Effect of Extrusion Temperature on the Machinability of Al Alloy 6061 Reinforced with SiC Particles

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Abstract In this study, the effect of extrusion temperature on the machinability of 6061 Al-alloy as cast and as matrix reinforced with 15% SiC particles were investigated for the as received and extruded at two different temperatures 600 and 620°C. Machinability of the 6061 Al-alloy is tested based on tool wear and surface roughness. The experimental work has revealed that decreasing the extrusion temperature from 620°C to 600°C %, results in increasing the tool wear by 50% and machined surface roughness by 9%.

Keywords Extrusion Temperature, Machinability, Al Alloy 6061 Reinforced, SiC Particles

1. Introduction

The aluminum industry has evolved over the past one hundred years from the limited production of alloys and products to the high manufacture volume of a wide variety of products. These products are used in a wide variety of markets, such as in building and in construction, and in transportation [1]. 6xxx series Aluminum alloys are of particular interest to both the aerospace industry and automotive industry because of their excellent properties. The 6xxx series alloys have medium strength, formability, weldability, corrosion resistance, and low cost. 6xxx series alloys have corrosion resistance which is superior to 2xxx series and 7xxx series alloys, traditional aerospace alloys that are prone to intergranular attack [2]. The 6061 alloy is one of the most widely used alloys from the 6000 Series. The 6061 alloy is have a standard structural alloy and one of the most versatile of the heat treatable alloys [3].

A Composite in engineering sense is any materials that have been physically assembled to form one single bulk without physical blending to form a homogeneous material [4]. The resulting material still has identifiable components as the constituent of the different materials. One of the advantages of composites is that two or more materials could be combined to take advantage of the good characteristics of

each of the materials [5].

The reinforcement material is embedded into the matrix (alloy). Reinforcement does not always serve as a reinforcing the component, but it is also used to change the physical properties such as friction coefficient; wear resistance or thermal conductivity [6]. The reinforcement can be discontinuous or continuous. Discontinuous metal matrix material can be isotropic and can be worked with the standard metal working techniques [7]. Continuous reinforcement uses monofilament fibers or wires such as silicon carbide or carbon fiber. Because fibers are embedded inside the matrix in a specific direction, the result is anisotropic structure because the alignment of the material affects its strength [8]. Discontinuous reinforcement uses short fibers, particles or whiskers. The most common reinforcing materials in this category are the silicon carbide and the alumina [9].

Machining is one of the most important manufacturing processes which is define as the ability of material to be machined with an acceptable surface finish [10]. Work to date has shown that little or no work has been carried on machining of aluminum as alloy or as matrix reinforced with silicon carbide particles. Also, there is no investigation about the effect of extrusion temperature on the machinability for aluminum alloy and aluminum composites.

This study investigated the effect of extrusion temperature (600 and 620°C) on the tool wear rate and surface roughness when turning 6061 Al-alloy as cast and as matrix reinforced with 15% SiC particles.

2. Materials and Experimental Procedure

The 6061 Al-alloy used in this investigation was supplied in the form of 70 mm diameter and 1500 mm length billets. Table 1 shows the chemical composition in weight percentage for 6061 alloy and table 2 shows chemical composition for SiC particles.

Table 1. Chemical composition of 6061 alloy

From	Chemical compositions (wt %)								
	Si	Fe	Cu	Mg	Mn	Ti	Zn	Cr	Al
Value	1.08	0.25	0.015	0.07	0.018	0.01	0.01	0.08	Balance

Table 2. Chemical composition of SiCp

From	Chemical compositions (wt %)							
	SiC	Fe	SiO ₂	Si	C	Al	Ca	Mg
Value	96	0.2	0.8	0.5	0.6	0.2	0.65	1.05

Figure 1. Photograph showing the apparatus used for preparing the composites.

Stir casting method as a production process for metal matrix composites was used in this work. All the melting was carried out in a graphite crucible in a furnace. Pieces of aluminum alloy 6061 were preheated at 450°C for 3 hours before melting, and before mixing the SiC particles were also preheated at 1100°C for 1 hour to make their surfaces oxidized and activated the SiC particles. The furnace temperature was first raised above the liquidus temperature (590°C) to melt the alloy pieces completely and was then cooled down just below the liquidus to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed manually. After sufficient manual mixing was done, the composite slurry was re-heated to a fully liquid state, and then automatic mechanical mixing (stirring) was carried out for about 20 minutes at an average stirring rate of 150-200 rpm according to the weight percentages of SiC particles. The molten slurry was stirred by a simple radial impeller. The impeller was made of low carbon steel and has four blades with diameter equal to 60 mm. Attached to a variable speed motor. Figure (1) shows the apparatus used for preparing the composites. After the

completion of particle addition the mixture was poured into permanent molds made of steel pre-heated to 150-200°C. Figure 2 shows Differential Scanning Calorimetry (DSC) for 6061 Al alloy.

A schematic view of the permanent mold used in this investigation is shown in figure (2). The Crucible has diameter equal to 80 mm.

Figure 2. The investigation permanent mold.

The deformation process used in this investigation was extrusion the apparatus used for extrusion is shown in figure (3). The design of this apparatus allows both or either force or temperature to change. In this work it was chosen to fix the ram speed and allow the load applied to change freely. The ram is pushed forward with a speed of about 2.5 mm/s to extrude the material. The extrusion temperature was selected such that the billet is in the semi-solid state, according to D. Abolhasani et al[7] the semi-solid state temperature for 6061 aluminum alloy is at 620°C. The extruded specimens had a diameter of 20 mm before extrusion and had a final diameter of 16 mm after extrusion with reduction ratio in area percentage equal to 36%. The reduction in area % was calculated from the following equation:

$$\text{Reduction in area \%} = [(A_b - A_a) / A_b] \times 100$$

Where: A_b = the cross section area before extrusion in mm².

A_a = the cross section area after extrusion in mm².

Figure 3. The apparatus used for extrusion

The turning tests were carried out using a conventional center lathe speeds ranging from 300 to 800 rpm. Sample was fixed in a fabricated holder to ensure specimen was stable during the test. The measurement was taken as average of three samples. Figure 4 shows fabricated holder and sample.

Figure 4. fabricated holder and extruded sample

The cutting tool used was HSS turning speeds are adjusted to the feed rate of the mini lathe (0.004/rev.) and a depth of cut of 0.040. Cutting Speeds used were ranged from 400 to 700 rpm. Machinability is evaluated based on the following

machinability criteria; tool wear measurements (by finding the weight loss for the tool), surface roughness measurements (by using surface roughness), and type of chip produced. Table 3 shows the cutting parameter for each experiment made at fixed time equal 10 minutes.

Table 3. cutting parameter

Cutting Parameter	Experiment 1	Experiment 2	Experiment 3
speed (rpm)	500	600	700
depth of cut (mm)	0.2	0.25	0.3

3. Results and Discussion

3.1. Microstructure

Figures 5 and 6 show the optical microphotographs of hot forged Al 6061 alloy and Al 6061/15 SiC Vol % as cast and as extruded at 600 and 620°C composites. It is observed that there is a homogeneous distribution for the reinforcement in the matrix alloy. There exists a good bond between the matrix and the reinforcement. The figure also reveals the effect of extrusion on the SiC particle distribution and on the porosity contents. Grain size effected with the extrusion force, smaller grain size was appeared on the sample extruded at 620°C. This could be occurred because the interconnections between grains in the slurry were too weak when forming temperature is relatively so high 620°C [8].

Figure 5. microstructure images for: a) Al 6061 as cast. b) Al 6061 as extruded at 600 °C c) Al 6061 as extruded at 620 °C

Figure 6. microstructure images for: a) Al 6061/15 vol. SiC as cast b) Al 6061/10 vol. SiC as extruded at 600 °C c) Al 6061/10 vol. SiC as extruded at 620 °C

3.2. Tool Wear

The tool wear for the cutting tool is investigated at selected cutting conditions. Figure 7 shows the wear rate for cutting tools after each experiment. The figure shows the effect of silicon carbide content on the wear rate. The figure includes the results of formation temperature on the tool

wear. The wear rate is calculated from the following equation [10]:

$$W = \frac{\Delta m}{\rho \times v \times t \times A}$$

Where:

Δm = weight loss (g)

ρ = average density of cutting tool

t = test time (s)

A = apparent contact area (mm²)

Figure 7 reveals the effect of adding hard particles on the tool wear. However the rotation speed also, effect on the tool wear this is may be due to subjected cutting tool to high friction force in the short time which increases the tool temperature. The figure also shows that tool wear value for 6061 as extruded at 600°C in experiment no. 1 is smaller than the value obtained for 6061 as extruded at 620°C experiment no. 1. This can be attributed to the combined effect of low hardness, and low porosity in this case.

3.3. Surface Roughness

Total machining time is found to be 10 minutes with constant feed rate at 0.5 mm/min. machined surface quality is evaluated by measuring the machined average surface roughness R_a at cutting parameters illustrated in table 3, the results are plotted in Figure 8. The figures reveal that the extruded temperature has small impact on the surface quality. However there is some improvement in the surface finish for the sample extruded at 600°C this may be due to the slight decrease in ductility. The figure also shows that quality of the surface decrease for the composite samples this due to the impact of hard material (SiC) that used to reinforce the aluminum alloy. The average surface roughness R_a increases with the increasing in the cutting depth this result due to the impact of the cutting tool. The surface quality improved with the increasing in cutting speed

Figure 7. wear rate for cutting tools after each experiment

At 500 rpm

At 600 rpm

Figure 8. Effect of depth of cut on total average Ra at a) 500 rpm b) 600 rpm c) 700 rpm

4. General Comments and Discussion

In order to study the effect of extrusion temperature on the machinability of the aluminum 6061 alloy as a matrix and as composite reinforced with silicon carbide particle, the results reveal the effect of adding hard particle to the aluminum alloy. This effect may be due to the changing in the grain structure for the matrix alloy. The hard material also increases the wear rate of the cutting tool. However the wear rate for the composite which extruded at 600°C was lower compared to the composite which extruded at 620°C this due to the ductility of the sample which extruded at lower temperature and finer grain as shown in the microstructure in figure (6) also extrusion at a relatively high temperature (620°C) results in the partial melting of the matrix alloy at the grain boundaries having a near eutectic composition. Therefore, the particles become suspended in the eutectic melt at the grain boundaries and get aligned under the applied stress [12]. Depth of cut has less effect on resultant tool life than does surface speed. As surface speed increases, tool life will decrease. The surface quality for the samples extruded at lower were better compared with the samples extruded at 620 °C.

5. Conclusions

1. The extruded composites exhibited reduced porosity, a more uniform particle distribution and improved ductility in comparison with the as-cast samples.
2. Extrusion process for the composite alloy improves the quality of surface. But with marked improvement in surface for the composite which was formed at 600°C and the improvement was less in the case of matrix alloy that have been formed at 620°C. Extrusions at 600°C give higher ductility's as compared to extrusion at 620°C.
3. Cutting tool wear tests results of 6061/SiCp reinforced composites showed that tool wear rate of composites is greatly higher than the unreinforced 6061.
4. The Cutting tool wears rate decreases as the extrusion temperature decreases from 620°C to 600°C.

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