Effect of Friction Stir Processing on Some Mechanical Properties and Microstructure of Cast (Al-Zn-/mg-Cu) Alloy

Jassim Mohammed Salman
University of Babylon, College of Materials Engineering.
jmsmaterials @yahoo.com

Abstract

Friction stir processing (FSP) is an emerging surface engineering technology that can eliminate casting defects locally by refining microstructures, thereby improving the mechanical properties of material. This paper presents the effects of FSP on microstructure and mechanical properties of cast aluminum alloy grade at three different transverse speeds viz. (116, 189 and 303) mm/min under two different rotational speeds 450 and 710 rpm. On processing, the work material was observed to have increased tensile, yield, impact strengths, ductility properties and hardness. The observations have been elaborated in detail along with the microstructures of parent and processed samples. Different heat treatment methods like annealing, normalizing and quenching have been applied to the samples of tensile test to evaluation mechanical properties like ultimate tensile strength, yield strength and percentage of elongation. Also results showed that when rotational speed increase and transverse speed decrease, the temperature was measured increase too.

Keywords: Friction Stir Processing, Heat treatments, Microstructure, Mechanical Properties.

الخلاصة:

عملية المعالجة بالاحتكاك والخلط ناشئة من تكنولوجيا الهندسة السطحية والتي يمكن من خلالها ازالة عيوب السباكة موضعيا عن طريق تعديل أو تنعيم البنية المجهرية وبالتالي تحسين الخواص الميكانيكية للمادة.

البحث الحالي يمثل دراسة تأثير هذا النوع من العمليات على الخواص الميكانيكية والبنية المجهرية لسبيكة ألمنيوم– خارصين– مغنيسيوم– نحاس تحت تأثير ثلاث سرع خطيه هي (١١٦، 189 ،303) ملم / دقيقه وسرعتين دورانيه (450 ،710) دوره/ دقيقة. لوحظ خلال العملية زيادة مقاومة الشد والخضوع ، مقاومة الصدمة ، الاستطالة وارتفاع طفيف في قيمة الصلادة ، وتم وضع الملاحظات بالتفصيل على طول البنية للعينات الاصلية والمعالجة كما تم تطبيق طرائق مختلفة من المعاملات الحرارية مثل التخمير ، المعادلة والاصلاد بالإخماد في الماء لبعض العينات التي بينت تحسنا في الخواص لعملية التخمير فيها .

أظهرت النتائج أيضا زيادة في الحرارة المتولدة خلال العملية عند زيادة السرعة الدورانية ونقصان في السرعة الخطية

الكلمات المفتاحية: المعالجة بالاحتكاك والخلط ،المعاملات الحرارية ، البنية المجهرية ،الخواص الميكانيكية

1 - Introduction

Friction stir welding (FSW), a solid state joining process invented at The Welding Institute (TWI), UK in 1991, is a technique for joining Al alloys [Feng and Ma 2007]. FSP (friction stir processing), a variation of FSW, though applies the same principle, does not join materials but selectively modifies the microstructure of specific areas to improve local properties [Cavaliere, 2005.Oh-Ishi and Mcnelley 2005]. For FSP, a location within a plate or sheet is selected and a specially designed rotating tool is plunged into the selected area. The tool has a larger diameter shoulder with a concentric small diameter pin. The rotating pin contacts and friction heats the surface as it descends to the part. When shoulder contacts the work surface, its rotation causes additional frictional heat and plasticizes a larger cylindrical metal column around the inserted pin. The area to be processed and the tool are moved relative to each other such that the tool traverses, until the entire selected area is processed to a fine grain size with the material transported from the leading to the trailing face of the pin. As the processed zone cools without solidification, it forms a defect free recrystallized fine grain microstructure [Ma et al 2006]. The process is illustrated in Fig. 1. The process has been successfully applied to modify the grain structure of various cast metals to improve the mechanical properties and also induce super plasticity

[Elangovan and Balasubramanian 2007,Santella et al 2005,Cavaliere and Squillaace 2005,]. For example in cast A356, FSP was applied to refine the microstructure and increases in the yield strength were observed [Ma et al 2006]. A319 alloy also had significant increase in the yield strength, ductility and hardness on friction stir processing [Santella et al 2006]. Super plasticity was also observed in the friction stir processed A356 and Al7075 alloys [Cavaliere and Squillaace 2005,Ma et al 2004]. Hence in this paper an attempt to study the effect of FSP parameters on mechanical properties and microstructure and also investigate the post weld heat treatment like annealing ,normalizing and quenching on (Al- Zn-Mg-Cu) alloy followed by tensile test .

2- Experimental Work

A-Alloy preparation

The alloy (Al-Zn-Mg-Cu) was prepared by mould casting process. The chemical composition of this alloy as shown in table (1). The casting process include firstly melting pure Aluminum at 700 °C in graphite crucible before addition elements in percentage required, the elements surround by aluminum foil to immersed in melting, the melting was mixed by ceramic mixer inside the furnace, the product alloy was air cooled to the room temperature .The three plates of the size of (188×١٢× ١٢٠) mm^3 were prepared to FSP.The tool of FSP made of alloy steel X12, shoulder diameter (16) mm, pin diameter (6) mm and (6) mm pen length. The FSP conditions used with this alloy as shown in table (2), eight FSP passes on each plate and (12) mm distance between each two samples.

B- Mechanical tests

-Tensile test:

The tensile samples prepared by cutting 10 mm width pieces from the PZ plates in parallel to the direction of processing by using vertical milling machine according to the ASTM B557M shown in Figure 2 .Grinding and polishing were done before subject samples to tensile test .

-Hardness test:

AVickers microhardness testing machine was type { TH-717 Digital Microhardness tester HV- 1000}used to conduct the test with load 200 grams for 20 seconds. The hardness determined at base metal, TMAZ, HAZ and process zone.

-Impact test:

Impact testing was performed on charpy testing machine using 55 mm length with 45° V- notch,2 mm deep with 0.25 mm root radius were used for the test according to ASTM E32.

C- Heat treatments methods

-Annealing process.

In this method, the samples of tensile test are heated in the muffle furnace up to 480°C and holding the same temperature for a period 2 hours. In order to get homogeneous structure and then cooled the furnace to the room temperature.

-Normalizing process.

In this method, the samples of tensile test are heated in the muffle furnace up to 480°C and holding the same temperature for a period 2 hours. In order to get homogeneous structure and then cooled the air to the room temperature.

-Hardening process.

In this method, the samples of tensile test are heated in the muffle furnace up to 480°C and holding the same temperature for a period 2 hours. In order to get homogeneous structure and then cooled the water to the room temperature.

D- Optical microscope

Standard metallographic examination using optical microscope type (union ME-3154) was used to reveal the samples structure .The samples surface was etched with solution (Keller's reagent) for 20 seconds.

3- Results and Discussion

A- Mechanical properties analysis

Table (3) summarizes the mechanical properties (tensile, hardness and impact) values of alloy and friction stir processed samples corresponding to different transverse speeds and tool rotational speeds. During friction stir processing, as the casting defects are eliminated in the processing zone. Stress–strain curves for the various transverse and tool speeds are shown in Fig. 3. The improvements in mechanical properties of the material as a consequence of the stirring properties are demonstrated by the room temperature tensile properties. With the increase in tool speeds, for a specific feed, improved mechanical properties have been observed [Elangovan and Balasubramanian 2007]. Increased tool rotation rates resulted in enhanced mechanical properties due to reduced porosity and grain size. This is because at higher tool rotation rates, an increased frictional heating and stirring is present which creates a higher temperature in the process zone. The rise in temperature causes a greater refinement of grains with more thorough material mixing and a uniform distribution of the grains in the parent material, thus enhanced mechanical properties were observed [Ma ZY et al 2006]. At lower tool rotation rates, lower heat input conditions are observed causing a reduced refinement of grains. An increase in feed rate, for a particular speed reduces the time of exposure of material to increased temperatures, thus comparatively less refined grains and a slight decrease in output, though considerably higher than parent material. Specimens showed considerable increases in ductility. The increases in the ductility can also be attributed to the same reasons. This study agrees with a previous study reporting an improvement in tensile strengths and ductility in aluminum alloys on friction stir processing [Nakata et al 2010].After heat treating at 480 °C, The results of the tensile test listed in the Table (4), Typical stress strain curve shown in figs.(4,5) , an improvements heat treatment samples tensile test which annealed condition compared to others (Normalizing and Quenching) due to the grain refinement of the FSP .The percentage of elongation is maximum for annealing condition .It is found that the softens through FSP which results degradation of the mechanical properties[Cavaliere and Demarco 2012].

The variations in the hardness values at various distances from nugget centerline are given in Figs. 6-8. The hardness is very different as measured location, and stir zone hardness is slightly increased and showing relatively uniform distribution [Cavaliere and Demarco 2012]. These kinds of tendencies are most likely to be due to recrystallized and fine grain structure, due to softer processed during FSP[Su et al 2003].If rotational speeds increased the grain size reduced and then hardness values increased [Fuller et al 2011]. Results showed that also the values of hardness are similarly to the cast alloy if distance from PZ increased.

The maximum charpy impact energy of PZ was 25J as compared to 12J for the base cast alloy. This significant increase in the absorbed impact energy can be attributed to the consider able decrease of an order of magnitude in the grain size of others rotation and transverse speed [Jian et al 2011].As can be seen from fig(9)increasing rotation speed decreasing absorbed energy .

Fig.(10)Shows the temperatures at various distances from the process zone at 450 and 710 rpm with different transverse distance from the process zone. The fig. show that higher rotational speed higher temperature generation in the process zone.

B- Microstructure analysis

The fig. (11) Shows the structure of as cast alloy, it was showed very coarse grains, and the fig. (12) shows the same alloy of the FSP ,(a) represent PZ generated with transverse speed of 189 mm/min and rotational speed of 710 rpm .(b) retreating side and (c) represent advance side ,(d) &(e) as cast alloy .in fig. (12) three zones with different microstructure can be distinguished: (1) PZ nugget center line, (2) thermo mechanical affected zone (THAZ) (3) heat affected zone the microstructure change can be attributed to break and uniform distribution of particles in nugget zone by stirring active of rotating and traversing tool.

The TMAZ showed elongated and distorted grains without recrystallization, grain structure of HAZ was similar to as cast alloy except that aluminum grains were significantly coarsened as [Rajeswarir and Itharaju 2013].

4- conclusions

The results of mechanical test and microstructure of FSP can be summarized in the following conclusions:

1- The FSP results in significant grain refinement of the microstructure alloy, and it was controlled by the rotation and transverse the tool.
2- HV variations are relatively small.
3- Improvement tensile strength, yield strength and percentage elongation during FSP.
4- Energy absorbed (12) J at base cast alloy with compared (25) J in FSP.
5- The maximum tensile strength and percentage of elongation was observed with annealing process of the FSP.

5- References

Cavaliere P. 2005" Mechanical properties of Friction stir processed 2618/Al2O3/20p metal matrix composite". Compos Part A – Appl. Sci. Manufact;36: 1657–65.

Cavaliere P, and Squillace A2005. "High temperature deformation of friction stir processed 7075 aluminum alloy". Mater. Charact;55:136–42.

Cavaliere P, and Demarco PP2012." Friction stir processing of a Zr modified 2014 aluminum alloy". Mater. Sci. Eng. A;462:209.

Elangovan K, and Balasubramanian V2007". Influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminum alloy". Mater. Sci. Eng. A;459:7–18.

Feng AH, and Ma ZY2007." Enhanced mechanical properties of Mg–Al–Zn cast alloy via friction stir processing". Scripta Mater;56:397–400.

Fuller MD, Swaminathan S, Zhilyaev AP and Mcnelley TR2011. "Microstructural transformations and mechanical properties of cast NiAl bronze: effects of fusion welding and friction stir processing". Mater. Sci. Eng. A;463:131.

Jian-Qing Su,Wnelson Tracy, and J Sterling Colin2011. "Microstructure evolution during FSW/FSP of high strength aluminum alloys". Mater. Sci. Eng. A;405:280

Ma ZY, Mishra RS and Mahoney MW 2004. "Super plasticity in cast A356 induced via friction stir processing". Scripta Mater;50:931–5.

Ma ZY, Sharma SR, Mishra RS 2006. "Effect of multiple-pass friction stir processing on microstructure and tensile properties of a cast aluminum–silicon alloy". Scripta Mater;54:1623–6.

Ma ZY, Sharma SR ,and Mishra RS 2006. "Effect of friction stir processing on the microstructure of cast A356 aluminum alloy". Mate.r Sci. Eng. A 2006ii;433:272.

Nakata K, Kim YG, Fujii H, Tsumura T and Komzaki T 2010. "Improvement of mechanical properties of aluminum casting alloy by multi-pass friction stir processing". Mater. Sci. Eng. A;437:274–80.

Oh-Ishi Keichirro and Mcnelley Terry 2005"The influence of friction stir processing on microstructure of As cast Ni Al Bronze". Metall. Mater. Trans. A;36A: 1575–85.

Rajeswariir and.itharaju. 2013 "friction stir processing of aluminum alloys", University of Kentucky, itharaju@engr.uky.edu

Santella ML, Engstrom T, Storjohann D and Pan TY 2005. "Effects of friction stir processing on mechanical properties of the cast aluminum alloys" A319 and A356. Scripta Mater;53:201–6.

Su, J.-Q., Nelson, T.W., Mishra, R.and Mahoney, M. 2003 "Microstructural investigation of friction of friction stir welded 7050-T651 aluminum", Acta Materialia; 51: 713-729

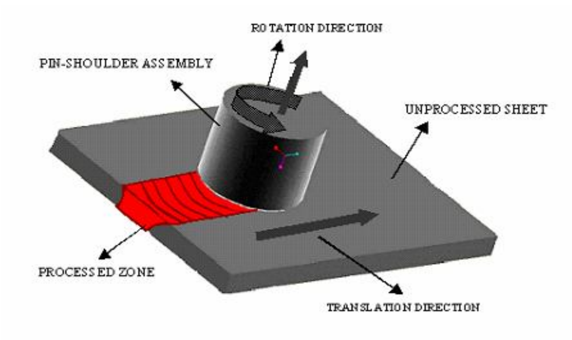

Fig. 1: Schematic of friction stir process [Ma ZY et al 2006]

Table (1): Chemical composition of (Al-Zn-Mg-Cu) alloy (wt%)

Elements	Zn	Mg	Cu	Fe	Mn	Ni	Ti	Zr	V	Pb	Sn	AL
%	1.2	0.5	0.2	0.0037	0.0005	0.0052	-	-	-	-	-	Bal.

Table (2): The processing parameters.

	Rotation speed(rpm)	
Travel speed (mm min-1)	450	710
116	X	X
189	X	X
303	X	X

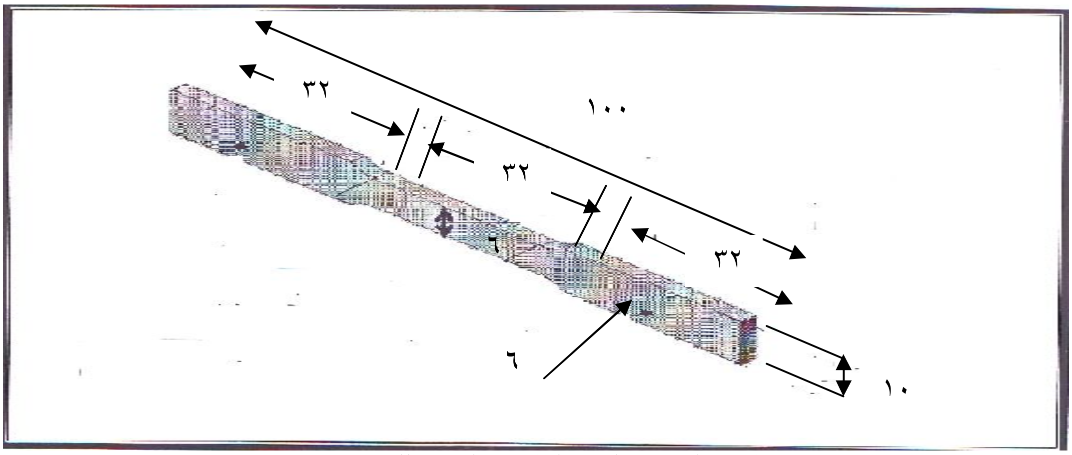

Fig. (2): Tensile specimen**.** (Dimensions are in mm)

Table (3): Results of evaluation of mechanical properties for alloy, samples friction stir processed at various .condition.

Impact (J)	Hardness (HV)	Total Elongation (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Transverse Speed (mm/min)	Tool Rotating Speed (rpm)	Sample Number
١٢	٥٩	14	70	77			AS CAST
١٥	٦٦	39	78	80	116	450	FSP1
٩	٦٩	10	70	١٤٠	116	710	FSP2
٢٥	٦٤	19	81	109	189	450	FSP3
٨	٦٥	24.6	81	١١٤	189	710	FSP4
١٣	٦٠	7.2	75	77	303	450	FSP5
٧	٦٢	5.8	80	82	303	710	FSP6

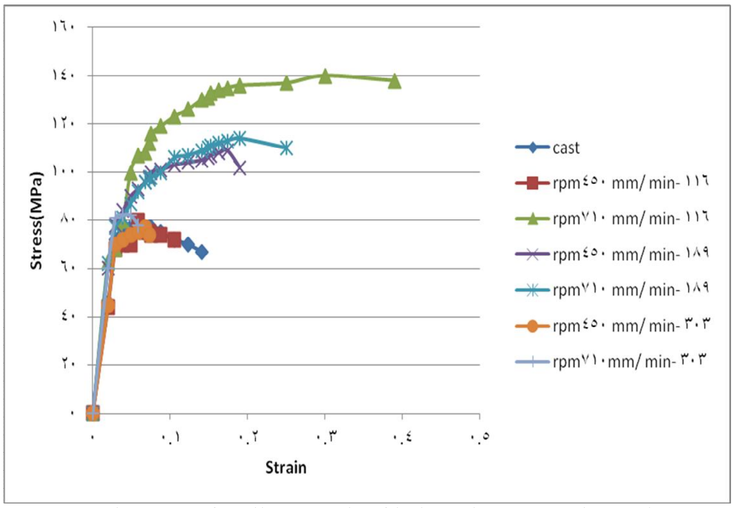

Fig. 3: Stress strain curves for alloy samples friction stir processed at various condition.

T able (4): Results of the tensile test for alloy samples friction stir processed at various conditionn after different heat Treating process..

Total Elongation (%)	Yield Strength (MPa)	Tensile Strength (MPa)	Transverse Speed (mm/min)	Tool Rotating Speed(rpm)	Samples condition
14	70	77			AS CAST
18	67	80	116	450	480 ˚C for 2 hrs. (Annealing)
8.8	٧٠	٧٨	116	710	480 ˚C for 2 hrs. [Normalizing]
7.4	٦٢	66	189	450	480 ˚C for 2 hrs. [Quenching(water)]
14	٦٥	٨٥	189	710	480 ˚C for 2 hrs. (Annealing)
13	67	82	303	450	480 ˚C for 2 hrs. [Normalizing]
10.3	65	77	303	710	480 ˚C for 2 hrs. [Quenching(water)]

.

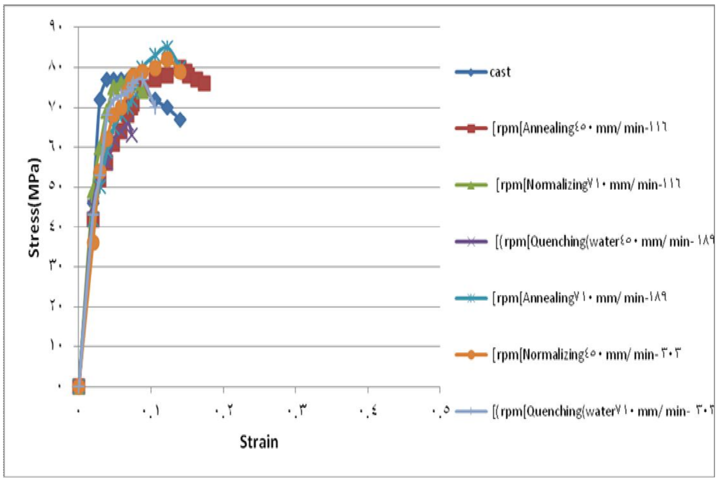

Fig. 4 ; Stress strain curves alloy samples friction stir processed at variousconditions after different heat treating process.

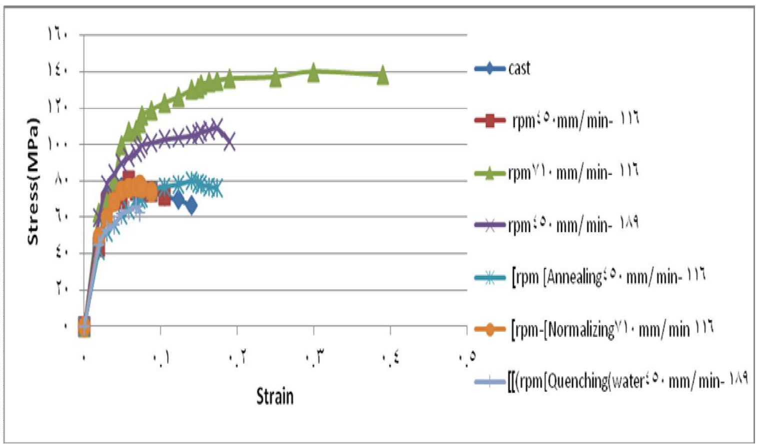

Fig. 5: Stress strain curves alloy samples friction stir processed at various condition before and after different heat treating process.

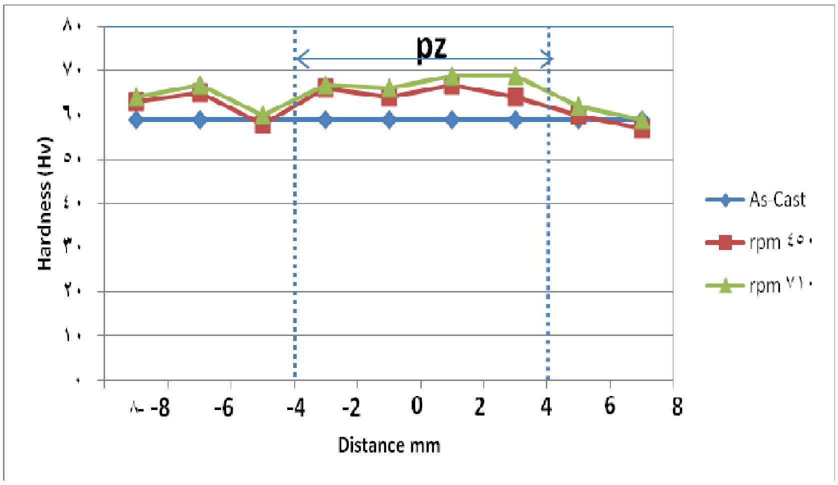

Fig .6: Hardness profiles across the PZ after FSP at a transverse speed of 116 mm min-1 and increasing rotation rate.

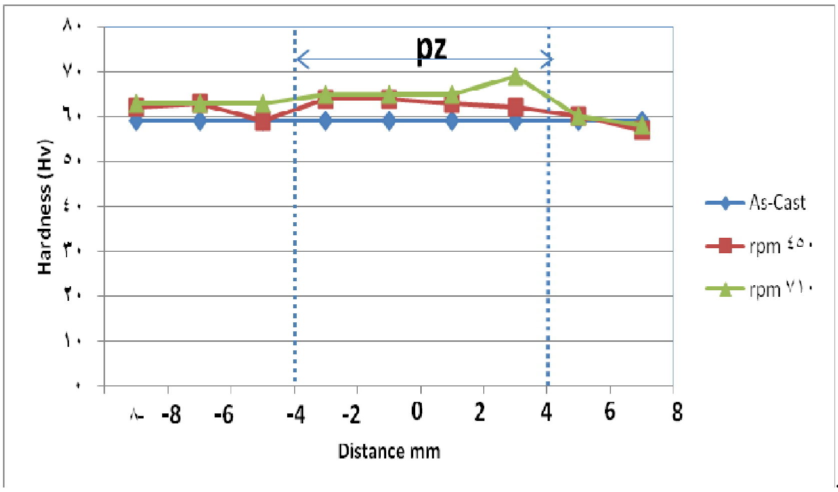

Fig.7: Hardness profiles across the PZ after FSP at a transverse speed of 189 mm min-1 and increasing rotation rate.

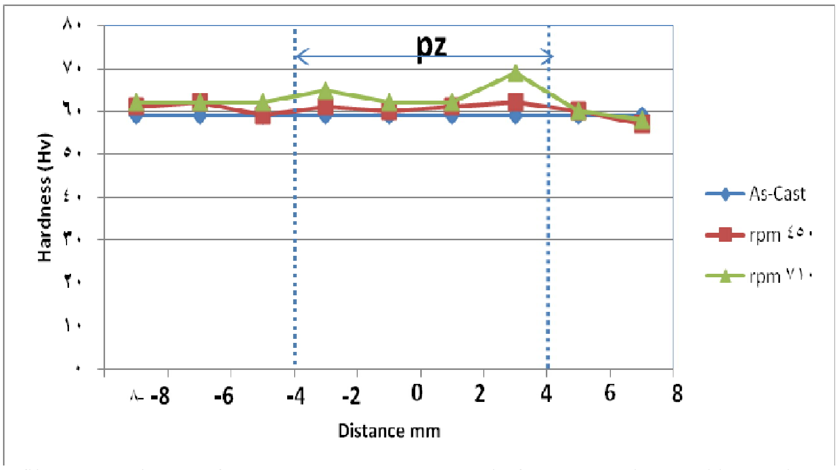

Fig.8; Hardness profiles across the PZ after FSP at a transverse speed of 303 mm min-1 and increasing rotation rate.

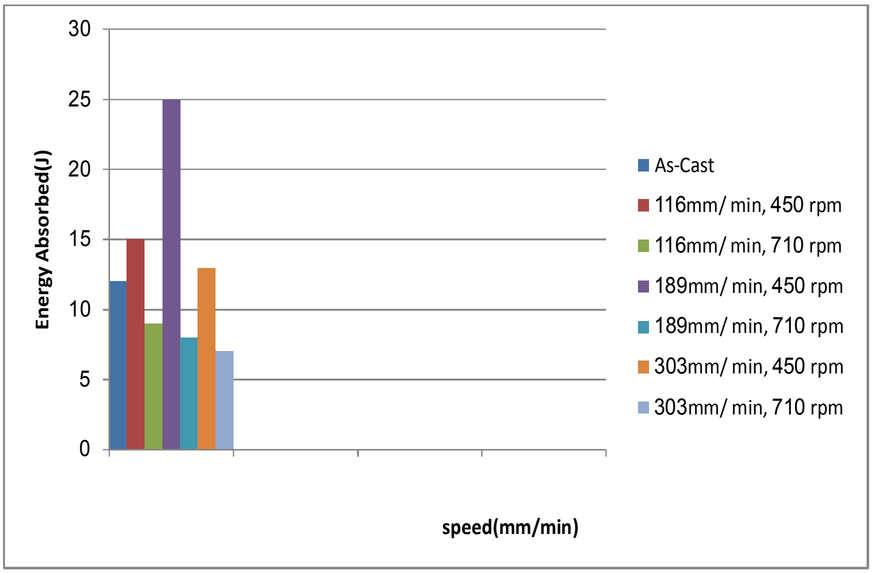

Fig.9: Effect of tool rotational speed and transverse speed on energy absorbed of the PZ after FSP**.**

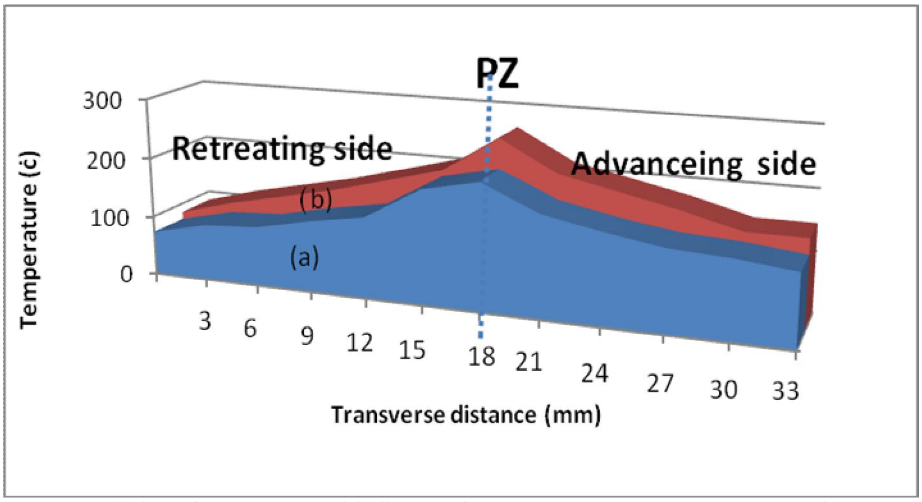

Fig.(10): Variation of temperature with distance from process center. at (a) 450 rpm. (b) 710 rpm

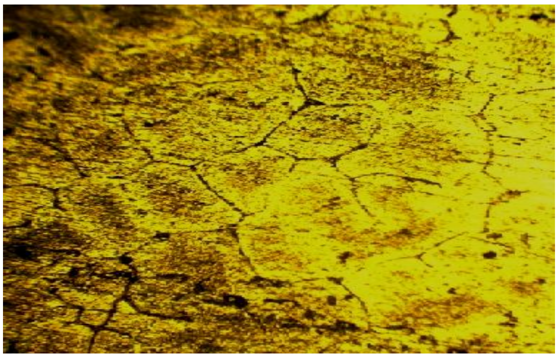

Fig. 11: Microstructure of Al cast alloy (40X)

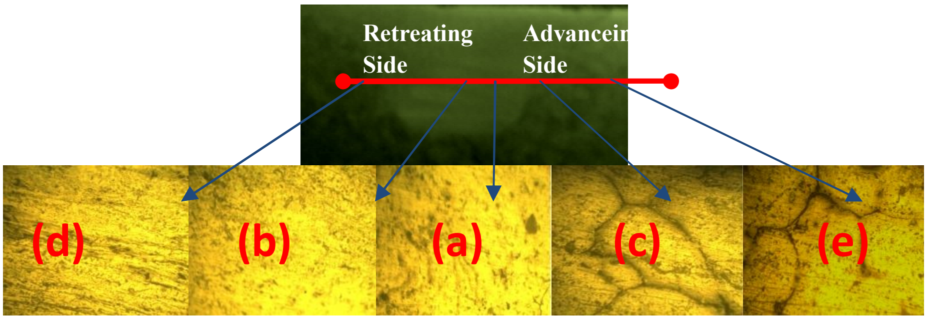

Fig.12: Microstructure generated with a transverse speed of 189 mm min-1 and a rotation rate of 710 rpm shows (40X): (a) nugget zone (b) the retreating side (c) the advancing side. (d)& (e) base alloy (as cast)