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THE INFLUENCE OF MATERIAL MICROSTRUCTURE ON THE CHIP FORMING PROCESS

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Abstract: For a number of alloys the process of metal cutting is accompanied by extensive plastic deformation and fracture. In the paper we investigate quick stop samples of the chip formation of materials with different chemical composition and microstructure. The type of chip formation is classified according to the mechanism of crack formation and propagation. During cutting, most samples that are used, quasi-continuous chips with built-up edge (BUE) are obtained. The formation of BUE is undesirable since it is a highly deformed body with a semi stable top which periodically breaks away giving rise to poor workpiece surface quality.
Keywords: chip formation, material structure.

1. INTRODUCTION

Machining by material removal process is the most common process in the production of machine parts, but still little is known about the mechanical, thermodynamic, tribological, chemical and other phenomena in the cutting zone. The practical importance of knowing the essence and principles of these phenomena is extremely high, as they directly affect the output characteristics of the cutting process, i.e. effectiveness, productivity and quality of conformity. The complexity of these phenomena prevents an introduction of reliable analytical models and thus today the study of these phenomena includes commonly used experimental methods (e. g. metallographic method).

The emphasis in the paper is on the analyses of material structure changes as a consequence of localized plastic deformation in the cutting zone.

Generally, machining by material removal process is the most common process in the production of machine parts. The cutting process is suitable for machining of almost all materials (ferrous and non-ferrous, soft and hard, ductile and brittle, etc.). Machinability of materials is one of very important characteristics of materials and represents the capability of machining by using the most economical methods [1, 2]. The characteristics of machine parts (as duration, fatigue, wear, etc.) depend not only on the construction shape, but also on the condition of the surface layer after metal cutting. The parameters and phenomena, like state and quality of surface layer, cutting temperature, cutting forces, etc., are strictly connected with the chip geometry and shape [2].

Researchers in metal cutting technology have been trying to predict the material behavior during metal cutting for many years. For this purpose only “post fact” parameters were taken in consideration, like cutting speed, depth of the cut, cutting forces and geometry of material flow near tool [3−5].

2. EXPERIMENTAL PROCEDURE

The chip forming process can be theoretically explained by different models. One of the best known is the Brix model [7], which represents chip forming like successive lamellas forming process (Figure 1).

The type of the chip formation is classified according to crack formation mechanism and propagation. The outside of the chip is rough (like a saw tooth) - it is because the deformation of grains on this surface is not limited, like on the rake surface of tool. On this side the end of the lamella (grain) is wider because it is squeezed during cutting and the material flows out.

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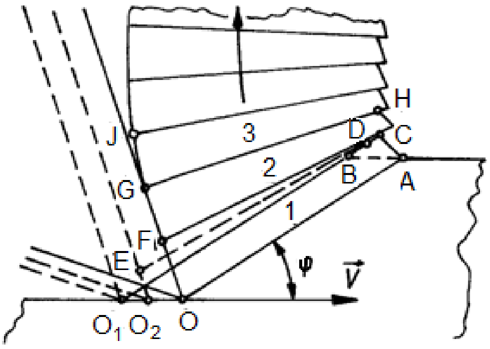


Figure 1. Brix model with lamellas formation during chip forming process [6]

The formation of the built-up edge (BUE) is undesirable since it is a highly deformed body with a semi-stable top which periodically breaks away giving rise to poor workpiece surface quality.

Most analyses of the cutting process are based on that the chip formation process is a stationary state. This well-known and widely used engineering approach means that the material is modeled as a continuum with a constant strain, and when it occurs, the chips strips are formed.

More recently, papers that have been published on chip formation focus on discontinuities in the microstructure, such as cracks and inclusions on the chip formation.

Beside the microstructure of metal matrix, nonmetallic inclusions have effects on shear instability in the cutting zone (Figure 2). This influence can be seen in the fact that nonmetallic inclusions reduce the carrier surface, which resists shear, while the surface nonmetallic impurity of steel base effect resulting stress concentration.

There are two mechanisms of microvoids that occur during the chip formation at lower voltages depending on the form of non-metallic inclusions:

• the round inclusions of the interface mechanism decohesion,

• elongated inclusions in fracture mechanism undeformable metal impurity inclusions − a metal base.

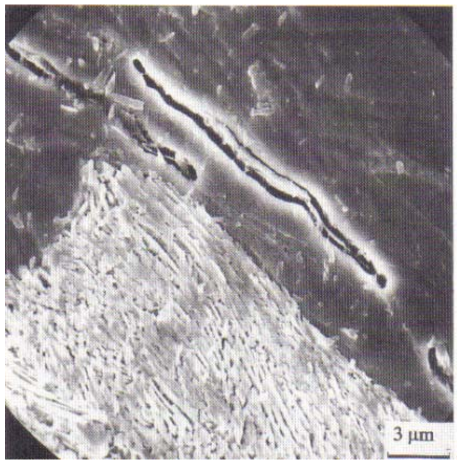


Figure 2. Nonmetallic inclusions

3. RESULTS AND DISCUSSION

With further increase of voltage occur microvoids and microcracks. In elongated nonmetallic inclusions appears the mechanism of decohesion appears. Further increase of voltage leads to microcrack coalescence with neighboring microvoids or microcracks, which leads to the formation of brittle and easily breakable brief filings.

The cutting zone due to a high degree of plastic deformation (over 97%), and microcracks occur independently of the metal base and non-metallic inclusions on the surface pearlite - ferrite due to the deformation gradient (Figure 3), as well as the microstructure of different plastic deformation [7].

Figure 3b) shows the root chips with machining Č.3990 steel which has a higher amount of nonmetallic inclusions MnS while Figure 3a) shows the chip root of steel Č.1730. In the chip root of Č.3990 steel a large number of microvoids and cracks around the shear plane can be seen [7].

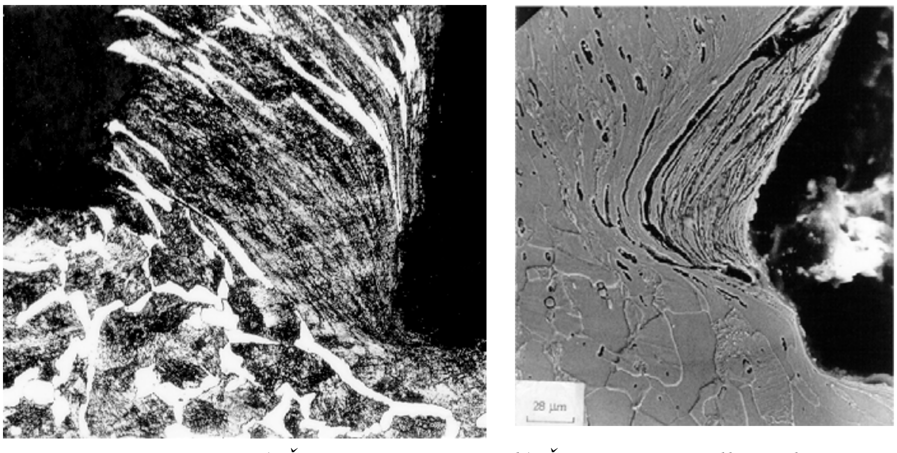


Figure 3. a) Č.1730 *b) Č.3990 nonmetallic inclusions MnS*

Machining of aluminum $AlSi_8Cu_3$ alloy and nodular cast iron in the cutting speed test range is characterized by quasi-continuous and discontinuous chips with and without built-up edge (BUE) formation (Fig 4, Fig 5) [8, 9] .

In all those specimens the chip formation process is a large strain deformation process, accompanied by partial fracturing due to internal cracking and voiding within or nearby the primary shear zone and cracks associated with the formation of BUE. The formation of the internal cracks is due to void formation on Si particles of the hypoeutectic $AlSi_8Cu_3$ alloy or at the non-metallic MnS inclusions and ferritic/pearlite interface for the steels.

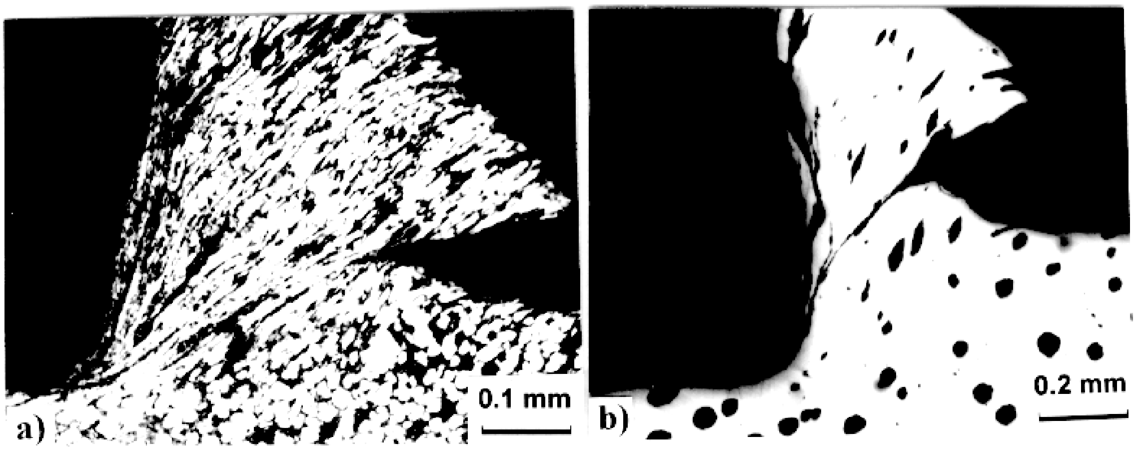


Figure 4. Optical micrographs of chip formation process a) $AlSiCu_3$ b) nodular cast iron

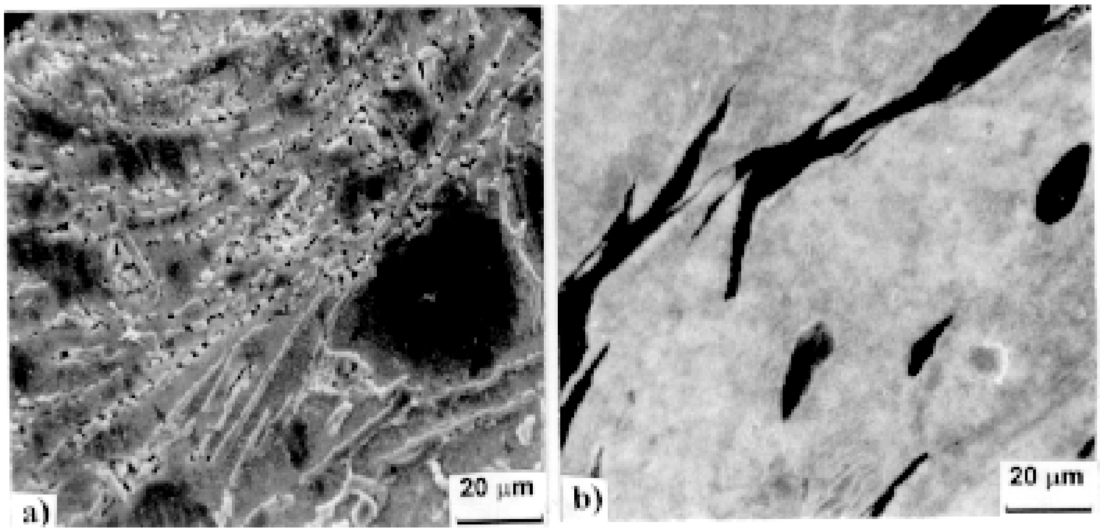


Figure 5. Primary shear zone a) $AlSiCu_3$, b) nodular cast iron

For a number of alloys the process of metal cutting is accompanied by extensive plastic deformation and fracture. Hypoeutectic Al-Si alloys have been studied in order to determine the influence of differences in microstructure on chip formation process and surface integrity. The type of chip formation is classified according to the mechanism of crack formation and propagation. During milling, in all specimens used, quasi-continuous chips with built-up edge are obtained, while during turning, quasi continuous and discontinuous chips with built-up edge are formed. The BUE is a highly deformed body. The top of the BUE is only semistable and periodically breaks away giving rise to a poor workpiece surface integrity (Figure 6, Figure 7) [8].

The goal of investigations was to study the influence on the chip forming process of different microstructure of Al-Cu alloy, produced by conventional casting and alloy in semi solid state (SSM) [6].

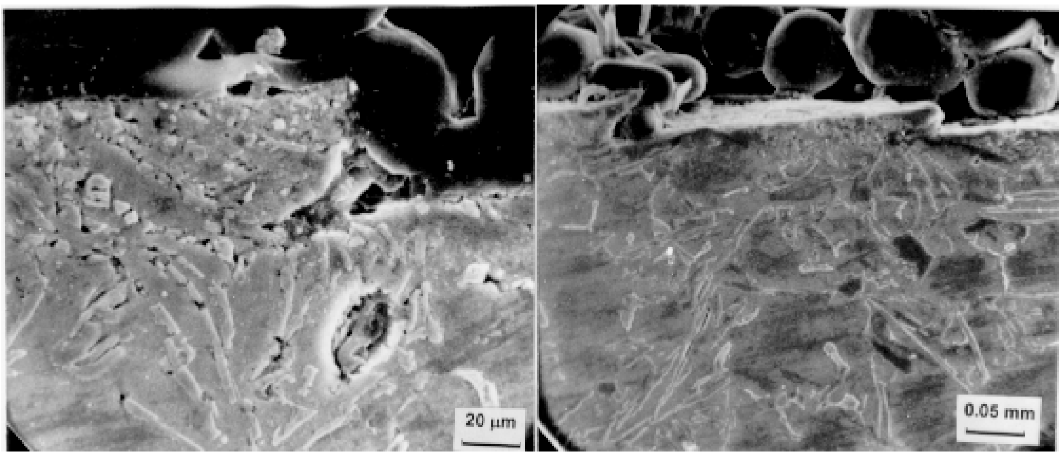


Figure 6. Fragments of BUE and cavity on the machined surface

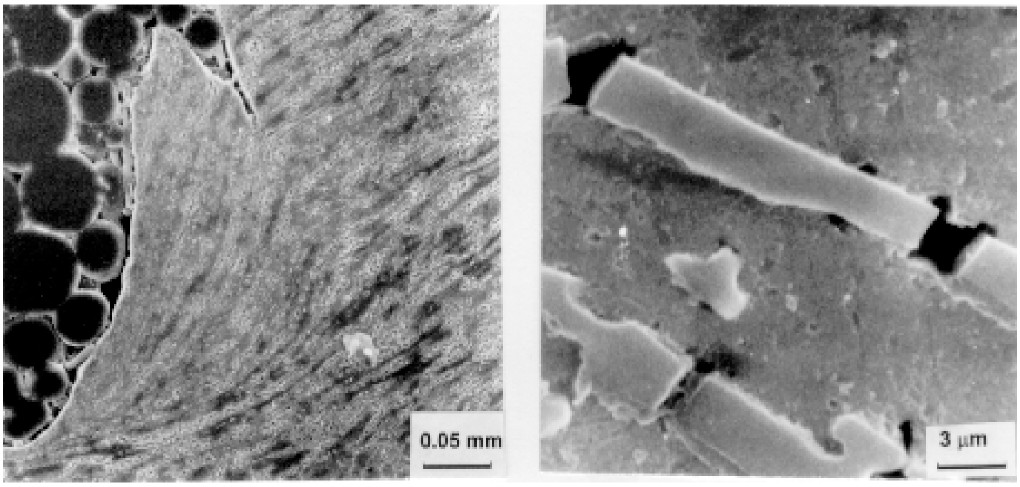
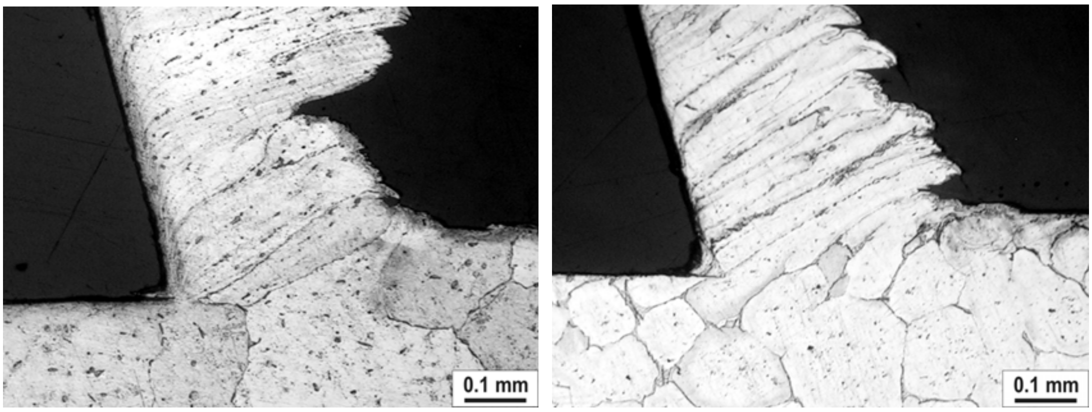


Figure 7. a) Chip root- the primary shear zone and BUE b) Microvoids around the Si crystal

It can be seen in Figure 8 that the grains texture line is approximately parallel along the whole width of the chip. The angle of the grain texture changes according to the cutting conditions and material properties. Only in a small area on contact surface of tool edge, the grain texture is bended (secondary deformation zone) - it is because of friction and pressure on the rake surface of the tool during chip forming process. The angle of texture is higher than the angle of shear plane. The lamellas (in chip forming models) are actually deformed grains and are approximately of equal thickness. Sliding of lamellas in the shear plane goes on the grain boundaries.

The outside of the chip is rough (like the saw tooth); it is because the deformation of grains on this surface is not limited, like on the rake surface of the tool. On this side, the end of the lamella (grain) is wider because it is squeezed during cutting and the material flows out. SSM has smaller grains and easily deforms so the lamellas are thinner than in conventionally cast Al. When the grains are smaller, the saw teeth on the opposite side of the chip are smaller as well. One lamella consists of one grain, when grains are bigger, and consists of more grains, when grains are smaller. The deformation in the shear plane goes on the grains boundaries. On the machined surface the cutting tool deforms grains in a thin layer and sometimes cuts the grains through.

One of the well-known Brix chip forming model (Figure 1), represents chip forming process like successive lamellas forming. The model ignores material properties and does not take into consideration the influence of material microstructure, so it did not manage to explain the fundaments of the chip forming process.



a) b)

Figure 8. Chip root with on a) commercial cast specimen b) SSM specimens [6]

The following samples describe micro structural observation (LM Leitz microscope and SEM - scanning electron microscope), which has been made on the samples of chip formation, either on metals (high-speed steels), (Figure 9 and Figure 10) or on Ti_3SiC_2 ceramic (Figure 11 and Figure 12). Compared to the conventional metal cutting, a significant difference in chip formation was noticed when Ti_3SiC_2 ceramic was machined. Although during machining, powder-like chip was produced, the chip pattern was also obtained when very careful machining was applied and it was noticed that breaking of the chip appeared without previous plastic deformation. During the investigation the cutting force was measured as well, and correlated to the cutting speed, feed and depth of the cut, respectively [10].

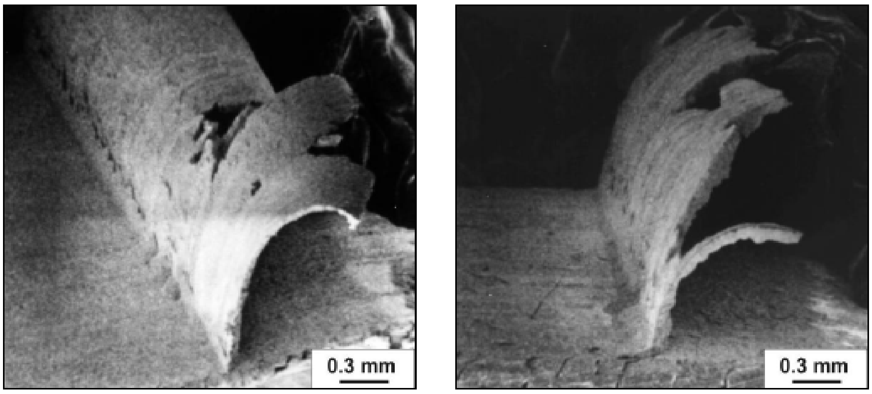
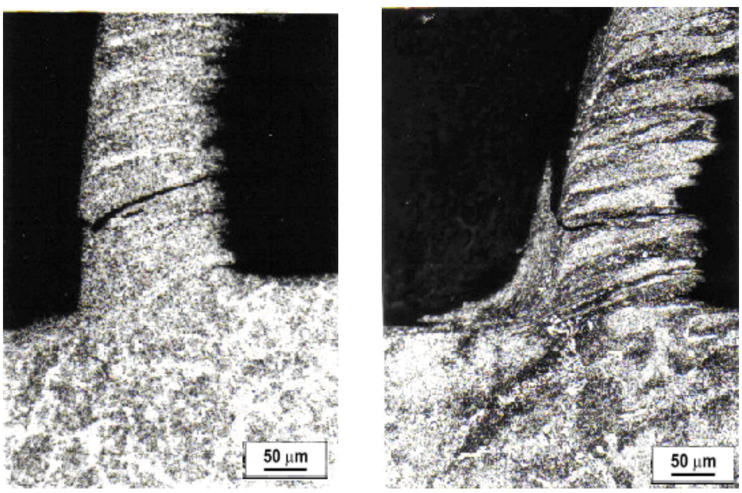


Figure 9. Chip root of high speed cutting steels: (SEM)



a) b)

Figure 10. a) Chip root of HS6-5-2-5 steel (LM) b) Chip root of HS6-5-2C steel (LM)

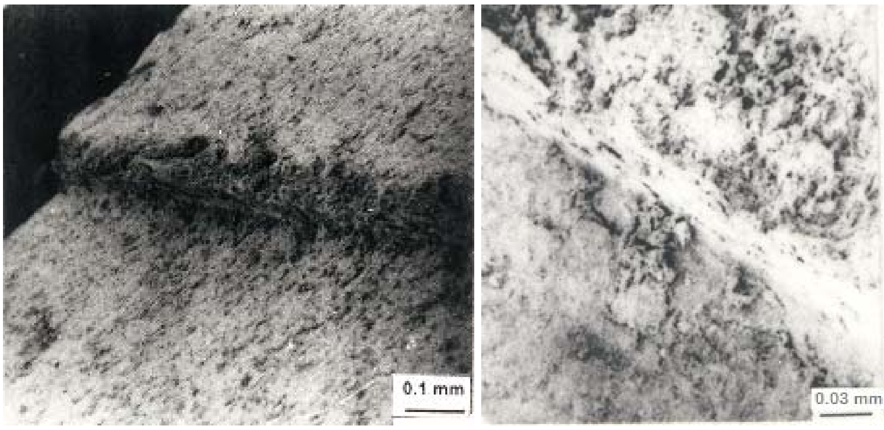


Figure 11. Chip roots of Ti_3SiC_2 ceramic (SEM): v = 0.93 m/s; s = 0.279 mm/t; a = 3.8 mm

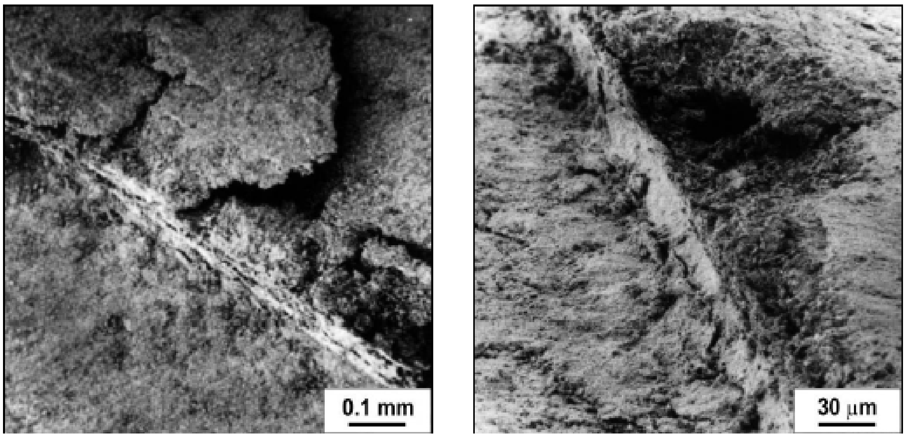


Figure 12. Chip roots of Ti_3SiC_2 ceramic (SEM); v = 1.18 m/s; s = 0.220 mm/t; a = 3.8 mm

The next investigations were conducted during cutting of two types of nodular cast iron alloyed with copper. Nodular cast iron is the cast iron whereby the graphite during the process of casting is shaped in the form of nodules, i.e. spheres. This form of graphite is very favorable for cast iron and in relation to all other cast irons this type has higher strength and the highest ductility. With further thermal treatments (austempering or isothermal improvement) ductile cast iron can obtain even better features, and the resulting material is due to its unique structure - ausferrit is called ADI (Austempered Ductile Iron) [11].

The following materials were used:

- Nodular cast iron alloyed with 0.45% Cu (designated NL1), (Figure 13).
- ADI material - where NL1 austerized at 900 °C/2h and austempered at 350 °C/2h indicated (A1), (Figure 14).

Below are micrographs of the chip root samples from which the values are the following:

– rake angle γ,
– shear angle Φ,
– angle of the texture line Ψ ($\Phi_1 = \Phi + \Psi$).

The sample of the chip root in Figure 15 was obtained almost like bands and a good quality of the machined surface was formed.

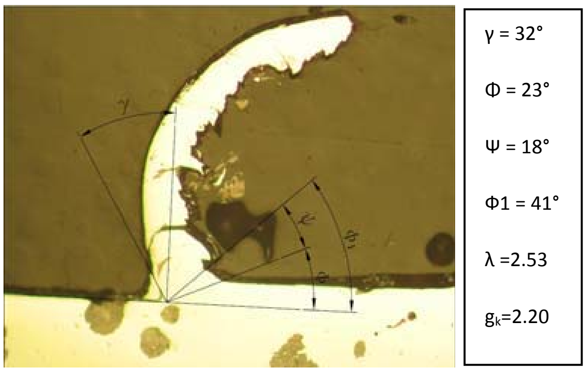


Figure 13. Chip root of ductile iron with 0.45% Cu

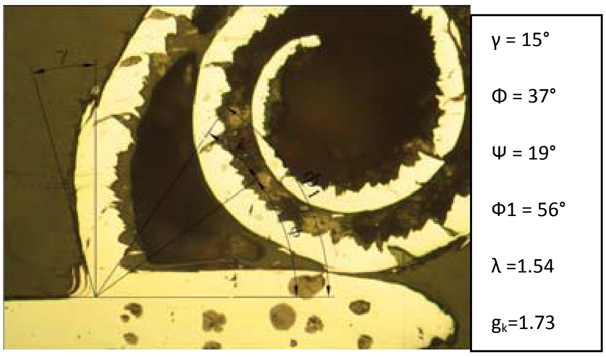
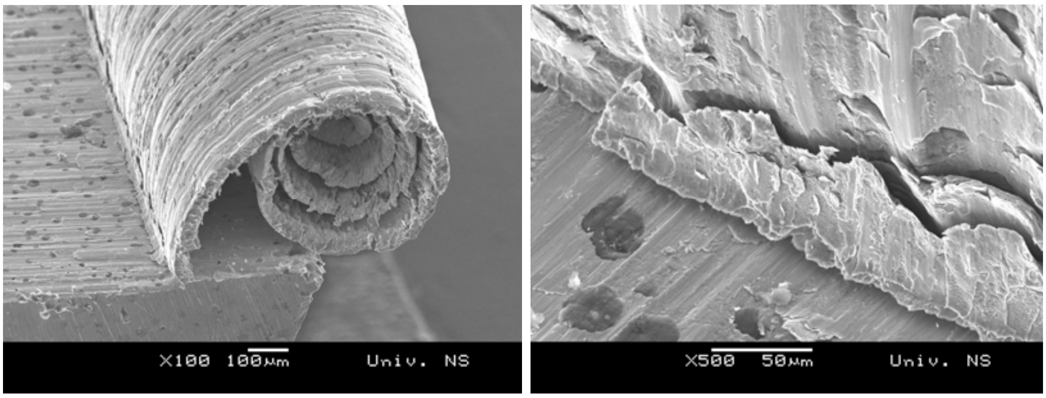


Figure 14. Chip root of ADI material with 0.45% Cu



a) *b)*

Figure 15. Microscopic image a) chip root of the ADI with 0.45% Cu recorded in the SEM b) without (BUE) formation

4. CONCLUSION

According to the results of investigations the following conclusions can be stated. Machining of aluminum $AlSi_8Cu_3$ alloy and nodular cast iron in the experimental cutting speed range is characterized by quasi-continuous and discontinuous chips with and without built-up edge (BUE) formation. The formation of the internal cracks is due to void formation on Si particles of hypoeutectic $AlSi_8Cu_3$ alloy or at the non-metallic MnS inclusions and ferrite/pearlite interface for the steels.

Samples of the chip formation of hypoeutectic Al-Si alloy have microvoids and microcracks in the material microstructure appearing around Si crystals in intermetallic phase. Coalescence of microvoids and microcracks and the chip type depend on the shape and distribution of crystals.

The top of the BUE is only semi-stable and periodically breaks away giving rise to poor workpiece surface integrity.

The processing of Al alloy, chip formation process and morphology of the chip depend on the amount of eutectic in the material. Higher amount of eutectic in SSM stimulate microvoids coalescence appearance of microcracks, resulting in easier machinability of SSM compared to conventionally cast Al alloy. Surface quality is poor because of constant BUE appearance.

During high speed steel machining a discontinual chip with BUE was produced. Chip forming process is a consequence of intensive plastic deformation with the fracture of primary (ledeburite) and secondary carbides and intensive appearance of microvoids and microcracks inside and near the shear zone.

During Ti^3SiC_2 ceramic cutting, powder like chip was produced. When very careful machining with special cutting parameters was performed, visible chip root on the workpiece was produced and the fracture appears without previous plastic deformation in primary and secondary cutting zones and fracture marks are visible on the machined surface as an effect of tool pressure.

Chips obtained during cutting of ductile iron and ADI material is in a very suitable form, most often bent in the shape of a roll with clearly expressed teeth on the outer surface of the chip, which is a result of relative sliding along the rake face of the tool.

ABBREVIATION:

BUE − Built-up Edge
SSM − Semi Solid State
LM − Leitz Microscope
SEM − Scanning Electron Microscope
ADI − Austempered Ductile Iron
Γ − Rake angle,
Φ − Shear angle
Ψ − Angle of the texture line

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УТИЦАЈ МИКРОСТРУКТУРЕ МАТЕРИЈАЛА НА ПРОЦЕС ФОРМИРАЊА КОРИЈЕНА СТРУГОТИНЕ

Сажетак: Процес резања метала је праћен великом пластичном деформацијом и пукотинама. У раду су изучавани узорци коријена струготине добијени брзим заустављањем процеса за материјале различите микроструктуре и хемијског састава. Циљ је био изучавање утицаја различите микроструктуре добијене различитим методама ливења на процес настајања струготине. Врсте струготине су класификоване на основу механизма настајања и ширења прслина. Током резања, у већини узорака настајала је квазиконтинуирано струготина са наслагама (БУЕ). Стварање БУЕ је непожељан процес, јер је то тијело састављено од високодеформисаних слојева материјала са полустабилним обликом, који повремено расте и одваја се, што доводи до лошег квалитета обрађене површине.

Кључне ријечи: настајање струготине, структура материјала.