ACTA STEREOL 1999; 18/3: 313-318
ORIGINAL SCIENTIFIC PAPER

USE OF LINEAR DISCRIMINATING FUNCTION FOR THE DESCRIPTION OF THE EFFECTS OF MICROSTRUCTURE ON SURFACE ROUGHNESS AFTER FINE - TURNING

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ABSTRACT

It has been proven that successful cutting of metal materials depends on the morphology, and the size and distribution of intermetallic phases in the basic microstructure. An analysis of the microstructure of some aluminium alloys was carried out on an automatic system for image acquisition and processing. For the analysis intercept linear and area measurement methods were used. The present report describes the plastomechanical mechanism of surface generation in machining various aluminium alloys with silicon and its influence on the workpiece surface. By relating the data on the mean arithmetic roughness and the corresponding intercept length of the solid solution crystals it is possible to get, with the aid of the linear discriminante function, the particular areas which define the classes of expected roughness with respect to the microstructural effects in the same fine turning conditions.

Key words: aluminium alloys, microstructure, structure parameters, size distribution, fine turning, roughness, linear discriminante function.

INTRODUCTION

The quality of a machined surface is becoming more and more important in satisfying the increasing demands for sophisticated component performance, longevity and reliability. A system analysis about the machinability of materials must include also investigations of their mechanical and physical properties as well as all the various effects that different machining processes leave on the workpiece surface. Integral research of material machinability should offer a full insight into the properties of materials or product and should include material machinability, with material integrity of workpiece and tool.

A surface machined by conventional metal removal processes such as fine turning consists of inherent irregularities left by a single tool, which are commonly defined as surface roughness. Surface roughness is predominantly considered as the most important feature of practical engineering surfaces due to its crucial influence on the mechanical and physical properties of a machined part (Grzeisk, 1996). Therefore, the estimation of surface roughness under given cutting conditions resulting from metal removal operations is one of the major parameter to know.

Most surface roughness modelling studies have assumed that geometric surface finish in fine turning is influenced by the cutting speed, feed rate and tool corner radius (Kim, et al., 1993). Moreover, it is suggested that surface roughness is additionally affected by depth of cut, tool wear, vibration, effects, presence of built-up-edge, material microstructure, workpiece hardness and microhardness, etc.. As a result, general effects of machining variables are expressed in the form of linear or second-order mathematical models. In practice, an alternative is to employ expensive and sophisticated models.

Usually, the fitting of the theoretical surface roughness to the measured results is not good especially under conditions of final machining when the feed rate is very small. It has been suggested (Koenig and Erinski, 1981) that the main sources of this discrepancy are plastic deformation in the primary zone extended into the material adjacent to the machined surface, elastic recovery of the material on the after machining surface, adhesive interaction between the chip and the cutting edge, and the vibrations between the tool and the workpiece.

The purpose of this paper is to improve a simple model to predict the surface roughness of a turned surface based on the assumption that the minimum undeformed chip thickness corresponds to the transition form ploughing to micro cutting. Thus, the surface finish can be assessed in terms of feed rate, corner radius and the minimum undeformed chip thickness which represents the contribution of the secondary cutting edge.

As cast Al-Si alloys are important wear resistant materials and have been widely used as piston materials for petrol engines because of their low thermal expansion coefficient and high wear resistance when alloyed with other elements such as copper, magnesium and nickel. It has been reported that the wear resistance of the binary Al-Si alloys improved when the silicon content was near the eutectic composition.

Many authors have studied heat treated commercial alloys of LM13 with 11% silicon and LM29 with 22% silicon by sliding on cast iron and steel. They found that the underaged alloys give a lower wear rate while overaging give a higher wear rate. The hypereutectic alloy shows higher wear resistance compared to the hypoeutectic alloy.

The alloying additions may also modify the wear characteristics of aluminium-silicon alloys due to sold solution strengthening and precipitation hardening. The possible precipitation of Al-Si-Ce compounds in Al-Si containing cerium has been discussed (Harun, et al., 1996). In general, the precipitation kinetics and precipitation distribution and the morphology can be controlled by appropriate heat treatment. The present investigation was undertaken to develop cast wear resistant Al-Si alloys based on the above principles.

EXPERIMENTAL PROCEDURE

Aluminium - silicon alloys and cutting conditions

Al-Si alloys were investigated after fine turning with respect to the microstructure and considering the surface integrity criteria. The chosen alloys are presented in Table 1 according to standard, the proportions of particular elements in an alloy and their hardness after casting. The AlSi5 alloy is a hypoeutectic alloy equal content of eutectic crystals and dendritic solid solution crystals. The AlSi12 is an almost eutectic alloy, which contains, due to non-equilibrant cooling, dendritic solid solution crystals and low proportion of primary silicon crystals and eutectic crystals in the majority. The hypereutectic AlSi20 alloy contains predominantly fine eutectic crystals and large crystals of primary silicon in a smaller amount.

The tool geometry and machining conditions are crucial in assuring fine turning of a surface. The tool geometry was chosen on the basis of previous research results for machining numerous aluminium alloys with high-speed cutting steel and cemented carbide. Sugano and Takendi, 1987 differ in the choice of the geometry with respect to the tool angles and corner radius.

Table 1: *Chemical composition and Brinell hardness of the analysed aluminium alloys.*

ALUMINIUM ALLOY	ELEMENTS /%/							BRINELL HARDNESS
	Si	Fe	Mn	Mg	Cu	Ni	Ti	HB
AlSi5	4,76	0,17	0,11	0,01	-	-	0,012	53
AlSi12	12,5	0,24	0,25	-	-	-	0,009	66
AlSi20	20,5	0,12	0,01	-	-	-	-	63
AlSi12CuNiMg	12,0	0,01	0,01	1,04	0,93	0,9	0,013	104

The tool geometry was:
clearance angle: α=5°, rake angle: γ=6°, cutting edge angle: κ=75°
inclined angle: ε=90°, corner radius: r=0,8 mm
Tool material is sintered cemented carbide ISO K10 (SPUN 120308 D12)

The research was limited to the process of fine turning as a process in final machining of rotational parts. The conditions of fine turning were set according to the size of the microstructure components in order to confirm the relationship between the microstructure components.

The machining conditions in fine turning are defined by the turning speed "v", feed rate "f" and depth of cut "a". An experimental turning lathe with high turning speed can produce considerably higher depth of cut "a" and feed rate "f", increased by a factor 5 to 40 in relation to those stated in the literature (Leskovar and Grum, 1986). The chosen machining conditions in fine turning are presented in Table 2 and were equal for all the analysed alloys.

Table 2: *Fine Turning conditions.*

MACHINING CONDITIONS IN FINE TURNING				
Cutting speed	v (mm/min)	20		
Feed rate	f (mm/rev)	0,08	0,016	0,032
Cutting depth	a (mm)	0,025	0,05	0,1

INFLUENCES OF ALLOY MICROSTRUCTURE ON SURFACE ROUGHNESS AFTER FINE TURNING

Considering the diametral different properties and morphology of individual microstructure components and their behaviour during the process of cutting and deformation, the linear and area method were chosen for the quantitative analysis.

The measured micro structural parameters were:

- distribution of particle size after casting,
- distribution of particle size after fine turning.

Figure 1 shows changes in the eutectic microstructure or hypereutectic aluminium - silicon alloy after fine turning. The silicon particles in a very thin surface layer are crushed very much and move closer to each other. The particles of eutectic silicon are more crushed towards the surface and directed longitudinally, but less so further away from the surface.

Figure 2 shows changes in the microstructure, composed of primary silicon and eutectic crystal after fine turning. Large crystals of primary silicon undergo marked changes at the hit of the turning tool; they are crushed and flow from the surface or wedge into each other, in connection with the soft matrix. These damaged crystals of primary silicon are not suitable for the operating conditions of machine parts. Therefore it is necessary to direct the production of an alloy in such a way that, in spite of larger concentrations of silicon, the primary silicon are not present in the alloy.

There are a number of mathematical procedures for classifying samples into particular categories of classes which are based on deterministic or statistical approach. The linear discriminate function is very frequently sufficient to solve technical problems and also has the advantage that the classifying procedure is very simple, quick and reliable (Tou and Gousales, 1974). This means that a given space described by certain features can be successfully divided into particular classes with common properties. In our case we studied different kinds of aluminium alloys with different amounts of silicon which were described by intercept length of particular microstructural components. Preliminary research has shown that it is possible to successfully predict the roughness of the generated surface, if we measure only one of the mentioned phases contained in the microstructure is measured. We chose the size of the solid solution crystals which was described by intercept lengths. Thus in the same alloy, the distribution of intercept lengths on the solid solution crystals was defined and after fine turning the surface roughness was measured. Surface roughness after fine turning depends on tool geometry and kinematic conditions. It is named as theoretical or predicted roughness due to disturbances in the machining process. Among the most important disturbances we can count also the microstructural effects in the material which can be described by the size and shape of particular phases. In general, we can see that the conditions in fine turning depend on size and shape of the distribution of the hard or soft phase in a given microstructure.

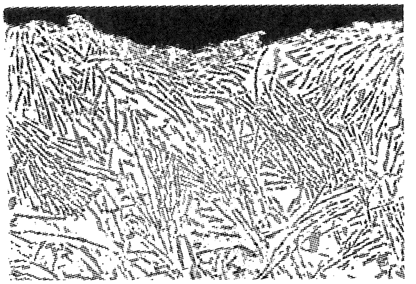

Figure 1: *Eutectic crystals and surface roughness after fine turning AlSi20 alloy of a cast rod form (100 x).*

Figure 2: *Primary silicon crystals and surface roughness after fine turning AlSi20 alloy of a cast rod form (900 x).*

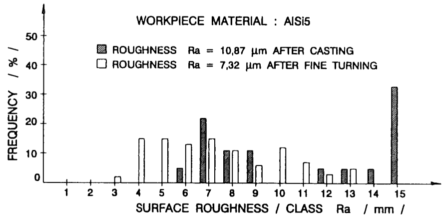

Figure 3: *Distribution of mean arithmetic roughness of AlSi5 alloy.*

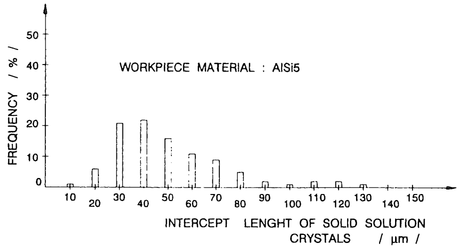

Figure 4: *Distribution of intercept lengths on solid solution crystals of AlSi5 alloy.*

Figure 3 shows the distribution of the mean arithmetic surface roughness for the alloy AlSi5 before and after fine turning. The data important for the assessment of surface quality is the average values of the mean arithmetic roughness, which is in our case 7.32 µm. Figure 4 shows the results of the measured intercept lengths on soft solid solution crystals for the same alloy AlSi5. From the distribution characteristic of the intercept lengths we can see what is the size and distribution of the soft solid solution crystals and define its average value.

The measurements of the mean arithmetic roughness after fine turning and the measurement of intercept lengths was carried out also on alloys AlSi12 and AlSi20.

By relating the data on the mean arithmetic roughness and the corresponding intercept lengths of the solid solution crystals, it is possible to get, thanks to the linear discriminate function, the particular areas which define the classes of expected roughness with respect to the microstructural effects in the same fine turning conditions. In figure 5, we can see the decision functions that successfully distinguish between the particular microstructural effects of different aluminium alloys on surface roughness subsequently to fine turning. Figure 5a shows the classification into particular classes for the depth of cut a=0.05 mm and Figure 5b for the depth of cut a=0.10 mm. The results are very similar, confirming that the expected roughness is greatly dependent on the type of the aluminium alloy.

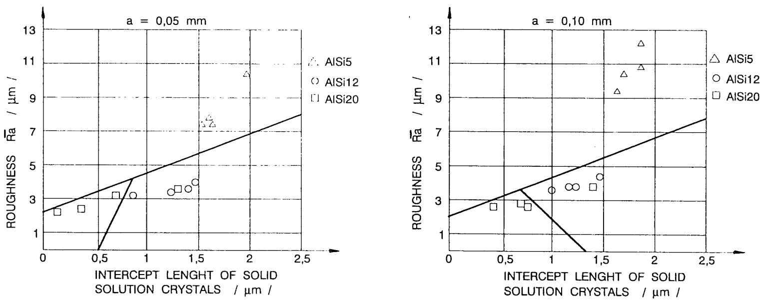

Figure 5: *Linear discriminant functions between intercept lengths of solid solution crystals and mean arithemtic roughness at a fine turning depth of a=0.05mm (Figure 5a) and a=0.10mm (Figure 5b).*

CONCLUSION

On the basis of these results it can be found that stereological methods enable a good insight into the microstructure of the individual aluminium alloys. Due to the different size and shape of the particular microstructure phases, different measurements were carried out using the linear method and the area method. The number of measurements made on the particular phases depended on the density and size of a phase. Thus between 45 and 100 fields of measurement were chosen, which should ensure the reliability of the results. Finally, a comparison was made between the cuttability and the microstructural characteristics of the particular alloys. It was found that at less harsh machining conditions the influence of the microstructural components on the cuttability was more pronounced, and that the cuttability was deteriorated if the cross-sectional area increased.

The experimental results show the following:

- Using the linear discriminating functions we proved the influence of the size of microstructural phases on surface roughness after fine turning particular aluminium alloys. The results of classifying particular types of alloys into classes with respect to the achieved surface roughness have confirmed that, besides machining conditions, a very distinctive role is played by the amount, size and distribution of solid solution crystals. It is a very significant fact that in the softest alloys AlSi5 with the highest amount of solid solution crystals, a considerably higher surface roughness is obtained. This is attributed to a greater ability for plastic deformation of the surface layer. The result of a more distinct plastic deformation of the surface layer is then the occurrence of a greater surface roughness.
- Using linear discriminante functions, surface roughness is classified with respect to the size of soft solid solution crystals in the microstructures of alloys with different amount of aluminium and silicon.

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Presented at the 7th European Congress for Stereology, Amsterdam, April 20th to 23rd, 1998.