Machinability and Tribological Properties of Stir Cast LM6/SiC/GR Hybrid Metal Matrix Composite

Montasser S. Tahat

Al-Balqa' Applied University, Al-Huson University College, Mechanical Engineering Department, PO Box 50, Al-Huson 21510, Irbid, Jordan

Abstract. Analysis on machining characteristics in turning of LM6/SiC/Gr hybrid metal matrix composites is made of (Al-11.8%Si)/SiC/Gr hybrid metal matrix composites. The process performances such as porosity, wear rate of the composites, tool wear, tool life, specific modulus, surface roughness and material removal rate with equal weight fraction of SiC and Gr particulates of 3%, 7%, 10% and 13% reinforcement are investigated. This experimental analysis and test results on the machinability of Al/SiCMMC will provide essential guidelines to the manufacturers. Hybird metal matrix composites reinforced with graphite particles posses better machinability and tribological properties.

1 Introduction

Lubricants are extensively used between the contacting surfaces to reduce friction and wear. These lubricants are usually toxic and not readily biodegradable and thus these lubricants can cause considerable damage to the environment. The use of external lubricants can be eliminated by designing self-lubricating composite materials. These composite materials have the ability to achieve low friction and wear at the contact surfaces without any external supply of lubrication during sliding. The metal matrix composites reinforced with various self-lubricating particles such as graphite are being used as self-lubricating materials for various engineering applications [1]

Nowadays manufacturing industries are constantly focused on lower cost solutions with reduced lead time and better surface quality in order to maintain their competitiveness and efficiency. The knowledge of cutting forces, tool wear and temperature developed in various machining processes under given cutting conditions is being a dominating criterion of material machinability, to both the designer manufacturer of machine tools, as well as to user.

Aluminum alloys are promising structural materials due to their high specific strength and stiffness. However, their applications are restricted because of their poor wear resistance. Aluminum alloys reinforced with SiCp particles composites are being considered for their superior mechanical and tribological properties over the conventional aluminum alloys, and therefore, these composites have gained extensive applications in automotive and aerospace industries. But Al/ SiCp are extremely difficult to machine (turning, milling, drilling,

threading) due to their extreme abrasive. As the presence of hard reinforcement particles makes them extremely difficult to machine as they lead to rapid tool wear [2]. Therefore, graphite particles were added in SiC/Al composites to improve its machinability [3], [4]. Meanwhile, their damping and wear resistance properties were also improved.

Characteristics of AMCs reinforced with soft reinforcement particles of Gr, and volume fraction of reinforcements, as well as machinability and testing condition have been reported [5]-[7].

The incorporation of SiC hard reinforcing particles into the AMCs improve their mechanical and tribological behavior, but may result in deteriorated machinability together with rapid counter-face wear [2], [8], [9]

Hybrid composites containing both hard and solid lubricant materials with improved mechanical and tribological behavior have been developed to enhance the machinability of the AMCs [10]-[13].

From the published literature it is clear that Al/SiC MMCs machining is one of the major problem which counter the industry. While machining Al−SiC−Gr hybrid composites, the criteria considered for the best performance are lower surface roughness, wear rate of the composites and tool flank wear of tool, and higher tool life, material removal rate and specific modulus. The present study has been carried out to investigate the machinability of the stir cast LM6/SiCp/Gr hybird metal matrix composites at varying equal weight fraction of SiC and Gr particulates of 3%, 7%, 10% and 13% reinforcement. The influence of reinforcement volume fraction on porosity, density, surface roughness, tool life and wear, the matrix wear rate, specific modulus and material removal rate has also been investigated. This

experimental analysis and test results on the machinability of Al/SiC/Gr-HMMCs will provide essential guidelines to the manufacturers.

2 Experimental procedure

2.1 Materials selected for processing composites

The main materials used in this project are LM6 aluminum alloy (Aluminum – 11.8% silicon) as a matrix material and SiC-Graphite as a particulate reinforced added in different percentages. The details of the LM6 alloy properties and composition is shown in Table 1. Silicon Carbide particles of 45 μm average size and graphite particles of 90 μm average size were used in this study.

Table 1. Composition of LM6 [14]

Elements	Al	Cu	Mg	Si	Fe	Mn	Others
Weight %	85.95	0.2	0.1	11.8	0.5	0.5	0.75

2.2 Preparation of composites

For the purpose of improving surface wettability and interface bonding between matrix alloy and graphite particles, the surface of graphite particles was coated with copper by a cementation process using aqueous and supersaturated copper sulphate solution [15]. The SiC particlues was preheated at 750-800 C for 2 hrs to make their surface oxidized to achieve better weldability and to prevent decarburization.

The stir casting technique is the simplest and the most economical process for producing particulate reinforced MMCs available for particulate reinforced metal matrix composites [16]. Two step stir casting method was used to fabricate the Al/Si-SiC-Gr hybird composites. Aluminium alloy LM6 was melted up to 750ºC. Varying equal weight fraction of SiC and Gr particulates of 3%, 7%, 10% and 13% reinforcement was added with this molten LM6. It is allowed to cool to solidus temperature and stirred at 120 rpm using steel impeller. In this way 100% of the SiC particles were transferred to the metal. Simultaneously, graphite was added with Aluminum – 11.8% silicon (LM6)-SiC. After that the composite alloy was roll poured into the pre-heated (250ºC) permanent mould. Composites were cast in required diameter and length. The silicon carbide particles exhibit in the form of solid crystal whereas the graphite particles appear to be flakes.

The different samples were precision weighed in an electronic balance to an accuracy of 0.1 mg. In general, the experiment data obtained from three specimens cut from the same composite were taken as the average value.

The density measurements were carried out to determine the porosity levels of the samples. The density of the samples was measured according to ISO 2738 standard. The measured density was compared to the value obtained using rule-of-mixtures so as to determine the volume fraction of porosity.

Composites wear of pin-on-disc tests were undertaken under the normal load of 20 N (resulting in a normal pressure of 1 MPa), the sliding velocity of 0.5 ms-1 and different sliding distance of 250, 500, 750, and 1000 m using a wear track diameter of 16 mm.

He machining tests were conducted using an ACE LT2 type of CNC lathe under dry turning condition. The as cast bars were machined with K10 Tungsten Carbide inserts (positive rake angle 14°, clearance angle 6°, and nose radius 0.3 mm) and MTJNL 2525M16 tool holder. The recommended levels of turning parameters to minimize surface roughness and flank wear, and to maximize material removal rate are: cutting speed (200 m/min), feed rate (0.075 mm/r) and at a constant depth of cut of 1 mm [Suresh, P, Marimuthu, K, Ranganathan, S & Rajmohan, T, 'Optimisation of machining parameters in turning of Al-SiC-Gr hybrid metal matrix composites using Grey-fuzzy algorithm', Trans. Nonferrous Met. Soc. China 24(2014) 2805−2814]. The maximum flank wear on the tool tip was measured by a SZX12-type Olympus toolmaker's microscope with measuring grids on the eye-piece. The maximum flank wear of 0.6 mm was chosen as the tool life limit.

Surface roughness values have been measured by using Mitutoyo Portable Surface Roughness Tester. The Material Removal Rate (MRR) is determined from the amount of material machined in the given period of time in minutes.
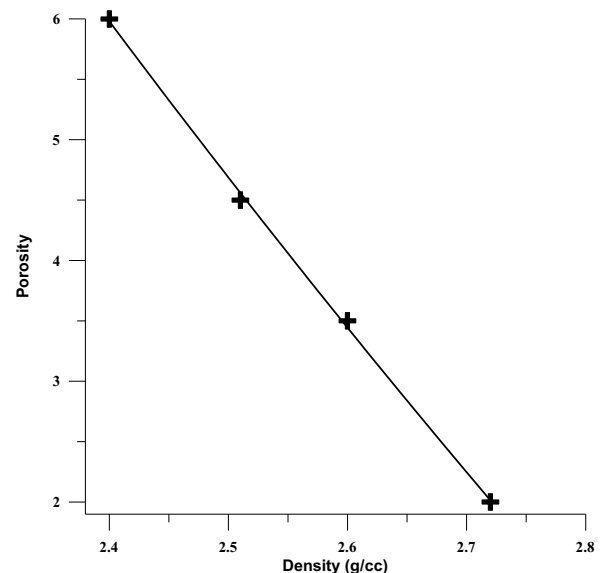
Figure 1. Porosity and density variations with increasing SiC/Gr contents.

3 Results and discussion

3.1. Density and porosity

Fig. 1 shows the variation of both density and porosity as a function of the SiC/Gr volume fraction. The densities of composites were found to increase linearly with the volume fraction, in accordance with the rule of mixtures. Also the percentage porosity present in the composites

reduces with the increase of the reinforcements content. Graphite is a solid lubricant material and facilitates movement and rearrangement of matrix and reinforcement particles resulting in higher densification. With relevance to characterization, the composites were found to be totally non-porous and microscopically homogeneous in the distribution of SiC particles. The volume fraction of porosity, and its size and distribution in a cast metal matrix composite play an important role in controlling the material's mechanical properties. It is necessary that porosity levels be kept to a minimum.

3.2 Wear of the composites

As shown in Fig. 2, with the increase of the SiC/Gr contents, the wear rate of Al/SiC/Gr HMMCs reduces. It was found that the amount of graphite released on the wear surface forms a tribofilm on the contact surfaces. This reduces the overall friction coefficient and wear rate. The presence of graphite tribolayer (or mechanically mixed layer) also increases the seizure resistance and enables to run under boundary lubrication without galling. Increasing of protrusion of SiC particles result in formation of more stable lubricating film on the tribosurface of hybrid composites.
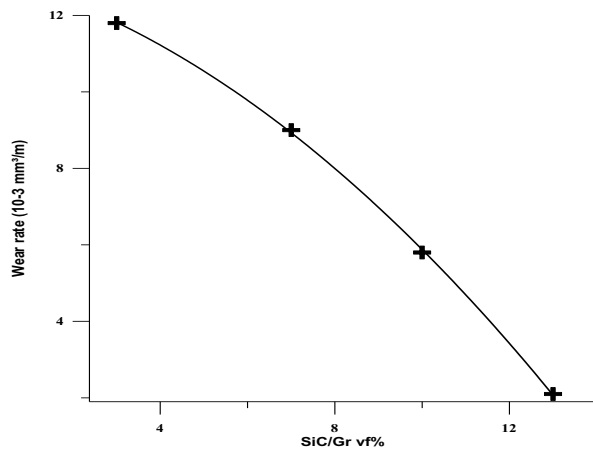
Figure 2. The effect of SiC/Gr addition on the matrix wear rate of the investigated composites.
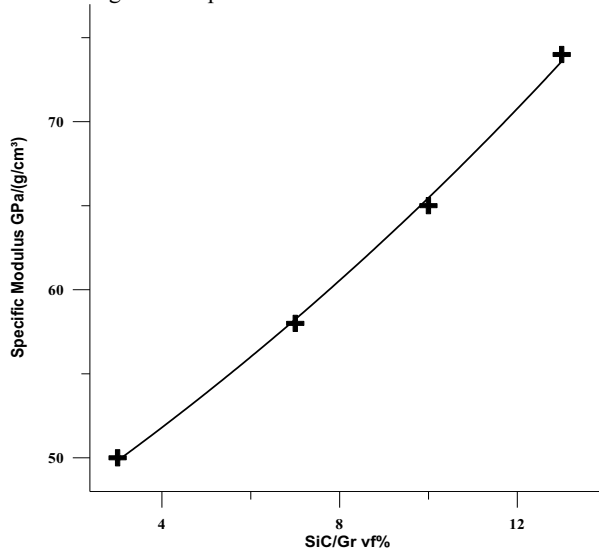

**Figure 3.** Specific moduli of the composites.

3.3 Specific modulus

As shown in Fig. 3, the specific moduli of 13%SiC/13%Gr/Al are approximately as twice as those of preferred inertial guidance materials. A high specific modulus would increase the dimensional stability of the materials used for the inertial instruments. Then an inertial guidance device could be made smaller and lighter. So this paper will provide a novel solution to machinable materials for precision instruments.

3.4 The surface roughness

The surface roughness affects the dimensional accuracy of the machined components. It is evident from the plot in Fig. 4 that the SR of Al–SiC–Gr hybrid composites decrease with increase in % reinforcement. This is due to increase in brittleness of the material and avoids build up edge formation in the tool tip.
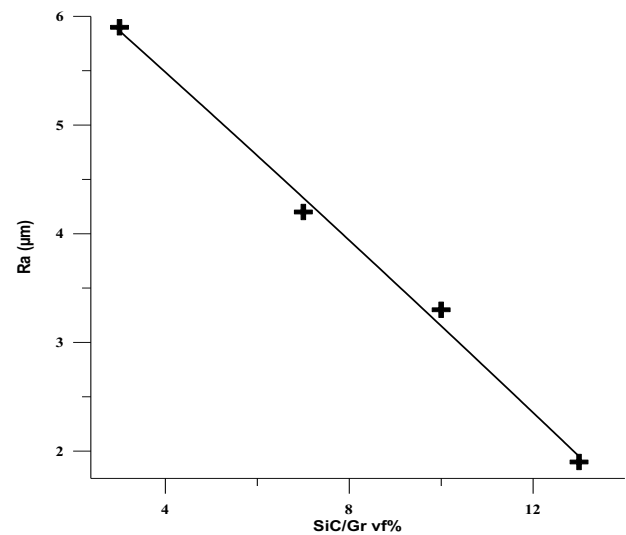
Figure 4. Variations in surface roughness of the composites.
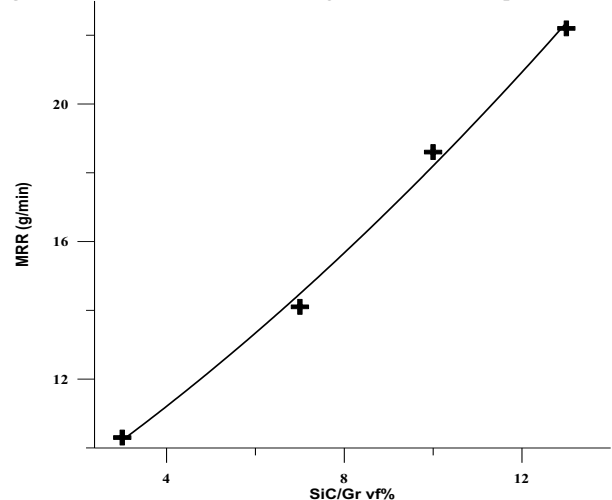
Figure 5. Effect of reinforcements volume fraction on material removal rate.

3.5 Material removal rate

MRR in is an important factor because of its vital effect on machining characteristics of the material in the industrial economy. As shown in Fig. 5, the MRR

increases with increase in volume fraction of SiC/Gr. The increase in combined % reinforcement of SiC and Gr particulates results in decrease in hardness and fracture toughness of Al-SiC-Gr hybrid composites. Therefore the machining of Al-SiC-Gr hybrid composites with higher weight fraction of graphite is easy with maximum MRR and less tool wear.

3.6 Tool wear and tool life

From Fig. 6a, it can be observed that an increase in mass fraction of SiC−Gr decreases the flank wear of the tool. The tool life values for specimens investigated in the present work are shown in Fig. 6b. By adding 3-13% SiC/Gr particles, the tool life is prolonged by 50-200%. The tool life can reflect the machinability of the composites. The flaky graphite in SiC/Gr/Al composites promotes chip formation and the SiC particle in matrix also act as chip breaker resulting in an improved machinability. The addition of graphite particles reduces flank wear of the tool due to the formation of tribolayer. Some of the crushed or removed graphite particles trapped between flank face of the tool and machining surface, and reduced friction at the machining interface.
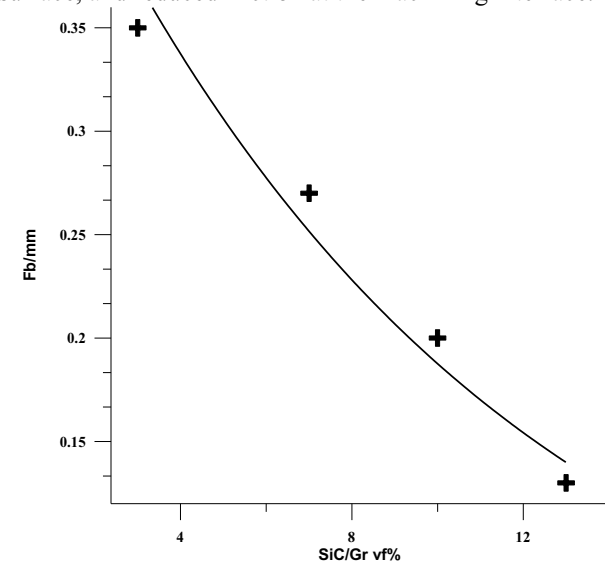
a. Effect of the SiC/Gr particles on flank wear of the tool
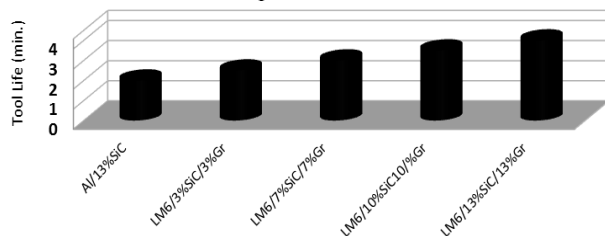
b. Variations in tool life when machining different composites
Figure 6. Effect of the SiC/Gr particles on the tool.

4 Conclusions

The following points were concluded from the conducted tests of the composites:

1. The processing employed in this paper would enable realization of electronic packages made out of Al-Si/SiCp MMCs.

2. The amount of porosity are decreased by increasing of silicon carbide and graphite contents in the composites.

3. It is obvious that the SR of Al–SiC–Gr hybrid composites decrease with increase in combined SiC-Gr % reinforcement.

4. Low wear rate was exhibited in the Al–SiC/Gr surface hybrid composite due to mechanically mixed layer generated between the composite pin and steel disk surfaces which contained fractured SiC and Gr. The presence of SiC particles serves as load bearing elements and Gr particles acted as solid lubricant.

5. Machining of Al−SiC−Gr hybrid composites with a higher mass fraction of graphite is easy with a maximum MRR and tool life and less tool wear.

6. The MRR increases with the increase in combined SiC-Gr % reinforcement. The increase in combined % reinforcement of SiC and Gr particulates results in decrease in hardness and fracture toughness of Al-SiC-Gr hybrid composites.

7. The high specific modulus of the investigated composites would increase the dimensional stability of the materials used for the inertial/ precision instruments.

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