PREPARING SURFACE COMPOSITE OF AA5086/SiC BY FRICTION STIR PROCESSING

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ABSTRACT

Friction stir processing (FSP) is a novel solid state process to produce surface composite. In this study, FSP was applied to produce surface composite for (AA5086) matrix reinforced with Silicon Carbide (SiC) particles . FSP tool of flat shoulder in diameter (18mm) and cylindrical pin with threaded profile in diameter (6mm), length (2.5 mm) was fabricated. The groove cut on the surface of base metal in (2mm) depth, (2.5mm) width, then groove filled with reinforcement particles. The process carried out at various rotational speed (500, 1000, 1600 rpm) and constant traveling speed (30)mm/min. Optical microscopy and scanning electron microscopy (SEM) are used to analysis the microstructure. Furthermore, the wear properties of the surface composites were evaluated by using a pin on disc wear test at room temperature at normal loads of (10,15, and 20 N). The results showed that microhardness profile along top surface improved after FSP) and the maximum microhardness evaluated at rotational speed (1000 rpm)for (AA5086) reinforced by (SiC) particles in three passes. The microhardness increased to (150 HV) as compared with the micro-hardness of the base metal (94HV). The practical purpose of this work is to improve the surface wear resistance by developing a layer of ceramic composite on the surface of (AA5086) .

KEY WORDS : friction stir processing(FSP) , surface composite, silicon carbide (SiC) AA5086 , wear

تحضير سطح مركب من AA5086 / SiC بواسطة عملية الخلط الاحتكاكي

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الخلاصة :

عملية الخلط بالاحتكاك (FSP) هي تقنيه لتصنيع المواد بالحالة الصلبة اذ تستخدم لإنتاج سطح من مواد مركبة . في هذه الدراسة يتم تطبيق FSP لإنتاج سطح من مادة مركبة من سبيكة الالمنيوم (5086) كماده اساس مقوات بحبيبات من كاربيد السليكون.صممت الاداة المستخدمة في (FSP) بحيث تتكون من جزئين الجزء العلوي يكون مستوي الشكل بقطر (mm18) والجزء السفلي يكون اسطواني الشكل و مسنن بقطر(mm6) وطول (2.5) .تم عمل أخدود بإجراء قطع على سطح المادة الاساس بعمق (mm2)وعرض (mm2.5)، وبعد ذلك يتم ملأ الاخدود بحبيبات التقوية.العملية نفذت بسرع دورانية مختلفة (rpm1600,1000,500) وسرعة خطية ثابتة (30 mm/min). تم استخدام المجهر الضوئي والمجهر الالكتروني الماسح لتحليل البنية المجهرية .علاوة على ذلك ،خواص البلى للسطح المركب يمكن حسابها بواسطة استخدام جهاز اختبار البلى (pin on disc) بدرجة حرارة الغرفة بسليط احمال (N10,15,20). اثبتت

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النتائج ان الصلادة الميكروية عند سرعة دورانية (rpm1000) لسبيكة الالمنيوم (5086) مقواة بواسطة حبيبات كاربيد السليكون في ثلاث تمريرات قد ازدادت الى (HV 160) بالمقارنة مع صلادة المعدن الاساس (HV94). الغرض الرئيسي لهذا العمل هو لتحسين مقاومة السطح للبلى بواسطة تكوين طبقة سيراميكية مركبة على سطح سبيكة الالمنيوم (5086) . اظهرت النتائج ان الحمل المسلط ،السرعة الدورانية ،ونوع دقائق التقوية في اختبار البلى لها تأثير مهم على فقدان الوزن .

INTRODUCTION

A composite material is a combination of two or more materials that results in better properties than those of the individual components used alone. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part[H.G. Rana,et.al,2016]. Particulate reinforced metal matrix composites (MMCs)have been developed for high performance applications in the aerospace and automobile industries because of several advantages, particularly high topological resistance and enhanced modulus and strength[*N. Sun*,et.al,2015]. Recently, friction stir processing (FSP) got great interest to develop based on the principle of (FSW), and is known as the surface modification technique. Similar to FSW, a rotating tool with a pin (often shorter than the thickness of the sheet) and a shoulder, is inserted into a single piece of material and travels as the tool in (FSW) does. This results in significant microstructural changes in the processed zone, due to the occurrence of intense plastic deformation [M. K. Besharati Givi,et.al,2014]. FSP has been demonstrated to be capable of locally modifying various material properties, including but not limited to (ductility/elongation), fatigue properties, static mechanical properties ,corrosion properties, hardness, etc. [C. B. Smith,et.al,2014]. FSP has been proved to be an effective way to refine the microstructure of a material, and thereby improve its mechanical properties. Also, it can be used to create surface composite layers by addition of ceramic powders during the process [M. K. Besharati Givi,et.al,2014]. **D. Deepak, et .al ,**(2013) investigated **"** preparation of 5083 Al-SiC surface composite by friction stir processing and its mechanical characterization". In this research, surface composite of AA5083 matrix strengthened with nano-sized (SiC) particles have been manufactured by the FSP. The tool rotational speed (1200 rpm) and the traverse speed (40 mm/min). In addition to this, a number of holes of diameter (2 mm) and (2 mm) depth were drilled on the surface of the matrix with keeping the center distance between two sequential holes as (4 mm). Microstructure, microhardness and wear properties of the surface composite have been studied and compared with those of(AA5083) matrix. As compared to (AA5083), it is shown that the samples produced by (FSP) possess better hardness, specifically in the nugget zone. The tribological studies illustrated that wear resistance of the surface composite is noted to be meaningfully to that showed for (AA5083), consequently of high coefficient of friction and greater friction force improved through the course of sliding wear. This performs to separation of (SiC) particles from the surface of specimens. Microstructural examines of wear debris and worn track show that the principal wear type in (FSP) is abrasive wear while (AA5083) both adhesive and abrasive wear types are effective. **H. Izadi, et .al,** (2013) studied "Friction stir processing of (Al/SiC) composites fabricated by powder metallurgy". Friction stir processing (FSP) was used to modification the microstructure of sintered (Al–SiC) composites with particle concentrations ranging from (4 to 16 vol%). Two SiC particle sizes (490N and 800 grades) were tested. Threaded pin which was (4 mm) at the end, and(5.1 mm) at the base. The shoulder had a (12 mm) diameter, and processing was conducted with a tool rotation speed of (454 rpm) and travel speed of (88 mm/min). After FSP, the(SiC) composite hardness of (490N) grade of (4 vol% SiC) raised from(130 HV) to (171 HV), while of the (8 vol% SiC) raised from (145 HV) to (177HV). The rise was explanation for by the severe deformation happening through FSP which homogeneously distributed of the reinforcement particles. The composites including (16 vol% SiC) could not be completely consolidated by FSP, and included lack of consolidation and residual pores which created from the as-received sintered microstructure. The hardness connected well with the mean inter-particle spacing for the (SiC) particles in the case of composites including (4 and 8 vol% SiC). **N. Yuvaraj, et. Al**, (2015) investigated "fabrication of (Al5083/B4C) surface composite by friction stir processing and its tribological characterization". The purity of micron size (B4C) particles (99%) and the average particle size of (20 μm) .The purity of nano size (B4C) particles of (99.5%) with the mean particle size of (30–60 nm) were working as reinforcement materials. The tool was used for FSP with a shoulder diameter (18mm) and a threaded pin diameter of (M6 × 1.0) and length of (5 mm) .A groove width (1mm) and depth (3 mm) was used . The constant traveling speed and rotational speed were fixed at (25 mm/min) and (1000 rpm) respectively .The specimen were exposed to several numbers of passes from one to three. The optical and scanning electron microscopical used for examined surface composite layer . In FSP the passes number and the reinforcement particles size play an important role in the improvement of surface composites. Mechanical properties of the samples produced by FSP were determined during microhardness and universal tensile tests. Tribological behavior of the samples is examined by pin on disk test. The surface composite layer resulted in three passes with nano particle reinforcement showed best features in hardness, tensile performance and wear properties compared to the performance of the matrix.

M. H. Shojaeefard, et. Al, (2016) investigated "effect of tool pin profile on the distribution of reinforcement particles during friction stir processing of B4C/aluminum composites". Fabrication of the composites was done in (10-mm) thick (A356 alloy) with commercially available (B4C) reinforcement with the average size of (10 mm) was employed in this work. A groove made with dimensions of (1.4mm) width and (3.5mm) depth. Different tool pin profiles of cylindrical, threaded, square, and hexagonal were utilized in this study. Effect of pin profile on the distribution of boron carbide in the stir zone of the friction stir processed specimens was investigated experimentally and numerically. The experiments were conducted at constant tool rotational and traverse speed of (1200 rpm) and (32mm/min), respectively. The material flow generated by the threaded and circular tool pin profiles, being the main reason for the distribution of particles in the metal matrix, was numerically modeled using a thermo-mechanically coupled three-dimensional finite element model. Numerical and experimental results show that threaded pin profile produces a more uniform distribution of (B4Cp) than other pin profiles. Hardness tests were performed in order to investigate mechanical properties of the composites. The wear resistance of the composite was evaluated and obtained results showed that the wear resistance and hardness of the composite significantly improved. the purpose of this work is to improve the surface wear resistance by developing a layer of ceramic composite on the surface of AA5086.

EXPERIMENTAL PART

The aluminum alloy (5086-H32) plate of(3.2 mm) thickness was used in this research to produce a composite material. This alloy is a non-heat treatable aluminum alloy. The chemical composition measured by SPECTRO MAX_X in State Company for Inspection and Engineering Rehabilitation(SIER) -Ministry of Industry and Minerals as shown in **Table (1)**. Reinforcement materials used for the production of metal matrix composite are ceramic particles of silicon carbide (SiC) . The average particle size of SiC (4 μm). The machine used in this research is milling machine (FU251M) made in (Bulgaria by Arsenal

Company). The tool has been used in the FSP were manufactured from alloy steel (X12), the chemical composition of this alloy is present in the **Table (2)**. The geometry of the tool is cylindrical shape. The pin was threaded in dimensions(6 mm) diameter, (2.5 mm)length while the shoulder of (18 mm) diameter shown in the **Fig. (1)**. After preparation of the sample and fixing will work groove in the middle of the plate. The groove creates by (2.5 mm) cutter of milling machine with 2mm in depth. The groove fully filled with reinforcement particles, then pin-less tool used to close the groove to prevent exit particles from the groove during the process. After covering the groove the FSP tool is inserted into the sample to perform FSP. Three specimens were produced using three tool rotation speeds (500,1000,1600) rpm and constant traveling speed(30 mm/min), three number of passes and tool tilt angle of 2°. At the starting point of the sample the tool must be stay some time (30 second) to obtain the necessary heat to soften the base metal and then the tool move along the process line. During movement the tool in the sample gets mixed between reinforcement particles and matrix plate to result surface composite. At the end of the process tool pulls of the sample and leave a sample to cool. At the end of FSP, the samples are prepared for testing. The samples is polished using diamond suspension and etched using Keller's reagent for optical micrographs and microhardness. The wear resistance is tested by wear device (pin on disc) type (MT-4003 version 10.0). The sample testing was cut from the stir zone of the FSP) samples in diameter (15 mm) and thickness (3.2 mm). The disc (sample) is polished down to (1000 grit) by grinding paper before the experiments, the pin is a steel ball in diameter (6 mm). The disc rotating at a constant sliding speed of (300 rpm) and the total sliding distance of (1000 m) at constant load (10N). Microhardness testing using Vickers microhardness method is working with a load of (200 g) at a loading time (10 sec) for microhardness measurements, the measurement is taken for each (1 mm) length. Microstructure for samples measured by the optical microscope, scanning electron microscopy(SEM) and (EDS). XRD was carried out at the top surface of composite after FSP using X-ray diffraction, (XRD6000) made by (SHIMADZU) Japan .

RESULT AND DISCUSSIONS

Wear

From results, it was noticed, that wear rate rises with the rise in the applied load. Uniformity of ceramic particles in the Al-alloy matrix enhance the mechanical and wear resistance properties. This result agrees with [E. R. I. Mahmoud, et. al.,2009] . The weight loss determined after testing, then drowning chart between weight loss and sliding distance and compare the results for different variables of FSP. When adding (SiC) particles to the base material increase wear resistance in all parameters of FSP. The effect of rotational speeds on the wear resistance shown in **Fig. (3).** Clearly, the high rotational speed(1600 rpm) produce more weight loss and lower weight loss at rotational speed (1000 rpm). High rotational speed generates more heat input in stir zone and softening this region .In lower rotational speed (500 rpm), insufficient heat input in stir zone to soften the grains and distribution of ceramic particles in stir zone. In moderate rotational speed (1000 rpm) the heat input seems quite enough to uniform distribution and softening. So the higher wear resistance obtains by using rotational speed (1000 rpm).

Microhardness

FSP produces dynamic recrystallization that leading to grain refinement . That grain refinement is supported by limited grain growth by the effect of the particles on the grain boundaries and dynamic recrystallization phenomenon . According to the Hall–Petch relationship, decrease in grain size increases the yield strength, which in turn increases the hardness value also. Hall-Petch relation is [N. Kumar& R.S. Mishra,2012]:

$$H=H_0 +K_H d^{-1/2}$$

where *H* is hardness, *d* is grain diameter and H_0 and K_H are Hall-Petch constant

It can be shown in **Fig. (4)** that the effect of increasing rotational speed on the values of microhardness in stir zone. Maximum microhardness occurs at (1000 rpm) The average microhardness calculated at (1000 rpm) in stir zone about (150 HV) for material reinforced by (SiC) as compared with base alloy microhardness about (94 HV). While the average microhardness at (500 rpm) about (142 HV) and about (103 HV) at (1600 rpm) for material reinforced by (SiC) in stir zone.

Microstructure observations

The distribution of particles can observed through use of the optical microscope. The **Fig.(5)** shows the optical micrograph at stir zone of the specimen formed by FSP in the rotational speed (1000 rpm) at three passes. Image **(A)** in **Fig(6)** illustrates bands of stir zone (SZ), this bands forming in surface composites by exchange layers of base material and reinforcement particles, when the stirring during FSP insufficient to produce a uniform distribution of reinforcement particle this bands appear. At **Fig(6)** the interface between base and SZ, the dark region act SZ this color refer to found reinforced particle in the stir zone . which reduces the grain size at SZ. **Fig(7)** shows SEM) images at the surface of specimens reinforced by (SiC) particles at (1000 rpm). It is clear more controlling between heat input and plastic deformation. Thus surface composite was very uniform, with the hidden defects and great precipitates. Heavy plastic deformation and heat input through FSP causes the refining of base material grains, the closing of porosity, thus producing a fine, homogeneous, and without defect structure. **Fig. (8)** shows the (EDS) analysis for sample reinforced by (SiC) particle at the **Fig (8) (b)** shows higher ratio of (Si) and fewest amount of (Al) according to the (EDS) analysis, that refer to the agglomerate of (SiC). The elements appear in the (EDS) pattern in **Fig (8) (b)** is (Al ,Si ,C). **Fig. (8) (c)** shows the (EDS) pattern at point (B) seen that good distribution of (SiC) particle in base metal so the higher ratio appears for (Al) and few ratios for (Si, C, Cr, Mg, Fe) .

X-ray

Fig. (9) shows the (XRD) analysis of (AA5086) reinforced by (SiC) particle. By using Bragg's law

$$\lambda = 2d sin\theta$$

Where λ is the wave length, (θ) is Bragg angle and (d) is the interplanar spacing.(d) can be calculated as measuring chart peaks , the (I/I0) ratio which represents the intensity for all peak (I) divide on the maximum intensity (I0). It was shown that peak number (1,2,3) for (SiC) according to the JCPDS cards(NO 29-1130) and other peaks (4,5,6,7) for (Al) according to the JCPDS cards (NO 04-0787) .

CONCLUSIONS

The conclusions of this research can summarize as follows:-

1- Surface composites fabricated by FSP is successfully produced a dispersion of SiC particles in the surface of (AA5086-H32) plates.

2- For given traveling speed, rotational speed and the passes are significant effect on the properties of surface composites.

3- Maximum hardness and wear resistance of surface composites by (SiC) can obtained in the (1000 rpm) of rotational speed.

4-The Al-alloy reinforced by (SiC) particle at three passes shows the fine grain size, higher micro-hardness and wear resistance than the base metal.

5- Dispersion hardening by (SiC) particle can suppress the coarsening of grains of α-aluminum solid solution and hence prevent the sliding of grain boundaries at high temperature.

Table (1): Chemical Composition of (Al 5086-H32) .

Element	Fe	Zn	Si	Mn	Mg	Cu	Cr	Ti	Others Al
Measured Wt%	0.282	0.0588	0.058	0.467	3.72	0.064	0.101	0.0101	Rem.

Table (2): Chemical composition (weight %) of alloy steel (X12) **.**

C%	Cr%	Mn%	Si%	Fe%
2.00	11.5	0.30	0.34	Rem.

Figure (1): Shows **(a)** FSP tool **(b)** pin-less tool.

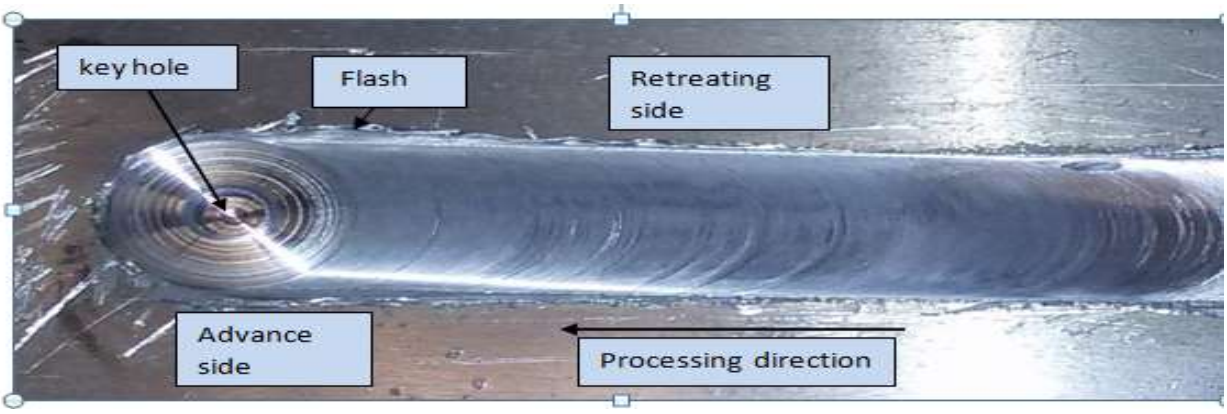

Figure (2): FSP of **AA5086.**

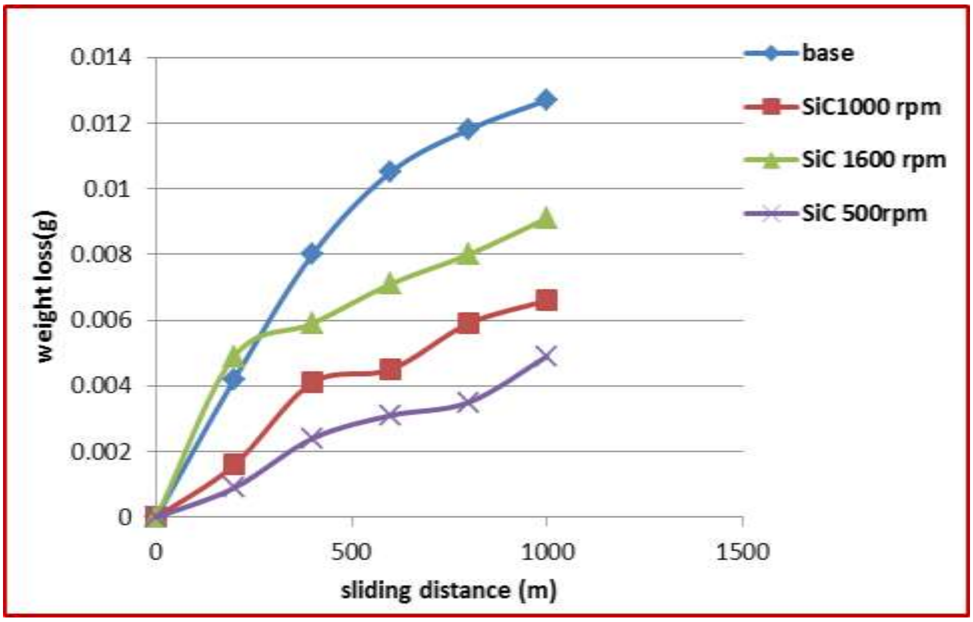

Figure (3): The effects, of variable rotational speeds on wear resistance of Al-alloy reinforced by (SiC) particles at three passes **.**

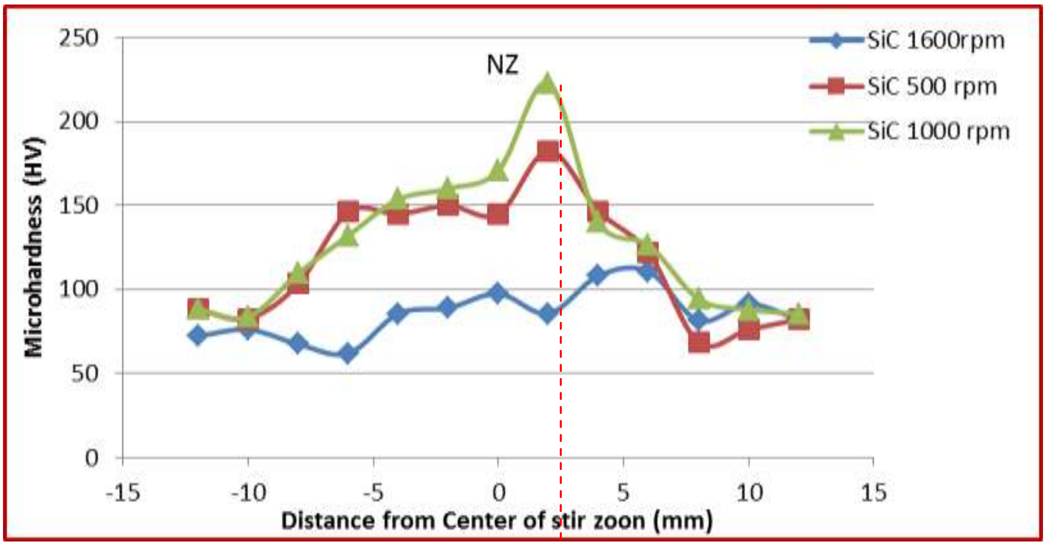

Figure (4): The effect of variable rotational speeds on microhardness of matrix reinforced by (SiC) particle at three passes.

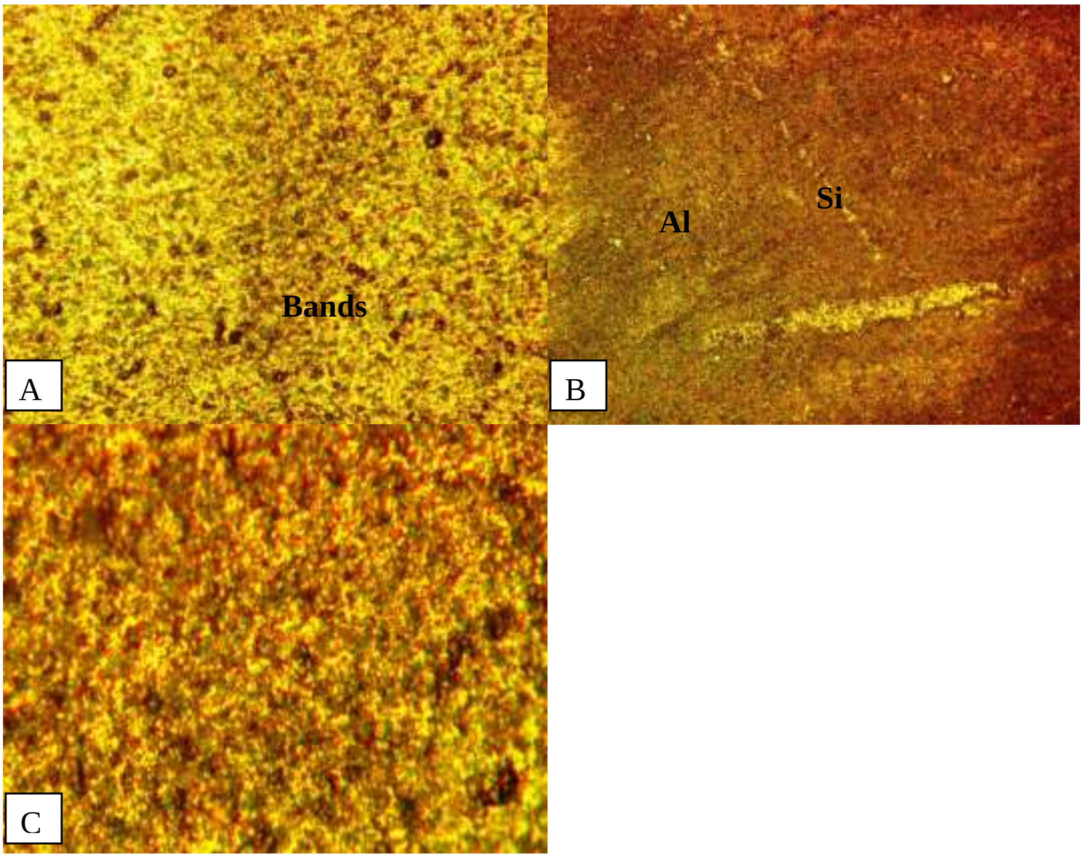

Fig.(5): Shows optical micrograph at stir zone of the specimen formed by (FSP) in the (rotational speed 1000 rpm) at three passes at :- (A)100X (B)400X (C)600X .

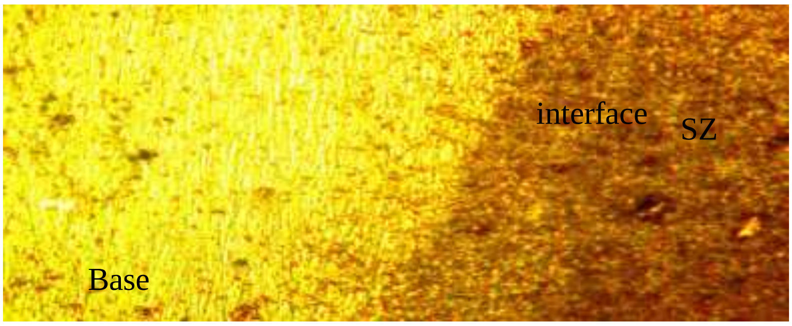

Fig.(6) : shows the microstructure of the specimen of (Al-SiC) composite formed by (FSP) in the rotational speed 1000 rpm at three passes .

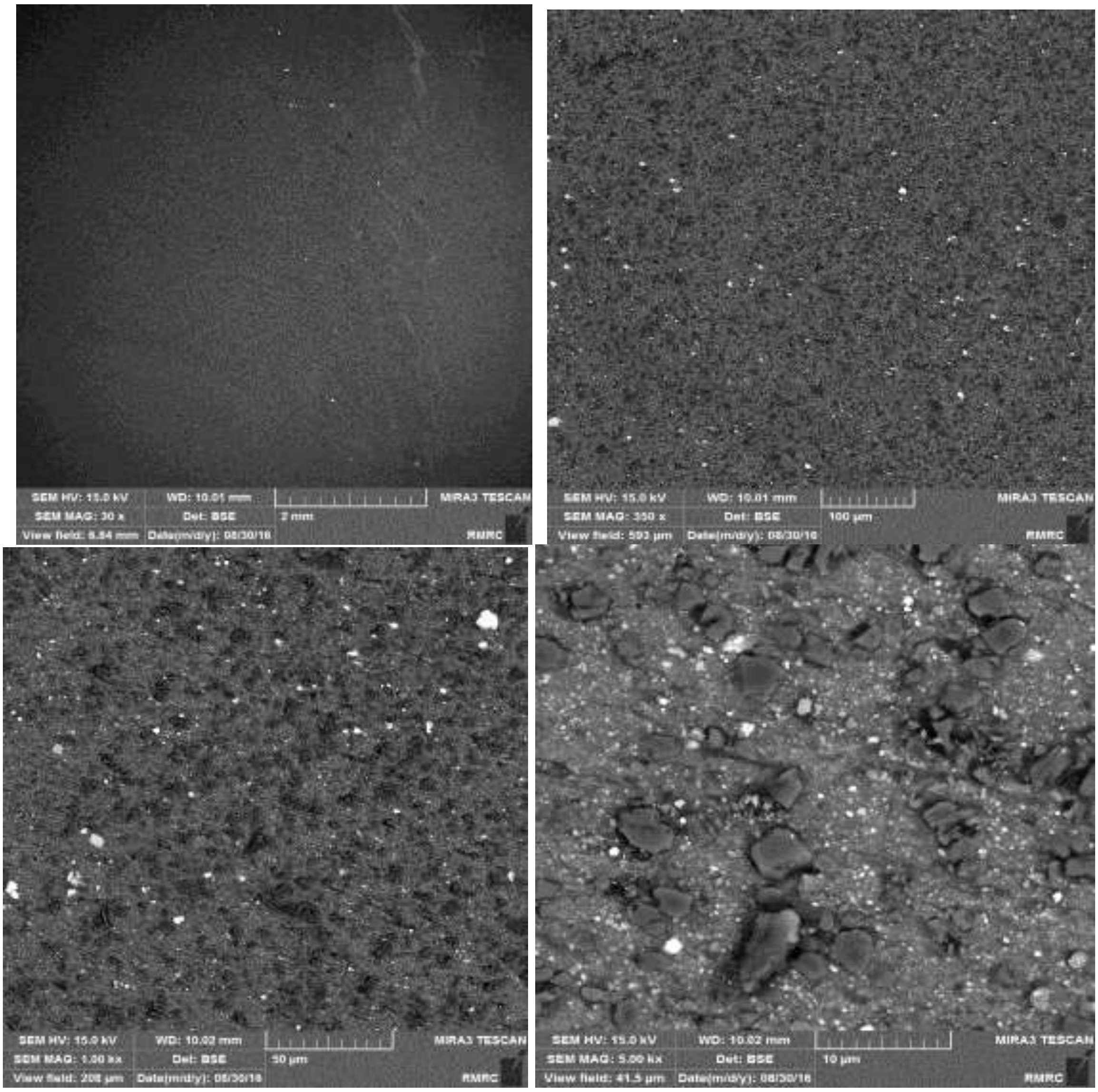

Figure (7): SEM images at the surface of specimens reinforced by (SiC)particles at (1000) rpm .

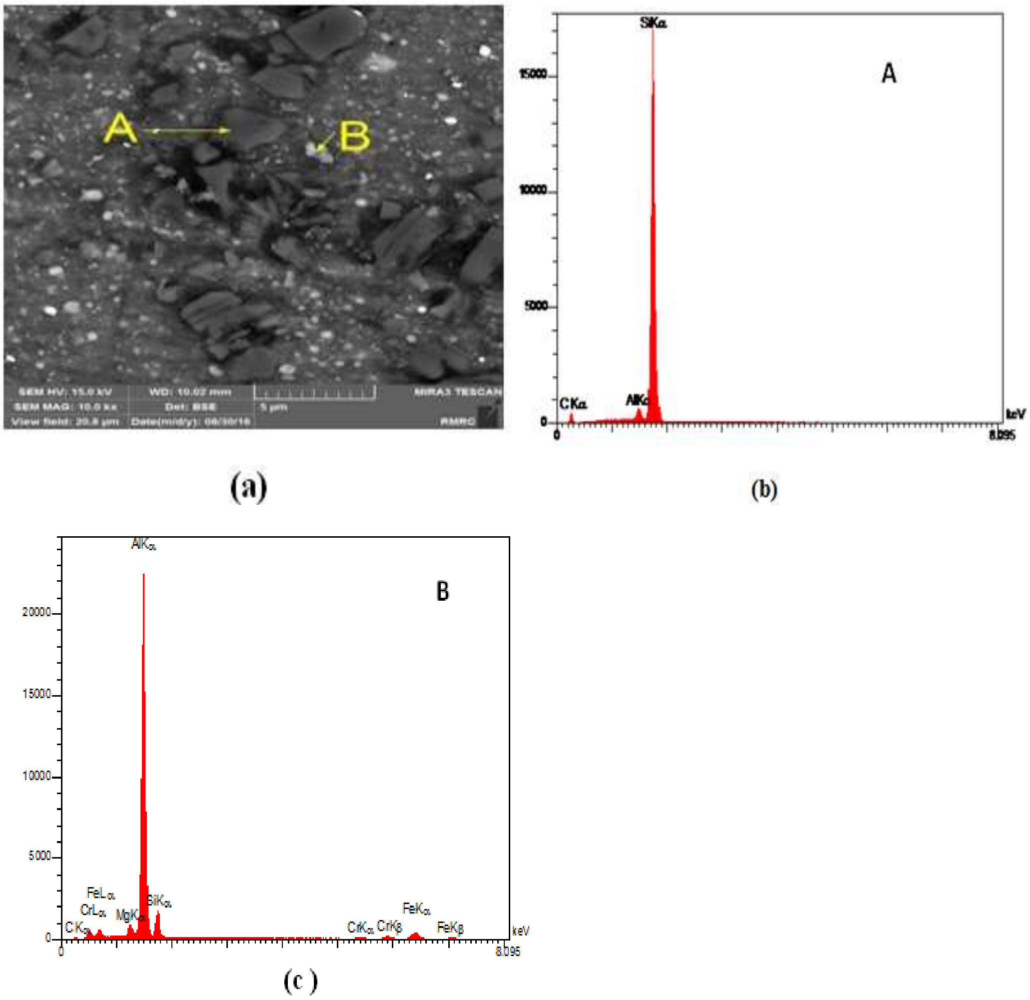

Figure (8): SEM with EDS for (AA5086/SiC) surface composite : (a) SEM image (b) EDS for point A (C) EDS for point B

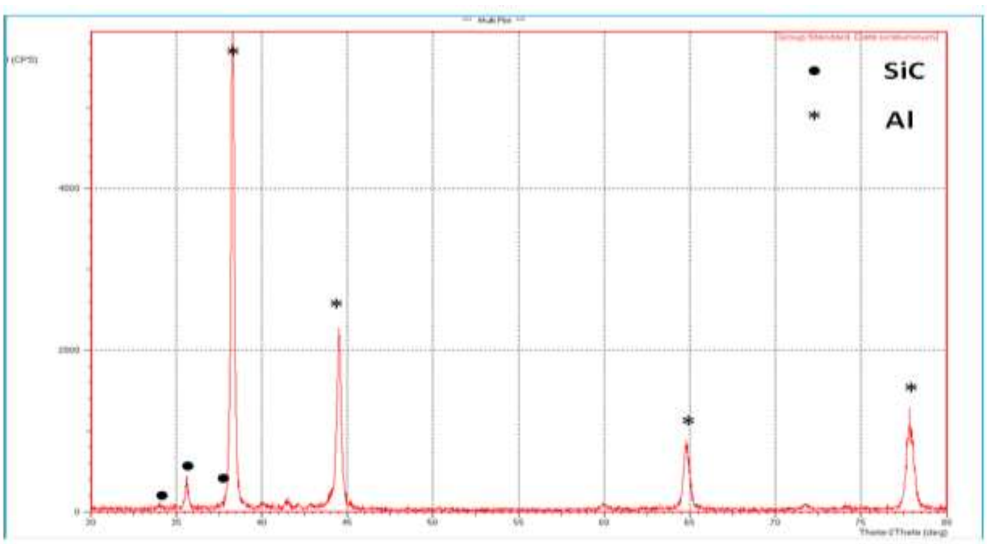

Figure (9): XRD for (AA5086) reinforced by (SiC) particle .

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