ACTA STEREOL 1994; 13/2: 349-354
PROC 6ECS PRAGUE, 1993
ORIGINAL SCIENTIFIC PAPER

QUANTITATIVE ANALYSIS OF STRUCTURAL CHANGES IN Al-Si ALLOYS SURFACE LAYER SUBSEQUENTLY TO FINE TURNING OPERATION

Janez Grum, Marija Kisin

Faculty of Mechanical Engineering, University of Ljubljana,
Slovenia

ABSTRACT

The paper deals with four typical Al-Si alloys after casting and fine turning with high turning speeds, low feed rates and small depth of cut. Several computer-aided microstructural analyses were made and surface and the surface layer were analyzed using optical and electron microscopy. The relationships between microstructure components and the magnitude or the frequency of the dynamic cutting force component were confirmed.

Kewords : quantitative analysis, structual changes, fine turning operation, Al-Si alloys.

GENERAL

The numerous aluminium alloys in use have good mechanical, physical, chemical as well as technological properties. Aluminium alloys can basically be cast, formed and some can be tempered by heat treatment. Due to the fact that several parts made from the mentioned alloys are built in the assembly directly after mechanical treatment, their technological properties have to be as good as possible. The technological properties include all the abilities of the material, related to the machining or manufacturing technology, namely: formability, weldability, cuttability and heat-treatability. The discussion focuses on the chosen Al-Si alloys with different Si proportions containing the characteristic alloy elements to improve the mechanical properties.

Sugano , Tekeuchi (1987) and Kim, Lee, Choi (1993) analyzed the of machining of aluminium and aluminium alloy mirror surfaces by fine turning. The tools chosen were from diamond and cubical boror nitride with specially adapted geometry, very small depth of cut and low feed rates. The tool geometry and turning speeds were set to assure the largest effect of surface flattening in turning.

A Slovenian manufacturer of aluminium alloys made it possible for us to research the chosen alloys since 1970, as was reported in Leskovar (1986), Grum, Kisin (1989, 1991).

EXPERIMENTAL ARRANGEMENT

Description of the alloys

Al-Si alloys were investigated after fine turning with respect to microstructure and considering the surface integrity criteria. The chosen alloys are presented in Table 1 according to JUS symbols, the proportions of single elements in an alloy and their hardness after casting. The AlSi5 alloy is a subeutectic alloy with equal content of eutectic crystals and dendritic solution crystals. The AlSi12 is an almost eutectic alloy, which contains, due to non-equilibrant cooling, dendritic

Table 1 : Chemical composition and hardness of the analyzed alloys.

ELEMENTS % MATERIAL	Si	Fe	Mn	Mg	Cu	Ni	Ti	HARDNESS 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

Table 2 : Machining conditions in fine turning.

Machining conditions in fine turning				
Fine turning velocity	v (mm/s)	20		
Feed rate	f (mm/rt)	0,08	0,016	0,032
Cutting depth	a (mm)	0,025	0,05	0,1

solution crystals and low proportion of primary silicium crystals and eutectic crystals in the majority. The supereutecitic AlSi20 alloy contains predominantly fine eutectic crystals and large crystals of primary silicium in a smaller amount. The fourth alloy is an eutectic AlSi12 alloy, additionally alloyed with Cu, Ni and Mg. With the given alloyed elements, the eutectic concentration for an alloy shifts towards higher concentrations of silicium, which means a higher probability of accepting larger amounts of silicium in the solution and in the eutectic. The structure of this alloy looks the same as the structure of typical subeutectic alloys and contains the solid solution of aluminium and silicium in the form of dendrites and fine eutectic crystals. While the hardness of the first three alloys is very similar and lies in the range between 53 and 66 HB, the hardness of AlSi12CuNiMg alloy is considerably higher and exceeds the values of 100 HB.

Figure 1 shows the metallographic pictures of the discussed alloys.

Fig. 1 : Microstructure of the analyzed alloys (optical microscopy).

Machining conditions

The tool geometry and machining conditions are crucial in assuring fine machining of a surface. The tool geometry was chosen on the basis of previous research results for numerous aluminium alloys with high-speed cutting steel and cemented carbide . Authors 1 and 2 differ in the choice of geometry with respect to tool angles and tool radius.

The tool geometry was :

clearance angle : $\alpha = 5^{o}$, rake angle : $\gamma = 6^{o}$, cutting edge angle : $\kappa = 75^{o}$

included angle : $\varepsilon = 90^{o}$, corner radius : r = 0,8 mm

Tool material: 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 microstructure components in order to confirm the relationship between the microstructure components and the magnitude of the cutting force.

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 larger depth of cut "a" and shift "f", larger by factor 5 to 40 in relation to those stated in the literature Sugano, Tekeuchi (1987). The chosen machining conditions in fine turning are presented in Table 2 and were equal for all the analyzed alloys.

EXPERIMENTAL SET UP

The experimental set up comprises the research on cutting force, roughness, hardness and microhardness and microstructure measuring instruments and the quality of the surface on the scanning electron microscope. .

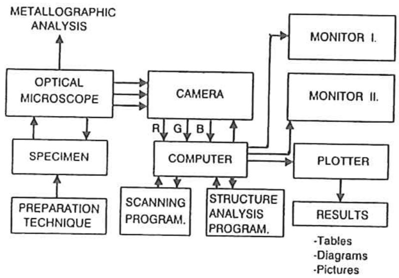

Fig. 2 : Schematic of microstructure analysis equipment.

Figure 2 shows a schematic presentation of the experimental equipment for measurement and the analysis of microstructure components. A standard optical microscope is followed by a connection to a camera, a computer and a plotter.

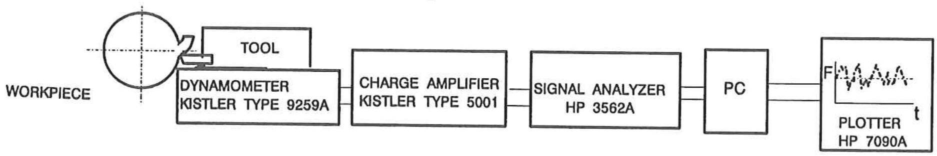

Fig. 3 : Cutting force measuring system in fine turning.

Figure 3 shows a measuring system for measurement of the main cutting force. The dynamic cutting force component was measured with a piezoelectric sensor. The holder for the cemented carbide was fixed to a dynamometer KISTLER TYPE 959A, which was connected to the input charge amplifier. To its output, the DYNAMIC SIGNAL ANALYZER was connected showing the variation of the main cutting force in time F(t) on a memory display. The output signal from the analyzer was printed by the HP-MEASUREMENT ROTTING PLOTTER.

EXPERIMENTAL RESULTS

Processes in fine turning

The cutting tool affects the workpiece surface directly and changes the morphology and the geometry of microstructure components. The quality of the surface and the surface layer is determined by the characteristic processes in the workpiece material, namely:

- cutting of the workpiece material,
- the microplastic deformation of the soft matrix,
- build-up of the plastic material on the workpiece,
- crushing of hard silicium crystals, such as eutectic crystals and the crystals of primary silicium,
- kneading of hard crystals and crushed parts into the soft matrix, which contributes to hardening of the material (soft matrix) at the point where it stopped on the workpiece as a built-up edge.
- hardening of the matrix, represented by a solid solution.

Structural changes in the surface layer of the workpiece

The structures in alloys differ to a great extent in shape and size. The solid solution is in the shape of dendrites, the eutectic phase is very fine and consists of the solid solution, acicules silicon crystals, large silicium crystals and finally very fine intermetal phase Al_3Ni, AlCuMgSi, AlFeSiMg and Al_6CuNi.

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

The measured structural parameters are given in the following way:

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

Figure 4 (left) shows the distributions of areas of eutectic silicium in AlSi12 alloy after casting (A) and after fine turning operation (B).

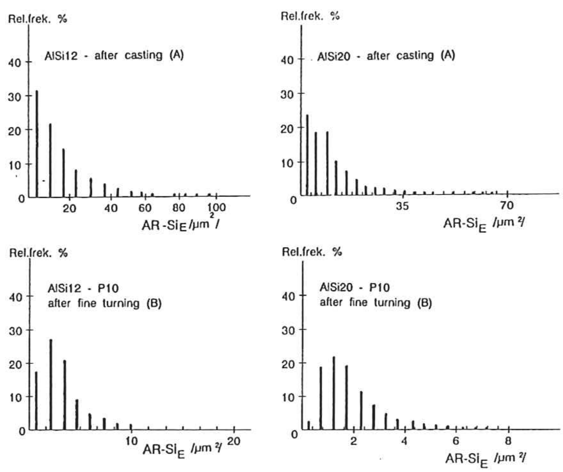

Fig. 4 : Distribution of eutectic silicium areas after casting (A) and fine turning (B) for AlSi12 and AlSi20 alloys.

The basis of the results of measurement on alloy AlSi12, it can be established that the eutectic silicium particle sizes predominate after casting (A) with surface area in the range of up to 27,5 μm^2. The highest freqeuncy of particles is in the size range up to 7μm^2, even though particles with area of up to 100 μm^2 can also be found. There is very little of such large crystals of eutectic silicium and they appear only with the frequency of up to some percent. The distribution of areas of eutectic silicium after casting in another alloy, AlSi20, is similar. The lower figures (B) show the same dependence of the distribution of areals of eutectic silicium after fine turning operation. The distribution is much different because the particles of eutectic silicium are crushed to a great extent, therefore their distribution is in the range of up to 10 μm^2.

Figure 5 shows the conditions on the eutectic structure or supereutectic silicium after fine turning. The particles in a very thin surface layer are crushed very much and move lie closer to each other. The particles of eutectic silicium are more crushed towards the surface and directed longitudinally, but less so further away from the surface.

Figure 6 shows the build-up of material on the alloy AlSi5 on the workpiece surface after the material moved from the tool onto the workpiece. The conditions are also similar on the eutectic alloy AlSi12, but due to solid solution this phenomenon is less noticeable on the workpiece surface and is due to the lower proportion of the soft matrix less frequent than it is the case with the subeutectic alloy. Figure 4 (right) shows the distributions of eutectic silicium areas in AlSi20 alloy after casting (A) and fine turning operation (B).

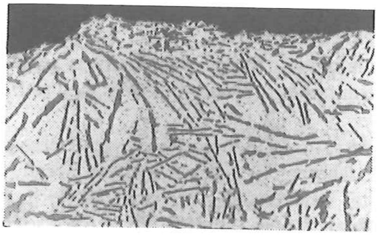

Fig. 5 : Eutectic crystals after fine turning of a cast rod in AlSi20 alloy.

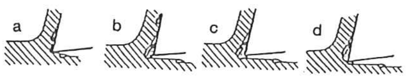

Fig. 6 : Formation of a built-up edge on the tool rake surface and on the workpiece surface. The results of build-up are shown in the sequence of pictures a, b, c, d.

Alloy AlSi20, cast under the same conditions, gave the following results:

- the particles of eutectic silicium are smaller and lie in the range of under 70 μm^2;
- in the first class of areas of up to 4 μm^2, frequency is the highest, up to 23%; after that the size of particles of eutectic silicium decreases gradually;
- the mean value of areas of eutectic silicium particles after casting is 16.7 μm^2.

The same alloy was also analyzed after fine turning and the following was established:

- the particles of eutectic silicium were smaller after fine turning, they ranged from 70 μm^2 to 10 μm^2;
- The distribution of eutectic silicium is changed considerably; the highest frequency of area size from 1.5 up to 2.0 μm^2 is achieved;
- The frequency of eutectic silicium particles is changed considerably in terms of particle range size as well as the distribution of particles of eutectic silicium;
- the mean value of particle areas of eutectic silicium is 2.4 μm^2 after fine turning.

Figure 7 shows the conditions in the microstructure, composed of primary silicium and eutectic crystal after fine turning. Large crystals of primary silicium undergo marked changes at the hit of the turning tool, they are crushed and fly from the surface or wedge into each other, in connection with the soft matrix. These damaged crystals of primary silicium are not suitable for the operating conditions, therefore it is necessary to direct the production of an alloy in such a way that in spite of larger concentration of silicium, they are not present in the alloy. It was proved that this is achieved in the alloy AlSi20CuNiMg, which is alloyed with Cu, Ni and Mg. Another possibility is to choose a diamond cutting tool, which cuts the solid silicium crystals but does not crush or knead them into the soft matrix. A safer and a more appropriate way is to choose an alloy without primary silicium crystals.

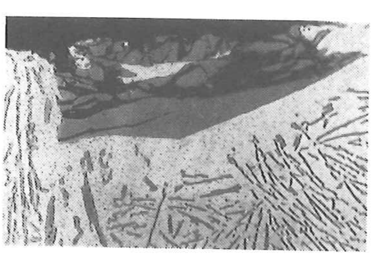

Fig. 7 : Primary silicium crystals after fine turning of a cast rod from AlSi20 alloy.

CONCLUSIONS

The experimental results show the following:

1. The chosen aluminium based alloys enabled a very good assessment of conditions in cutting from the microstructure components point of view as well as from the point of view of the main cutting force;

2. In the process of fine turning, in the surface layer there is cutting, plastic deformation and hardening of the soft matrix, whereas hard crystals crush already at very small energy input. Different sequences are noticeable - from cracks in the crystals of primary silicium, eutectic silicium and intermetal phases, to total destruction and shifting of the finer solid phase into the soft matrix. The surface of eutectic silicium crystals of alloy AlSi12 in the zone under the machined surface decreases by 83% and the soft matrix, represented by the solid solution, decreases by 71.5%.

3. The depth of the deformed layer is largest for alloy AlSi5, 150 μm, followed by the alloy AlSi12 with 50 - 70 μm and finally alloy AlSi20, where the thickness of the hardened layer is only 30 - 40 μm. The depth of the hardened layer was determined by measuring microhardness in depth, with the value of transition into the microhardness of the basic material without damage or changes.

4. To describe the quality of the surface layer, surface roughness was measured in addition to microhardness measurement. With the alloys of the same microhardness but different shape and size of silicium crystals, the obtained roughness was lower with the increased proportion of silicium in the alloy.

5. For equal conditions in fine turning and equal microhardness on the surface, the static component reaches the highest value for alloy AlSi5. In the given case, an important role is played by the soft matrix - the solid solution and the formation of the plastic deformed zone in the surface layer of the workpiece and the related formation of the built-up edge on the workpiece surface.

It is our opinion that the static component of the main cutting force is structurally dependent, because in cutting of alloy AlSi20 it has higher values in all the conditions than it is the case for alloy AlSi12, which is in concordance with the distribution function of individual components.

6. The magnitude of the dynamic cutting force component is influenced by: the type of the basic structure, the size of individual structural components, the distribution of individual structural components and the related microhardness and the deformability of the individual microstructure components.

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