INFLUENCE OF THE PROCESSING CONDITIONS ON THE SURFACE PROPERTIES OF WEAR RESISTANT CAST IRON GJS2131 PARTS

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Summary

This work presents the results of the effect of cutting materials on a surface properties of the elements produced from cost iron utilized in combustion engines. The cast iron GJS2131 was subjected to finishing turning on a CNC Talent 6/45 lathe with cutting tool made of sintered carbide hard alloy type K10, ceramic CC6090 and regular boron nitrade CBN7050. The speed of machining ranged from 300 to 1100 m/min and feed rate from 0,03 to 0,3 mm/rot. The best features of geometric structure of the processed surface guarantees using CBN7050, the worst ones (non-uniform outline of the protrusion irregularities, grooves, edgings etc.) – carbides K10. The results of microhardness from the surface layer show distinct hardening of the surface layer to the depth of 200 μm, yet they are quite varied depending on the working conditions and do not prove a unison advantage of any tool material. From the possible associations of machining parameters one may propose the best association: low speed – high feed rate.

Keywords: cast iron, turning, toolmaterials, surface geometrical structure, strengthening of the surface layer

Wpływ materiału narzędziowego na właściwości warstwy wierzchniej odlewów żeliwa GJS2131 odpornego na ścieranie

Streszczenie

W pracy przedstawiono wyniki badań wpływu materiału narzędzi na właściwości warstwy wierzchniej elementów wykonanych z żeliwa stopowego odpornego na ścieranie i stosowanego w silnikach spalinowych. Żeliwo GJS2131 toczono wykończeniowo na tokarce CNC Talent 6/45 nożami z węglików spiekanych K10, ceramiki CC6090 oraz regularnego azotku boru CBN7050. Stosowano prędkości skrawania od 300 do 1100 m/min i posuw od 0,03 do 0,3 mm/obr. Najlepsze wskaźniki struktury geometrycznej powierzchni obrobionej zapewnia stosowanie narzędzi z azotku boru CBN7050, najgorsze natomiast (nierównomierny zarys występów nierówności, bruzdy itp.) – węglików K10. Wyniki pomiarów twardości warstwy wierzchniej wskazują utwardzenie warstwy wierzchniej na głębokości do 200 μm. Stwierdzono dużą różnicę w twardości w zależności od warunków obróbki. Uzyskane wyniki nie wskazują jednoznacznie materiału narzędziowego. Z możliwych skojarzeń parametrów skrawania jako najlepsze jest „mała prędkość – duży posuw."

Słowa kluczowe: żeliwo stopowe, toczenie, materiały narzędziowe, struktura geometryczna powierzchni, umocnienie warstwy wierzchniej

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1. Introduction

Analyzing the technical development, one may observe that using of new technical solutions is closely connected with the application of the best possible materials adapted to new extreme usage requirements.

There are plenty of methods of the surface layers shaping taking into account their later use. A wide range of techniques of surface turning are described in the literature [1]. The tool materials [2-4], used in machining must fulfill very high demands because of the conditions in which the turning inserts made from these materials must work in. The most important demands to be expected in tool materials are: high level of hardness (higher than the turned material itself), high impact resistance, resistance wear or good heat conductivity [5]. These demands are important in processing contemporary engineering materials. The integrity of processed materials has been in the area of interest of scientists for many years [6, 7]. A lot of efforts have been put into the analysis of reasons of damaging the tools used in machining and their wear.

These requirements are important particularly when cutting of contemporary constructional materials. For example, cast iron cutting conditions are very varied and their machinability depends on the graphite form [8]. In grey cast iron graphite have the form of flakes easy to separate as small chip fragments, while in spheroid cast iron graphite has the form of spheres, which makes it more difficult for cutting. The appropriate selection of cutting inserts produced from the right tool materials enables compensation for these differences.

The destruction processes of machines and equipment begins in the material surface layers [9]. The conditions of the contact areas of the team-worked elements influence on it. The wear of machine parts is the wear of surface layers identified with change of mass, change of surface geometry or shape. Under these factors, it is necessary to know how to create such conditions of the surface layers of parts to assure their optimal durability. The heterogeneity of surface layers of machine parts may be the result of structural changes caused by the effects of external loadings. Thus, it is necessary to meticulously develope the surface layers properties, counteracting the destructive action of the machine work conditions on the material, from which the part is produced [10].

The usage durability of machine parts is closely connected to the properties of the surface layer. Therefore, different technological and exploitation methods may be used to form these layers, based on the various methods, among them cutting process. The conditions of machine working define the requirements concern of the surface layers properties of its parts [11]. If one accepts the actual construction of metal as an integration of interruptions in the continuity of macro and microscopic structures consisting micro fissures, porosity and irregular structures with a layered, mosaic character or caused by the inclusion of foreign parts [12], then the leading role of the surface layer is still clearer in sliding contact of machine parts.

2. Materials researched

The purpose of the research was to define the tool material, which allows to obtain the most suitable surface properties with the maintenance of shape dimension tolerances. EN-GJS2131 cast iron has been tested, which has high wear resistance and is used in piston inserts and piston rings in combustion engines. It is a material designed by industrial factories producing mould parts, which is widely used in the constructions of motor vehicles. The microstructure of the tested EN-GJS2131 cast iron is shown in Fig. 1. Chemical composition and tensile strength *Rm* is presented in Table 1.

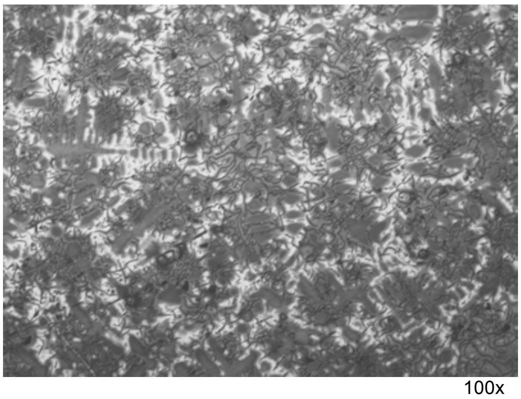

Fig. 1. Cast iron GJS2131 with perlite-ferrite structure. Magnification ×100

Table 1. Chemical composition and tensile strength Rm of GJS2131cast iron

Element, % mas.									*Rm*, MPa
C	Cu	Si	Mn	P	S	Cr	Mo	Ni	
2.49	5.42	2.20	1.05	0.33	0.04	0.04	0.01	7.47	150

3. Research methodology

When turning cutters with indexable inserts (index CNGA 120408) were used. They were produced from:

- regular boron nitride CBN, covered by a layer of titanium nitride TiN (CBN7050 of ”Sandvik Coromant”) [13],

• ceramic based on silicon nitride (CC6090 of ”Sandvik Coromant”) [13]; this material has good abrasive resistance at high temperatures,

• sintered carbide hard alloy type K10 of ”Mitsubishi” company [14], which is characterized by good abrasive resistance and impact resistance.

Two basic indexes of the surface layer state were researched – the surface geometrical structure and strengthening of the surface layer. Geometrical structure have been analyzed on the base of measurement of surface roughness parameter *Ra* and registration of single surface faults – scratches, scabbing, gumings etc. Strengthening of the surface layer was defined on the base of such indexes of substructure phases of the tested material as medium dimension of coherent dispersal zone D_{HKL} according to the Sherrer equation; relative root-mean-square microdeformation according to the Sherrer equation, which defines the degree of atomic surface defects in crystal lattice; dislocation density; micro-hardness.

Processing of parts was carried out CNC lathe model Talent® 6/45 of the ”Hardinge” firm in dry turning conditions with the following cutting parameters: cutting depth a_p = 0.25 mm, feed f from 0.03 to 0.3 mm/rev, cutting speed V_c from 290 to over 1100 m/min.

Such range of cutting parameters corresponds to minimal and maximal roughness parameters of the turned surface [15].

Surface roughness were determined by a computerized unit Perthometer type S2 of ”Mahr” firm. Conditions of the surface were analyzed using the stereoscopic microscope type MST 127 and Bresser camera USB0,3MP.

Submicrostructure parameters were measured by using a general purpose diffractometer ДРОН-3.0 with monochromatic CuK_α X-radiation. The secondary monochromatic aberration was executed using pyrolytic graphite with sample rotation in own plane of part. Difractogram registration have been registered using continuous method with an angle step equal 0.1°. 2Θ Angle range based on card 31-0619 (γ-Fe, austenite) and card 06-0696 (α-Fe, ferrite) ASTM collection was selected – 40-105°.

A “Micromet-II” unit produced by “Buehler-Met” was used for microhardness measurements with the force 0.5 N.

4. Results of research

Changes in value of parameter *Ra* of roughness for various insert materials are shown on the Fig. 2. It may be seen that surfaces turned by inserts from ceramic CC6090 are characterized by more stable *Ra* parameters in comparison with the surfaces turned by inserts from sintered hard alloy type K10 in the range of the applied cutting parameters. However, it can be observed that as in the case of turning by uncovered ceramic inserts as in the case of turning by sintered hard alloy inserts the *Ra* parameter values are almost equal. It is a type of ceramic sintered from pure silicon nitriade, which is suitable for cutting of cast iron at high speeds in stable turning conditions [10]. Turning by CC6090 material caused an even surface profile and in effect allow obtaining a surface with lower roughness. However, the lowest surface roughness was obtained in the case of CBN7050 inserts when turning with feed $f = 0.15$ mm/rev and cutting speed $V_c = 435$ m/min.

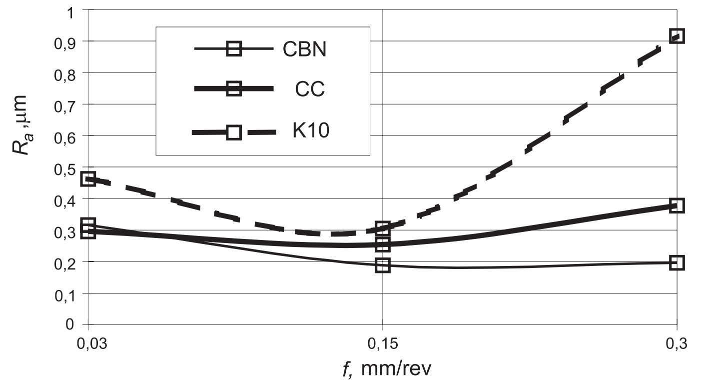

Fig. 2. Roughness parameter *Ra* of GJS2131 cast iron surface, obtained when turning by various insert materials

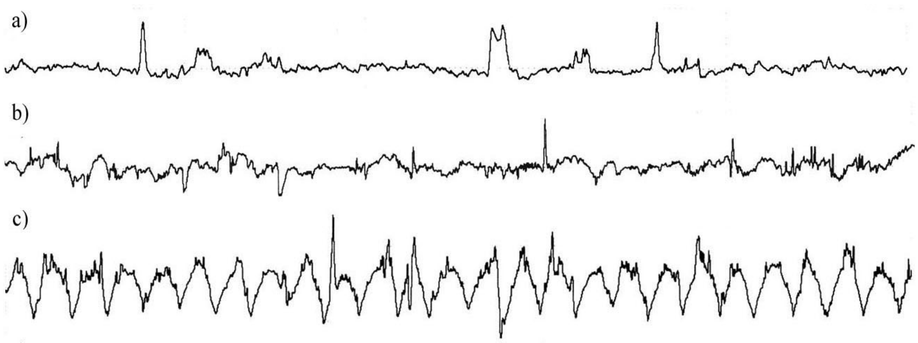

Fig. 3. Roughness profilograms: a) CBN7050, b) CC6090, c) K10 (scaling factors in the horizontal plane 0.800 mm and in the vertical plane 2.50 µm)

The character of surface roughness changes depending on the insert material used is presented in Fig 3. It may be seen, boron nitride (when turning wear resistant cast iron parts) has an essential influence on reducing of roughness (Fig. 3a), which is connected to its low reactivity with the machined material, resistance to high temperatures and resistance to oxidization [4]. On the other hand, the surface turned by CC6090 and K10 inserts is characterized by the higher roughness, as it is shown on Fig. 3b and c.

The topography of surfaces turned by the tested inserts is shown on Fig. 4. Visual observation enables to reveal state of surfaces which are smooth, without indentations or surface scabbing in the case of CBN inserts (Fig. 4a). The surfaces turned by CC6090 inserts are lesser smooth although also without scratching, indentation and fracturing (Fig. 4b).

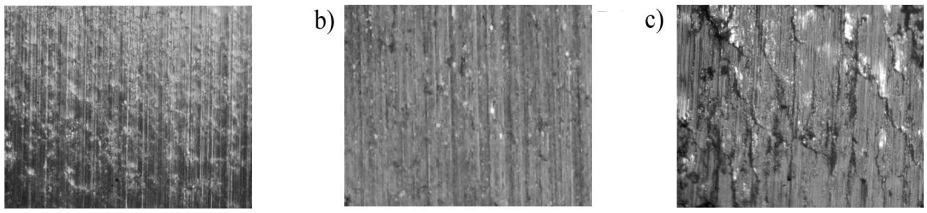

Fig. 4. Condition of GJS2131 surfaces turned by inserts from:
a) CBN7050, b) CC6090, c) K10. Enlargement ×87.5

In Figure 4c one may see the surface turned by inserts of K10 type sintered carbide alloy. It has low surface roughness irregular depressions which corresponded with profile of the roughness (Fig. 3c). The profile of the surface turned by K10 inserts is characterized by varied values of irregularities, sharp and jagged in a horizontal direction. It corresponds with the irregularities of the turned surface.

Examination of the condition of the surface layer is conducted by application of a fraction plan of type 2^2. Examination conditions are defined in Table 2.

Table 2. Conditions for testing of surface layer state

No	Normalized value		Actual value	
	X_1	X_2	V_c, m/min	f, mm/rev
1	–1	–1	292	0.03
2	–1	+1	292	0.3
3	+1	–1	1118	0.03
4	+1	+1	1118	0.3

Results of difractograms changes calculated by means of “WinDif” program are presented in Fig. 5.

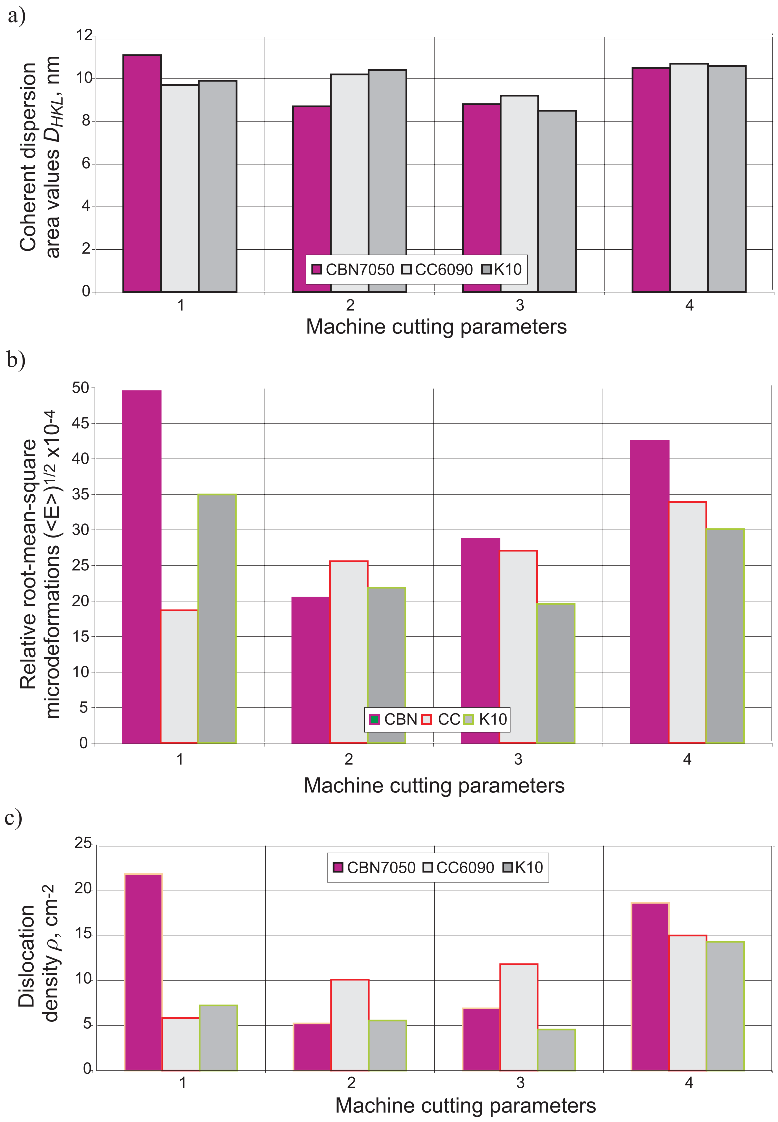

Fig. 5. Indexes values of GJS2131 surface layer parameters: a) dimension of coherent dispersal zone D_{HKL}, b) relative root-mean-square microdeformations $\sqrt{<E^2>}$, c) dislocation density ρ (marking 1-4 accord to line numbers of the Table 2)

Testing of the role of different indexes of surface layer on general state was the subject of many research works. Their analyses are described in [6]. It has been determined that D_{HKL} dimensions of coherent dispersal zones and micro-distortion $\sqrt{\quad}$ have a various effect on the material strengthening. At the time of testing of material strengthening when it's tempered it was determined that the temperature of the beginning of intensive increase of coherent dispersal zones is close to the temperature of beginning the removal of strengthening when tempering, but the temperature of micro stressing relaxation is not approximate. Based on the simplest physical related conceptions, Bragg showed that the durability of materials is inversely to the D_{HKL} dimensions. Later material strengthening while phase's changes and plastic deformations was associated with fragmentation of coherent dispersal zones, with changes of their heterogeneity degree, mutual turning etc. It explains the plastic deformation mechanism of metal. The slide along the crystal planes does not take place as a result of simultaneous displacement of groups of single atomic planes, but as a result of one type of displacement of atomic groups dispersing in crystal grids in defined directions. Such displacement sequence may go on in particular directions for long distances, as long as periodic correctness of the crystal grid remains at one direction. The process interrupts itself if the displacement encounters the disturbance of a properly constructed crystal grid, e.g. the border of a coherent dispersal zone. Therefore, the fragmentation of such zones causes the increase of metal resistance to plastic deformation.

Microstresses have an auxiliary function in the strengthening of metal. They are not associated with resistance to plastic deformation but are characterized the properties of the given material crystal grains. It has been defined that multiply increase or reduction of microstressing may not cause significant changes in the values of material resistance to plastic deformations. The boundary of plasticity and hardness do not change even in the event of almost total disappearance of microstressing. Such interactions between coherent dispersal zones and microstressing may be explained, treating deformation of single areas as the atomic planes bending. If inter atomic forces are large enough to resist the bending of the coherent dispersal zone, this zone may exist in the metal. Though, if these forces are insufficient and the destruction of this zone take place, then each of the new make zones shall have lesser dimensions and lesser plastic deformation. Because plastic deformation connects with the dislocation movement [3, 16], the occurrence of the hardening phenomenon means that there is an increase of resistance to dislocation movement in the deformed metal. And on scattering dimensions of coherent dispersal (subgrains). Though efficiency of blocking of movement is in comparison with interaction of grain in this case smallest considerably [17] dislocation, however, outsized amount of boundary boosts efficiency of braking of movement subgrain dislocation. Part has been strengthened in crystals dislocation and it evokes internal, this resistance increases together with the increasing dislocation density, which blocks mutually. Part of dislocations remains in crystallites and causes internal stressing, which counteracts relocation of other dislocations. In consequence, it causes a reduction of plasticity and strengthening of the material.

On the base of X-ray analysis one may confirm the superiority of CBN7050 material. The best combination of turning parameters are number 2 and 3 according to the Table 2.

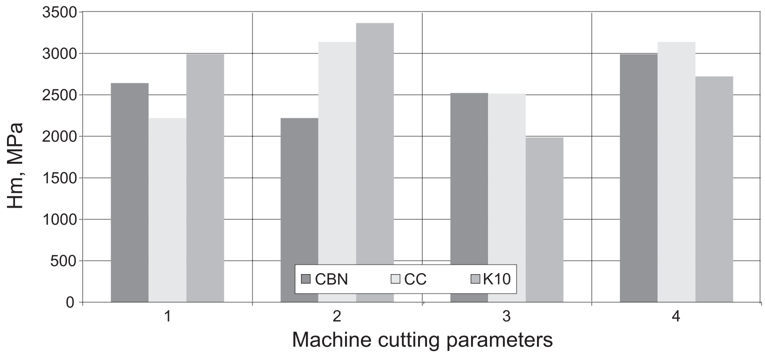

Fig. 6. Microhardness of GJS2131 surface layers (a measure depth is equal 50 μm)

The results of microhardness testing are shown on Fig. 5. In some cases microhardness values are substantially varied depending on the turning conditions. One may suggest the superiority of the conditions in line number 2 of the Table 2, but it is essential to test the tribological properties of the processed parts in various conditions.

5. Conclusions

The influence of the tool material on the surface geometrical structure of the turned parts produced from wear resistant cast iron was defined.

1. After analyzing of the test results of the geometrical structure of worked surfaces including changes in *Ra* roughness parameters it was determined, that the best surface properties were obtained when turning by CBN inserts. On the other hand the highest (3 times higher than CBN) parameter *Ra* value was obtained after turning with inserts of type K10 sintered hard alloy. This situation also connects with the visual image of the processed surface.

2. The analysis of X-ray results such as dimensions of coherent dispersal zones, dislocation density or also relative root-mean-square microdeformations indicates the reduction of dimensions of coherent dispersal zones and to a lesser degree of atomic plane's deformation in crystal lattice in the event that using inserts from CBN. This is observed as in the event of situation "relatively low speed – great feed" as in the event "great speed – low feed".

3. Microhardness of surface layer results are substantially varied depending on the processing conditions and do not indicate a clear advantage for tested tool

material. Between the possible associations of cutting parameters, one may suggest the situation "relatively low speed – high feed rate" as the best.

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Received in March 2009