Effect Of Friction Stir Processing On Mechanical Properties And Microstructure Of The Cast Pure Aluminum

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Abstract: Friction stir processing (FSP) has the potential for locally enhancing the properties of pure AL. A cylindrical tool with threaded pin was used. the effect of FSP has been examined on sand casting hypereutectic pure AL. The influence of different processing parameters has been investigated at a fundamental level. Effect of (FSP) parameters such as transverse speed (86,189,393) mm/min, rotational speed (560,710, 900) rpm on microstructure and mechanical properties were studied. Different mechanical tests were conducted such as (tensile, microhardness and impact tests). Temperature distribution has been investigated by using infrared (IR) camera; the thermal images were analyzed to point out the temperature degree on limited points. The results show that the heat generation increase when rotational speed increase and decrease when transverse speed increase. Hardness and impact measurements were taken across the process zone(PZ), and tensile testing were carried out at room temperatures. After FSP, the microstructure of the cast pure Al was greatly refined. However, FSP caused very little changes to the hardness of the material, while tensile and impact properties were greatly improved.

Keywords: Friction stir processing,(FSP), Microstructure, Heat Distribution, Mechanical Properties.

1- INTRODUCTION

Recently, a new processing technique, friction stir processing (FSP), was developed by Mishra et al, Friction stir processing (FSP) is based on the basic principles of friction stir welding developed by the Welding Institute (TWI) of United Kingdom in 1991 to develop local and surface properties at selected locations[1],and the following unique features of friction stir welding can be used to develop new processes based on the concept of friction stirring, low amount of heat generated, extensive plastic flow of material, very fine grain size in stirred region, healing of flaws and casting porosity, random misorientation of grain boundaries in the stirred region, mechanical mixing of the surface and subsurface layers . In this case, a rotating tool with pin and shoulder is inserted in a single piece of material, for localized microstructural modification for specific property enhancement [1,2]. Furthermore, the FSP technique has been used for the fabrication of a surface composite on aluminum substrate [3], and the homogenization of powder metallurgy (PM) aluminum alloys, metal matrix composites, and cast aluminum alloys [4,5].

2- EXPERIMENTAL WORK

In this study includes the experimental work used for this research to assess the effect of FSP on the microstructure and mechanical properties of pure Al .The mechanical properties of the material, before and after FSP, were measured via hardness ,impact and tensile testing. The material used for friction stir processing experiment was pure Al throughout this investigation .The chemical analysis of this alloy, as following(Al-99.7%),shown in Table(1).The casting process include sand mould casting for this alloy, were prepared separately by melting, pure aluminum (99.7%) in clay bonded graphite crucible using gas furnace and the melts were held at 660 ˚C with the continuous mixing by graphite mixer until. Mould as size (200mm x 130 mm) plate, with a thickness of 15mm. The material was then air cooled back down to room temperature, therefore due to non-uniform cooling and shrinkage from casting, the surfaces of the plates were rough and uneven. Therefore, in order to generate flat surface for FSP,2mm of material was milled away from the top and bottom surface of each plate before FSP. The friction stir processing experiment has been carried out using tool made from alloy steel (X12)which is tool, bearing and die steel, with chemical composition listed in Table(2). FSP tool is designed and machined as shown in fig.(1). The FSP conditions used with this alloy as shown in table(3). Experiments were limited to seven FSP passes on each plate. Each run was offset by11mm between the next pass as shown in fig.(2). **Uniaxial tensile test** was performed by gripping a specimen at both ends and subjecting it to increase axial load until it breaks. Recording of load and elongation data during the test allows the investigator to determine several characteristics about the mechanical behavior. So to perform tensile test the tensile specimens prepared as follows:1.Cutting 10 mm width pieces from the process zone plates in, parallel to the processing direction, using horizontal milling machine. 2.Making tensile specimens using vertical milling machine according to the ASTM B 557 M-02a sub size specimen geometry shown in Fig.(3).3. Removing thin layer from the top and bottom surface using vertical milling machine. 4.Smoothing the tensile specimens using abrasive paper to ensure there is no surface scratches. **Microhardness testing** was used using a (Digital Microhardness tester HV- 1000) TH-717 type, It is to determine the hardness over small positions on the surface of base metal, TMAZ, HAZ and process nugget to indicate the variation in hardness for each place, in accordance with ASTM E3841. A load of 200 g was employed and loading time was 20 seconds. **The specimens for microstructure test** were prepared in consistent with the standard metallographic techniques. The ultimate objective of such a process was to obtain a flat scratch free, mirror like surface. **The impact tests** were carried out on processed samples using an instrumented pendulum machine. According to ASTM E23, Sub-size charpy V specimens (10 X 5 X 55) mm^3, with 2mm deep V- notch , were used for the tests . **Measurement of heat distribution** One of the key factors that control microstructures is the heat generated during FSP. Therefore, temperature determination of the FSP is of interest in understanding microstructures and properties. Furthermore, diffuse heat source in the (FSP) process and relatively low transverse speed often results in low cooling rate in (FSP). In order to record the temperature field generated during(FSP)infrared(IR)camera.

3. RESULTS AND DISCUSSION

Heat Distribution The temperature distributions during the (FSP) have been recorded by the IR camera which provide with software to analyze the thermal image of process zone .The temperature profile represent the temperature degree along the line perpendicular to the processing line at a length 11 mm. Two points selected (A)and (B) as illustrated in figs.(4,5) to record the peak temperature.

Effect of Rotation Rate and Transverse Speed

The sufficient heat is useful to make defect-free processed, the temperature experienced by the material was seen to be greatest at the interface between the tool shoulder and the workpiece, Furthermore, the process temperature was found to increase with increasing rotation rate, and/or reducing transverse speed, which is not surprising as the rate of energy generation is mainly dependent on the surface velocity of the tool, which has also been found and reported by other authors, experimentally and theoretically [6,7]. Fig.(6) reveal the peak temperature recorded from point (A) after dwell time about (30) second during (FSP),increasing the rotation rate from 560 to 710 RPM was predicted to have increased the peak processing temperature about 18°C, and a similar change to the peak processing temperature about 50°C was also observed when the transverse speed was reduced from 393 mm /min- to 86 mm/ min at a constant rotation rate of 560 RPM, when transverse speed 86 mm/ min has higher peak temperature about 62 °C than transverse speed 393 mm/ min, shown in fig.(7). From fig. (8) shows the temperature on advancing side of process zone was higher than on retreating side, for all conditions employed, with the average difference of 45°C. The difference is a result of asymmetry of the (FSP) process.

Microstructures Prior to FSP

Grain Structure Analysis

Before FSP, the grain structures of pure Al after casting were found to be very coarse. In addition, the grains closer to the surfaces of the plates were also found to be finer than those developed at the centre of the material, due to the higher cooling rate.

Grain Refinement in FSP

Images of a typical FSP track, processed at a transverse speed of 189 mm/ min and a rotation rate of 710 rpm, are shown in fig. (9), where the sample has been anodized, and the region indicating the processed zone (PZ) marked. Fig.(10) shows that the PZ develops several observable features. Firstly, FSP resulted in significant microstructural evolution within and around the processed zone as [8]. A grain size in very small was observed in samples processed with tool travel speed of 189 mm/min and 710 rpm tool rotational speed. The increase in the tool rotational speed causes plastic deformation and thereby intense breaking and redistribution of grains, microstructure after friction stir processing causes an improvement in the mechanical properties of the processed alloy as compared with the parent metal. The contribution of intense plastic deformation and high temperature exposure within the processed zone during FSP results in recrystallization of grains.

Impact Test Results.

The results of the charpy impact test for pure Al as show fig.(11). This significant increase in the total absorbed impact energies can be related to the microstructural changes induced by the FSP, such as grain refinement and dynamics recrystallization of process zone which result in remove strain hardening effect. Another observation of impact results are transverse speed effect, where increasing transverse speed, the absorbed energy decreased due to little rate of softening of process zone and high density of dislocations. Also, increasing the rotational speed results in decreasing absorbed energy similarly as[9]. From fig. (12) of pure Al, the impact test specimen after fracture are bent but not broken apart. This due to high ductility of process zone due to microstructure changes.

Tensile Test Results

In order to determine the tensile strength of the FSP material, tensile samples were cut from the PZ parallel to the transverse direction. The results of the tensile test listed in the table(4) (average values on three tests).the mechanical properties of the as-cast alloy was very poor. Typical stress strain curves shown in fig.(13). It is possible to see that the mean ultimate tensile strength (UTS) of pure Al was only 61 MPa, with total elongation of only 24.8% to failure. This is mainly due to the presence of large pores and large grain size, which existed within the material after casting and acted as crack nucleation and propagation sites [10]. Directly after FSP, the alloys demonstrated significant improvements in tensile properties. The UTS of pure Al were increased to greater than 80MPa, and ductility higher than 30%, which is mainly due to the elimination of porosities and the refinement of the microstructure. Other researchers have shown that the tensile properties of cast pure Al alloy alloys increased with decreasing pore size and density [11]. It is notable that the sample processed at 710 RPM appeared to show better properties than the material processed at 560 RPM. This difference is most likely related to the processing temperature experienced by the material during FSP.

Hardness Test Results.

The hardness values of the original as- pure Al had hardness (31Hv) of cast alloy . After FSP, there appeared to be only small changes in hardness for pure Al within the PZ. It has been demonstrated that refinement of the microstructure resulted in very little influence on the hardness of the material. The results of hardness test for alloy shown in figs.(14,15). The hardness profiles across the PZ of alloy after FSP at different rotation rates are summarised in figs.(14,15).

4. CONCLUSIONS

The mechanisms of particle refinement during FSP of pure Al, and the effect of various processing parameters on particle refinement have been studied in detail. The main findings are summarized below:

1. The microstructure of pure Al was greatly refined after FSP. However, microstructural homogeneity was not necessarily achieved throughout the processed zone.

2. Very little change in material hardness was observed after FSP. It has been shown that the refinement of the microstructure demonstrated very little influence to the hardness of the material.

3. From tensile experiments, the tensile properties of the as-cast pure Al was found to be very poor. Failure was dominated by the link up of voids in high porosity density regions. However, the ductility of the material was greatly improved after FSP

4. For pure Al, impact energies increased in FSP material with respect to the corresponding base metals, from (15J), B.M. impact energy, to (32J) for FSP1, (710 RPM, 189 mm/min).

5. At low rotational and high transverse speeds the amount of heat input has been reduced, so softening effect of tool as it passes the material also reduced.

6. Heat distribution between advancing and retreating sides, where higher peak temperature was recorded in advancing side.

5. REFERENCES

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TABLE 1

Compositions of pure Al used in the experiments.

Alloy	Si	Cu	Ni	Mg	Fe	Mn	Zn	Ti	Zr	V	Pb	Sn	AL
Pure AL	0.0638	0.0008	0.001	0.0029	0.168	0.0005	0.0095	0.001	0.0003	0.0005	0.0005	0.001	99.7

TABLE 2

Chemical composition (weight %) of the FSP tool.

C	Cr	Mn	Si	Fe
2.00-2.30	11.5-13.00	0.30-0.35	0.34-0.40	Rem.

A	M6×1LH
B	21 mm
C	6 mm
D	Ø=31.5, 22turn per inch
E	10°
F	2.96 mm
G	22 mm
H	120mm

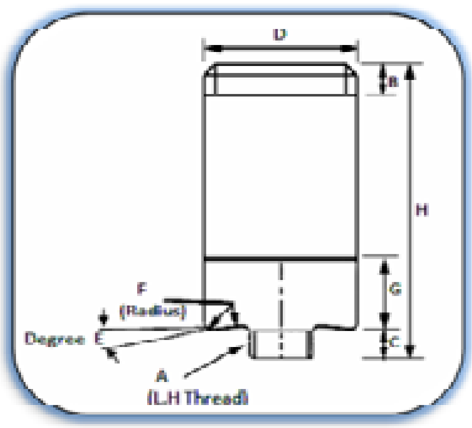

Fig. 1. Dimensions of the friction stir processing

Table 3

the processing parameters used in the investigation.

Alloy	Travel speed (mm /min)	Rotation Speed (RPM) 560	710	900
PURE AL	88	X	X	X
	189	X	X	X
	393	X	X	X

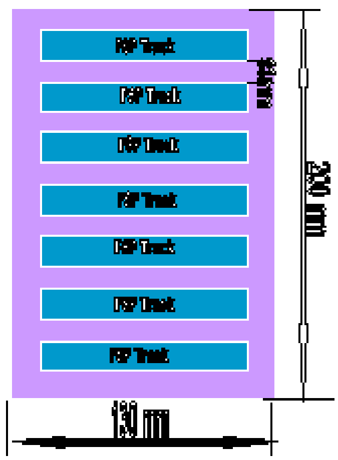

Fig. 2. Schematic representation of the plates used for the experiments, showing the positions of the FSP tracks

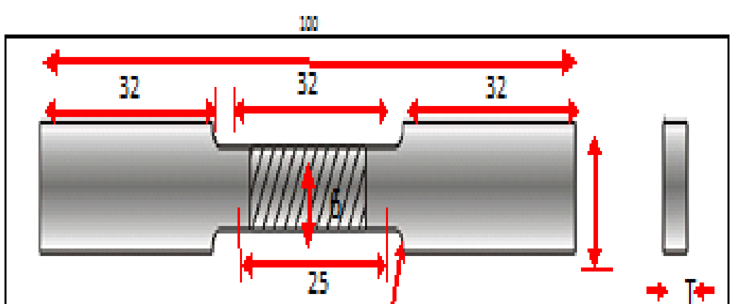

Fig. 3. ASTM sub-size sample for tensile test. (dimensions are in mm)

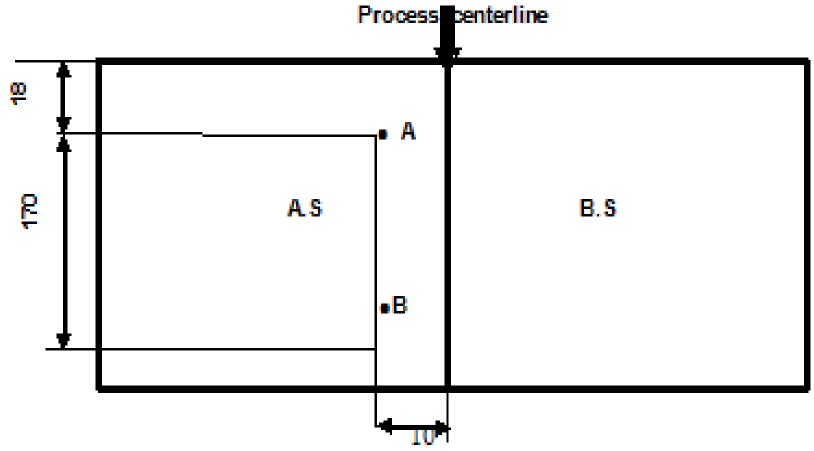

Fig. 4.A and B point at processed plate (dimensions are in mm)..

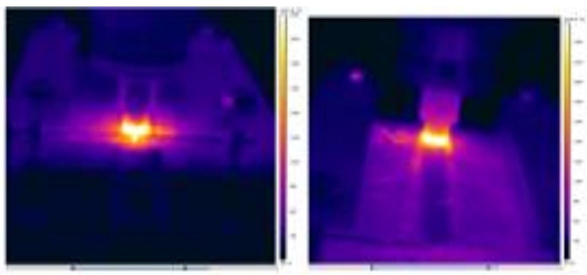

Fig. 5. Thermal image. (a) Thermal image at point A. (b) Thermal image at point B.

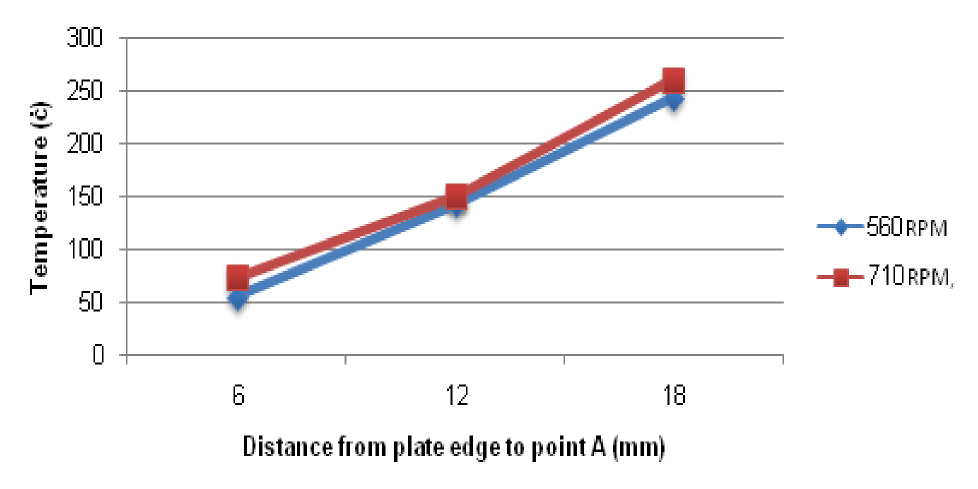

Fig. 6. peak Temperature in point (A) at various conditions.

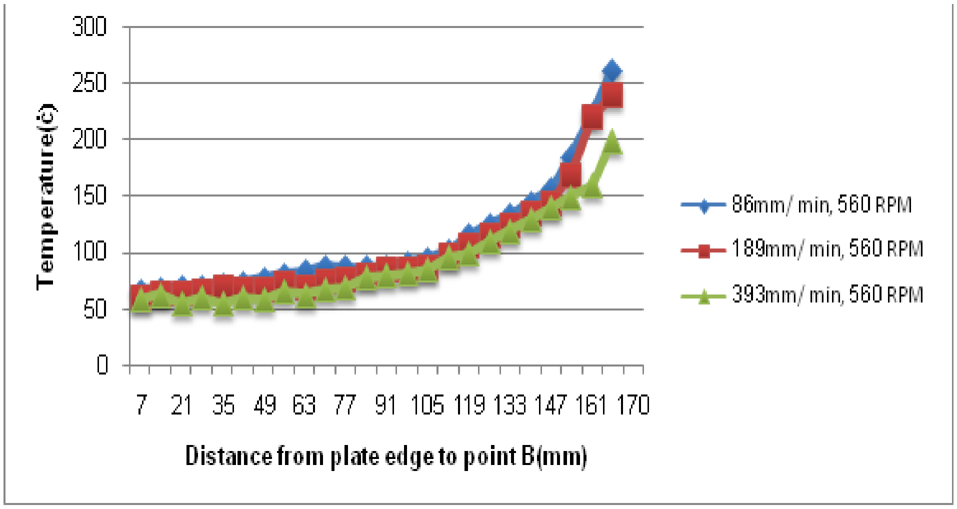

Fig. 7.Peak temperature in point (B) at various conditions.

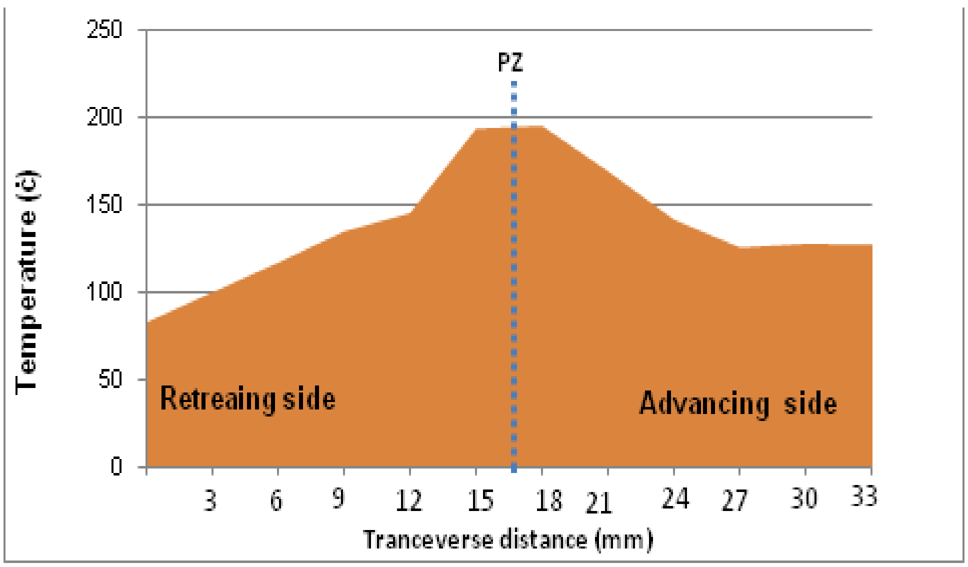

Fig. 8. Heat distribution in advancing and retreating sides for all conditions employed.

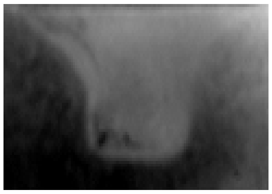

Fig. 9.Images of the cross section from a friction stir processed track, produced in pure Al, using a, transverse speed of 86 mm/ min and rotation rate of 710 RPM. The process zone (PZ) appears 'misty' white in the image .

Fig. 10.Optical micrographs of the (a) original cast microstructure of pure Al ,and after FSP with a 189 mm min-1 travel speed and 710 RPM rotation rate, from (b) the advancing edge and (c) retreating side, at mid-depth of the PZ.

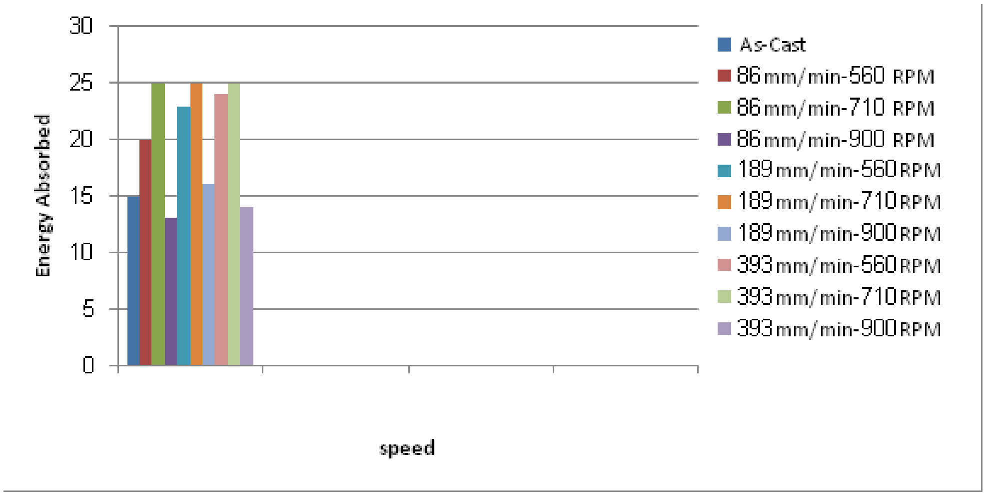

Fig. 11.Interactive Effect of tool rotational speed and transverse speed on energy absorbed of the PZ of pure Al after FSP

Fig. 12. Impact test specimens after fracture.

TABLE 4

Results of the tensile test for pure Al

Sample Number	Tool Rotating Speed (RPM)	Transverse Speed (mm/min)	Tensile Strength (MPa)	Yield Strength (MPa)	Total Elongation (%)
AS CAST			61	50	24.8
AS FSP1	560	86	70	55	21
AS FSP2	710	86	74	57	23
AS FSP3	900	86	65	50	20
AS FSP4	560	189	82	67	30.6
AS FSP5	710	189	80	87	21
AS FSP6	900	189	41	32	9.3
AS FSP7	560	393	84	69	30.5
AS FSP 8	710	393	78	67	20.3
AS FSP9	900	393	60	42	15.7

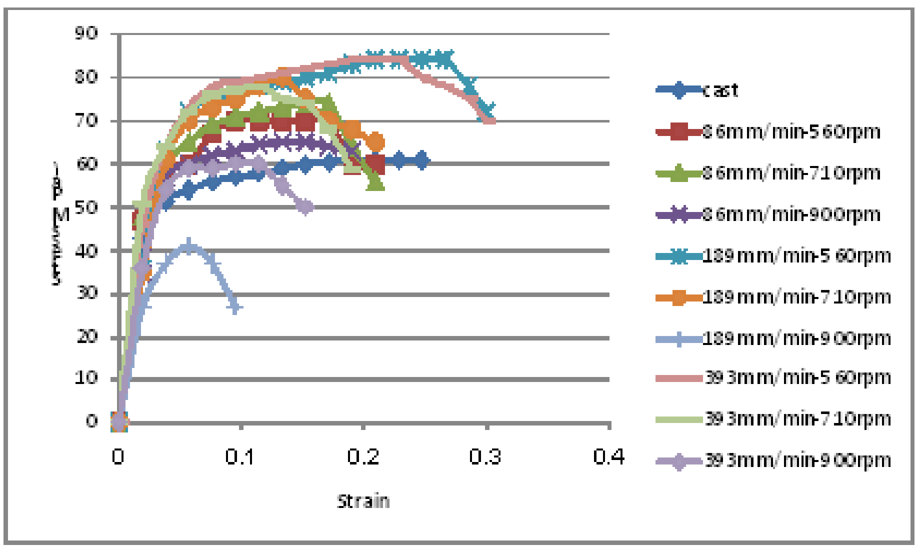

Fig. 13.Typical stress strain curves tested at for pure Al samples friction stir processed at various conditions

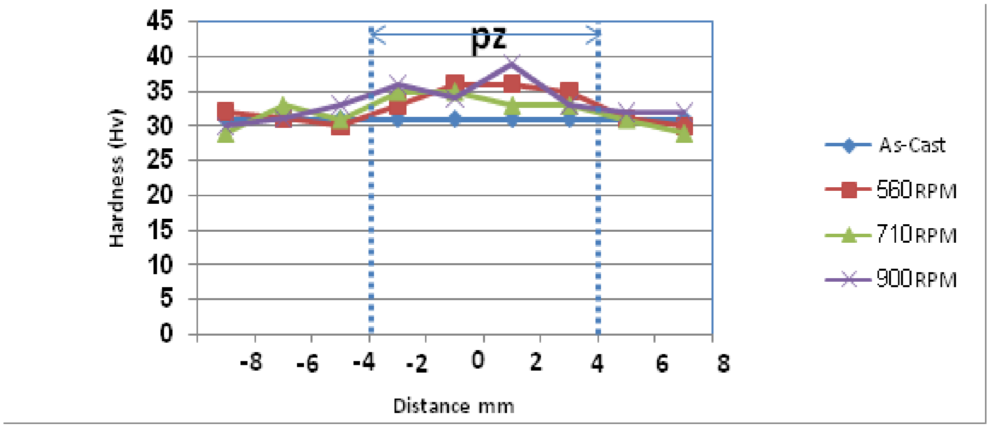

Fig. 14.Hardness profiles across the PZ of pure Al after FSP at a transverse speed of 86 mm/ min and increasing rotation rate

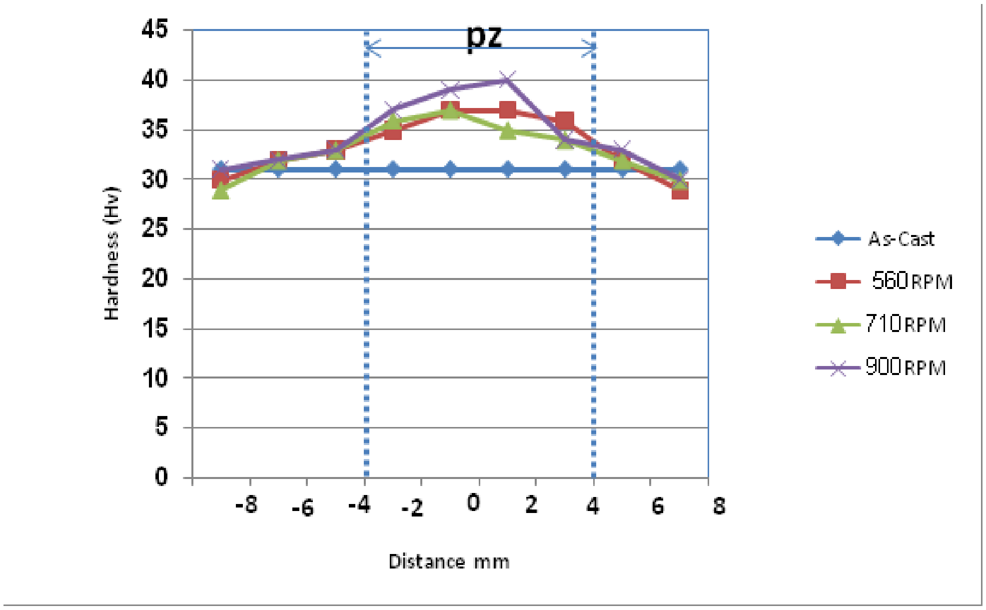

Fig. 15. Hardness profiles across the PZ of pure Al after FSP at a transverse speed of 189 mm/ min and increasing rotation rate