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RESEARCH ARTICLE

EFFECT OF OPTIMISED PROCESS PARAMETERS ON FSP AZ31B ALLOY

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ABSTRACT

Friction stir welding (FSW) is a solid state welding process, widely emerging its usage in various manufacturing applications, used for joining similar & dissimilar metals mostly used for aluminum alloys. The present investigation is carried out on magnesium alloy (AZ31B) plates using FSW technique by varying the process parameters viz. tool material and tool pin profile while keeping the other parameters to a constant value. The output parameters are ultimate tensile strength, hardness and joint efficiency were studied for the above parameters for rotational speed of 900rpm & 1400 rpm, feed rate of 20mm/min, tilt angle 1° and axial force of 5KN. The optimum conditions have been found for the best weld quality with superior mechanical properties.

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INTRODUCTION

Friction stir welding (FSW) was invented and patented by Thomas *et al.* (1991) of the Welding Institute in Cambridge, UK. In FSW, a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, which are butted together. Most of the research conducted on FSP focuses on aluminum alloys. Despite the potential weight reduction that can be achieved using magnesium alloys, very little is reported on FSP of commercial AZ31B-H24 magnesium alloy sheets (Shude Ji *et al.*, 2013). Magnesium is the lightest metal for complex structures, with a density of 2-3 times lower than aluminum and a quarter of steel density. Experimental program had developed a welding system sited on a milling machine with characteristics fitted for the FSW process. At this moment, a special attention is given to using Al and Mg alloys in automotive industry, transport and aeronautics, for reducing the weight and reducing fuel consumption (Darras *et al.*, 2007). The experiments were carried out as per Taguchi parametric design concepts and an L9 orthogonal array was used to study the influence of various combinations of process parameters (Cojocaru *et al.*, 2008). Statistical optimization technique, ANOVA, was used to determine the optimum levels and to find the significance of each process parameter. The effect of tool shoulder profile on the mechanical and tribological properties (Ugender Singarapu *et al.*, 2015) of friction stir processed AZ31B magnesium alloy also influences the weld strength. Magnesium alloy by Friction stir welding. Friction stir welding (FSW) is carried out at different rotational speeds of 900 rpm, 1120 rpm, 1400 rpm and 1800 rpm and with change of tool materials such as High speed steel (HSS) and Stainless steel (SS) at a constant welding speed of 40 mm/min, tilt angle of 2.50 and axial force of 5 KN. Observations concludes that SS tool material provided fine grained microstructures and better mechanical properties as compared to HSS (Ganesa Balamurugan and Mahadevan, 2013).

The absence of defects in weld region, presence of very fine equiaxed grains in the weld region and higher hardness in the weld region are the main reasons for superior tensile properties of joints. Five tool pin profiles, five tool materials and three tool shoulder diameters were used to fabricate the joints. It is found that the joint fabricated using threaded pin profiled tool made of high carbon steel with 18 mm shoulder diameter produced mechanically sound and metallurgically defect free welds compared to their counterparts (Ugender *et al.*, 2014). Tool geometry is consider a major parameter in FSW, the operation efficiency and weld quality are mainly based on the tool geometry used for the friction stir welding process. Different working materials and which tool materials are used in that operation of friction stir welding (Afrin *et al.*, 2008). The effect of flute geometry in tool pins on material flow velocity by the software ANSYS FLUENT. The results of that study demonstrate the geometry of the flute of a rotational tool during the friction stir welding process greatly influences the

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material flow behavior (Afrin *et al*., 2008). Several previous studies reported (Ugender *et al*., 2014; Mishraa and Ma, 2005; Mohan, 2014; Kah and Martikainen, 2012; Sevvel and Jaiganesh, 2014) the effect of process parameters on mechanical and micro structural properties for FSW AZ31B Mg alloy to achieve better weld quality by raising the joint strength. The different optimized parameters and their influence is investigated experimentally for cast metal plates of AZ31B Alloy.

Experimental Work

Wrought AZ31 Mg alloy sheets (2.75% Al, 0.91% Zn, 0.001% Fe, 0.01% Mn and remaining being Mg by wt.%) of size 100 × 50 × 6 mm^3 were obtained. The tool used for the friction stir welding was manufactured from high speed steel and stainless steel for which the tool design is shown Fig 1. The welding pins have shoulder and pin, the diameter of shoulder and pin are 20mm and M4 respectively. The length of the pin is 5.7mm. The hardness of pins was improved through oil quenching and heat treatment process before conducting the experiment. The friction between pin and the plasticised metal is also influenced by the tool material hardness; the plasticised material under the tool is pulled from advancing side and redeposited on the retreating side, the friction between the tool pin and extruded metal must be less to achieve smooth metal flow.

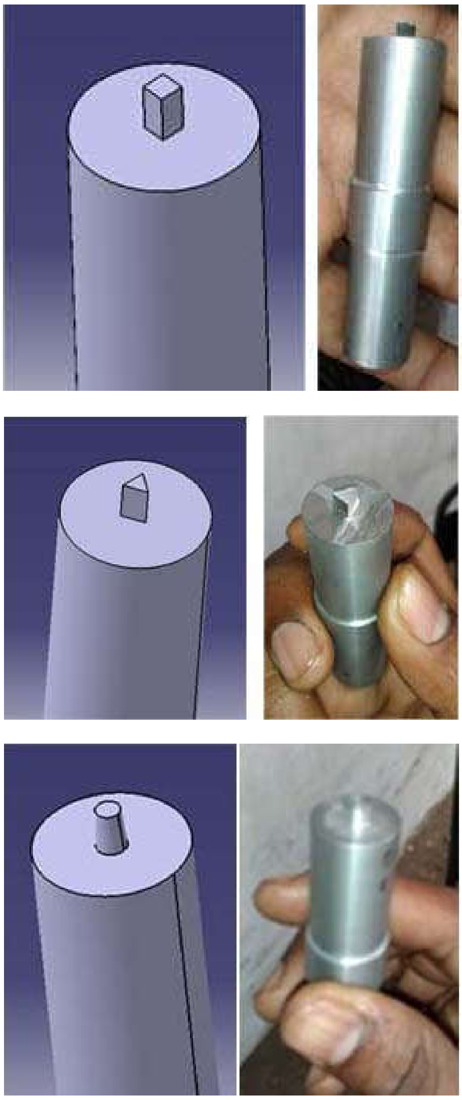


Fig.1. Different types of tool pin profiles used

The alloy plates are kept on the backing plate as it acts as a support for the plates so as to bare the forging force. Welding was performed at constant welding speed of 20 mm/min and tilt angle of 1° by varying the tool material, tool pin geometry and tool rotational speed. The tool pin should be 0.2mm lesser than the plate thickness so as to avoid the welding of plates to the support plate. For avoiding oxidation reaction of magnesium oil lubricant is used in minimal quantity. The welding was performed as per the optimized parameters shown in Table 1.

Table 1. The optimized parameters

Parameters	Levels		
	1	2	3
Material	SS	-	HSS
Pin geometry	Square	Tapered Cylinder	Triangular
Tool rotational speed	900	-	1400

Fig. 2. FSW on vertical milling machine

RESULTS AND DISCUSSION

Tensile properties

The effect of optimized process parameters on mechanical properties such as tensile strength, hardness and joint efficiency are presented in the table 2.In FSW, the tool rotational speed plays a major role in mixing the of material around the rotating pin which in turn increase the temperature of the metal but during the plunge stage the material tries to escape out where it becomes a major cause of route flaws so a tapered flute profile (Shude *et al*., 2013) with screw threaded reduces the material loss also enhances better material flow. Tool material (Ugender Singarapu *et al*., 2015) also influences major changes in the weld material where transitional speeds helps in reducing macro defects where SS tool material provided fine grained microstructures and better mechanical properties as compared to HSS (Ganesa Balamurugan and Mahadevan, 2013) where heat generation capacity is low for HSS, during plunge stage the material is sticking up to cause root flaws. The root cause of decreasing strength is due to coarse grain size after performing FSW is revealed through micro structural examinations (Afrin *et al*., 2008), where hardness vale is also influenced by grain refinement, it can be achieved by selecting the proper shoulder and pin diameter of the tool (Padmanaban and Bala Subramanian, 2009) which generates optimum heat. The welded joints with different parameters are marked and cut into different shapes required for testing, by using wire cut EDM (Electrical Discharge Machining).

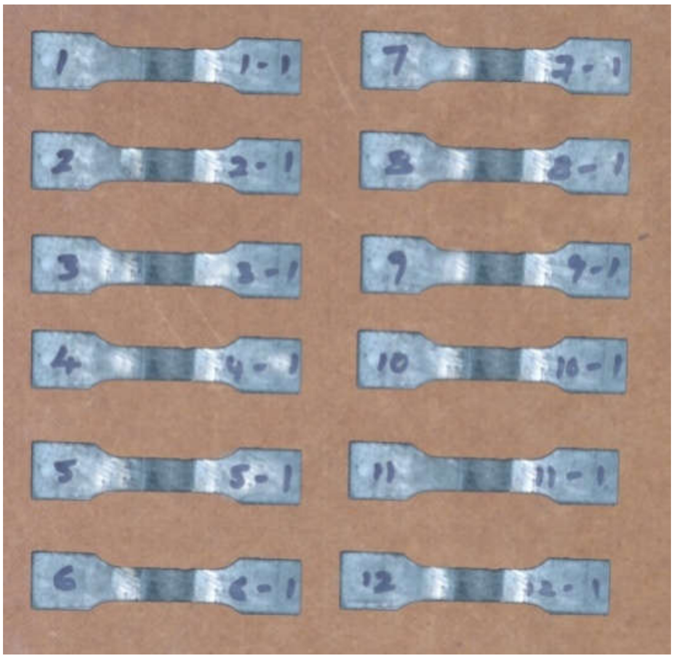


Fig.3. Tensile test specimens prepared from FSW AZ31B

It is observed that higher ultimate tensile strength of 38.634N/mm^{2}is obtained when SS tool material having tapered cylindrical profile is used for constant feed rate of 20 mm/min mean while the lowest tensile strength of 33.681N/mm^{2}is obtained when HSS tool material with square profile is used. Also the second higher tensile value is obtained in case of tapered cylindrical tool profile made from SS material for tool rotational speed of 1400 rpm. In case of using SS tool material the lowest tensile value of 35.836N/mm^2 is obtained for triangular profile having tool rotational speed of 1400rpm and 20mm/min feed rate. Also the average tensile strength of 36.284N/mm^2 is obtained for triangular tool profile rotating at 900 rpm. Similarly by using HSS tool material the material strength of 36.421N/mm^2 is obtained for tapered cylindrical profile for tool speed of 900 rpm and lower tensile strength is obtained for triangular tool profile with rotational speed of 1400 rpm. Also the average tensile strength is obtained for tool speed of 900 rpm using triangular tool profile. The maximum tensile strength of 36.421N/mm^2 is obtained for HSS tool with tapered cylindrical profile having tool speed of 900rpm and lower tensile strength is obtained for triangular profile with tool speed of 1400 rpm. Also the average strength value is obtained at low spindle speed using triangular tool profile. From the tensile results, it is clear that the triangular tool profile can be used as secondary tool profile after cylindrical tool profile.

The joint efficiency of the weld joint directly depends up on the tensile strength exhibited by the weld area with respect to the base material. From the results we can say that the joint efficiency and tensile strength are directly proportional to each other. It is clearly evident that in every step the joint efficiency is decreased for higher tool rotational speeds and vice versa in other case. By using tapered cylindrical tool profile higher joint efficiency of 95.96 % is obtained using SS tool for rotational speed of 900 rpm and lower value of 82.63% is obtained for HSS tool material using triangular profile and rotational speed of 1400 rpm. Also it is observed that the average value is obtained using triangular tool profile for low spindle speed. The lower joint efficiency value of 88.48% is obtained in case of using SS tool material using triangular profile for 1400 rpm and average value is obtained for triangular tool profile at 900 rpm. Similarly in case of HSS tool material, the maximum value of joint efficiency obtained is 89.92% for cylindrical tool profile at 1400 rpm. Also the average joint efficiency is obtained at low spindle speed for triangular profile.

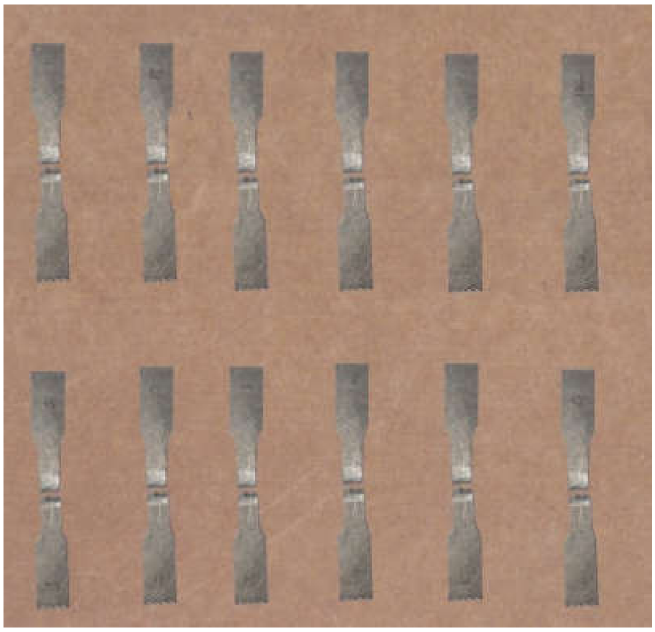
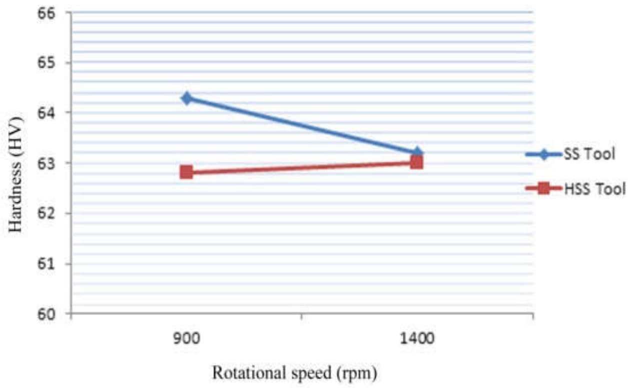


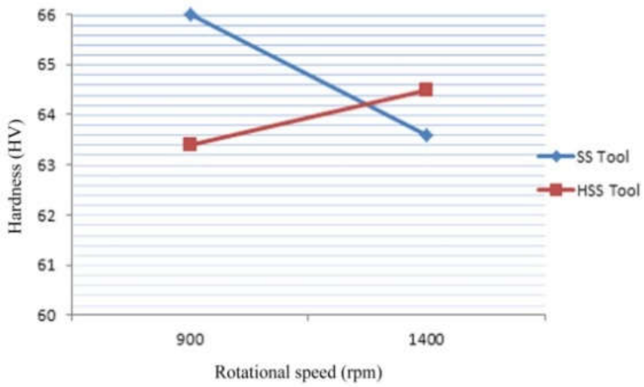
Fig.4. Work pieces after Tensile test

Hardness

Micro hardness test was conducted for the welded joints using Micro Vickers Hardness test with Diamond Indenter at an applied load of 10 kgs and found the impressions in nugget zone. The hardness of the base metal is 55 Hv. The result clearly shows that the hardness of the processed material is extremely sensitive to the processing parameters. Higher hardness value of 66.0 Hv is achieved at rotational speeds of 900 rpm using SS tool material having tapered cylindrical profile. Lower hardness value of 62.1 Hv is obtained for rotational speed of 1400 rpm using HSS tool material with square tool profile. Also the average hardness value of 63.4 Hv is achieved using tapered cylindrical tool profile made from HSS material. From the results it is found that the hardness value is affected by the rotational speed, tool material and profile of the tool. Also the Hall-Petch relationship states that the hardness is inversely proportional to grain size. It is due to the grain size at stir zone, where the grain refinement plays an important role in material strengthening. The threaded cylindrical profile helps in smooth mixing of the material and also enables heat dissipation, due to this much finer grain structures are formed with equalised grain size, which resulted in achieving higher hardness value in this case.



(a)



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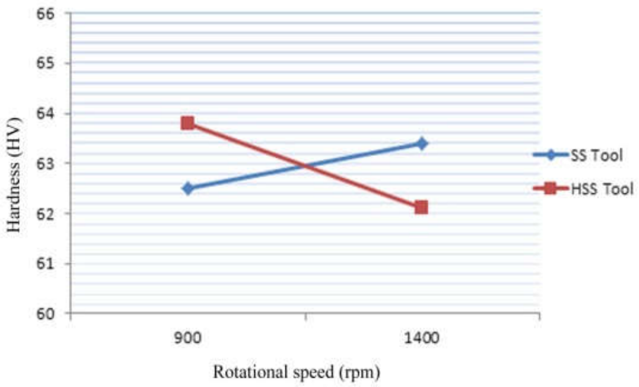


(c)

Fig.5. Graphs showing the variation of hardness of FS processed sample using SS & HSS tool material for (a) Square (b) Tapered cylindrical and (c) Triangular profile

Table 2. Effect of optimized process parameters on mechanical properties of AZ31B Mg alloy using SS and HSS tool

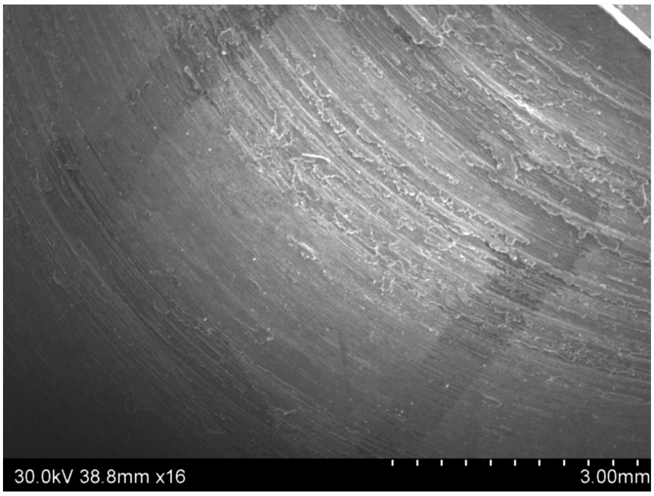
Tool	Profile	Feed(mm/min)	SPEED(rpm)	UTM(N/mm^2) Max 40 .5	Vickers Hardness(HV)	Joint Efficiency (%)
	Square	20	900	37.634	62.5	92.92
			1400	36.572	63.4	90.30
	Tapered Cylinder	20	900	38.864	66.0	95.96
SS			1400	37.872	63.6	93.51
	Triangular	20	900	36.284	64.3	89.59
			1400	35.836	63.2	88.48
	Square	20	900	34.456	63.8	85.07
HSS			1400	33.681	62.1	83.16
	Tapered Cylinder	20	900	36.421	63.4	89.92
			1400	35.359	64.5	87.30
	Triangular	20	900	34.642	62.8	85.53
			1400	33.469	63.0	82.63

Microstructure

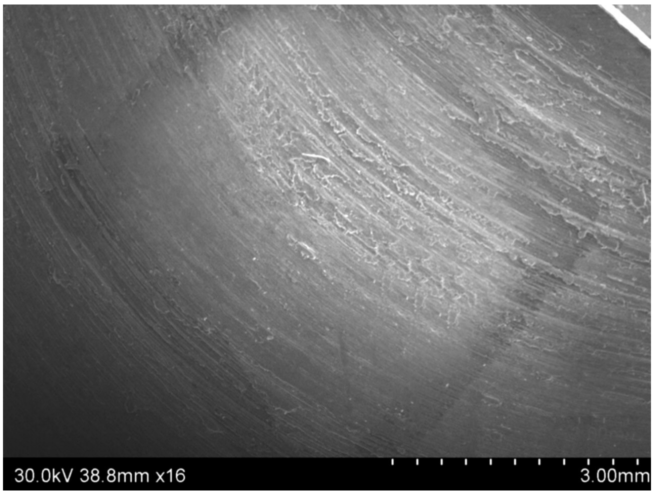
Optical microscopy was used to determine the grain size evolution, while scanning electron microscopy (SEM) was used to observe the precipitation state. The specimens were then metallographically polished using different graded emery sheets followed by polishing using diamond paste and cleaned with ethanol. Chemical etching of the polished specimens was done using picric acid reagent (comprised of 5 g of picric acid, 5 ml acetic acid, 5 ml distilled water and 100 ml ethanol), then rinsed with ethanol and dried in hot air. Samples 1 cm^2 were ground down to a thickness between 100 and 200 lm using several silicon carbide polishing papers. They were then electrochemically polished in a Struers Tenupol-3 jet polisher at a 40º c temperature.

X-ray diffraction

Residual stresses were determined by lattice parameter displacement measurement on the {104} diffracting plane using a SEIFERT MZ6TS diffractometer with CuKα radiation (k = 0.228975 nm) and a PSD detector. Measurements were performed across the weld line on the top surface of the weld. The gauge volume was determined with a 2.2 mm tape mask. The $\sin^2 \Psi$ method was used to determine the residual stresses. Generally it is believed that residual stresses are low in friction stir welds due to low temperature solid-state process of FSW. However, compared to more compliant clamps used for fixing the parts in conventional welding processes, the rigid clamping used in FSW exerts a much higher restraint on the welded plates.



(a)



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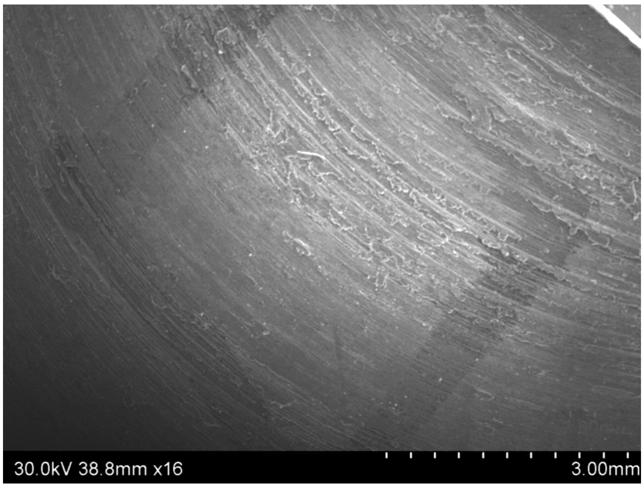

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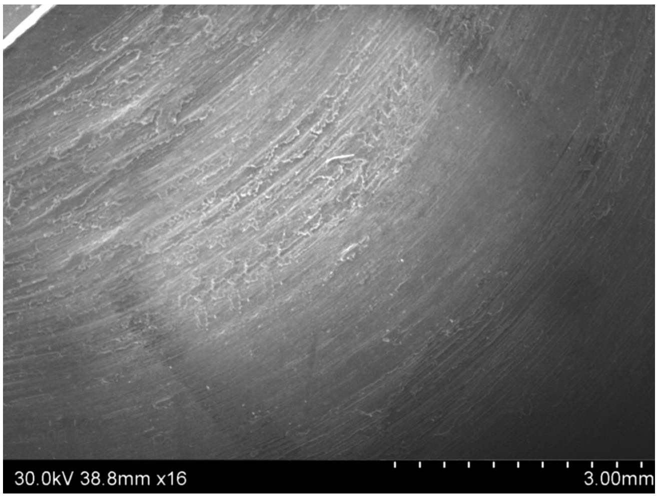

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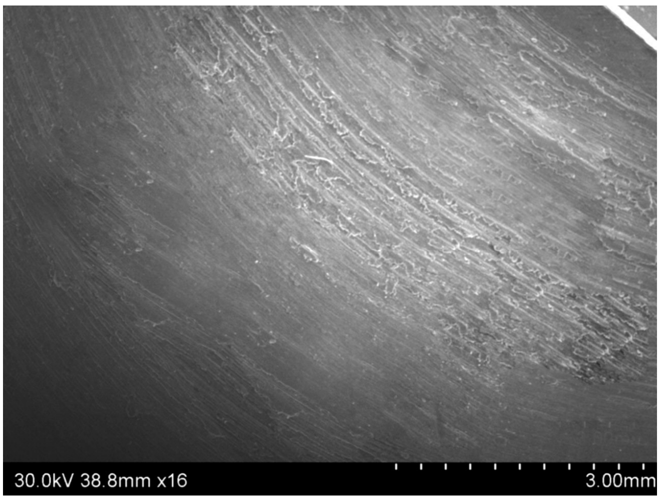

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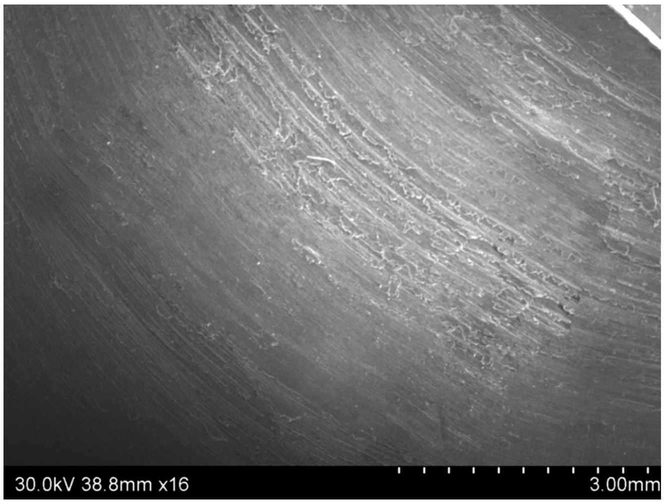
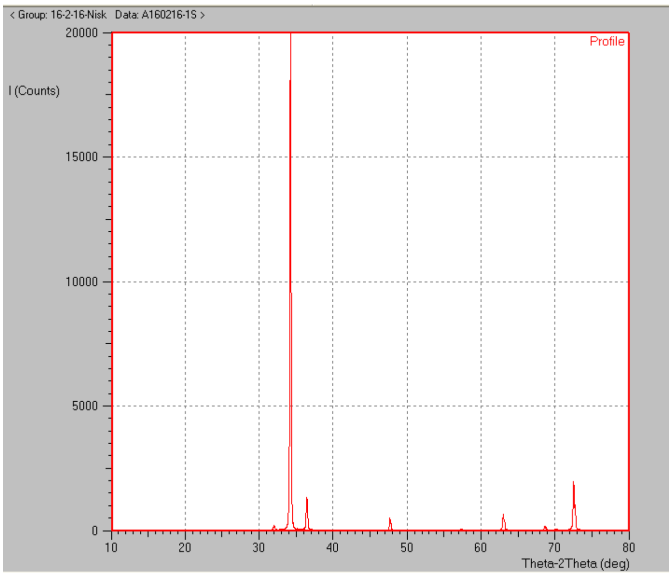


(f)

Figure 6. SEM micrographs of FSP region for SS tool at (i) 900 rpm a) Square b) Tapered cylindrical and c) Triangle (ii) at 1400 rpm d) Square e) Tapered cylindrical and f) Triangle



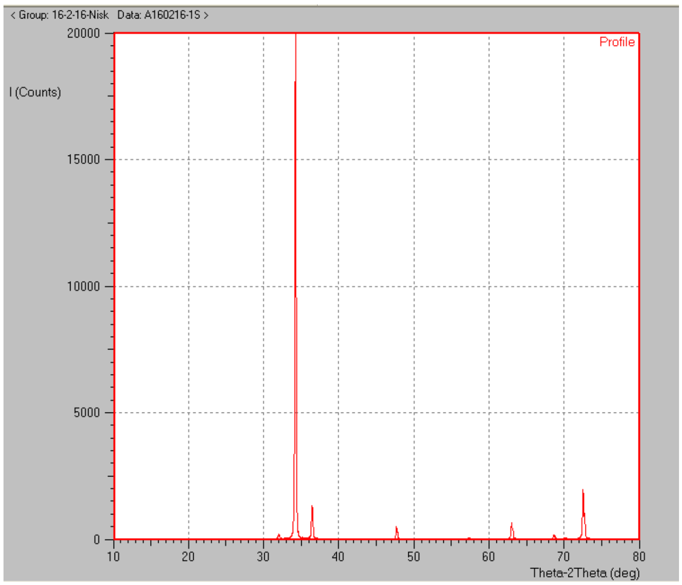


Fig.7. XRD graphs

These restraints impede the contraction of the weld nugget and heat-affected zone during cooling in both longitudinal and transverse directions, thereby resulting in generation of longitudinal and transverse stresses. The existence of high value of residual stress exerts a significant effect on the post-weld mechanical properties, particularly the fatigue properties. Therefore, it is of practical importance to investigate the residual stress distribution in the FSW welds. From the XRD results obtained, it we observed that the residual stresses are along the advancing side from the weld zone line. The lattice points helps to determine the arrangement of atoms along the material, where the x-ray scattering intensities takes place according to the misalignment and grain size across the scan surface. A high peak during the scan indicates the coarse grains and similarly lower peaks indicate the small variation of grain size. Also the uniform grain structures can be identified when frequency is not altered with a constant peak value. Here the negative values are not identified because the nugget zone is scanned, so only positive peaks are displayed.

Conclusion

1. The ultimate tensile strength of the joint is maximum, when tapered cylindrical tool profile is used for both HSS and SS tool materials.
2. Maximum hardness value is obtained at 900 rpm, 1400 rpm for SS and HSS materials respectively for tapered cylindrical tool.
3. Grain refinement takes place during FSW for both SS and HSS materials.
4. Tool geometry, speed, profile and tool material play key role for enhancement of various properties.
5. Weld quality was improved by using optimized parameters taken into consideration and the grain size evolution is consistent with the models developed, taking into account the strain rate and the processing temperature.
6. Grain growth is observed with an increase in the processing parameters that promote heat generation and tool with more heat dissipation capacity generated finer grain structures.

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