

Effect of Friction Stir Processing on (2024-T3) Aluminum Alloy

Fadhel A. Hashim¹, Raid K. Salim², Basheer H. Khudair³

Asst. Prof. Materials Engineering Department, University of Technology, Baghdad, Iraq¹.

Asst. Prof. Babylon Technical Institute, Al-Furat Al-Awsat Technical University, Babylon, Iraq².

P.G. Student, Welding Engineering Department, Engineering Technical College-Baghdad, Middle Technical
University, Baghdad, Iraq³.

ABSTRACT: In this work, friction stir process (FSP) was used to enhance surface properties of AA2024-T3 alloy. The effect of friction stir shoulder rotation in addition to its pressing effect on surface topography and mechanical properties was studied. Samples were FS processed with a flat pinless cylindrical shoulder of 10mm diameter with a constant rotational and travel speeds 945 rpm and 85mm/min respectively. Results show that processed layer thickness of about 45 μm was produced after FSP. Microscopic examinations (OM and SEM) revealed refining grain size of second phase particles as a result of mixing effect of the tool. XRD results show changes in the height and width of the strengthening phase $\theta(\text{Al}_2\text{Cu})$ peaks, while EDX results show that Al and Cu created at another energy (KeV) compared with those that are not in phase before FSP. The maximum hardness increment is about 40-45% and the maximum value obtained at the surface is 190Hv compared to 130Hv before processing. A little bit increase was recorded in yield and tensile strengths by an amount of 15% and 9% respectively after FSP.

KEYWORDS: Friction Stir Processing (FSP), SFSP, Thermo-mechanical Processing (TMP), AA2024-T3, Al_2Cu .

I. INTRODUCTION

The strong requirement for weight reduction in aircraft and car fabrication urges for the design optimization of products employing low weight materials. Aluminum and its alloys including AA2024 (aluminum-copper alloy) are used extensively in aerospace and automotive industries because of their low density and high strength to weight ratio [1], Al-Cu alloy is a high-strength alloy in which a heterogeneous microstructure is obtained by thermo-mechanical processing (TMP) to obtain optimal mechanical properties [2]. Al_2Cu is the major intermetallic in Al-Cu alloys, which imparts strength to this alloy at the same time decreasing the corrosion resistance due to the formation of galvanic cells between the noble Al_2Cu and the Al matrix. Improvement of the surface properties of the aluminum alloys can be done by a variety of processes like thermo-mechanical treatment (TMT), equal-channel angular processing (ECAP), high pressure torsion (HPT), accumulative roll bonding (ARB), etc., all of which can be used to produce a fine grain size, are complex and time consuming, e.g., during TMT a solution treatment, over-aging, reducing the thickness reducing the thickness of plates, etc. and are involved, with a resultant reduction in the overall economy of the process [3]. In addition, none of these processes are capable of producing localized surface modification. So that, Friction Stir Processing (FSP) were the first to use by Mishra et al. [4] in (1999), as TMP for super-plasticity, and then was developed by Mishra et al. (2003) Microstructural modification and fabrication of matrix composites [5], and recently by Mishra and Mahoney (2004)[6] superplasticity enhancement and forming process. FSP is an emerging surface engineering technology based on the principles of Friction Stir Welding (FSW), where a nonconsumable rotating tool (with/or without pin) and shoulder is inserted into a single piece of material and traversed along the desired path to cover the region of interest. It relies on solid-state deformation. During this process, the severe plastic deformation and thermal exposure of material, results in a significant evolution in the local microstructure, also eliminates inherent defects in the starting material and thereby improves its strength, ductility, corrosion resistance, fatigue resistance, formability, and a host of other properties [7].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

It is worth mentioning that the development of two types of material modification has been carried out; the first, in-volume FSP (VFSP) is based on the full thickness modification and second the surface FSP (SFSP), or Friction Surface process as named by Ben James M. (2010) [8] is based on the modification of materials surface up to 2 mm depth [5]. Current research relies on the surface FSP (SFSP).

B. Zahmatkesh et al.(2010) [1]study the effect of FSP as a means to enhance the near-surface material properties of AA2024-T4, the results show that FSP was beneficial to improvement of hardness and wear resistance. XRD patterns show dissolution of CuMgAl₂ particles in NZ as a result of an increase in temperature, Mg with bigger atomic radius dissolved to Al lattice and rejection of Cu with lower atomic radius and formation of Al₂Cu.

L. Karthikeyan et al.(2011) [7]studied the effects of FSP on microstructure and mechanical properties of cast aluminum alloy of 2285 grade. Results show improved mechanical properties have been observed for all parameters.

II. MATERIALS AND METHODS

The material used in this work is AA2024-T3 alloy with the nominal composition in wt.% shown in Table 1. The AA2024-T3 plates (250×100×5 mm in size) were friction stir processed, with a classic vertical milling machine at constant rotation and travel speeds of (945 rpm and 85 mm/min) with a non-consumable tool made of tool steel have a shoulder diameter of 10 mm without pin. The tool inserting depth was 0.25 mm in a 5 mm thick plate.

Table 1 Chemical composition of AA2024-T3 (as received)

Element	wt%
Cu	4.67
Mg	1.50
Mn	0.644
Fe	0.211
Si	0.050
Cr	0.003
Zn	0.073
Ti	0.029
Ni	0.002
Ga	0.0005
V	0.008
Al	remainder

The microstructural analysis of the friction stir processed samples was carried out by optical microscope and scanning electron microscope (SEM), samples were etched with Keller's reagent to reveal the grain boundaries. Microhardness measurements were carried out using (Zwick/Roell Z HV) Vicker's micro hardness tester at 50g load for 15s according to ASTM-E384. The readings were taken starting from the center of friction stirred zone near the surface, the other readings were distributed as a straight line to the left and right of the center, the interval between the neighboring measurements is 1mm, Fig. (1). Transverse tensile specimens were prepared for the base metal and friction stir processed samples according to ASTM (B557M), test was carried out by (Tinius 200 super L) computerized universal testing machine. In order to analyze the phases of the samples a Philips diffractometer (40 kV) with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) was used for X-ray diffractometry (XRD) measurements. The XRD patterns were recorded in the 2 θ range of 10-90° (step size 0.05° and time per step 1s).

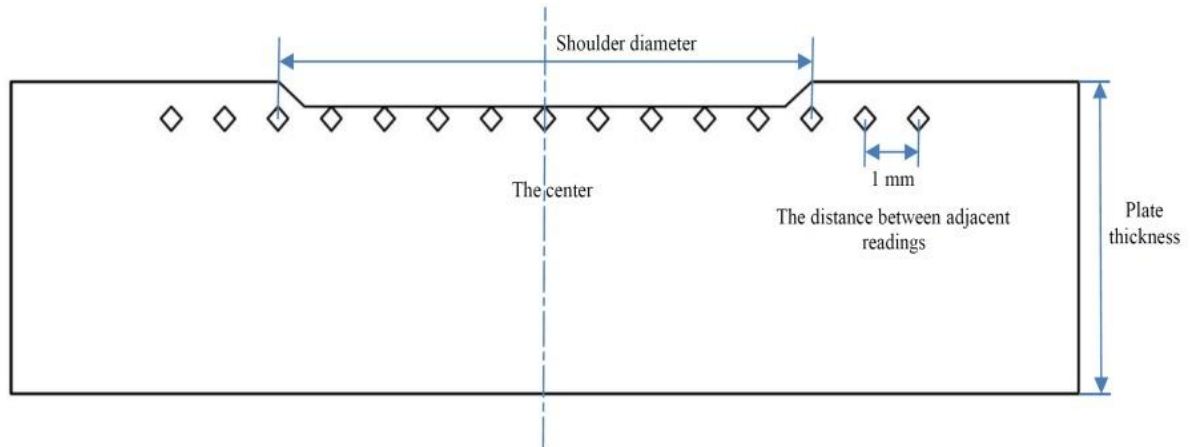


Fig. 1 Microhardness readings procedure

III. RESULTS AND DISCUSSION

1. Friction Stir Processed Layer

The as-received aluminum 2024-T3 alloy consisting of large elongated grains with an average grain length of $192\ \mu\text{m}$ and length to thickness ratio (aspect ratio) of 3.09, with large particles of precipitates distributed non-homogeneously as shown in the optical and scanning electron micrographs Figures (2) and (3).

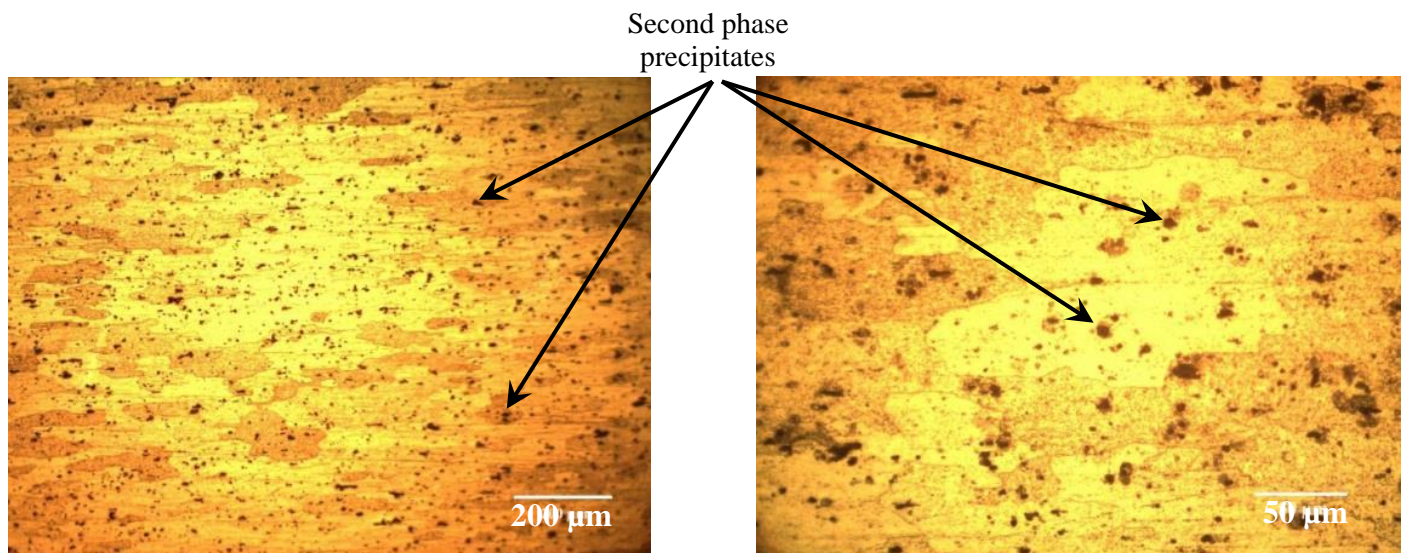


Fig. 2 Base metal optical micrographs at different magnification powers.

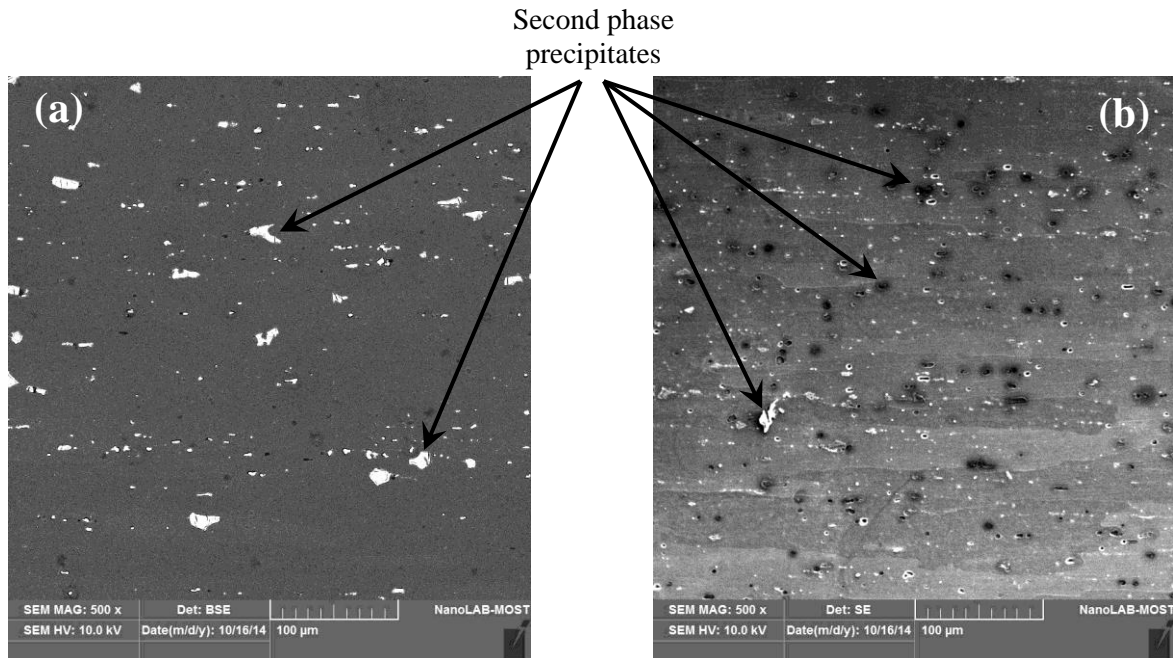


Fig. 3 SEM micrograph of the base metal (a): backscattered electrons (BSE) micrograph and (b):secondary electrons (SE) micrograph

Due to the rotating and pressing effect of the friction stir tool shoulder on the plate surface and heat generated due to plastic deformation, a surface stirred layer (modified surface) will be produced underneath the tool shoulder to about micrometers level, Fig. (4). Adem Kurt et al. [5] produced the same layer properties on the plate surface of 1050 aluminum alloy by using a plain cylindrical shoulder without pin in their research (Surface modification of aluminum by friction stir processing).

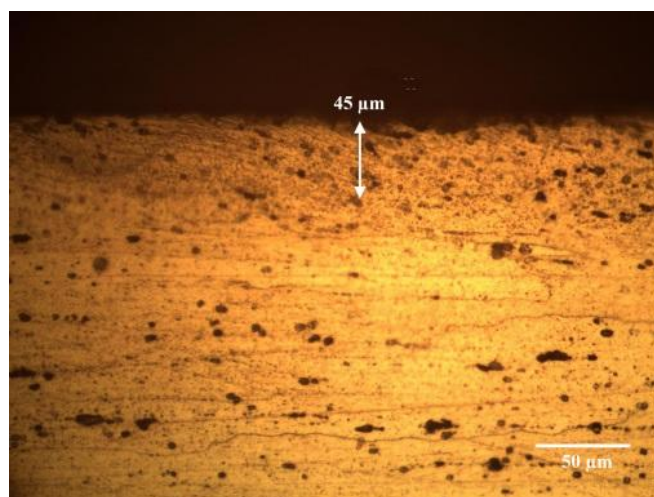
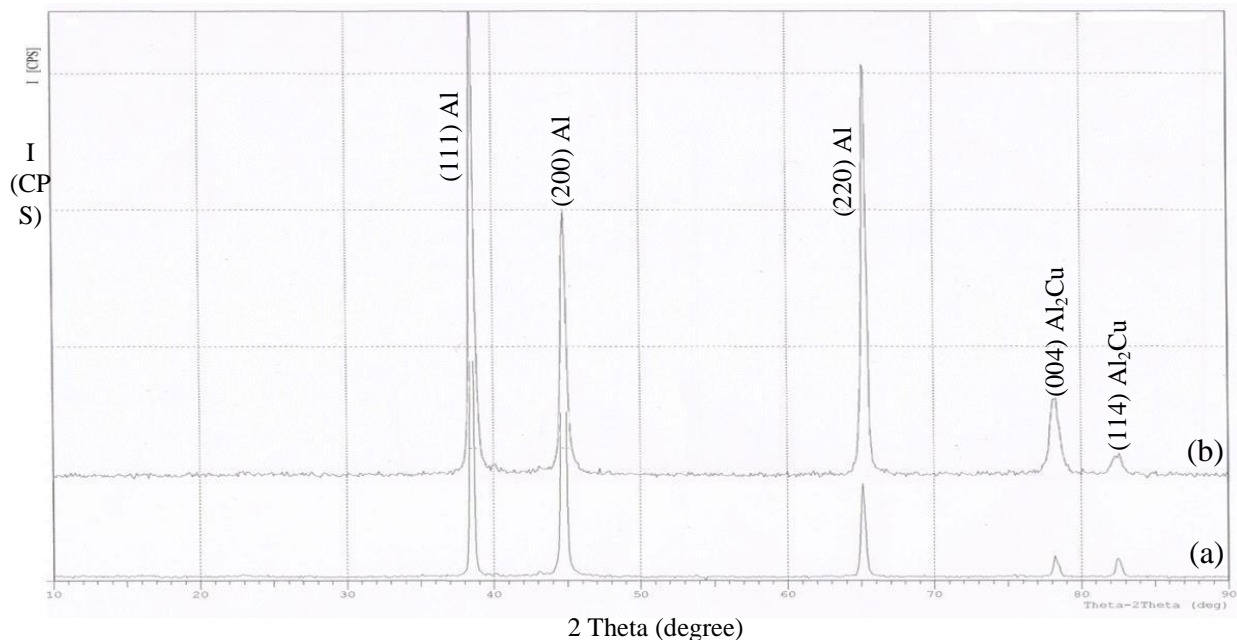


Fig. 4 Optical micrograph of friction stir processed surface.

1. Stir Layer Characterization

In this manner optical microscopy technique is the main path for its simplicity. Fig. (4) shows that a layer of about 45 μm in thickness can be created in general by FSP, due to the friction temperature (about 300 $^{\circ}\text{C}$ according to other researches) and the strain work (or plastic work) of tool. The temperature and strain which are applied for short time depend upon the revolution and speed of tool. The combination of temperature, strain and its period will be responsible for the creation of a new Surface layer which has a clear structure of Al_2Cu as shown in XRD Fig. (5). Referring to Fig. (5), the width at half of XRD peak regarding the FSP sample is wider than that of one concerning the initial coarse-grain specimen. The peak width pertaining to crystalline grains varies inversely with their size. In other words, as the grains get smaller, their relative peaks become broader [9].



Peak Data List

peak no.	2Theta (deg)	d (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (Counts)
1	38.5245	2.33500	66	0.27760	3806	10977
2	44.7495	2.02358	100	0.29230	5746	17945
3	65.1107	1.43148	17	0.31800	983	3427
4	78.2157	1.22118	4	0.32650	226	878
5	82.4897	1.16840	4	0.35230	223	910

(c)

Peak Data List

peak no.	2Theta (deg)	d (A)	I/I1	FWHM (deg)	Intensity (Counts)	Integrated Int (Counts)
1	38.5628	2.33277	98	0.37710	1733	7772
2	44.7837	2.02211	55	0.41990	970	4874
3	65.2437	1.42888	100	0.33000	1760	6621
4	65.8296	1.41758	3	0.17510	59	240
5	78.1624	1.22188	17	0.62570	302	2260
6	82.7164	1.16577	3	0.20000	61	476

(d)

Fig. 5 XRD pattern and peak data for: (a),(c) base metal. (b) and (d) FSPed sample.

The plastic deformation and temperature caused the large precipitates particles of the base metal to be broken and refined and distributed homogenously. The refining of grain size as a result of mixing process of tool, gives another morphology as clearly shown in SEM micrograph, Fig. (6).

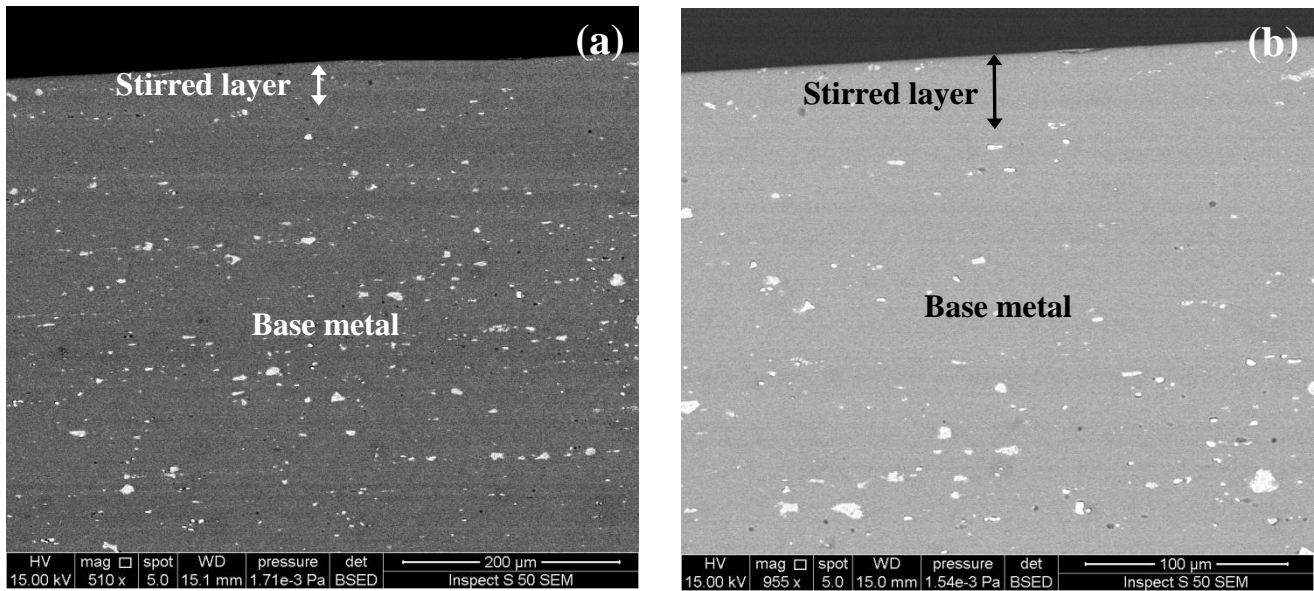


Fig. 6 (a) and (b) SEM micrographs of surface stirred layer at different magnification powers.

The elemental analysis for the surface layer (20 μm from the surface towards the base metal) before and after stir processing is shown in Figures (7. a) and (7. b), which submit our previous results, that the original structure contain aluminum and copper not in phase Fig. (7. a), while Fig. (7. b) shows that aluminum and copper created at another energy (keV), which pointed out our work mechanism.

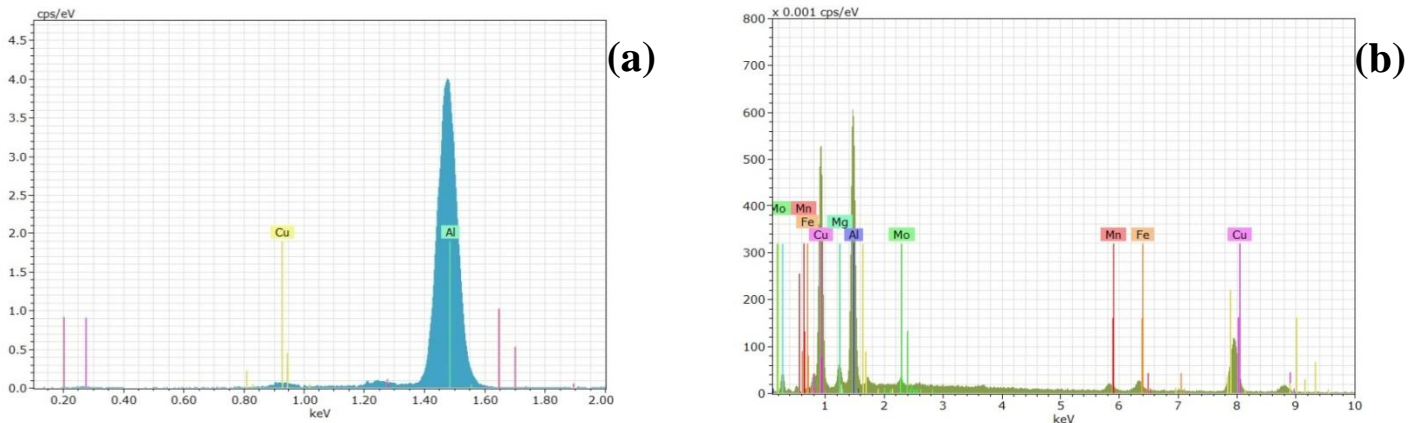


Fig. 7 EDX pattern for (a): base metal and (b): FSPed sample.

1. Stir Layer Mechanical Properties

The microhardness of stirred layer almost increases compared to that of the base metal. The maximum incremental of this property is about 40-45%. FSP with (945 rpm, 85 mm/min), increases the microhardness to about 190 HV (compared to 130 HV of the base metal), Fig. (8), which presented the microhardness profile of friction stir processed surface.

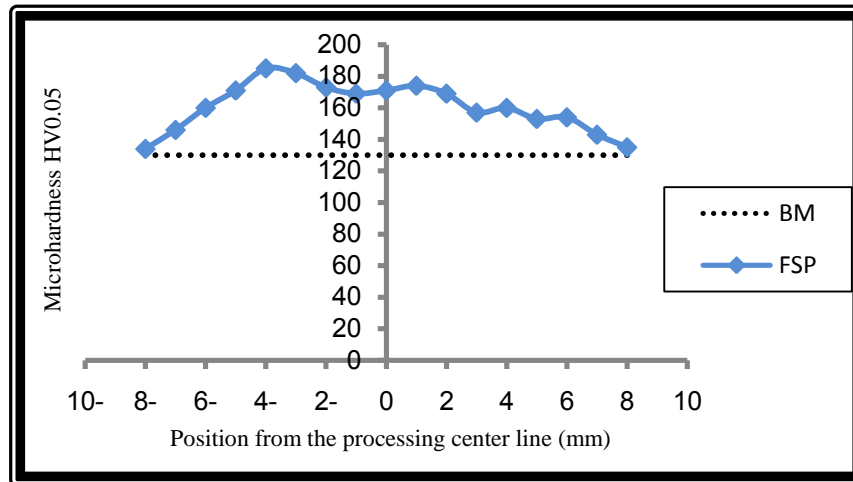


Fig. 8 Microhardness distributions at the surface of FSPed sample

Fig. (9) show the hardness distribution from top to bottom of the plate thickness. from this figure it can be seen that the hardness value drops from the hardness of friction stir processed surface to the hardness of the base metal as we go toward the other side of the plate surface, this confirms that the processing in this work affects the properties of the FSPed surface without affecting on the all base metal section.

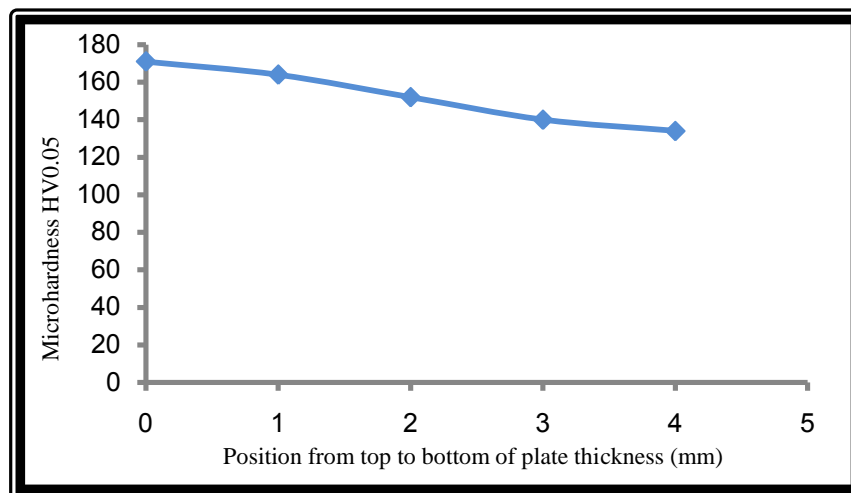


Fig. 9 Microhardness distributions along plate thickness of FSPed sample

The yield and tensile strengths of the base metal were 323 and 446 MPa respectively with 16% percentage of elongation, after FSP these strengths increase to 372 and 487 MPa and 17% E. which points out that the effect of FSP increases the yield strength by 15% and tensile strength by 9% compared to the base metal. Results also show that the FSP has no effect on ductility of the alloy represented by El %, so it can be concluded that the toughness of the alloy is increased somewhat since this properly depends largely on strength and ductility.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

IV. CONCLUSION

1. FSP is a complex thermomechanical process in which the combination of temperature, strain and their period are responsible for the creation of a new surface layer.
2. In FSP of AA2024-T3, due to a mixing action of the tool, second phase particles are refined, so properties of the base metal are changed.
3. The microhardness of stirred layer is almost increased compared to that of the base metal. The maximum incremental of this property is about 40-45%.
4. The yield and tensile strengths of FSPed samples are 372 and 487 MPa, with an increment of 15% and 9% respectively.
5. Toughness of the surface layer increases to some extent since its ductility is almost unchanged during FSP with the little increase in strength.

REFERENCES

- [1] B. Zahmatkesh, M.H. Enayati and F. Karimzadeh, "Tribological and Microstructural Evaluation of Friction Stir Processed Al2024 Alloy", *Materials and Design*, Vol. 31, pp. 4891-4896, 2010.
- [2] L. Lacroix, L. Ressler, C. Blanc and G. Mankowski, "Combination of AFM, SKPFM, and SIMS to Study the Corrosion Behavior of S-phase Particles in AA2024-T351", *Journal of The Electrochemical Society (JES)*, Vol. 155 (n° 4), ISSN 0013-4651, pp. 131-137, 2008.
- [3] Ma ZY, "Friction Stir Processing Technology: a Review", *Metal Mater Trans A*, Vol. 39A; No.3, pp. 642-658, 2008.
- [4] R.S. Mishra, M.W. Mahoney, S.X. McFadden, N.A. Mara and A.K. Mukerjee, "High Strain Rate Superplasticity in a Friction Stir Processed 7075 Al Alloy", *Scripta Materialia*, Vol. 42, pp. 163-168, 2000.
- [5] A. Kurt, I. Uygur and E. Cete, "Surface Modification of Aluminum by Friction Stir Processing", *Materials Processing Technology*, Vol. 211, pp. 313-317, 2011.
- [6] Mishra RS and Mahoney MW, "Metal superplasticity enhancement and formingprocess", US patent 6,712,916 (March 30, 2004).
- [7] L Karthikeyan and V.S. Senthil Kumar, "Relationship between Process Parameters and Mechanical Properties of Friction Stir Processed M6063-T6 Aluminum Alloy", *Materials and Design*, Vol. 32, pp. 3085-3091, 2011.
- [8] Ben James M., "The use of Friction-Surface Processing as a method of Corrosion Protection of Friction-Stir Weld in the Al-Li-Cu Alloy AA2050-T851", MSc Thesis, Department of Metallurgy and Materials The University of Birmingham, September 2010.
- [9] A. Chabok and K. Dehghani, "Formation of nanograin in IF steels by friction stir processing", *Materials Science and Engineering A*, Vol. 528, pp. 309-313, 2010.