Burnishing of Aluminum-Magnesium-Graphite Composites

Mohammed T. Hayajneh, Adel Mahmood Hassan, Moath AL-Qudah

Abstract—Burnishing is increasingly used as a finishing operation to improve surface roughness and surface hardness. This can be achieved by applying a hard ball or roller onto metallic surfaces under pressure, in order to achieve many advantages in the metallic surface. In the present work, the feed rate, speed and force have been considered as the basic burnishing parameters to study the surface roughness and surface hardness of metallic matrix composites. The considered metal matrix composites were made from Aluminum-Magnesium-Graphite with five different weight percentage of graphite. Both effects of burnishing parameters mentioned above and the graphite percentage on the surface hardness and surface roughness of the metallic matrix composites were studied. The results of this investigation showed that the surface hardness of the metallic composites increases with the increase of the burnishing force and decreases with the increase in the burnishing feed rate and burnishing speed. The surface roughness of the metallic composites decreases with the increasing of the burnishing force, feed rate, and speed to certain values, then it starts to increase. On the other hand, the increase in the weight percentage of the graphite in the considered composites causes a decrease in the surface hardness and an increase in the surface roughness.

Keywords—Burnishing process, Al-Mg-Graphite composites, Surface hardness, Surface roughness.

I. INTRODUCTION

BURNISHING is a finishing process, which could be used on cylindrical or plane surfaces. At the same time it is considered as plastic deformation process [1]-[3], where most of the surface irregularities are deformed under the application of pressure through either a hard ball or roller [4]. This plastic deformation requires a pressure between the burnishing tool and workpiece that exceeds the yield point of the workpiece material [5]-[7]. The deformation in the surface of a metallic material by burnishing is shown schematically in Fig. 1. Force Py is normal to the workpiece surface; Px is tangential force to work surface. The magnitude of Px is very much smaller than Py, depending on the workpiece material, initial roughness, speed and other burnishing parameters [8].

When the workpiece turns, the pressed ball or roller onto the metallic surface will rotate as a result of frictional engagement. The metal from the protrusion of the metallic surface is displaced plastically and will fill the depressions.

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The principal action takes place in the central plastic deformed zone, were the metal in both the peaks and the valleys is plastically deformed. Since there is a plastic deformation of the surface irregularities, burnishing process will induced compression residual stress on the surface of the workpiece, which in turns improving the surface finish.

When the cylindrical workpiece turns, the tool will rotate as a result of frictional appointment. As each portion of the surface of the work is cross, metal from the projection is displaced plastically and will fill the depressions.
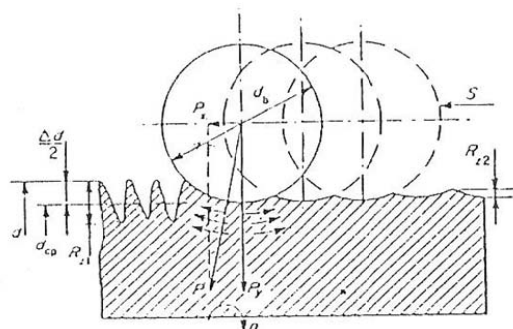

Fig. 1 Deformation of surface irregularities in burnishing process [8]

The term "composite" generally refers to a material system which is composed of the reinforcements dispersed in the matrix, which gains its distinctive characteristics from the properties of its constituents, geometry, architecture of the constituents, and from the properties of the boundaries between different constituents. Composite materials are usually categorized on the basis of the chemical and physical and nature of the matrix phase [9], [10].

Metal Matrix Composites (MMCs) are composed of a metal matrix and a reinforcement, which grant excellent mechanical performance, and can be categorized according to whether the reinforcement is continuous or discontinuous (such as particle, whisker or short fiber). The most broadly used matrix material of MMCs is aluminum and its alloys [11].

In Aluminum Matrix Composites AMCs, magnesium is added as wetting agent. This alloy forms penetrate network, where other elements is inserted in this aluminum alloy matrix and serve as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al2O3. Properties of AMCs can be tailored by varying the nature of constituents and their volume fraction, where volume fraction is volume of an ingredient of a mixture divided by the sum of volumes of all ingredients prior to mixing.

The main advantages of Aluminum Matrix Composites

compared to unreinforced materials are improved stiffness, greater strength, improved high temperature properties, controlled thermal expansion coefficient and reduced weight, improved damping capabilities, enhanced electrical performance, improved abrasion and wear resistance, control of mass [12].

Most of the works already published in burnishing studied the surface roughness, surface hardness, and micro-hardness of subsurface, corrosion resistance, fatigue life and tensile strength. Also, the published works considered the effect of the most important process parameters, such as speed, feed rate, force, number of tool passes and tool dimensions on metallic materials neglecting the possible application of the burnishing process on metallic matrix composites. The present work has taken into consideration the study of the effects of burnishing feed rate, speed and force on metal matrix composites. Aluminum-Magnesium-Graphite composites with different weight percentage of graphite particles were chosen, in order to examine, also, the effect of graphite on the applied ball burnishing process.

II. MATERIALS AND METHODS

A. Materials

The matrix used in the experimental investigation was made of high grade commercial pure aluminum blocks with ~99% purity with 4% wt. magnesium granules with 99% purity as wetting agent. The reinforcement was graphite particles with 99% purity having particles size of ~5.0 μms.

B. Burnishing Tool

A simple tool was designed and built to perform the experimental work. The tool is shown in Fig. 2. Disposable carbon chromium steel balls were used in the tool. The balls are commercially available and are usually used in ball bearings. The balls have Rockwell hardness HRC = 63 and arithmetical surface roughness average Ra of 0.012 μm.
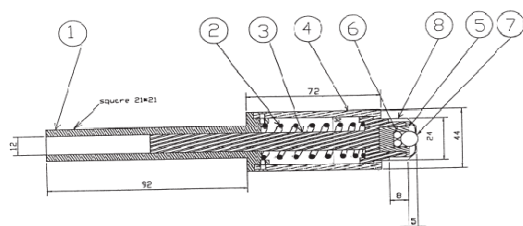

Fig. 2 Ball burnishing tool, all dimensions in (mm) 1: Shank 2: Calibrated spring 3: Sliding tool stem 4: Casing 5: Balls adapter 6: Supported balls 7: Burnishing ball 8: Ball holder [8]

The burnishing ball is located on three small balls and rotates with frictional engagement. As shown in Fig. 2, the shank (1) is bolted to the casing (4), which includes the sliding tool stem (3) to carry the pre calibrated spring (2). The spring function is to provide a means to measure the applied vertical burnishing force, and to reduce the sticking effect due to the friction between the ball and the workpiece. The ball holder (8) is designed in such a way that the ball can be removed with

relative ease to be cleaned or replaced by a new one [8].

C. Casting the Workpieces

Compocasting technique was used to produce the Al-4 wt.% Mg-graphite composites. Commercial pure aluminum ingot block was used as base matrix in each casting process was placed in a graphite crucible and inserted inside an electric furnace. The aluminum was kept in the furnace until the temperature was 900°C to insure that the aluminum was completely melted. After that 4% wt. magnesium, depending on the weight of the matrix, was wrapped in aluminum foil and put into the molten aluminum and stirred. An estimated loss of about 10-20% due to the evaporation and burning was considered. The Al-4% wt. Mg alloy was reheated to a temperature of 850°C.

Depending on particle content desired in the composite, graphite wrapped in aluminum foil and preheated to 400°C for 1 hr. The molten alloy was stirred while the graphite particles added to the melt to produce some kind of slurry. Stirring of the slurry was maintained while the melt cooled down until the alloy became in a semi-solid state trapping the graphite particles in a uniform dispersion. At the end of the stirring, the cast composite inside the crucible was taken out from the furnace and poured inside a metallic mold with cylindrical cavity (30 mm diameter and 170 mm length). Then, the mold was left in air to be cooled. Finally, the mold was opened to obtain the cast bars [13].

This procedure was repeated when the graphite particles were added in amount of 0.5, 1.0, 2.0 and 3.0 weight percentages. Then each of the cast composite bar was cut into two parts, each of them has 80 mm in length and 22 mm in diameter.

D. Burnishing Process

Each cast bar was held between centers of a Clochester Master 2500 lathe machine and a ball burnishing tool was applied to burnish the surfaces of the bars. The burnishing experiment was carried out by using different burnishing feed rates of 0.03, 0.06, 0.10 and 0.13mm/rev, burnishing speeds of 8.99, 16.25, 29.39 and 39.41 m\min and burnishing force of 50, 100, 150 and 200 N, No lubricant and only one tool pass were used in all the carried out experiments.
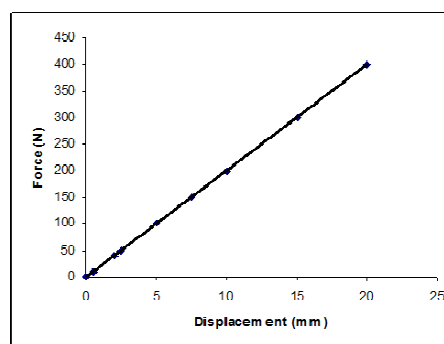

Fig. 3 Calibration curve of the burnishing tool spring

When the ball is pressed against the surface of the workpiece, the spring supporting the balls (as shown in Fig. 2) will be compressed. The amount of spring compression with relation to the applied vertical force (Fb) is calibrated. The calibration curve is shown in Fig. 3. Only the effect of vertical force was studied, as the effect of other forces is considered to be negligible, because their amounts are very small in comparison with the vertical burnishing force. A schematic presentation of the burnishing process is shown in Fig. 4.
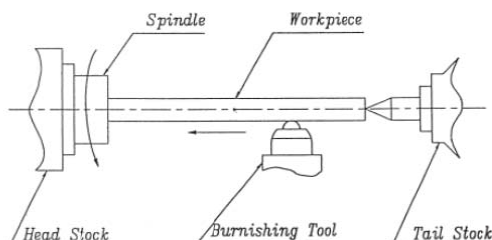

Fig. 4 Set-up of a ball burnishing process [8]

III. Results and Discussion

Three samples were used to study the effect of each considered test parameter on surface hardness and surface roughness, in order to verify the consistency of the results.

Fig. 5 shows the effect of graphite weight percentage on surface hardness of the burnished workpieces. From this figure, it can be seen, that the surface hardness is decreased with the increase in graphite weight percentages. As graphite being a lubricant, facilitates the deformation process and causes a reduction in hardness.

Fig. 6 shows the effect of feed rate on the surface hardness of burnished workpieces. From this figure, it can be seen the surface hardness decreases with the increase in feed rate. This is due to the increase in distance between the successive burnishing traces that are formed by the burnishing tool, so the hardness decreases due to the smaller deformed total area of the burnished surface compared to the total surface area of the considered workpiece.
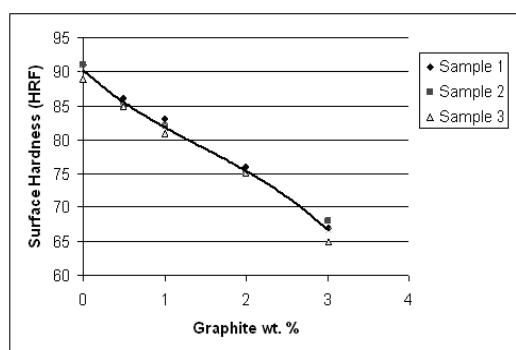

Fig. 5 Effect of graphite weight percentage on surface hardness at burnishing feed rate= 0.06 mm/rev, burnishing speed = 16.25 m/min and burnishing force = 100 N

Fig. 7 shows the effect of speed on the surface hardness of burnished workpieces. From this figure, it can be seen that the surface hardness is decreased with the increase in speed. This is due to the increase in the total amount of heat, which softens the workpiece. An increase in the speed causes more heat to be developed within the surface and an additional decrease in the hardness.
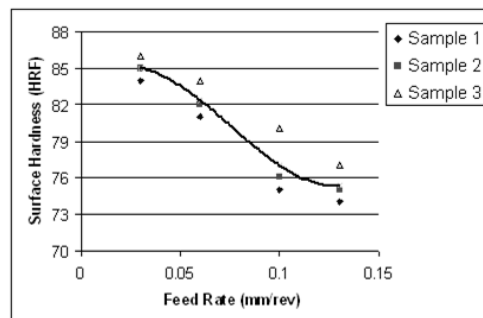

Fig. 6 Effect of feed rate on surface hardness at graphite weight percentage = 0.5 % and burnishing speed = 29.39 m/min and burnishing force = 100 N
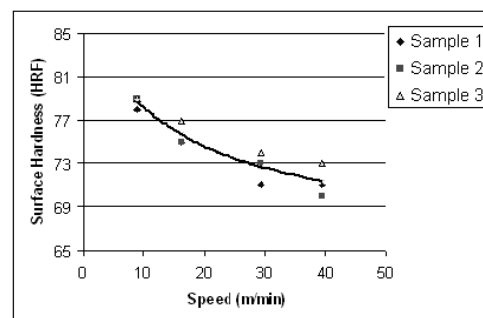

Fig. 7 Effect of speed on surface hardness at graphite weight percentage = 0.5 % and burnishing feed rate = 0.1 mm/rev and burnishing force = 50 N

Fig. 8 shows the effect of force on the surface hardness of burnished workpieces. From this figure, it can be observed, that the surface hardness is increased with the increase in force. This is due to the increase in the stress induced by the burnished ball on the workpiece surface, which leads in turn to an increase in the plastic deformation causing an increase in the hardness of the composite surface.
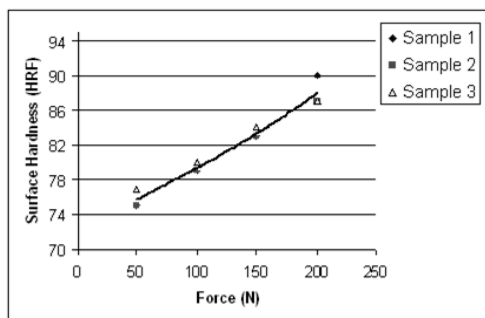
Fig. 8 Effect of force on surface hardness at graphite weight percentage = 1.0 % and burnishing speed = 29.39 m/min and burnishing feed rate = 0.06 mm/rev

Fig. 9 shows the effect of graphite weight percentage on surface roughness of the burnished workpieces. The figure shows, that the surface roughness increases with the increase in graphite weight percentage. The increase of surface roughness of the composites with the increasing in graphite weight percentage is due to the porosity of the graphite. Under the same stress, it is expected that the graphite particles will be depressed more than the metallic matrix. This will cause an increase in the roughness, in addition to the possible graphite particles pullout from the surface.
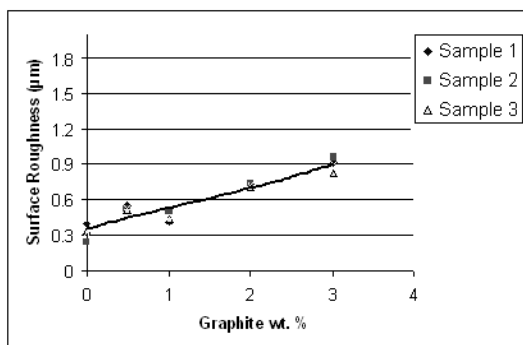

Fig. 9 Effect of graphite weight percentage on surface roughness (μm) at burnishing feed rate = 0.10 mm/min and burnishing speed = 16.25 m/min and burnishing force = 200 N

Fig. 10 shows the effect of feed rate on surface roughness of the burnished workpieces. From this figure, it can be seen that the surface roughness decreases with the increase in feed rate to a certain value and then the roughness increases with the increase in feed rate. At low values of feed rate, it is expected that the burnishing action will cover nearly all the surface area. When the feed rate increases, there will be a reduction in the total covered burnished area of the surface, causing an increase in surface roughness.
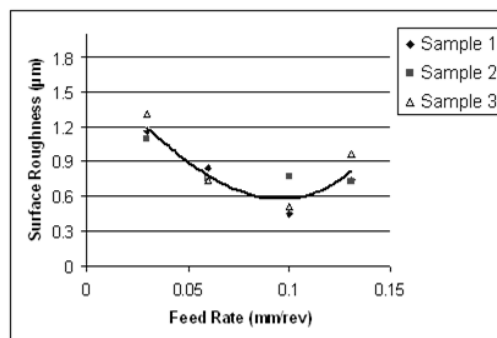

Fig. 10 Effect of feed rate on surface roughness (μm) at graphite weight percentage = 1.0 % and burnishing speed = 39.41 m/min and burnishing force = 150 N

Fig. 11 shows the effect of speed on surface roughness of the burnished workpieces. From this figure, it can be seen that the surface roughness is decreased with the increase in speed to a certain value and then it increases. This can be explained that at low values of speed, the metal surrounding the ball is exposed to compressive stresses, so at low speed the surface roughness will be decreased. While at high values of burnishing speed, the surface of the material will be subjected to rather a high amount of repeated plastic deformation causing the surface to strain hardened and to deteriorate [14]. There is a limited capacity of most metal to accept large amount of plastic deformation. If the repeated plastic deformation is encountered on the surface being burnished, micro-cracks will be developed leading to possible peeling of the metallic surface, which will cause an increase in surface roughness.
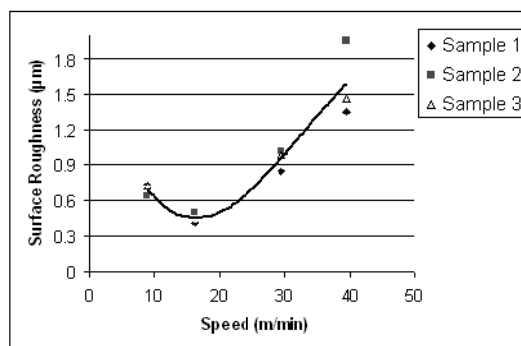

Fig. 11 Effect of speed on surface roughness (μm) at graphite weight percentage = 1.0 % and burnishing feed rate = 0.10 mm/rev and burnishing force = 200 N

Fig. 12 shows the effect of force on surface roughness of the burnished workpieces. The figure shows, that the surface roughness is decreased with the increase in the burnishing force to a certain limit, then it increases with the increase in force. This is caused by the pressing action of the burnishing ball, but when the force exceeds certain limit, the surface roughness starts to increase due to the increase in the amount of cold working, which causes an increase in the work

hardening of the metallic surface, leading to a deterioration of the metallic surface as explained earlier in [15].
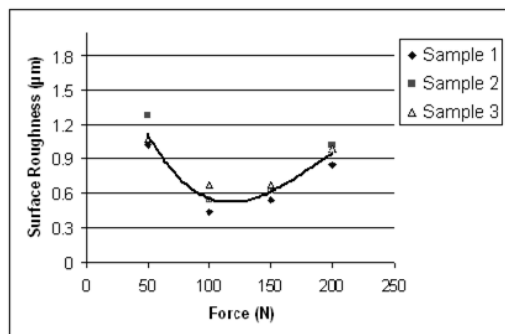

Fig. 12 Effect of force on surface roughness (µm) at graphite weight percentage = 1.0 % and burnishing feed rate = 0.10 mm/rev and burnishing speed = 29.39 m/min

IV. CONCLUSIONS

The following are the most important points that can be withdrawn from the present work:

1. Increasing in graphite weight percentage causes a decrease in the surface hardness and an increase in the surface roughness.

2. Increasing in the burnishing force leads to an increase in the surface hardness and a decrease in surface roughness to certain limit, and then the surface hardness starts to increase after this limit with the increase in the applied burnishing force.

3. Increasing the feed rate or the speed lead to a decrease in the surface hardness, and a decrease in surface roughness to certain limits, but the surface roughness starts to increase after these limits with the increase in feed rate or speed.

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