Diamond turning of metallurgical and mechanically modified Al-Mg Alloy

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Abstract

In this paper, diamond turning cutting tests results of an Al-Mg alloy metallurgical and mechanically modified, by means of refining grain size (fine grain) and cold rolling reduction (CR - 80% reduction) prior to machining will be reported. The results of surface finish and chip microstructure are going to be compared with that from an as-received (a-r) grain size sample. Optical profilometry was used in order to evaluate qualitatively and quantitatively the surface finish of the machined samples.

1. Introduction

Polycrystalline metals are stronger than their single crystal equivalent, which means that greater stresses are required to initiate slip and attendant yielding [1]. During micromahining, due to different grain crystallographic orientation in the workpiece, some effects such as different grain heights and chip thickness variation are normally observed. This difference in grain height/chip thickness is originated from a mechanism of mechanical response to cutting tool/single crystal grain interaction which yields shear angle change from grain-to-grain due to material properties such as elastic modulus (E). This anisotropic effect may be attenuated during ultraprecision machining by increasing material strength. This may be done by means of grain refining or strain hardening the material before machining. When material is strain hardened or the area of grain boundary is increased by grain refining, dislocation movement will be constrained or even hindered causing the increase of materials strength. In addition, cold rolling can be used in order to make the properties of a polycrystalline aggregate homogeneous. This would provide texture to the crystal grains, i.e., grains with preferential orientation [2].

This paper presents experimental results on diamond turning of an Al-Mg alloy, mechanically and metallurgically modified: samples with grain size reduction and cold rolled (reduction of 80 %) samples are machined and compared to the *as-received* sample . Surface roughness and microhardness measurements were taken in order to evaluate the effect of the machining conditions upon surface integrity.

2. Experimental details

Three samples of the same Al-Mg alloy were used in the tests. One with the microstructure *as-received (a-r) (average grain size* 75-100 μm; $H_{V0,01}$ = 65 kgf/mm^2), one with grain size reduction (average *grain size* 10-20 μm – cold rolled with 80% reduction, heat treated at 300°C for 35 min cooled in water at 25°C, $H_{V0,01}$ = 70 kgf/mm^2 and one cold rolled with 80% reduction ($H_{V0,01}$ = 110 kgf/mm^2*)*. All samples were face cut. Table 1 describes the experimental conditions and diamond tool geometry used in the cutting tests. After machining, the microtopography of the surface was inspected by means of optical profilometer (Wyko NT 1100) using a high pass window filtering for roughness evaluation. The selected parameter used to evaluate the surface finish was root mean square (RMS) roughness (R_q) because is generally used to describe the finish of optical surfaces of the machined surface is more representative. Average results of four repeated measurements were plotted in graphs. Microhardness of the machined samples was measured with a *BUEHLER* Micromet III Digital microhardness tester. A diamond Vicker's Hardness indenter was pressed into the sample using a cycle time of 15 seconds. The indentations tests were performed with several loads: 10g, 50g, 100g, 200g e 500g. Average results of four repeated tests were plotted.

Table 1. Tool geometry and cutting conditions.

Nose radius	Rake	Clearance	*f* (μm/rev)	ap (μm)
4.0 mm	0°	5°	5, 10, 15 and 30	5, 10, 15 and 30

3. Results and Discussion

Figure 1 shows the values of the root mean square surface roughness (R_q) of the machined samples versus feedrate. For lower values of feedrate (5–10 μm/rev) the surface roughness all samples presented similar values between 8 and 10 nm with trend of smaller values for the samples with larger strength. The standard deviation amplitude of the surface roughness profile shows that due to elastoplastic deformation and to the elastic recovery process, which are more prominent in higher strength materials which lowers the values of roughness in this case [3]. Since the cold rolled material is capable of sustaining less plastic deformation, because the work hardening, the surface roughness is expected to be smaller. The effect of depth of cut on *peak-to-valley* roughness is shown in Figure 2. It was found that the *RMS* roughness varied with increasing depth of cut is maximum for a-r sample when the largest depth of cut reached 30 μm. This was less evident in the cold rolled and fine grain samples which shows a RMS variation between 8 and 10 nm.

Figure 3 shows the microhardness values measured for the machined samples. The microhardness value of the *cold rolled* (CR) sample is always greater than the other samples and does not show clear variation within microhardness with the increase in loading. This effect is more prominent for the *fine grain* and *as-received* samples. For lower loads such as 10g, the surface microhardness of the *fine grain* and *as-received* samples are similar to that of the CR workpiece. In this case, since the penetration depth of the indenter is very shallow it is possible to assert that the microindentation process occurred within the work hardened layer generated by the tool/workpiece material interaction during cutting. It is important mentioning that at larger loads ($H_{V0.2}$ and $H_{V0.5}$) the hardness of the samples returns to its nominal value meaning that the strain hardened surface layer no longer affects the measurement. Figures 4, 5 and 6 present 3D images examples of the surface finish of the three samples machined with feed rate of 15 μm/rev and depth of cut of 10 μm.

4. Concluding Remarks

The surface roughness is larger for the AR sample when compared to the other machined samples. The fine grain workpiece presented smallest values of surface roughness similar to the cold rolled sample. This was attributed to the difference in microhardness: the surface of the CR sample did not present a detectable microhardness variation neither before nor after being diamond turned. This results in smaller elastic surface deflection which is more important than elastic recovery for the surface roughness formation. The CR machined sample did not present a noticeable variation in microhardness with the increase in loading. The results showed that, for optical application, a refined grain microstructure can be considered an important characteristic for achieving high performance optical components.

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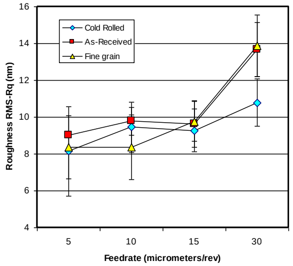

Fig. 1. Surface roughness Rq *versus* feed rate for the three samples.

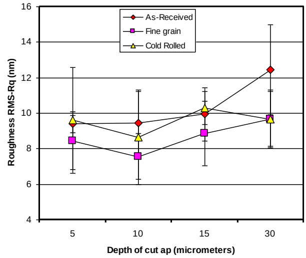

Fig.2. Surface Rq *versus* depth of cut for the three samples.

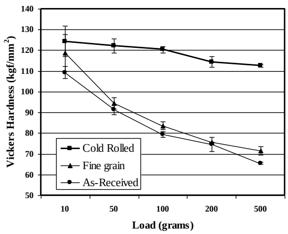

Fig. 3 Microhardness Vickers versus applied load for three samples.

Fig. 4 3D image of the surface finish of the as-received sample.

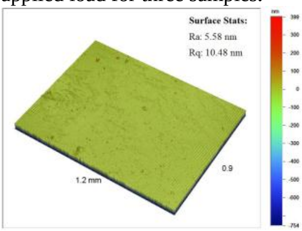

Fig. 5 3D image of the surface finish of the cold rolled sample.

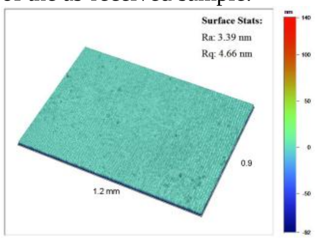

Fig. 6 3D image of the surface finish of the fine grain sample.

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