INTERNATIONAL JOURNAL OF MECHANICAL ENGINEERING AND TECHNOLOGY (IJMET)

ISSN 0976 – 6340 (Print)
ISSN 0976 – 6359 (Online)
Volume 5, Issue 4, April (2014), pp. 61-71
© IAEME: www.iaeme.com/ijmet.asp
Journal Impact Factor (2014): 7.5377 (Calculated by GISI)
www.jifactor.com

IJMET
© I A E M E

EFFECT OF GRAPHITE ON MECHANICAL AND MACHINING PROPERTIES OF AL-BASE HYBRID COMPOSITE

Dr. Haydar A. H. Al-Ethari[1], Israa Adnan Njem[2]

[1](Prof. at Dept. of Eng. Metallurgy, College of Material's Eng./
University of Babylon-Hilla-IRAQ)
[2](Msc. Student at Dept. of Eng. Metallurgy, College of Material's Eng./
University of Babylon-Hilla-IRAQ)

ABSTRACT

Aluminum metal matrix composite AMMCs reinforced with ceramic particles have a wide acceptance in engineering application due to their properties, but continuing problem with these materials is the difficulty of their machining due to hardness and abrasive nature of the reinforcing ceramic particles. The present work is aimed at studying the preparing of hybrid AMMC reinforced with both SiC particles and particles of graphite that have a lubricant effect. Stir casting technique was used to prepare samples with 6wt% SiC, and a hybrid sample with 6wt% SiC and 6wt% graphite. The effect of such reinforcements was investigated. The investigation included: hardness, compressive strength, required cutting force, surface roughness, as well as microscopic analysis, SEM-EDS analysis and also XRD analysis. Cemented carbide turning tool (P10) was used in all machining experiments with wide ranges of machining conditions to measure the surface roughness, and the cutting force.

The results showed that an improvement of (184.8%) in macrohardness and (85%) in compressive strength had been achieved by reinforcing with 6wt% SiC, while these properties were improved by (33%) and (23%) by reinforcing with both SiC and graphite. The results of machining experiments showed that reinforcing with SiCp alone caused the surface roughness and the main cutting force to be increased by (32-80%) and (50.5–100%) respectively in comparison with the base matrix. In hybrid composite graphite reduces the effect of SiCp on the surface finish, so as the roughness of the machined hybrid sample was increased only (22.9 - 70.4%) in comparison with that for base matrix, while the main cutting force was increased only (42 - 66%).

Keywords: Al Base Hybrid, Cutting Force, Graphite, Roughness, Sic, Stir Casting.

1. INTRODUCTION

Aluminum metal matrix composites (AMMCs) refer to the class of light weight high performance material systems. Most reinforcement in AMMCs are in the form of particulates. Due to their thermal expansion coefficient, hardness, wear resistance, and high specific strength even at elevated temperature, aluminum reinforced with ceramic particles have been successfully used as components in automotive industry, the aerospace sector, and the leisure market. However, interest is also growing in the field of mechanical applications and electronic applications [1, 2].

The most commonly used ceramic particles to reinforce AMMCs are: AlN; alumina; graphite; boron carbide; rice husk ash; silicon carbide; fly ash; MgO; Yttria; and Glass. Silicon carbide is used as reinforcement due to its low cost, resistance to any attack from acids or alkalis or molten salts up to 800°C, high thermal conductivity and low thermal expansion, high elastic modulus, high strength, and thermal shock resistant [3,4]. It is possible to produce high-quality MMCs components to near-net shape through various manufacturing techniques, but additional machining is unavoidable to achieve the desired surface quality and dimensional tolerance for efficient assembly, so it is essential to study the machineability of such materials. Aluminum reinforced with ceramic particles is difficult to be machined due to the very hard and abrasive reinforcements which lead to increase the machining time, high wear rate of cutting tools, high cutting force, irregular material removal rate and so poor surface finish, and relatively high rate of cutting temperature increase [5]. Few published works studied the effect of SiC_p on AMMCs performance. Dunia Abdul Saheb in 2011[6] made an attempt to develop aluminum based silicon carbide particulate MMCs, or graphite particulate by stir casting method. The best results (maximum hardness) were obtained at 25 % weight fraction of SiC and at 4% weight fraction of graphite**.** In 2013 Madeva Nagaral and his coworkers[7] studied the mechanical behavior of (Al6061/Al_2O_3/Graphite) reinforced hybrid composites. It was found that the addition of graphite particulates doesn't vary the tensile strength and hardness in so scale as Al_2O_3. In 2013 Karthik Raj K.V [8] studied Al2014 alloy reinforced with graphite using liquid metallurgy method. The hardness increases with increased particulate addition up to 5% and thereafter a decrease in hardness value is observed. In 2013 Basavarajappa and J. Paulo Davim [9] presented an experimental investigation on surface roughness and chip formation in turning of Al2219/15SiCp and Al2219/15SiCp-3graphite. The composites were fabricated by using liquid metallurgy technique. Results indicated that the value of surface roughness Ra is higher at low cutting speeds due to the inability of the cutting tool to cut these particles. In case of graphitic composites, fractured SiCp particles will squeeze the graphite and forms a valley on the machined surface.

The main objective of this work is to prepare AMMCs with increased mechanical properties and improved machineability. This will be achieved by using graphite particles along with SiC_p as a reinforcing elements. The graphite particles act as solid lubricant which improve the surface finish and reduce the heat generation during machining, which exhibit superior tribological properties, such as low friction, low wear rate and excellent antiseizure effects[10,11]. The investigation will include the effect on mechanical properties as hardness, compressive strength, required cutting force, and roughness of the machined surface. Physical tests will include: XRF, X-ray diffraction, SEM-EDS analysis, and optical microscopy tests.

2. SAMPLES PREPARATION AND TESTS

2.1. Samples Preparation: A base sample and two types of composite were prepared by stir casting as coded in Table 1. All samples were prepared using high purity aluminum wires with a chemical composition shown in Table 2. Powders of SiC with 20-25µm grain size and graphite of 70 µm grain size were used.

Table 1: Samples prepared by stir casting

Sample code	Composition
S	Al-base
SS	Al-base+6wt%SiC
SG	Al-base+6wt%graphite+6%SiC

Table 2: Chemical composition of aluminum wire.

Si %	Fe %	Cu %	Mn %	Mg %	Zn %	Ti %	B %	V %	Cr %	Others %	Al %
0.06	0.12	0.01	0.01	0.02	0.03	0.01	0.005	0.01	0.01	0.10	Bal

Pieces of aluminum wire with required weight (plus an addition of 10%) was melted in a ceramic crucible at 700°C in a gas furnace. The weighted ceramic particles were immersed gradually to the melt. The particles were covered with aluminum foil, pressed carefully, and heated at 300°C for 15 minutes before immersion. The semi solid molten was mixed for 20 minutes with electrical mixer rotating at a speed of 630 rpm. The temperature then was raised slowly above liquideous temperature (850°C) to increase fluidity of molten metal, then the melt was poured into a preheated to 150°C cast iron die with a cavity of 20mm diameter and 200 mm height. The casting was left to cool in a still air. The samples were heated to 300°C for 2hours for stress relief.

2.2. Physical Tests

2.2.1. Chemical composition tests: The tests had been done via testing machine type (X-ray Tluorescence Spectrometer). The tests included all the prepared Samples.

2.2.2. Microscopic Analysis: Specimens were prepared in consistent with the standard metallographic techniques. The sectioned specimens were abraded in a sequence of steps using progressively finer abrasive papers (180, 400, 600, 800, 1000, 1200, 2000 grit size). Grinding has done on polishing machine type (MP200V). Polishing stage was carried out using paste type (nature diamond, with size 15 µm, 6 µm, and 1 µm). Etching treatment for 15 sec in an etchant solution (0.5%HF+99.5% distilled water) was performed by repeated dipping of the specimen [12]. Etching would be stopped by immediate washing with distilled water, rinsed with ethyalcohol and dried by air. Standard metallographic examinations were conducted using professional metallurgical microscope with polarizing dark field reflected light model (1280XEQ-MM300TUSB).

2.2.3. X-Ray Diffraction Analysis: This analysis covered a selected for all samples. The tests were conducted with: Cu target, 1.54060 A^o wave length, 40 KV voltage and 20 µA current.

2.2.4. SEM-EDS test: Surface analyses, chemical analysis and imaging on a variety of materials are performed using this test. Surface for tested samples was prepared in similar manner to that of optical microscopy.

2.3. Mechanical Tests

2.3.1. Macrohardness test: Specimens of (13 mm diameter × 15mm height) were cut from the casted and treated samples. Before subjecting to the hardness tests the specimens prepared by appropriate grinding and polishing operation. The tests were achieved on a universal digital hardness machine with a ball indenter of 2.5 mm diameter and a loading of 32.2 kg for 5 sec. For each test an average of three readings was recorded.

2.3.2. Compression test: Compression tests were carried out on cylindrical specimens of height to diameter ratio of 1.2 according to the ASTM standard [13]. The tests were conducted at room temperature using a computerized universal testing machine with a rate of 0.1 mm\min.

2.4. Machining Experiments Program:

External, longitudinal turning was used for machining experiments. The turning was conducted on a lathe machine with a power of 2.2 kw and a spindle speed of (40-2500 rpm) and feed rate of (0.03-1 mm/rev). Cylindrical specimens with a diameter of 18mm and a length of 180mm were used, wet cutting was used at a constant depth of cut of 0.2 mm, gas oil was used as a cooling solution. To study the surface roughness four spindle speeds (180, 370, 540, and 800 rpm) for each of which four feed rates (0.03, 0.06, 0.16 and 0.5 mm/rev) were used as machining conditions. For cutting force measurements four spindle speeds (160, 250, 400, and 630 rpm) for each of which four feed rates (0.04, 0.063, 0.1, and 0.16 mm/rev) were used as machining conditions at dry cutting. The turning had been carried out using cemented carbide tips type P10 with a chemical composition of (65% W, 9% Co,26% (TaC +TiC) [14]. The tip has a tool angle of (55°) and a nose radius of (1.6mm). A tool holder type (A G.CO Tools) was used. The surface roughness was measured for each cutting operation after the first minute of machining via TR 200 roughness tester. An average of three readings was recorded. Ieicon lathe tool dynamometer with accuracy < ± 1 was used to measure the cutting force. The cutting force was measured for each cutting operation after an identical distance of machining.

3. RESULTS AND DISCUSSION

3.1. Physical Tests

3.1.1. Chemical Composition of the Prepared Samples

Table 3 demonstrates the chemical compositions of the prepared samples. Unfortunately there is no ability to detect the graphite. The results of the chemical composition indicate that there is no effective percentage of alloying element in composition of the prepared samples. This ensures the preparation of aluminum base composites and not any of its alloys.

Table 3: Chemical compositions of the prepared samples

Sample code	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ni %	Zn %	Ti %	Pb %	B %	Al %
S	1.87	0.226	0.005	0.001	0.007	0.0005	0.001	0.006	0.003	0.0005	0.0007	Bal.
SS	4.98	0.471	0.045	0.003	0.002	0.0005	0.003	0.028	0.004	0.001	0.001	Bal.
SG	3.92	0.167	0.005	0.001	0.016	0.0008	0.001	0.001	0.004	0.0005	0.001	Bal.

3.1.2. X-Ray Diffraction Analysis: Figure 1 represents the charts of the X-ray diffraction for S and SS samples. It is clear that the only element appeared is aluminum. This ensures the purity of the aluminum used to prepare the samples. The chart of SS shows existence of complex compound due to chemical reactions between Si, carbon, and aluminum caused by high pouring temperature. The strengthening of the composites will be affected by such compounds.

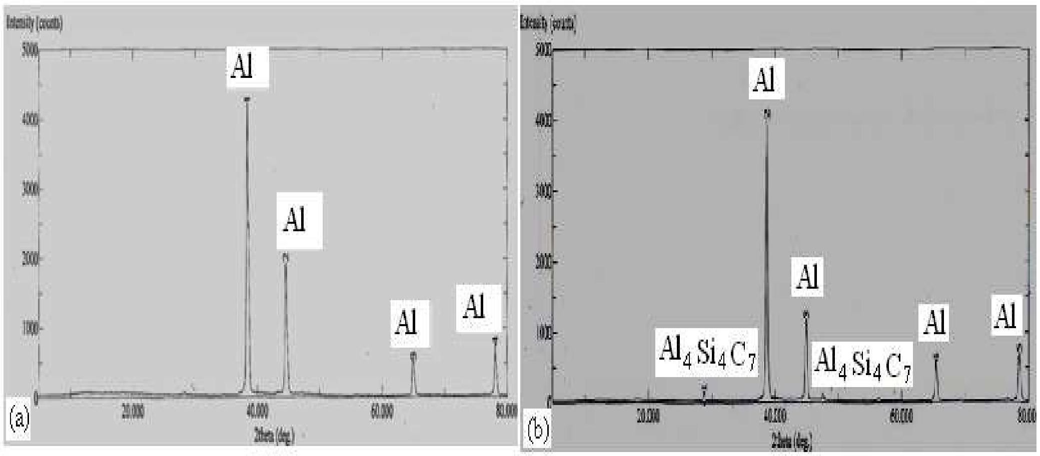


Figure 1: Charts of the X-ray diffraction for: (a) S sample; (b) SS sample

3.1.3. Results of Optical Microscopic Analysis

The microstructures of the prepared samples, are shown in Fig.2. The microstructure of SS sample shows the existence of SiC particles in aluminum matrix with acceptable distribution, but this may be reflected on the mechanical and machining properties of the samples.

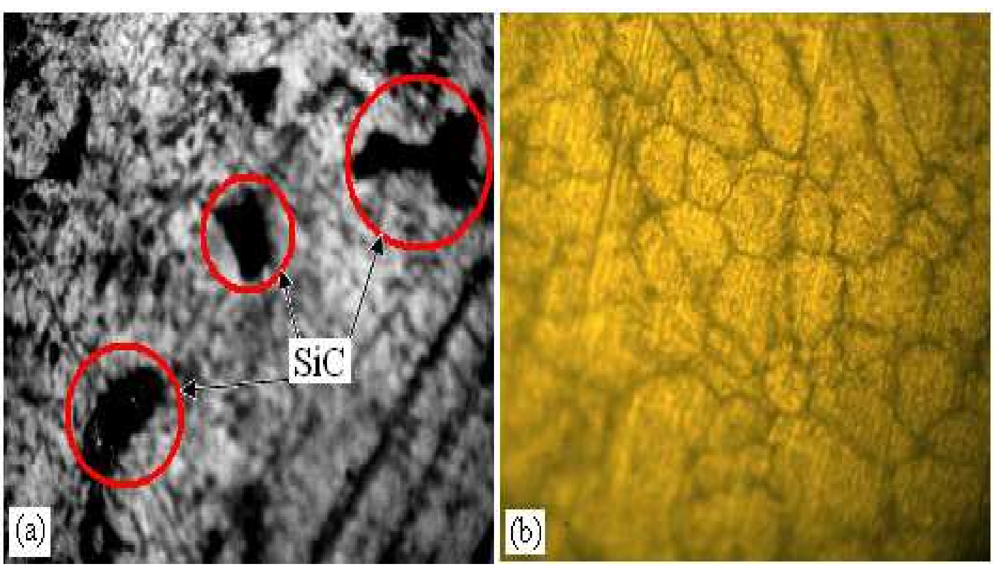
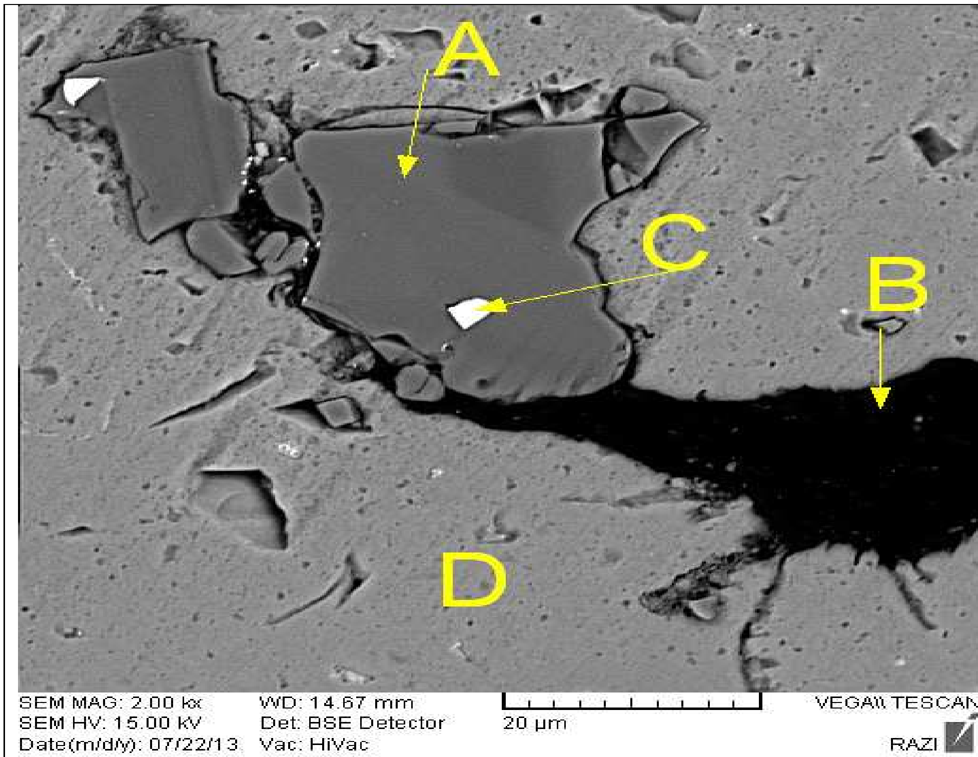


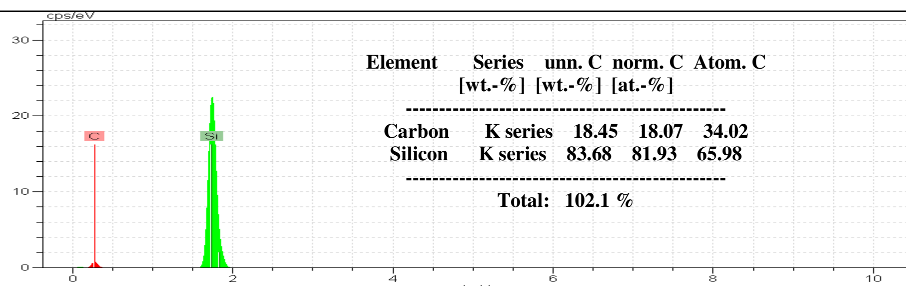
Figure 2: Microstructure of: (a) SS sample; (b) S sample (100 X magnification)

3.1.4. SEM-EDS Analysis

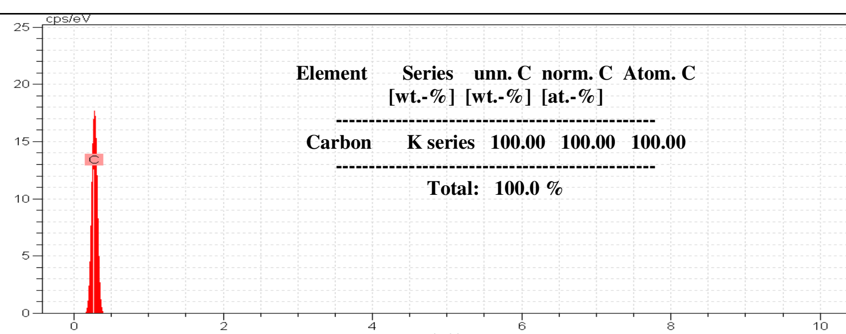
Fig. 3 shows the SEM- EDS analysis for SG- specimen. The Figure shows the reinforced aluminum matrix by both SiC and graphite particles.



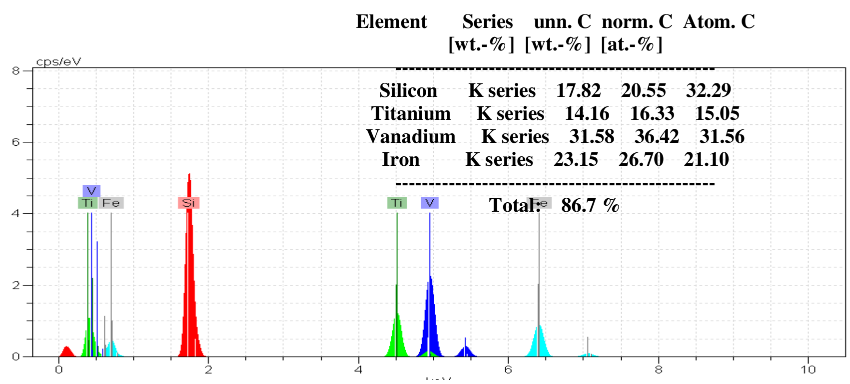
SG – Specimen-SEM



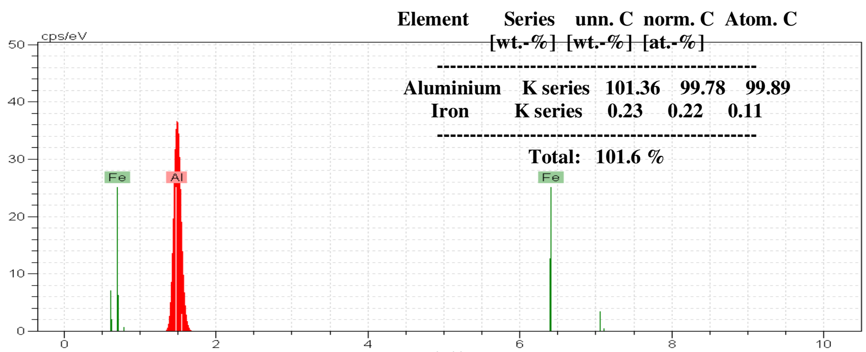
SG – Specimen, spot A



SG – Specimen, spot B



SG – Specimen, spot C



SG – Specimen, spot D

Figure 3: SEM - EDS of the SG – Specimen

3.2. Mechanical Tests

3.2.1. Macrohardness: The tests showed a Brinel hardness of 24.2, 68.92, and 32.2kg/mm^2 for S, SS, and SG specimens respectively. The increase in hardness of the composites can be attributed to the relatively high hardness of particles itself which acting as barriers to the movement of dislocations within the matrix as reported in [6]. The hardness of SG- sample is more than that for S-sample but lower than that for SS-sample. This behavior may be due to agglomeration caused by increased viscosity with increasing in percentage of the reinforcement, also it may be due to weak chemical compounds formed during casting.

3.2.2. Compressive Strength: The tests showed a **compressive strength** of 120.68, 223.37, and 149.145 MPa for S, SS, and SG specimens respectively. It can be observed that the compressive strength had been improved in all samples. The higher improvement was recorded due to the addition of SiC particles, while a lower was observed due to adding both types of reinforcing particles. The reinforcing effects is due to the particles role as obstacles preventing the dislocations movement.

3.3. Machining Experiments

3.3.1. Cutting Force: The measured cutting force for each set of the cutting conditions used in machining each sample are shown in Fig. 4 and Fig. 5 The following can be noticed clearly:

The main cutting force decreases with increase in cutting speed. This is true for all samples at all feed rates. Increasing cutting speed causes the chips to be thinner and shear angle increases thus decreasing chip reduction coefficient and chip strains, so the plastic deformation of metal takes place with less strain. Also at higher cutting speeds, build up edge (BUE) formation disappears and chip-tool contact length decreases resulting in the reduction of cutting force. The main cutting force increases with increase in feed rates as shown in Fig.5. Greater feed, means the larger volume of the deformed metal and consequently greater resistance of the material to chip. Also an increase in feed rate causes excessive friction between the tool and work piece, which increases the cutting force. The values of the required cutting forces are different from one sample to another. This is belong to the difference in mechanical properties of the used reinforcing elements. The cutting force required for SS is more in comparison with other samples due to the existence of harder particles (SiC), while SG exhibits lower cutting force due to the existence of graphite, which act as lubricant reducing the frictional force wherever it will be.

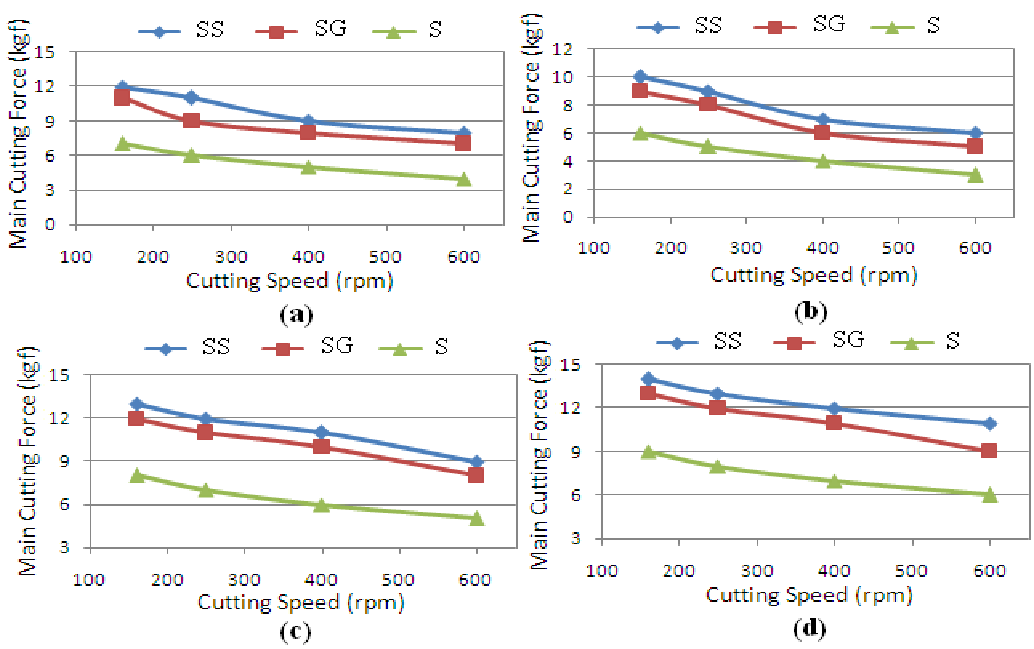


Fig. 4: Effect of cutting speed on the main cutting force for S_0, SG, and S_3 – Samples with a depth of cut of 0.2 mm and feed rate of: a) 0.04 mm\rev.; b) 0.063 mm\rev.; c) 0.1mm\rev.; and d) 0.16 mm\rev

3.3.2. Surface Roughness: The measured surface roughness for each set of the cutting condition used in machining each sample are shown in Fig.6 and Fig.7. The Figures indicate the following:

- Surface roughness decreases as the cutting speed increases. At low cutting speed, the unstable built-up edge (BUE) is formed and also the chips fracture readily producing rough surface. As the cutting speed increases, the BUE vanishes, chip fracture decreases and, hence, the roughness decreases.
- Surface roughness increases with increase in feed rate at all cutting speed. Higher feed rate values increases temperature and this cause to decrease bonding effect between particles and Al matrix.

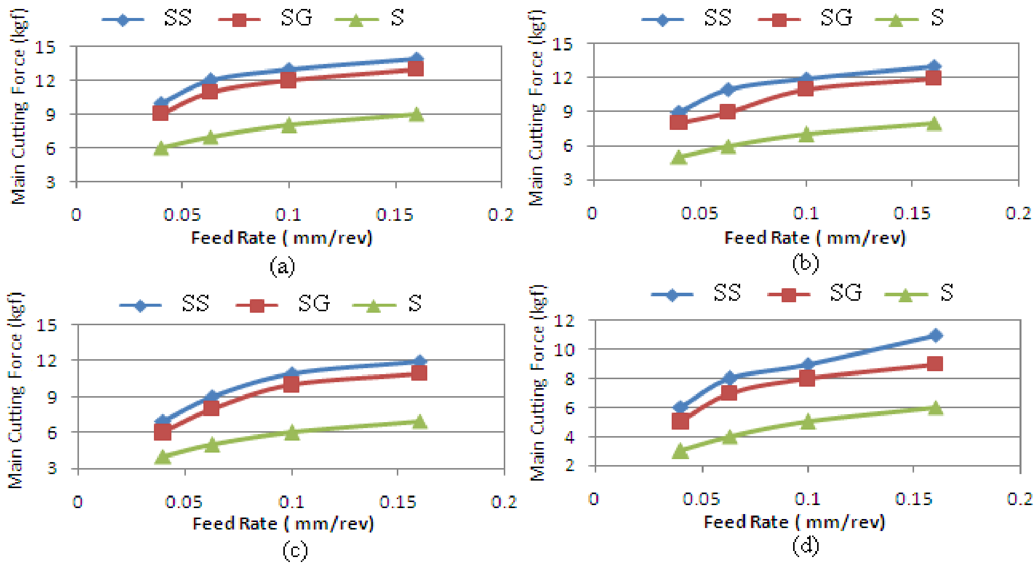


Fig. 5: Effect of feed rate on the main cutting force for S_0, SG, and S_3 – Samples with a depth of cut of 0.2 mm and cutting speed of: a) 160 rev\min.; b) 250 rev\min; c) 400 rev\min.; and d) 630 rev\min

- The SS sample recorded higher surface roughness. This may be due to the presence of hard SiCp which rolls over the surface during turning and ploughs the turned surface resulting in grooves on the machined surface. Also SiC reduces the ductility of the reinforced matrix and makes it ideal to produce discontinuous type chips which increases the roughness.
- The presence of graphite in SG-sample reduces the coefficient of friction between the tool and the workpiece, and hence allows the cutting tool to slide easily over the machined surface. This lead to improve the surface finish.

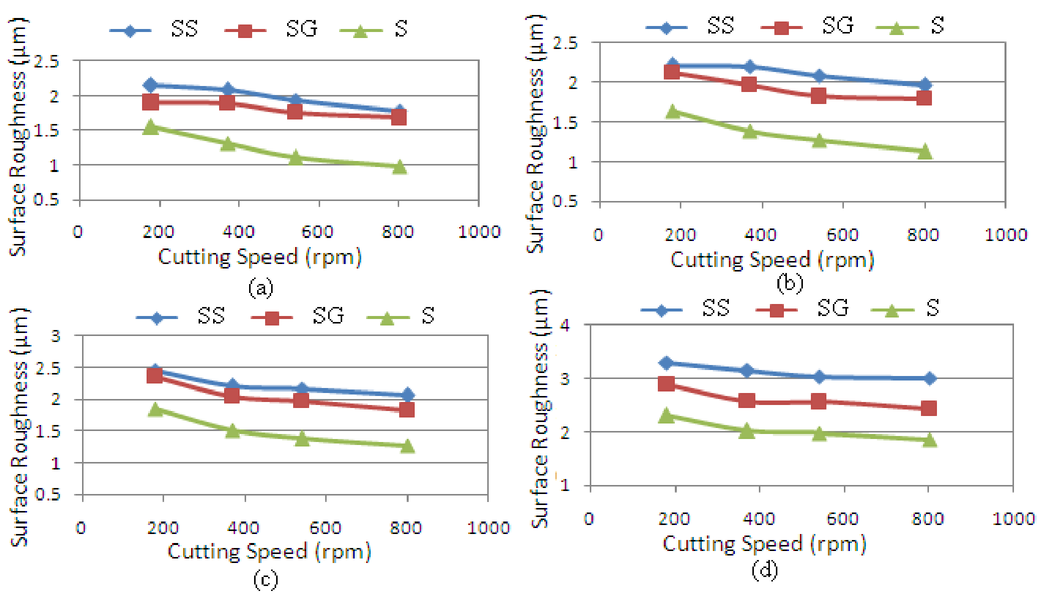


Fig. 6: Effect of cutting speed on surface roughness for S, SG, and SS – Samples with a depth of cut of 0.2 mm and feed rate of: a) 0.03 mm\rev; b) 0.06 mm\rev; c) 0.16 mm\rev.; and d) 0.5 mm\rev

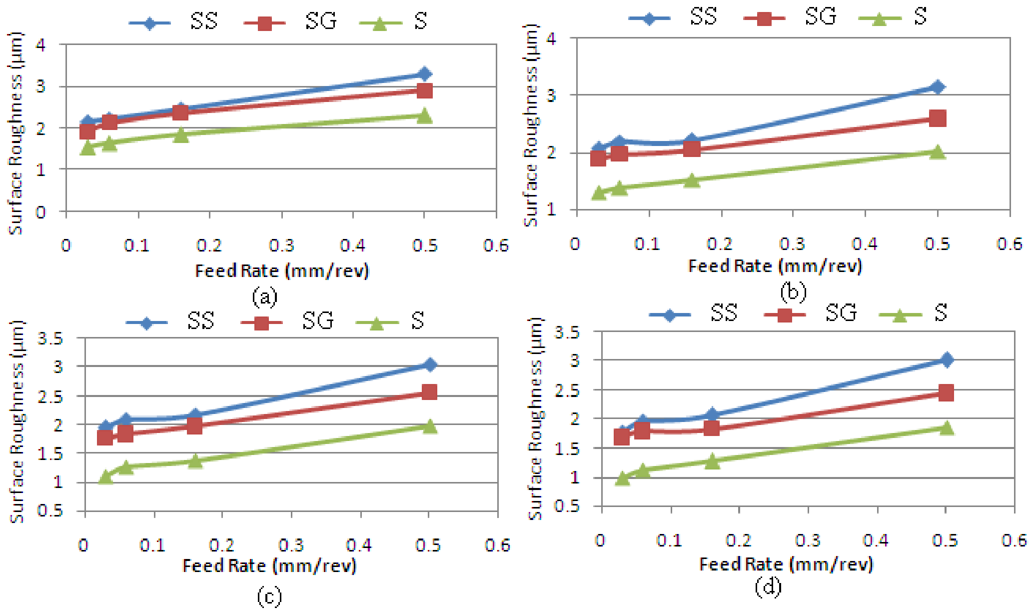


Fig. 7: Effect of feed rate on surface roughness for S, SG, and SS – Samples with a depth of cut of 0.2 mm and cutting speed of: a)180 rev\min.; b) 370 rev\min; c) 540 rev\min.; and d) 800 rev\min

4. CONCLUSIONS

According to the results of the present work, the following can be concluded:

1. An improvement of 184.8% in macrohardness had been achieved by reinforcing with 6wt% of SiC, and 33% by reinforcing with 6wt% SiC and 6wt% graphite, while compressive strength was improved by 85% by reinforcing with SiC, and by 23% by reinforcing with both SiC and graphite.
2. SiC particles have a significant effect on machining properties of AMMCs, so as the surface roughness and the main cutting force were increased by (32% to 80%), and (50.5 to 100%) respectively in comparison with the base matrix when turning with the used machining conditions. In the hybrid composite graphite reduces the effect of SiCp on these variables, so as the roughness of the machined hybrid sample was increased by only (22.9 to 70.4%), while cutting force was increased by only (42 to 66%).
3. In spite of agglomeration and chemical reactions stir casting is acceptable to prepare AMMCs reinforced with SiC and graphite particles with high mechanical and machining properties.

5. REFERENCES

1. Surappa.M.K., Aluminium Matrix Composites: Challenges and Opportunities, Sadhan, Vol. 28, Parts 1 and 2, 2003, 319 –334.
2. Daniel Gay, Suong V. Hoa, Stephen W. Tsai, Composite Materials Design and Applications, CRC, press, 2003.
3. Deborah D. L. Chung, Composite Materials Science and Applications, Second Edition, Springer- Verlag London Limited, 2010.
4. Rana. R. S., Rajesh Purohit, and S. Das, Review of Recent Studies in Al Matrix Composites, International Journal of Scientific & Engineering Research Vol. 3, issue 6, June-2012.

5. Dr. Haydar Al-Ethari, Ahmed Rabeea Hayawi, Zaidun Ayad Ahmed, and Omyma Hazem Yaseen, Some Properties of Al-Mg + Glass Powder + Graphite Hybrid Composite, The Iraqi Journal of Mechanical and Materials Engineering, Special issue for the papers presented in the 2nd international scientific conference of the collage of Materials Eng.-University of Babylon, Iraq-Babylon, 2013.
6. Dunia Abdul Saheb, Aluminum Silicon Carbide and Aluminum Graphite Particulate Composites, Arbn Journal of Engineering and Applied Sciences, Vol. 6, No. 10, 2011, 41-46.
7. Madeva Nagarl, Auradi.V and Ravishankar.M.K, Mechanical Behaviour of Aluminum 6061 Alloy Reinforced With Al_2O_3 and Graphite Particular Hybrid Metal Matrix Composite, International Journal of Research in Engineering & Technology (IJRET), July 2013, Vol. 1, Issue 2, 193-198.
8. Karthik Raj K.V, Annaiah M.H., Manjunatha B, Davis P Skariah, Harendra Kumar H.V, "Dry Sliding Wear Behavior of Heat Treated A2014 Reinforced with Graphite", International Journal of Innovative Research in Science, Engineering and Technology, May 2013, Vol. 2, Issue 5, 1681-1685.
9. Basavarajappa S., Paulo Davim J., Influence of Graphite Particles on Surface Roughness and Chip Formation Studies in Turning Metal Matrix Composites, Material Research., ahead of print Epub, June 2013, print version ISSN 1516 -1439.
10. Jaspreet Singh, Deepak Narang, N.K. Batra, Experimental Investigation of Mechanical and Triboligical Properties of Al-SiC and Al-Gr Metal Matrix Composite, International Journal of Engineering Science and Technology (IJEST), June 2013, Vol. 5, No.06, 1205-1210.
11. Hocheng H., Yen .S.B., lshihara. T. and Yen. B.K., Fundamental Turning Characteristics of a Tribology-Favored Graphite/Aluminum Alloy Composite Material, Composites PartA 28A (1997) 883-890, 1997 Elsevier Science Limited.
12. Awham Jumea Salman," Experimental Analysis of In- situ Composite Al-Si Eutectic Alloy", MSc thesis, Babylon University-Iraq, 2009.
13. Babu Rao .J, Venkata Rao .D. and Bhargava, Development of light weight Alfa composites, International Journal of Engineering, Science and Technology, 2010, Vol. 2, No. 11, 50-59.
14. Mushtaq Talib Ali, Studying of The Effect of Physical and Mechanical Properties of Carbide Tools, MSc thesis, Babylon University-Iraq, 2003.
15. R.Maguteeswarana, Dr. R.Sivasubramanian and V.Suresh, “Methodology Study and Analysis of Magnesium Alloy Metal Matrix Composites”, International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 2, 2012, pp. 217 - 224, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
16. Ajay Dev Boyina, M. Vijaya Sekhar Babu, K. Santa Rao and Dr. P.S. Rao, “Investigation of Mechanical Behaviour of Ilmenite Based Al Metal Matrix Particulate Composites”, International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 5, 2013, pp. 111 - 115, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
17. V.Suresh, Dr.R.Sivasubramanian and R.Maguteeswaran, “Study and Investigation of Analysis of Metal Matrix Composite”, International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 2, 2012, pp. 171 - 188, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.