test

4. Specimen corresponding to Pentagonal tool

TABLE 6

TENSILE STRENGTH OF FSW SPECIMENS OBTAINED WITH DIFFERENT TOOL PROFILES

S.No.	Tool Geometry	Tensile Strength(MPa)
1	Triangle	67.6
2	Square	82.4
3	Pentagon	91.2
4	Hexagon	102.4

The necking zone generally occurs at the HAZ because of dynamic recrystalization occurs at the HAZ.Hardness tests are also conducted using Brinell hardness testing machine along the transverse direction of the weld on both sides of the centerline i.e on the advancing as well as the retreating side and are tabulad below.

TABLE 7

HARDNESS TEST RESULTS CORRESPONDING TO DIFFERENT TOOL PROFILES

S.No.	Tool Geometry	Brinell HB	
		AS	RS
1	Triangle	81	82

2	Square	86	85
3	Pentagon	91	92
4	Hexagon	100	98

There is no difference in hardness on advacing side(AS) and retreating side(RS) of the weld.

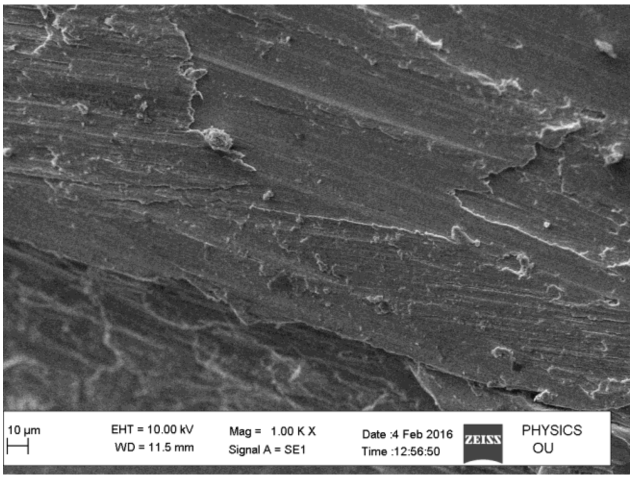

Fig. 9. SEM Micrograph at the fracture zone corresponding to Triangle Tool

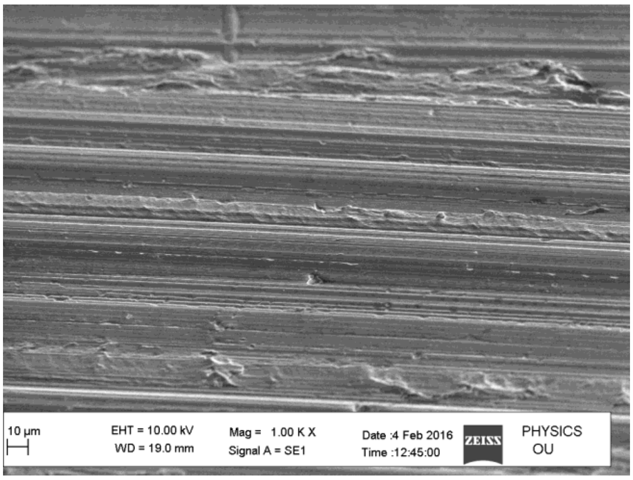

Fig. 10. SEM Micrograph at the fracture zone corresponding to Square Tool

During the welding process the AA6061 plate is positioned on the retreating side and AA6052 plare is positioned on the advancing side.The micrographs obtained at the fracture surfaces of the specimens obtained with various tool profiles are shown in the Fig.9, Fig.10, Fig.11,and Fig.12 for the tool profiles triangle,Square,Pentagon and Hexagon respectively.Similarly EDX studies are also carried out.EDX results for the specimen welded using hexagonal tool is shown in the Fig.13..

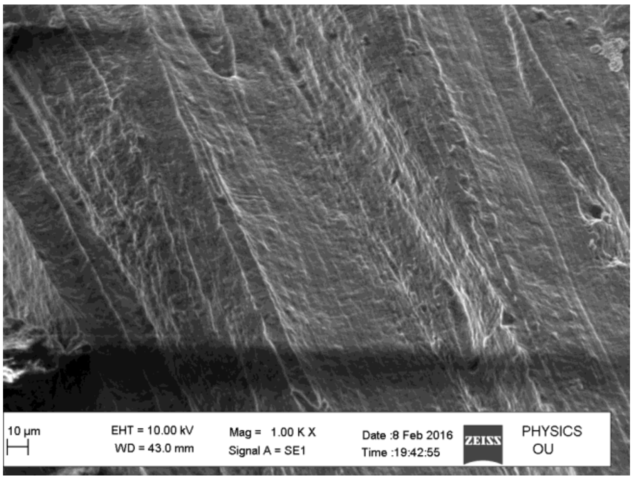

Fig. 11. SEM Micrograph at the fracture zone corresponding to Pentagonal Tool

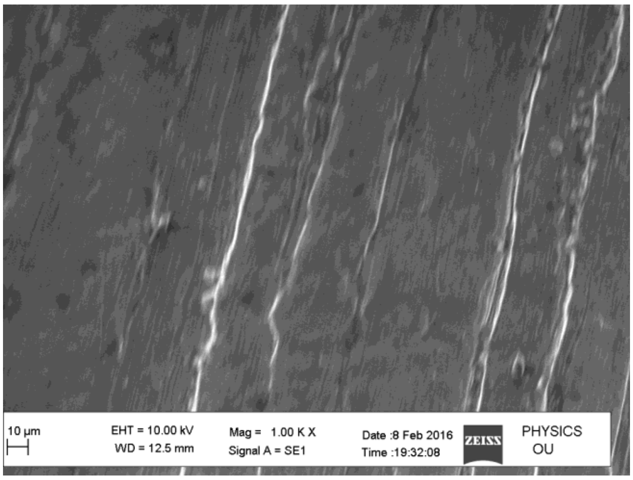

Fig. 12. SEM Micrograph at the fracture zone corresponding to Hexagonal Tool

The observations of the micrographs which suggested low mechanical strength and failure through the stir zone is due to inadequate material intermixing.The micrograph corresponding to traingle tool features vortex structures of material correponding to both base materials.By observing the micrographs it is observed that spacing between the material bands along the longitudanal sections decreased with increase in the number of sides of the tool pin which is in correlation with the temparature distribution and mechanical properties. As the material mixing increases the joint strength increases.EDS studies revealed the presense of oxide layer which may result in enhancing corossion properties.

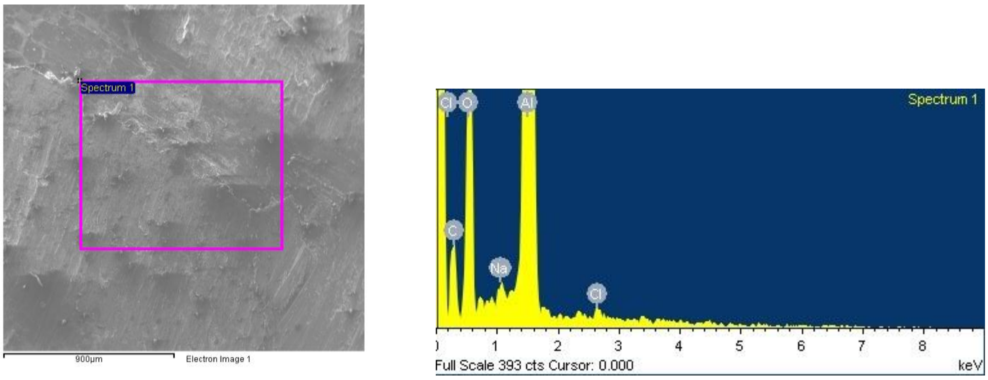

Fig. 13. EDS Studies of the specimen-hexagonal Tool

3. RESULTS AND CONCLUSIONS

In this study the friction stir welding process was studied by conducting experiments with different tool profiles trangle, square, pentagon and hexagon for joining dissimilar aluminium alloys AA6061 and AA6082 by placing AA6061 on retreating side and AA 6082 on the advancing side with constant tool rotation speed and welding speed for all the experiments . Temparature distributions are obtained using thermography and it is observed that the hexagonal tool generated maximum temperature of 452.24^{o}C and minimum temparature of108.3^{o}C and the triangle tool generated maximum temperature of 220.52.^{o}C and minimum temparature of 52.1^{o}C.it is observed that as the number of sides of the tool is increased there is more frictional heat resulting in increasing in the maximum and minimum temperatures and the corresponding range in the thermal histories. Similarly tensile test results and hardness test results are in correlation with the temparature distributions. The temparature distribution in the case of the hexagonal tool showing high average temperatures of 300^{o}C to 350^{o}C reveals that adequate frictional heat is generated which results consistent material flow and allow proper intermixing of the welding materials resulting in a good weld formation which resulted in good mechanical properties of the welding joints. The tensile test and hardness test results which are obtained and tabulated above justify this as the welded joint obtained using hexagonal tool exhibited tensile strength of 102.4MPa and that with triangle tool exhibited tensile strength of 67.6MPa.Similar results are obtained in the case of hardness test with the specimen obtained with hexagonal tool has 100 Brinell HB while that with triangle tool is 81 brinell HB.A successive progression in tensile stress and brinell HB is observed with successive increase in the number of sides of the tool pin. Finally the micrographs obtained at the fracture surfaces are studied which revealed that the fracture is caused due to the lack of proper intermixing of the materials which is direct consequence of improper material flow. It is observed the tool pin profile affects the frictional heat generation which in turn affects the temparature distribution which causes improper material flow which results in improper intermixing of the materials leading to the failure of the joints. Hence it can be concluded that the tool pin profile is an important process parameter and its design plays an important role in deciding the material flow pattern in the friction stir welding process. The results present a comparative study of the temparature distribution, Tensile strength behaviour, resulting hardness and formation of microstructures with various tool pin profiles and it is observed that hexagonal tool shows good results compared to other tool profiles keeping other process parameters constant.

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