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The Effect of Graphite Particles Addition on the Surface Finish of Machined Al-4 Wt.% Mg Alloys

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Metal matrix composites (MMCs) are a new class of materials finding various applications, especially in transport industries. Compocasting technique was used in the present study to produce aluminum, magnesium, and graphite (MMCs) cast bars. These cast bars were machined to investigate the effect of graphite addition on the surface finish. The obtained results show that the addition of graphite particles to the aluminum and magnesium alloys produce slight improvement on the machined surface finish, for all the percentage of graphite additions considered.

Keywords compocasting, MMC, machinability, porosities, surface finish

1. Introduction

Many of the modern technologies require materials with a superior combination of properties over those of metal alloys and ceramic and polymeric materials. In very early times, the problem of finding the most suitable material resulted in a search for such a material for a specific job. Originally, the search of suitable materials was a search among the already existing materials. In many new applications, it has been found that there is a need for the combination of several properties together. These desired material property combinations might be achieved by the development of new composite materials. Composites have a wide range of applications in industry especially in automotive and aerospace industries.[1] After more than 30 years of active research, metal-matrix composites (MMCs) are beginning to make a significant contribution to industrial applications. The tailored properties in composite are achieved by systematic combinations of different constituents.[2] Interest in MMCs reinforced either with fibers or with particles is directed mainly toward aluminum matrix system. The combination of lightweight, low cost, environmental resistance and useful mechanical properties has made aluminum well suited for many applications as a matrix metal. Also, improvements of its strength and hardness can be induced by the addition of some reinforcement particles such as alumina and silicon carbide. The tensile strength and hardness of aluminum showed an increase due to the addition of 3 wt.% alumina particles of 100 μm.[3]

Among the available techniques to synthesize MMCs, solidification processes are particularly attractive, due to their simplicity, economy, and flexibility. The cost of producing cast MMCs has decreased rapidly through the casting of particulate metal matrix composites (PMMCs). The PMMCs have attracted more and more attention in industrial sectors, due to ease of supplying low cost particulate reinforcement such as graphite and silicon carbide. The cheapest route for solidification processing of composites is found in the stir casting and compocasting processes.

The widespread application of MMCs is facing a serious problem due to the rapid tool wear in machining, which results from the abrasive nature of the reinforcements. This abrasive tool wear results in poor machinability, because tool life is one of the basic methods to indicate machinability. Surface roughness can also be considered as another acceptable method to indicate machinability.[4] Barnes *et al*.[5] have studied the effect of preheating of the 2618 aluminum alloy reinforced with 18 wt.% silicon carbide particles on its machinability. The surface roughness results showed that, when a buildup-edge (BUE) was present, surface finish was extremely poor irrespective of cutting conditions. At conditions where BUE was absent, similar surface finishes were produced for all preheat temperatures with some indication that a preheat to 400 °C generated higher surface roughness values than one to 200 and 300 °C.

Tomac and Tonnesen[6] have investigated the cutting conditions for $AlSi_7Mg$ alloy reinforced with 14 volume SiC particles. The hard SiC particles result in a high flank wear rate in the cemented carbide cutting tools. Therefore, they recommended that this type of cutting tool is not preferred for finishing such composites. An increase in surface roughness was observed with the increase in feed rate and the cutting speed.

Due to the superior properties of aluminum-graphite particle composites such as low friction, improved wear resistance, and excellent antiseizing properties, considerable work has been done on the PMMC in recent years. These composites are basically developed for self-lubricating tribological applications.[7]

Accordingly, the present work was undertaken as an attempt to investigate the effect of graphite particle addition on the surface roughness of machined Al-4 wt.% Mg to indicate the change in the machinability of this alloy, due to this addition of graphite particles.

2. Experimental Work

2.1 Materials

Commercial aluminum of 99.85% purity and fine graphite particles were used for fabrication of cast aluminum-graphite

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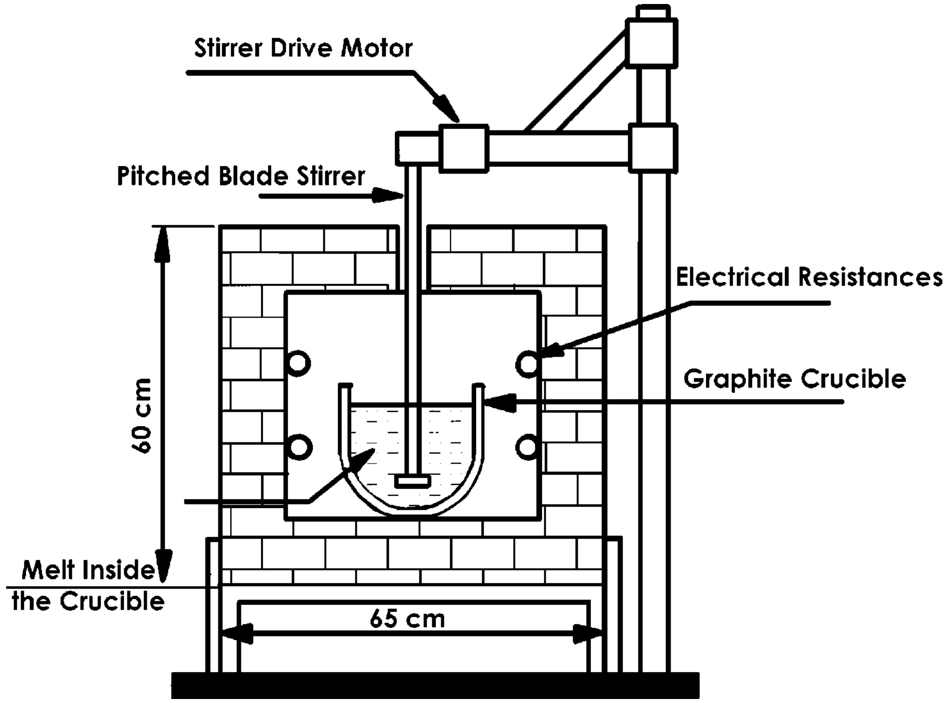

Fig. 1 Schematic diagram of the experimental setup

Table 1 The chemical composition of the aluminum

Al	Fe	Si	Cu	Mn	Mg	Zn	Ti	B	Ni
99.85	0.08	0.04	0.0004	0.0009	0.0008	0.0032	0.0043	0.0003	0.0014

particle metal composites. The chemical composition of the aluminum is shown in Table 1. Magnesium was added to the molten aluminum in order to promote wettability between graphite particles and the molten aluminum.

2.2 Experimental Setup and Equipment

The schematic diagram of the experimental setup for both stircasting and compocasting is shown in Fig. 1. The setup consists of an electric furnace and the stirring arrangement. The pitched blade stirrer shown in Fig. 2 was used to stir the graphite particles added to the melt. The electric furnace was designed and constructed to fabricate the cast bars needed for our investigation. The dimensions of the furnace were selected to permit the use of different sizes of graphite crucibles and different types of stirrers. The stirring rod, which is 10 mm in diameter, is introduced into the melt from a hole at the top surface of the furnace. The stirring rod is fitted to a motor having a speed range from 150 to 1200 rpm. The motor of the stirrer was held rigidly over the furnace. The stirrer holder was designed in such a way that the stirrer could be inserted in the central axis of the crucible and at any desired elevation. The maximum temperature obtained from this furnace was 1200 °C. The setup was connected with a control unit to monitor the temperature inside the furnace and also to determine the period of stirring before we start the stirring process. A special K-type thermocouple was used to measure the temperature of the metal inside the crucible during melting. The thermocouple was covered with stainless steel in order to protect it from damage by high temperature inside the furnace. The thermocouple was connected to a digital display to read the temperature of the molten aluminum.

2.3 Casting Procedure

The processing of Al-4 wt.% Mg-graphite composite was achieved by placing about 900 g of pure aluminum in a graphite crucible. The graphite crucible was inserted inside an electric furnace. The furnace was heated to 850 °C until aluminum was completely melted. After melting of aluminum, the furnace was switched off to allow the temperature to decrease. The temperature of the melt was monitored by the K-type thermocouple, which is inserted inside the melt at a depth of about 10 to 15 mm from its surface. The desired quantity of magnesium was 65 g taking into consideration an estimated loss of 20% due to evaporation and burning. Magnesium was wrapped in aluminum foil and plunged into the melt at a temperature between 710 and 740 °C with the aid of a holder. The magnesium lump was manually stirred inside the melt until it was completely melted in the molten aluminum. The surface of the melt

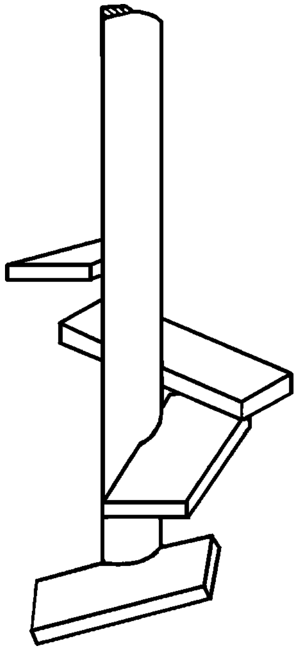

Fig. 2 The pitched blade stirrer used to stir the graphite particles added to the melt

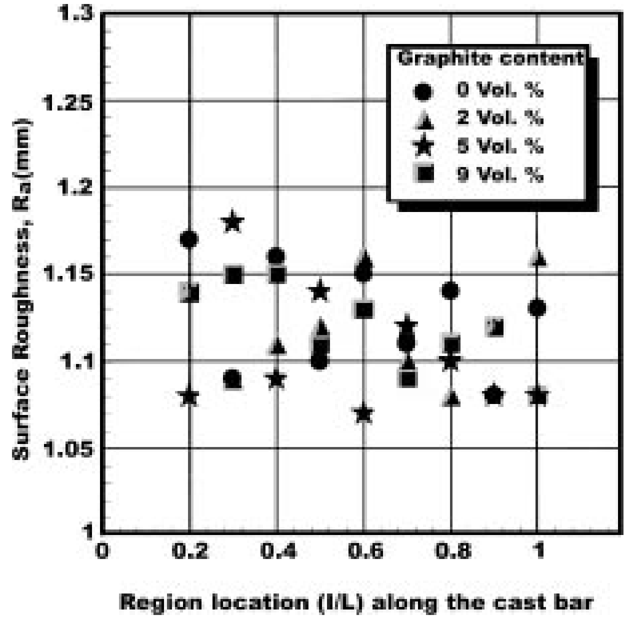

Fig. 3 The effect of region location (l/L) along the height of the cast bar on surface roughness for specimens containing 0, 2, 5, and 9 vol.% of graphite additions

was cleaned by skimming it with steel rule. The stirrer was inserted inside the furnace to preheat it before stirring stage. The stirrer was coated by slurry of alumina powder in sodium silicate and dried in air in order to prevent dissolution of the stirrer material in molten aluminum. When the temperature of the melt was about 638 °C, the stirrer was inserted into the melt and was vigorously agitated at a speed of 600 rpm. As the temperature of the melt reached 635 °C, the furnace was switched on in order to have a constant holding temperature of 635 °C.

Depending on particle content desired in the composite, graphite wrapped in aluminum foil and preheated to 400 °C for 1 h was inserted inside the crucible. Stirring took place for 4 min after addition of graphite particles. In the case of the addition of 4 vol.% or more of graphite particles, the graphite was added in two equal stages; after each stage, the graphite was stirred for 2 min. At the end of stirring period, the metal inside the crucible was taken out from the furnace and poured inside a metallic mold. Then, the mold was left in air to cool to room temperature. Finally, the mold was opened to obtain the cast bars.

3. Experimental Details and Results

Ten bars of Al-4 wt.% Mg were cast starting from 1 to 10 vol.% graphite content. Also, other cast bars were made of aluminum and 4 wt.% magnesium (with no addition of graphite) by following the same procedure described above. The cast bars were used to study the effect of the addition of graphite particles on the surface finish produced by machining on the matrix cast bar (Al-4 wt.% Mg). After reducing the diameter of the cast bars to 15 mm diameter by turning, the cutting tool was replaced by a new high speed steel tool to carry out the experimental tests of the present work. The turning parameters were held constant as follows: the cutting speed was 60 m/min, the cutting feed was 0.02 mm/rev, and the depth of cut was 0.08 mm. The surface roughness of the ten regions mentioned above was taken. Then, the average surface roughness of the cast bar was obtained from these ten regions.

Figure 3 shows the surface roughness of each region along each cast bar. The location of the regions was parameterized by the dimensionless parameter (l/L), where l is the height of the region from the top of the cast bar and L is the total length of the cast bar. It can be seen from the curves of this figure that the surface roughness was not affected significantly by the position of the region along the considered cast bars. Generally speaking, the surface roughness values for the cast bars with graphite additions were slightly less than those values of the matrix alloy ingot.

The effects of different graphite additions on the surface roughness as volume percentages of all considered cast bars are shown in Fig. 4. It can be said from this figure that there is a general slight reduction in the surface roughness with the addition of the grahite particles to the metal matrix alloy.

Figure 5 shows the structure of the Al-Mg alloy with and without graphite particle addition. This figure shows the uniform distribution of the graphite inside the metal matrix due to the compocasting technique.

4. Discussion

Figure 3 shows a slight change of the surface roughness of the ten regions along the length of each cast bar considered.

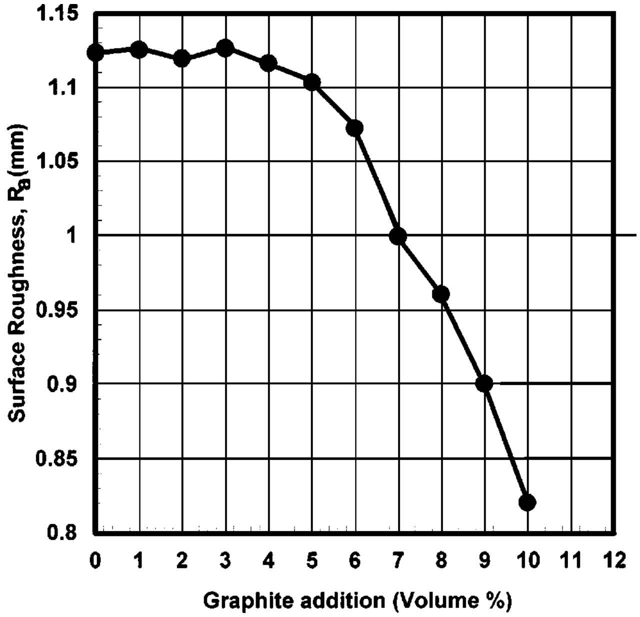

Fig. 4 The effect of increasing graphite addition on the surface roughness

This means that the compocasting process can give uniform distribution of the graphite inside and along the cast bars. Also, it indicates that this process of casting can prevent the flotation of graphite particles to the surface of the melt because of its light density. It seems that, in this casting process, the graphite particles are trapped by the semisolid or pasty matrix alloy during stirring

Also, it can be observed from Fig. 3 and 4 that the surface roughness decreases slightly with the addition of the graphite particles, if it is compared with the original metal matrix alloy. In these composites, graphite particles impart an improvement in the tribological properties due to the formation of graphite-rich film on the tribosurface, which provides solid lubrication at the chip/tool interface. In addition, graphite particles dispersed in the metal matrix act as chip breakers, similar to the action of graphite in cast iron, which causes a reduction in surface roughness. A strong vortex is formed during the mixing of the graphite particles by the blade stirrer. This vortex will suck a considerable amount of air, which causes higher dissolution of gases inside the melt, thereby increasing the level of porosities. These porosities are well distributed throughout the cast bars produced by the compocasting technique. The presence of these porosities on the surface of the machined Al-4 wt.% Mg-graphite bars will counteract the lubricity action of the graphite particles. In this respect, it may be suggested that, if the compcasting procedure is done under vacuum, the amount of porosities could be reduced, leading to further improvement in surface finish of the considered Al-4 wt.% Mg graphite cast bars. Unfortunately, the equipment to carry out such a procedure was, at present, not available. However, the observed discontinuity of the chips formed during machining, which prevent the formation of BUE, and the reduction in tool wear observed after the addition of graphite to the test cast bars may support the above-mentioned suggestion. These observations will be published in the near future.

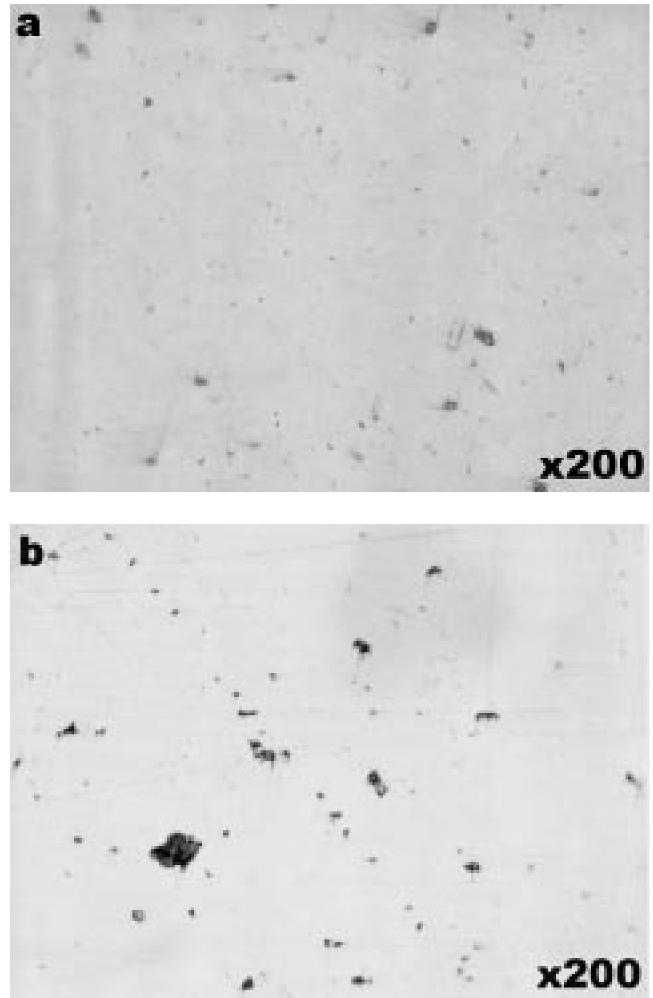

Fig. 5 Microstructure of two cast bars after lapping: **(a)** Al-4 wt.% Mg alloy and **(b)** Al-4 wt.% Mg + 2 vol.% of graphite

5. Conclusions

The results showed that the dispersion of graphite particles in the Al-4 wt.% Mg matrix improves slightly the machinability of the composite material considered in the present study by decreasing the surface roughness values of the machined cast bars. This slight decease in the surface roughness is due to the effect of graphite particles as a lubricant and as a chip breaker, because graphite can be sheared easily during machining because of its structure weak interplane bonds. This type of structure will reduce the possibilities of the formation of continuous chip and continuous chip with BUE. Due to the nature of the compocasting process, porosities are formed inside and on the surface of the test bars. These porosities counteract the lubricity action of the graphite to produce considerable improvements in surface finish; hence the machinability of the test cast bars. It is thought that more improvement in surface finish of the machined Al-4 wt.% Mg- graphite composite may be achieved by carrying out the compocasting procedure in vacuum, in order to reduce the amount of the porosities formed during this casting process.

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