Mansoura Engineering Journal

Volume 42 | Issue 2 Article 8

5-13-2020

Influence of (Gr+ Cu) Particles on Wear and Mechanical Properties of Aluminum Based Surface Hybrid Composites Fabricated Via Friction Stir Processing.

Mohamed EL-Meniawi
Materials Engineering Dept., Faculty of Engineering, Zagazig University, Zagazig, Egypt, maelmenyawy@eng.zu.edu.eg

Recommended Citation

EL-Meniawi, Mohamed (2020) "Influence of (Gr+ Cu) Particles on Wear and Mechanical Properties of Aluminum Based Surface Hybrid Composites Fabricated Via Friction Stir Processing.," *Mansoura Engineering Journal*: Vol. 42 : Iss. 2 , Article 8.
Available at: https://doi.org/10.21608/bfemu.2020.88887

Mansoura University
Faculty of Engineering
Mansoura Engineering Journal

Influence of (Gr+ Cu) Particles on Wear and Mechanical Properties of Aluminum Based Surface Hybrid Composites Fabricated Via Friction Stir Processing

تأثير حبيبات الجرافيت والنحاس على الخواص الميكانيكية والبري لسطح هجين مؤتلف ذات الأساس من الألومنيوم منتج بطريقة التقليب بالاحتكاك

M. A. H. EL-Meniawi

KEYWORDS:
Aluminum hybrid composite, graphite particles, copper, friction stir processing, friction coefficient, microhardness, microstructure

الملخص العربي:-في هذا البحث تم استخدام عملية التقليب بالاحتكاك (FSP) لتقليب وخلط حبيبات من النحاس والجرافيت علي سطح شريحة الومنيوم نقي لتكوين طبقة مؤتلفة بسمك 3 مم . معمليا، كما تم دراسة اختبار البري ومعامل الاحتكاك باستخدام جهاز (Pin-on-disc) عند ظروف أحمال مختلفة (5، 10، 15، 20، 25) نيوتن مع سرعات مختلفة (0.5، 1، 1.5، 2، 2.5) متر لكل ثانية. أيضا تم تقييم خواص الشد والصلادة الدقيقة بالتفصيل.كم وضحت البنية المجهرية لسطح الهجين المؤتلف توزيع منتظم للنحاس والجرافيت في منطقة التقليب (SZ). كما أظهرت النتائج ان حبيبات الجرافيت نتيجة عملية التقليب اصبحت دقيقة وموزعة بانتظام مادة الاساس. هذا التأثير حسن الخصائص الميكانيكية. أظهرت النتائج ان معامل الاحتكاك يزداد عند زيادة سرعة الانزلاق

***Abstract*— In the current study, Friction stir processing (FSP) was used to stir and mix Cu and graphite particles (Gr) into the surface of a pure aluminum plate to form a composite layer up to 3 mm thick. Wear test and friction coefficient of hybrid composite layer are investigated experimentally using a pin-on-disc apparatus at different normal load conditions 5, 10, 15, 20 and 25 N with different sliding speeds 0.5, 1, 1.5, 2 and 2.5 m/s. Also, tensile and micro-hardness properties were evaluated in detail. Microstructure of the surface hybrid composite revealed that Cu and Gr are uniformly dispersed in the stir zone (SZ). The results showed the Gr particles were refined and uniformly distributed in the matrices as a result of stir processing. This significantly improves mechanical properties. The results revealed that the friction coefficient increases when sliding velocity is increased.**

Received: 27 March, 2017 - revised: 29 March, 2017 - accepted: 3 April, 2017.

M. A. H. EL-Meniawi, Materials Engineering Dept., Faculty of Engineering, Zagazig University, Zagazig, Egypt, P.O. Box 44519 (e-mail: maelmenyawy@eng.zu.edu.eg).

I. INTRODUCTION

In recent times, self-lubricating composites of aluminum alloy-graphite (Al/Cu/Gr) particulate are being traveled for wide applications. This is due to their low friction coefficient, reduced temperature rise at the wearing contact surface, low thermal expansion and high damping capacity. Thus, it benefits in lowering friction and wear resistance of the composite. Self-lubricant composites such as aluminum–graphite, and copper–graphite, not only reduce friction coefficient but also decrease the wear of counterparts [1]. Copper–graphite composites possess the properties of copper, i. e. excellent thermal and electrical conductivities, and properties of graphite, i.e. solid lubricating and low thermal expansion coefficient [2]. Aluminum alloys are widely utilized in aircraft, defense, automobiles and marine areas due to its good strength, lightweight and better corrosion properties. But, it exhibits inferior tribological properties in extensive usage [3, 4]. Hybrid metal matrix composites (HMMCs) have enhanced mechanical, tribological and thermal properties in comparison with unhybridized composites [5]. A suitable technique can be employed to refine the microstructure and homogeneous dispersion of reinforcements on metallic surface since wear is a surface deprivation property [6]. Dispersion of reinforcement particles on metal surface and the control of its dispersal are more difficult to attain by conventional surface modification techniques [7]. Guptha et al. [8] and Mabhali et al. [9] stated that the thermal spraying and laser beam techniques were utilized to make surface composites. These techniques are operated at higher temperatures and difficult to avoid the reaction between the reinforcements and the matrix. So, friction stir processing (FSP) is best suited for preparation of surface composites. Friction stir processing (FSP) is defined as a severe plastic deformation technique used in order to modify microstructural and mechanical properties [10]. In FSP a rotating tool with shoulder and pin is plunged into the surface of material which generates frictional heat and dynamic mixing of material area under Neath the tool [11], it leads to incorporation and/or dispersion of the reinforcement particles in the matrix material such as Aluminum alloys. Pin profile plays a vital role in material flow [12]. Hybrid composites are prepared by reinforcing with a mixture of two or more different types of particles which combines the individual properties of each type of particle. Tool rotational speed is the most important process parameter in FSP which has greater influence in uniform distribution of reinforcement particles, grain refinement and heat input during the process. It is accepted that the stirring action during FSP causes a break up of clustered reinforcement and homogenous distribution in the stir zone due to the mixing of material and severe plastic deformation [13-15]. The surface of the tool has dual actions for heat generation and mechanical sweeping of softened metal. The heat input through the frictional action between the tool and workpiece leads to softening of the area around the pin. Meanwhile, the softened materials are swept in the form of severe plastic deformation from the advancing side (AS) to the retreating side (RS) to form a solid state joint [16]. The objective of the present investigation is to study the influence of (Gr + Cu) particles on wear and mechanical properties of aluminum based surface hybrid composites fabricated via FSP. Immediate stirring of materials during manufacture process which is one of the features of this process, can solve the agglomeration of graphite particles. Thus, FSP was engaged to produce these composites.

II. EXPERIMENTAL PROCEDURE

Commercially pure Al sheets with the dimensions of 100 mm *70 mm * 4 mm from General Company for Metals, Tebbin, Helwan, Egypt were used as base metal 0.1 gm. of 18 μm in average size of Cu and 0.1 gm. of Gr particles of 2 μm in average size were used as addition elements. The process experiments were performed using a vertical milling machine with a tool having a threaded pin. The FSP tool had a shoulder of 16 mm in diameter and a threaded pin of 4.5 mm in diameter and 2.7 mm in length. The tool was made of H13 and tilted 2^o from the plate normal direction. A square groove was made with dimensions of 0.7 mm width and 2 mm depth, which is tangential to the pin in the advancing side and 2 mm far away from the Centre line of the tool rotation on the aluminum plate. The groove opening was initially closed by means of the tool which has shoulder without pin to avoid the escapement of mixture particles from groove while processing. Samples were subjected to FSP passes from one to two .The constant rotational and travel speeds were 1040 rpm and 52 mm/min, respectively.

2.1. Microstructures

Microstructural observations were carried out at the cross section of the nugget zone (NZ) of surface hybrid composites normal to the FSP direction, mechanically polished and etched with Keller's reagent (2 ml HF, 3 ml HCl, 20 ml $HNO_3$and 175 ml H_2O) by employing optical microscope (OM).The SEM was also utilized for observing the mixture particles distribution pattern of surface hybrid composites.

2.2. Microhardness tests

Microhardness tests were carried out at the cross section of SZ of surface hybrid composites normal to the FSP direction. Samples were tested with a load of 50 g using a Vickers digital microhardness tester.

2.3. Tensile tests

The tensile specimens were taken from the surface hybrid composites normal to the FSP direction and made as per ASTM: E8/E8M-11 standard by using Wire cut Electrical Discharge Machining to the required dimensions. The tensile test is carried out on a computer controlled universal testing machine (Zwick/Roell Z-100) at a cross head speed of 0.5 mm/min.

2.4. Friction coefficient and wear test:

The abrasive wear test is carried out with a pin-on-disc tester. Rectangular specimens having dimensions 6 mm * 20 mm are used for the dry sliding wear measurements. The sliding speeds employed are 0.5, 1.0, 1.5, 2 and 2.5 m/s. The applied normal loads used are 5, 10, 15, 20 and 25 N. The sliding time is kept constant at 1200 sec for each sample. The wear rates of the composite are calculated by dividing the difference in weight of the specimens measured before and after the tests (measured with an analytical balance of 0.0001 g precision) by the sliding distance. The counterpart disc with 180 mm in outside diameter and 10 mm in thickness is fabricated using hardened alloy steel with hardness HRC 60 and surface roughness Ra of about 0.54 µm. The test pins are loaded against the disc with a dead weight. All the tests were carried out at the temperature of 20±2 ^{O}C and ambient humidity (~50%). Friction coefficient was determined by tribometer automatically.

III. RESULTS AND DISCUSSIONS

3.1. Microstructure:

The optical micrographs of Al/Cu/Gr at 1040 rpm, surface hybrid composites and as received aluminum are shown in (Fig. 1.) The particles of Cu, and Gr were observed to be dispersed uniformly in the SZ for the conditions of composites one and two paths made by FSP.

3.2. Microhardness:

It is well known that in stir zone (SZ) occur refining of grain size and strain hardening .Thus the strength is increasing. Moreover, the mechanical properties of self-lubricating composites and the formation of self-lubricating layer at the contact surface are strongly influenced by the size and distribution of the solid lubricants [5]. Microhardness of Al/Cu/Gr at 1040 rpm, surface hybrid composites are shown in (Fig. 2). It was shown that, the microhardness decreases due to the heat input through the frictional action between the tool and workpiece leads to softening of the area around the pin [17-19]. Generally, the microhardness value depends on the presence and uniform distribution of Cu and Gr particles. This was due to fact that at 1040 rpm, the tool shoulder supplied enough heat input and shear force to make the reinforcement particles more easily wrapped by the softening metal and rotated with FSP tool, which results in well separation and distribution in the stir zone. The Gr particles acted as solid lubricant during wear that produces a tinny layer between the deformed surfaces. And also due to presence of graphite as a solid lubricant and decrease in number of metal to metal contact points leading to decrease in coefficient of friction and enhances the wear resistance [20].

3.3. Wear characterization

The effect of normal load on the friction coefficient is shown in Figure 3 and these results show a comparison of friction coefficient of hybrid composite layer and pure aluminum. Results show that as the normal load increases from 10 to 20 N, coefficient of friction decreases from 0.35 to 0.20 and 0.55 to 0.37 for hybrid composite layer and pure aluminum respectively. Moreover, it is apparent that for identical conditions, hybrid composite layer shows much lower friction than pure aluminum [21]. From the obtained results it can be noticed that time duration is different to reach steady friction depending on the sliding velocity. The influence of sliding velocity on the friction coefficient is presented in Figure 4. It was found that as the sliding velocity increases from 1 to 2 m/s, friction coefficient of hybrid composite layer increases from 0.25 to 0.36. On the other hand, friction coefficient of pure aluminum increases from 0.46 to 0.60 as the sliding velocity increases from 1 to 2 m/s. This is due to the interaction of the asperities of two contact surfaces, frictional heat generation occurs and hence temperature increases at the contact surfaces. Also due to more adhesion of pin material on the disc with the increase in sliding velocity, friction increases [22]. The effect of normal load on the wear rate of hybrid composite layer and pure aluminum is shown in Figure 5. It is observed that for the increase in normal load from 10 to 20 N, wear rate of copper increases from 0.85 to 1.45 mg/min. On the other hand, pure aluminum shows the increased wear rate from 2.5 to 3.15 mg/min as the load increases from 10 to 20 N. The influence of sliding velocity on the wear rate of hybrid composite layer and pure aluminum is shown in Figure 6. It is observed that for the increase in sliding velocity from 1 to 2 m/s, wear rate of hybrid composite layer increases from 1.15 to 2.25 mg/min. On the other hand, wear rate of pure aluminum increases from 2.85 to 4 mg/min as the sliding velocity increases from 1 to 2 m/s. This is due to the fact that a higher speed, a higher sliding distance for the same rubbing time. Thus, the temperature is high the softening of the aluminum metal matrix in the composites and the overall wear rate will increase. [23]. It's important to notice that for the normal contact loads and for using different sliding speeds, the value of the wear rate is higher in the case of pure aluminum .This is may be due to the self-lubricating characteristic of the graphite. The main reason for the reduction in wear rates of Al/Cu/Gr composites than that of pure aluminum could be due to the presence of a smeared graphite layer at the sliding surface of the wear sample.

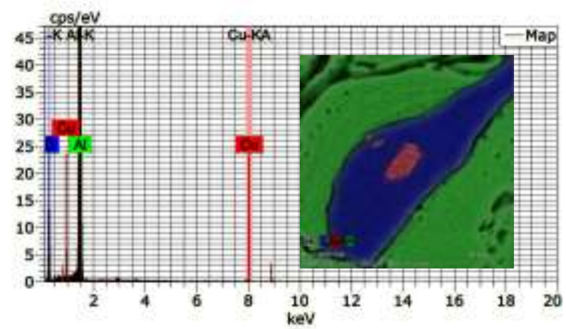

Fig.1. Optical micrographs with EDX of Al/Cu/Gr at 1040 rpm, surface hybrid composites and as received aluminum

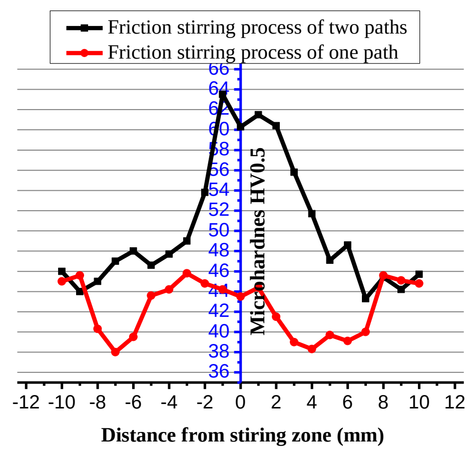

Fig.2. Microhardness distribution for composite material (one and two paths)

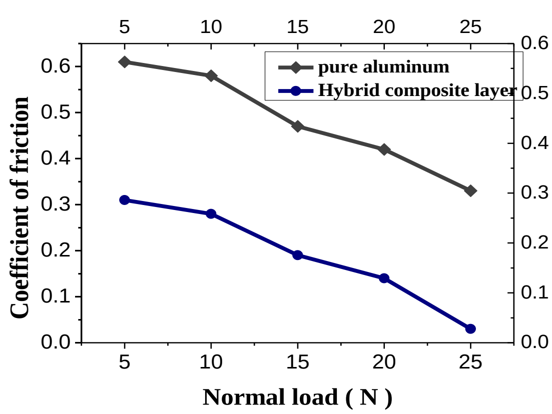

Fig.3. Comparison of friction coefficient as a function of normal load (sliding velocity: 1 m/s, relative humidity: 50%).

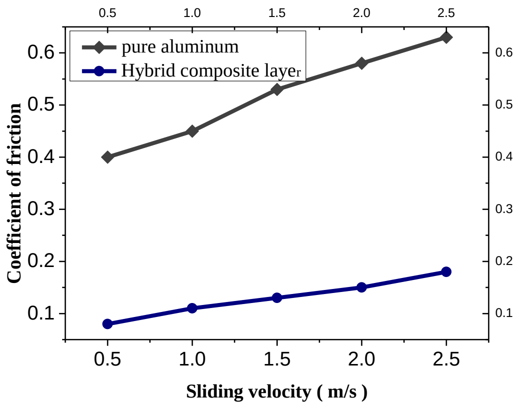

Fig. 4. Comparison of friction coefficient as a function of sliding velocity (normal load: 15 N, relative humidity: 50%).

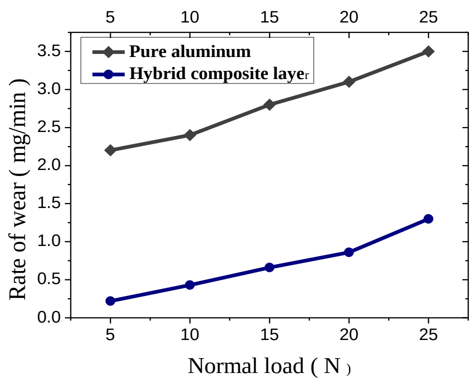

Fig. 5. Comparison of wear rate as a function of normal load (sliding velocity: 1 m/s, relative humidity: 50%).

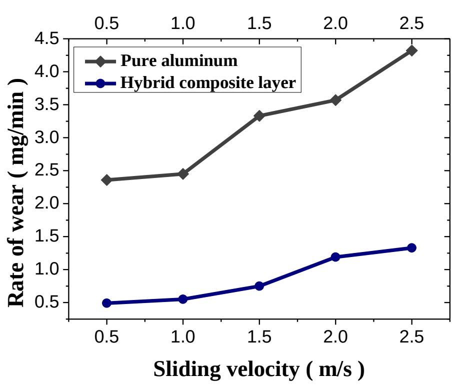

Fig. 6. Comparison of wear rate as a function of sliding velocity (normal load: 15 N, relative humidity: 50%).

3.4. Microstructure investigations

The microstructure of the stirring area has been examined on the cross section of the workpieces. The optical micrograph of one path stirring workpieces is illustrated next. As shown there are remarkable layers of copper (figure 7) as the reason of weak mixing between the matrix and the reinforcement. On the other hand, enriching graphite layers are also outstanding with different sizes of grains, coarse grains (figure 8-a) and fine grains (figure 8-b). Figure 9 represents the microstructure of two paths stirring workpieces through the stirring zone and the enrichment graphite layers (figure 10). There was a significant change in the microstructure rather than one path stirring in copper. The effect of increasing the number of stirring reflected on the solubility of copper in the matrix material.

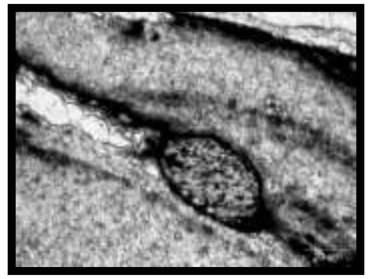
Fig. 7.Enriching copper layer in 1-path stirring workpiece

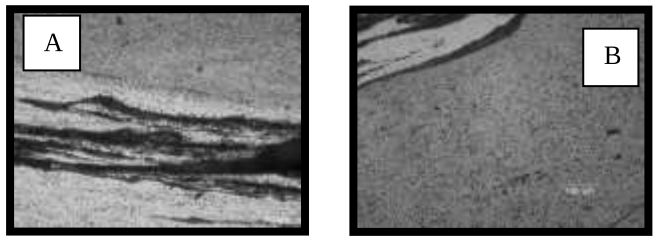

Fig. 8. Enriching graphite layer in 1-path stirring workpiece **A)** Coarse grains, **B)** Fine grains

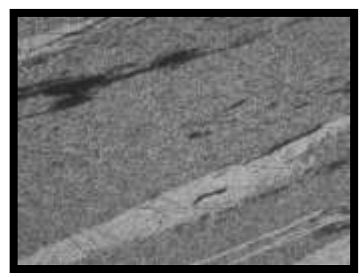
Fig.9. Stirring zone in 2-path stirring workpiece

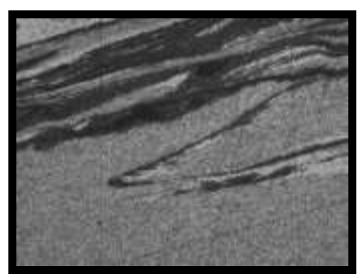
Fig.10. Enrichment graphite layer in one-path stirring workpiece

The scanning electron micrographs for one-path workpiece are analyzed. Figure 11 represents the stirring zone with enriching copper layer. EDX showed that around 30 wt% of copper with 40 wt% of Aluminium with other elements (figure 12).


Fig.11. SEM of enrichment copper layer in 1-path stirring workpiece

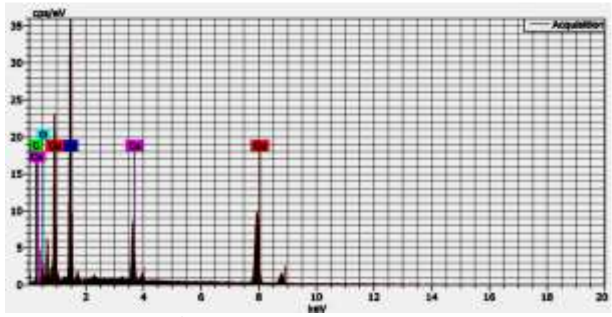

Fig.12. EDX analysis of enrichment copper layer in 1-path stirring workpiece

For enrichment graphite layer; EDX analysis of Aluminum and carbon wt% for two paths stirring has changed from the coarse grains (figure 13-a) and the fine grains (figure 13-b). As carbon is 12 wt% and 74 wt% for coarse (figure 14-a) and fine grains (figure 14-b), respectively.

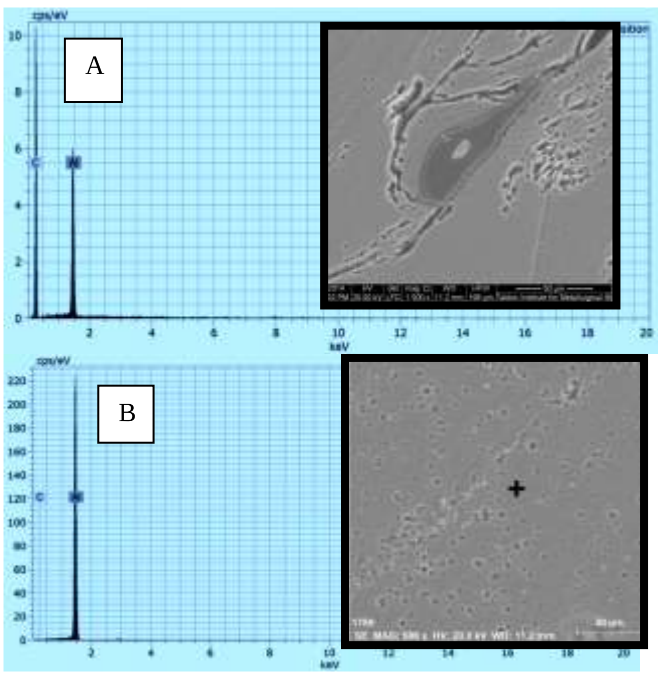

Fig.13.EDX analysis of enriching graphite layer in one path stirring work piece **A)** Coarse grains, **B)** Fine grains

Corresponding analysis has been carried out in case of 2-paths stirring (figure 14). There is no difference for the stirring zone when using different paths. However, the copper particles reduce with increasing the number of paths due to the effect of good mixing.

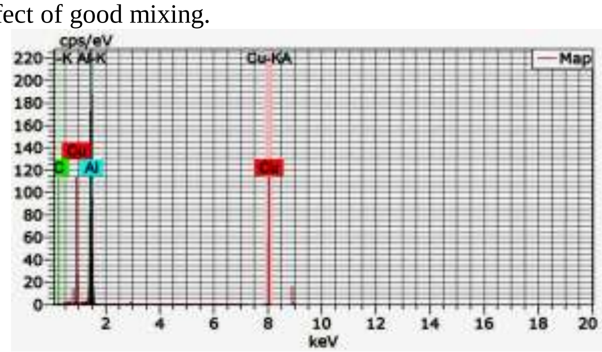

Fig.14.EDX analysis of stirring zone in two paths stirring workpiece

In comparison to one path, the enrichment graphite layer has the same behavior with about 75 wt% Carbon. EDX analysis clears at figure 15.

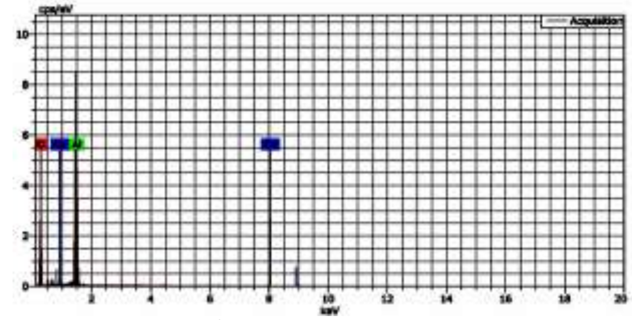

Fig.15. EDX analysis of enrichment graphite layer in 2-paths stirring workpiece

3.5. Microhardness measurements

Microhardness has been measured for stirring workpiece with thickness 3.0 mm with one path and two paths techniques. Firstly, it is well accepted that the highest hardness value occurs in the center of the SZ followed by a gradual decrease across the TMAZ and HAZ until reaching the hardness value of the BM [24-26]. This is attributed to more grain refinement in the SZ due to dynamic recrystallization and more uniform distribution of finer reinforcement particles in the stir zone due to FSP action. Microhardness of the base material is almost 47 HV0.5. For stirring workpiece, microhardness has been measured on the middle of the workpiece horizontally, starting from the base material passing by the stirring zone until the base material on the other side. It is observed from the following results that (figure 2) represents the microhardness values of the friction stirring process with one and two paths. Near the middle of the stirring zone of one path, the microhardness values were around 53 HV0.5 due to the graphite particles consolidate at specific zone and do not spread freely through the surface. In contrast, the sticky zone to the stirring zone (thermo mechanical zone) has 35 HV0.5 as this zone has a plastic deformation effect which lead to be a brittle zone. On the other hand, for the stirring process with two paths, the microhardness values have the same behavior but in the middle of stirring process there is a small amount of graphite particles due to the effect of stirring paths.

3.6. Effect of stir paths on tensile strength

Microscopic examination of one path samples was observed heterogeneity in the distribution of graphite and it is in the form dense clusters, as is evident in Figure 8, has led to a decline in tensile strength as shown in the Figure (16A). Microscopic examination set out in Figures 7,10 and11 shows the presence of copper, which is not surrounded by graphite. This is due to low solubility of carbon in copper (it does not exceed 0.02 at%), there is no chemical and metallurgical bonding between copper and graphite atoms and the bond between them is only very weak mechanical bonding, therefore, separating of graphite particles from copper matrix and movement of them to sliding surface do not need considerable force .It can be summarize to say Figure (16 A) of the tensile results in the case of one path stirring workpieces showed reduction of the tensile strength compared to Figure (16 C) of the substrate and this is due to the following reasons:-

1- The presence of graphite layer formed on the surface leads to an increase slipping incident between levels, which leads to an increase in the plastic deformation and thus a decrease in resistance alloy.
2- Figure 8 illustrates the lack of homogeneity in the distribution of graphite and he is in the form dense clusters are considered weak areas serves as a defect causes a decrease in resistance.
3- Figure 9 shows the aluminum oxide in the form of impurity represent defect within the alloy give rise to a lack of resistance.
4- It is noted figures 7,11,and12, showing that copper in the alloy is not surrounded by graphite and this is due to lack of chemical bonding between them, causing weakness in the tensile strength of the alloy.

On the other side, Figure (16 B) of the tensile results in the case of two paths stirring work pieces showed an increase of the tensile strength compared to Figure (16 C) of the substrate and this is due to the following reasons:-

1- Fact that with the increase stirring granules become a smaller meaning more fining leading to increased tensile strength
2- Regular distribution of graphite as shown in Figure 9, which leads to an increase in tensile strength
3- The presence of copper is surrounded by graphite conjoined together as shown in Figure 9, which leads to an increase in tensile strength

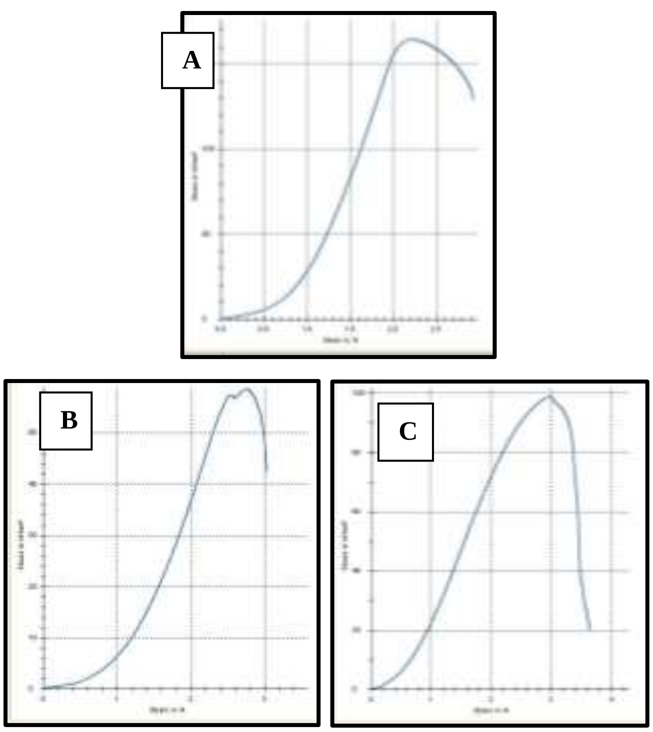

Fig.16. Tensile test of specimens A) Tensile test of base substrate B), Tensile test of one path and C) Tensile test of two paths

IV. CONCLUSION:

In the present research, microstructural, mechanical and tribological properties of the surface hybrid composite of Al/Gr/Cu fabricated by FSP process was investigated. Based on results of the present work, following conclusions can be made:

1- Fabrication of copper/graphite composites via friction stir processing (FSP) is possible. By this technique leads to more homogenous distribution of particles in surface of composite
2- The results showed that the increasing in the stirring number of paths leads to good mixing between the matrix and the particles (graphite and copper) with freely spread through the surface. Moreover, the increase in the stirring number of paths generates rise in the mechanical properties.
3- The formed graphite layer is reducing alleviating the plastic deformation of the subsurface of the self-lubricating composites.
4- The addition of Gr particles, decreases wear rate of the composites due to severe deterioration in mechanical properties.
5- The wear rate of hybrid composite layer (graphite and copper) is much lower than that of pure aluminum for the range of sliding velocity.

REFERENCES:

[1] S.F. Moustafa, S.A. El-Badry, A.M. Sanad, B. Kieback, Friction and wear of copper–graphite composites made with Cu-coated and uncoated graphite powders, Wear 253(2002) 699–710.

[2] Michael Oluwatosin Bodunrin, Kenneth Kanayo Alanemea, Lesley Heath Chown," Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics," Journal of Materials Research and Technology, 2015 ;4 (4):434–445

[3] Bakes H, Benjamin D, Kirkpatrick CW. Metals handbook, vol.2. Metals Park, OH: ASM; 1979. p.3–23.

[4] Ravi N, Sastikumar D, Subramanian N, Nath AK, MasilamaniV. Microhardness and microstructure studies on laser surface alloyed aluminum alloy with Ni–Cr. Mater Manuf Process 2000;15:395–404.

[5] A. Mostafapour Asl, S.T. Khandani," Role of hybrid ratio in microstructural, mechanical and sliding wear properties of theAl5083/Graphitep/Al2O3p a surface hybrid nanocomposite fabricated via friction stir processing method", Materials Science & Engineering A 559 (2013) 549–557

[6] Rabinowicz E. Friction and wear of materials. New York: John Wiley and Sons; 1965.

[7] Budinski KG. Surface engineering for wear resistance. NewJersey: Prentice-Hall; 1988.

[8] Gupta M, Mohamed FA, Lavernia EJ. Solidification behavior of Al–Li–SiCp MMCs processed using variable co-deposition of multi-phase materials. Mater Manuf Process1990;5(2):165–96.

[9] Mabhali LAB, Pityana SL, Sacks N. Laser surface alloying of aluminum (AA1200) with Ni and SiC powders. Mater Manuf Process 2010;25(12):1397–403.

[10] Ma ZY. Friction stir processing technology: a review. Metall Mater Trans A 2008;39:642–58.

[11] Mishra RS, Ma ZY, Charit I. Friction stir processing: a novel technique for fabrication of surface composites. Mater Sci Eng A 2003;341: 307–10.

[12] Mishra RS, Ma ZY. Friction stir welding and processing. Mater Sci Eng R 2005; 50:1–78.

[13] D.R. Ni, D.L. Chen, D.Wang, B.L. Xiao, Z.Y. Ma, Influence of microstructural evolution on tensile properties of friction stir welded joint of rolled SiCp/AA2009-T351sheet,Mater.Des.51(2013) 199–205.
[14] F. Cioffi, R. Fernández, D. Gesto, P. Rey, D. Verdera, G. González-Doncel, Friction stir welding of thick plates of aluminum alloy matrix composite with a high volume fraction of ceramic reinforcement, Compos. A: Appl. Sci.Manuf. 54 (2013) 117–123.
[15] B.L. Xiao, D.Wang, J. Bi, Z. Zhang, Z.Y. Ma, Friction stir welding of SiCp/Al composite and 2024 Al alloy, Mater. Sci. Forum 638–642 (2010) 1500–1505.
[16] Y.N. Zhang, X. Cao, S. Larose, P.Wanjara, Review of tools for friction stir welding and processing, Can. Metall. Q. 51 (3) (2012) 250–261.
[17] Y.N. Zhang, X. Cao, S. Larose, P. Wanjara, Review of tools for friction stir welding and processing, Can. Metall. Q. 51 (3) (2012) 250–261.
[18] R.S. Mishra, Z.Y. Ma, Friction stir welding and processing, Mater.Sci. Eng. R Rep.50(1–2),(2005)1–78.
[19] P. Threadgill, A. Leonard, H. Shercliff, P.Withers, Friction stir welding of aluminium alloys, Int. Mater. Rev. 54 (2) (2009) 49–93.
[20] H. Sarmadi , A.H. Kokabi, S.M. Seyed Reihani, Friction and wear performance of copper–graphite surface composites fabricated by friction stir processing (FSP), Wear304(2013)1–12
[21] M. A. Chowdhury, M. K. Khalil, D. M. Nuruzzaman, M. L.Rahaman, The Effect of Sliding Speed and Normal Load on Friction and Wear Property of Aluminum,International Journal of Mechanical & Mechatronics Engineering, Vol. 11, .(2011), pp. 53-57.
[22] D. M. Nuruzzaman, M. A. Chowdhury, Effect of Normal Load and Sliding Velocity on Friction Coefficient of Aluminum Sliding Against Different Pin Materials, American Journal of Materials Science, Vol. 2, pp.26-31 (2012).
[23] M. A. Chowdhury, M. M. Helali, , The Effect of Frequency of Vibration and Humidity on the Wear rate, Wear, Vol. 262, pp. 198-203, (2007).
[24] K. Kalaiselvan, I. Dinaharan, N. Murugan, Characterization of friction stir welded boron carbide particulate reinforced AA6061 aluminum alloy stir cast composite, Mater. Des. 55 (2014) 176–182.
[25] P. Periyasamy, B. Mohan, V. Balasubramanian, Effect of heat input on mechanical and metallurgical properties of friction stir welded AA6061-10% SiCp MMCs, J. Mater. Eng. Perform. 21 (11), (2012), 2417–2428.
[26] A. Kumar, M.M. Mahapatra, P.K. Jha, N.R. Mandal, V. Devuri, Influence of tool geometries and process variables on friction stir butt welding of Al–4.5%Cu/TiC in situ metal matrix composites, Mater. Des. 59 (2014) 406–414.

Mohamed Abdalla Hussein EL-Meniawi, November 24, 1957 Kafr-Sakr, Sharkia, Egypt

Current Position: Associate Prof. In the Materials Engineering Department, Faculty of Engineering, Zagazig University, Zagazig , Egypt, Zagazig University
Major: Mechanical Design & Production Engineering.
Fine: Materials Engineering.
E-mail: Elmeniawy57@yahoo.com & maelmenyawy@eng.zu.edu.eg
Phone: Mobile: (002) 01010490460
Fax : (002) 055-2341185