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Analysis of Cutting Surface During Cutting of Electric Sheets

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The contribution evaluates the influence of the size of the cutting gap on the quality of the cutting surface during the cutting process. Four types of electrical sheets were evaluated. Examined sheet types have the nominal thickness of 0.65 and 0.5 mm. Sheets differ in mechanical properties (yield strength, ultimate tensile strength, and elongation). For the impact analysis, four values of the 0.02, 0.05, 0.1, and 0.2 mm cutting gap were used.

Keywords: electric sheets, cutting surface, cutting gap, hardening.

Introduction. From the process of shearing, it is known that the quality of the cutting surface is highly influenced by the cutting gap, apart from the other parameters. Formation of the cutting surface, with the cutting gaps at various sizes, is described in many articles and related literature [1, 2]. Terms such as optimal cutting gap in terms of the minimization of the shear force and optimal cutting gap in terms of the quality of the cutting gap [3–5] often appear in the literature. The formed cutting surface can be generally characterized by the areas of pressing (rounding), plastic cut, shear, and burr (Fig. 1). Ratios of these individual parts made of the same materials change according to the size of the cutting gap (Fig. 2). Formation of the cutting surface, with the cutting gap at various sizes, is presented in Fig. 2.

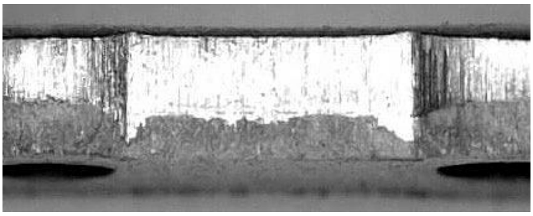


Fig. 1. Cutting surface.

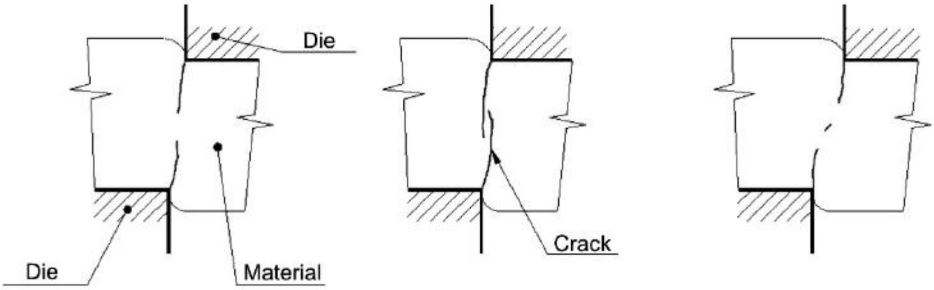
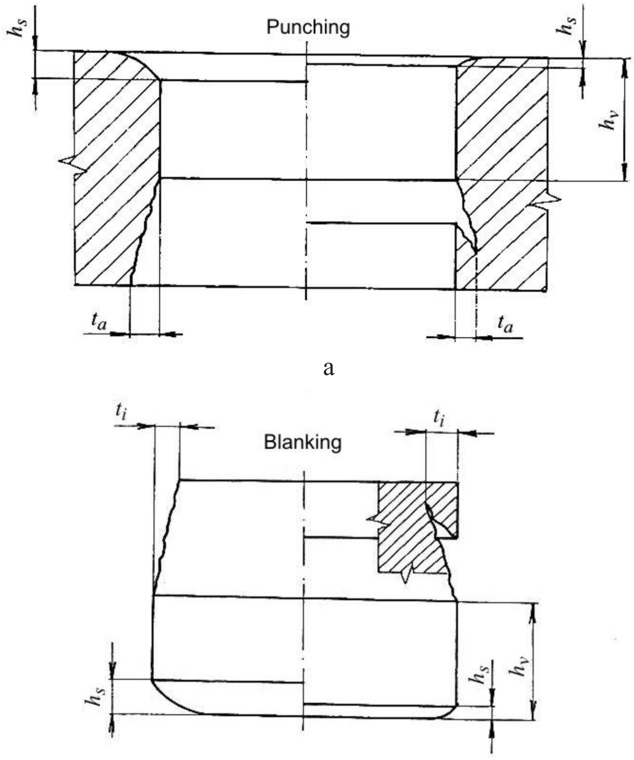


Fig. 2. Influence of the size of the cutting gap on the cutting surface.

In this contribution, we deal with the influence that cutting gaps at various sizes have on the quality of the cutting surface during the cutting of electric sheets. These sheets were chosen for the experimental research, because of the quality of the cutting edges and its considerable influence on the effective use of wattage in all the rotating electrical machines [2, 6].

In Fig. 3 we can see the influence of the size of the cutting gap on the shape of the cutting surface during the process of punching and blanking. Figure 3a shows us the optimal cutting gap in terms of the minimal shear force and Fig. 3b depicts the cutting surface with the small cutting gap [3, 5].



a

b

Fig. 3. Shape of the cutting surface with the large and the small cutting gap.

Not only the quality of the cutting surface expressed by the individual zones but also the change of the properties of the cut material in the area of cut (hardening of material) has a considerable influence on the so-called watt losses of the rotating electrical machines [4, 7].

Due to the shape of the formed (cutting) surfaces after the cutting and the shape of the hardening in the area of cut, it is necessary; in the case of most of the products, mainly rotors and stators of the rotating electrical machines; to adjust the surfaces of the cut-outs put together into bundles. Adjustments are realized by (chip) machining, most often by face turning of the perimeter of a bundle.

However, it is an "additional" kind of operation and that is why there is an effort, for the individual kinds of the qualities and thicknesses of electric sheets, to set the conditions that would eliminate the operations of the (chip) machining and minimize the losses caused by the low-quality cutting surface and the hardening in the area of cut.

There are new methods proposed and presented in the contemporary literature and the contributions. Methods of production of the rotor and stator laminations bound into the bundles by plasma arc cutting, laser cutting and waterjet cutting [6–8]. Considering the ability of the technology of laser cutting, or waterjet cutting, we must point out that even though better properties can be achieved in terms of the surface in the area of cut, these kinds of technologies can be used only in piece and batch production.

The speed of production of the rotor or stator bundle, while using above technologies, cannot compete with the cutting process provided by the cutting tools. Contemporary cutting tools are double-row and multi-row and apart from punching they enable binding cut-outs into bundles, see the tool in Fig. 4.

Apart from the size of the cutting gap, deformation of the cut material during the process of cutting has a considerable influence on the quality of the cutting surface as well. The forces acting on the edges of punch and die during the process of cutting are shown in Fig. 5. These forces and the moments of acting forces are dependent on the size of the cutting gap, but also on the way a sheet is held down during the process of cutting [4, 5].

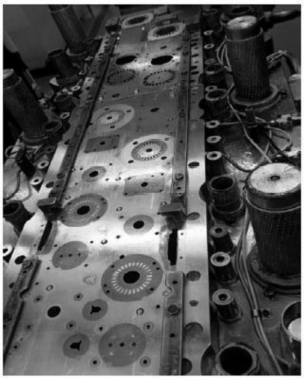


Fig. 4

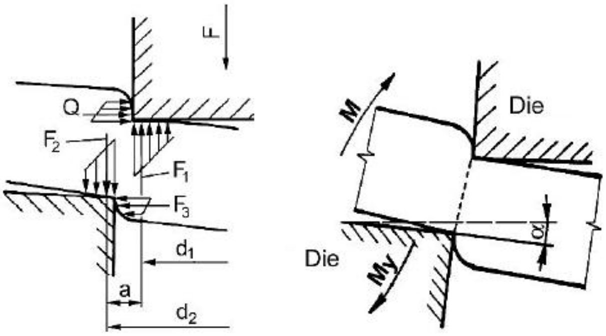


Fig. 5

Fig. 4. Double-row tool for the production of rotor and stator bundles.
Fig. 5. Shear forces and the moments acting during the process of cutting.

To prevent the deformation of the cut sheet, like the deformation shown in Fig. 5, contemporary cutting tools for rotor and stator laminations are constructed the way that guide plate, while it manages the tools (punches), has a spring-back and it also functions as a blank holder.

1. Experimental Material. For this experimental research, we used the material of nominal thickness 0.65 and 0.5 mm. Two types of the used materials differed in various mechanical properties. We examined a cold rolled material and a material processed by annealing. Mechanical properties and the production of used materials are shown in Table 1.

The chemical composition of the sheets is shown in Tables 2 and 3. Used materials differed mainly by the content of silicon. In the case of DL/FL sheets, the content of Si was 0.601% and in the case of DH/FH material it was 2.453%.

In Fig. 6, there is a structure of the examined materials presented. Used materials after annealing differ in grain size. In the case of the material FL it is the case of a fine grained structure. Material FH features structure with a considerably larger grain.

To obtain strength and plastic properties of the examined materials, the tensile test was performed on them. Materials after rolling and after annealing acted differently during the tensile test. Records of the tensile test of the examined materials are presented in Fig. 7. From the respective diagram it is obvious that the material after annealing had a considerably higher elongation and a lower tensile strength.

Table 1

Mechanical Properties of Tested Sheets (Average Values) and the Marking of Sheets

Material	Thickness (mm)	Material processing	Direction (deg)	$R_{p0.2}$, MPa	R_m, MPa	A, %
DL	0.65	cold-rolled	0	838.3	840.9	1.5
			90	925.2	959.2	1.9
FL	0.65	annealed	0	262.7	389.0	30.0
			90	283.4	405.1	30.0
DH	0.50	cold-rolled	0	1076.2	1076.7	2.4
			90	978.5	1063.0	2.0
FH	0.50	annealed	0	347.9	482.8	29.9
			90	360.8	492.6	30.0

Table 2

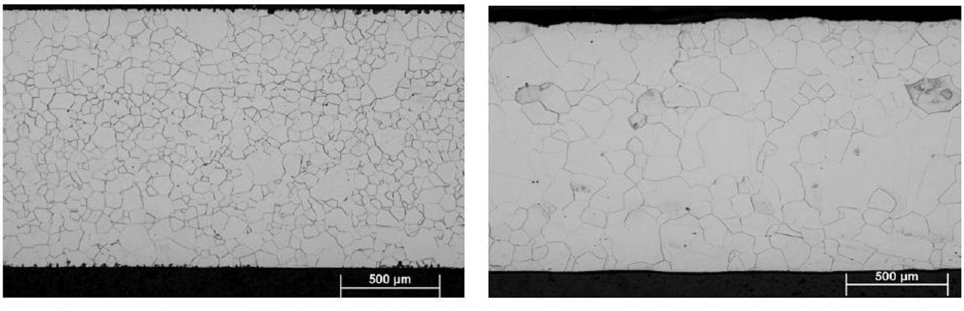
Chemical Composition of the DL/FL Electric Sheets (mass.%)

C	Mn	Si	P	S	Ta	N_2	Cu	Ni	Cr
0.0053	0.241	0.601	0.123	0.0049	0.002	0.0015	0.014	0.01	0.031
As	Ti	V	Zr	Nb	Mo	B	Ca	Sn	
0.001	0.001	0.002	0.002	0.002	0.002	0.0004	0.0003	0.005	

Table 3

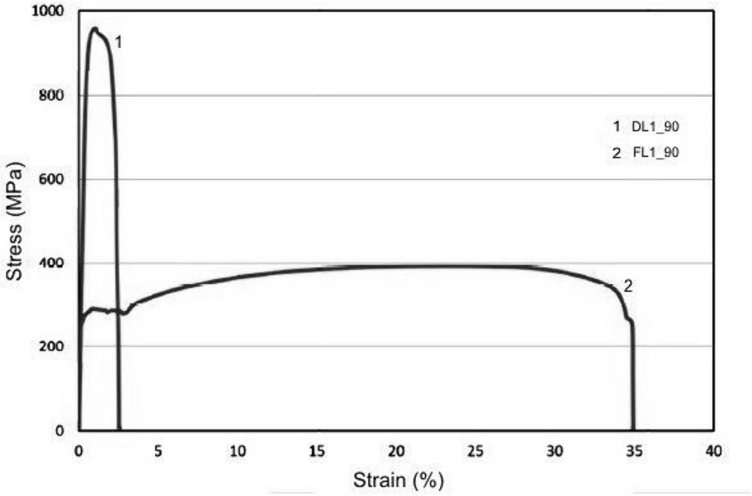
Chemical Composition of the DH/FH Electric Sheets (mass.%)

C	Mn	Si	P	S	Ta	N_2	Cu	Ni	Cr
0.0033	0.229	2.453	0.008	0.0027	0.355	0.0023	0.013	0.006	0.021
As	Ti	V	Zr	Nb	Mo	B	Ca	Sn	Sb
0.001	0.003	0.001	0.003	0.002	0.002	0.0003	0.0002	0.005	0.058



a b

Fig. 6. Structure of the material after annealing: (a) FL (0.6 mass.% Si); (b) FH (2.45 mass.% Si).



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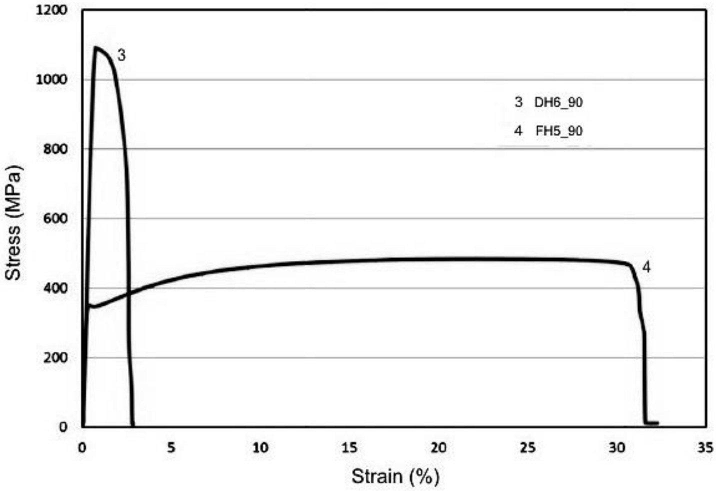

b

Fig. 7. Diagram of the tensile test of the examined materials: (a) FL (0.6 mass.% Si); (b) FH (2.45 mass.% Si).

2. Measured Results. To prove the influence of the cutting gap on the quality of the cutting surface, four sizes of the cutting gaps were chosen, namely: 0.02, 0.05, 0.1, and 0.2 mm.

Quality of the cutting surface was measured by the ratio of the area of plastic cut to the total material thickness. From the results, we can expressly state that in the case of the smallest cutting gap, the area of plastic cut reached almost 100% of the material thickness. With the increasing cutting gap, the ratio of the area of plastic cut to the total material thickness gradually decreased. Shear stress in the cut area caused the pull-outs of the ferritic grains in multiple cases. These phenomena can be observed in Figs. 8 and 9.

Hardening in the area of cutting surface was set by the nanoindentation measurement on the thin sections perpendicular to the cutting edge. Nanoindenter Agilent G200 with the Berkovich tip was used. The measurement was realized in the direction parallel with the surface of a sheet and perpendicular to the surface of a sheet in the 9 parallel rows (*X-1* to

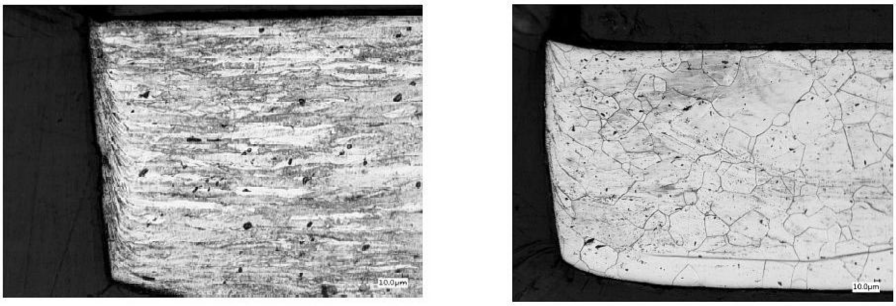

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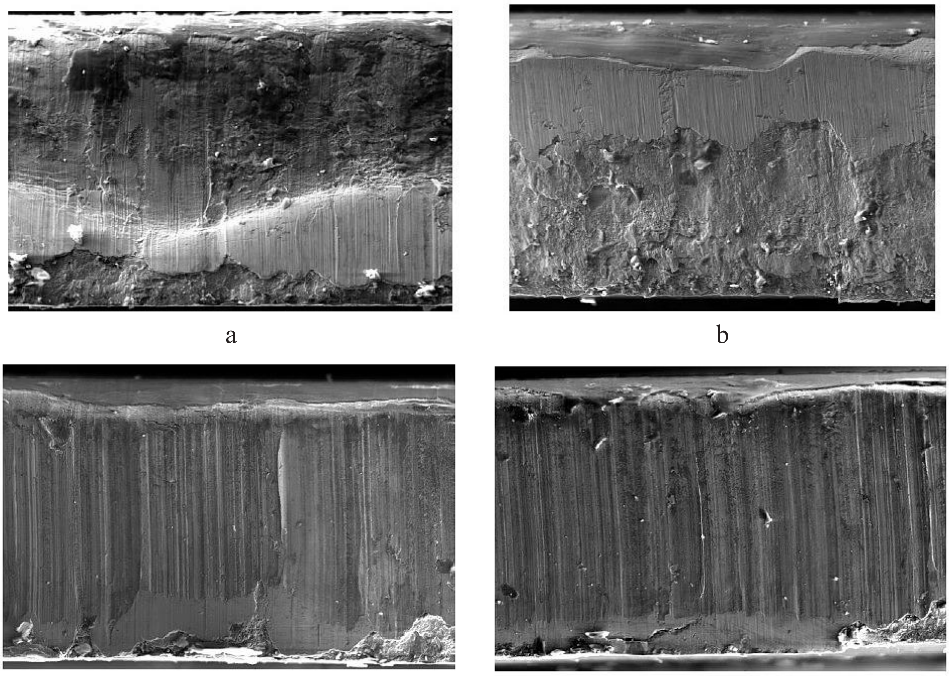
Fig. 8. Material FH after rolling (a) and annealing (b).



c d

Fig. 9. Cutting gaps: 0.2 (a), 0.1 (b), 0.05 (c), and 0.02 mm (d).

X-9), 45 micrometers from each other. In every row, there was the position data of the imprint of the indenter measured from the edge of the cutting line (Fig. 10). The intensity of hardening was expressed by the ratio of the nanoindentation hardness measured in the specific point to the indentation hardness measured in the area distant from the area of cut (Fig. 10). Parameters of the test: maximum indentation depth 2000 nm, dwell in the maximum depth 10s.

From the measured results of microhardness in the area of cutting surface, we can state that the largest values of hardening were measured out when the cutting gap was the largest. With the cutting gap of 0.05 mm, the smallest values of hardening were measured out. In terms of the distance from the area of cut, largest hardening was measured out with the cutting gap of 0.02 mm. From this fact it is obvious that with the smallest cutting gap the area of hardening in the area of cutting surface is the largest, even though the values of

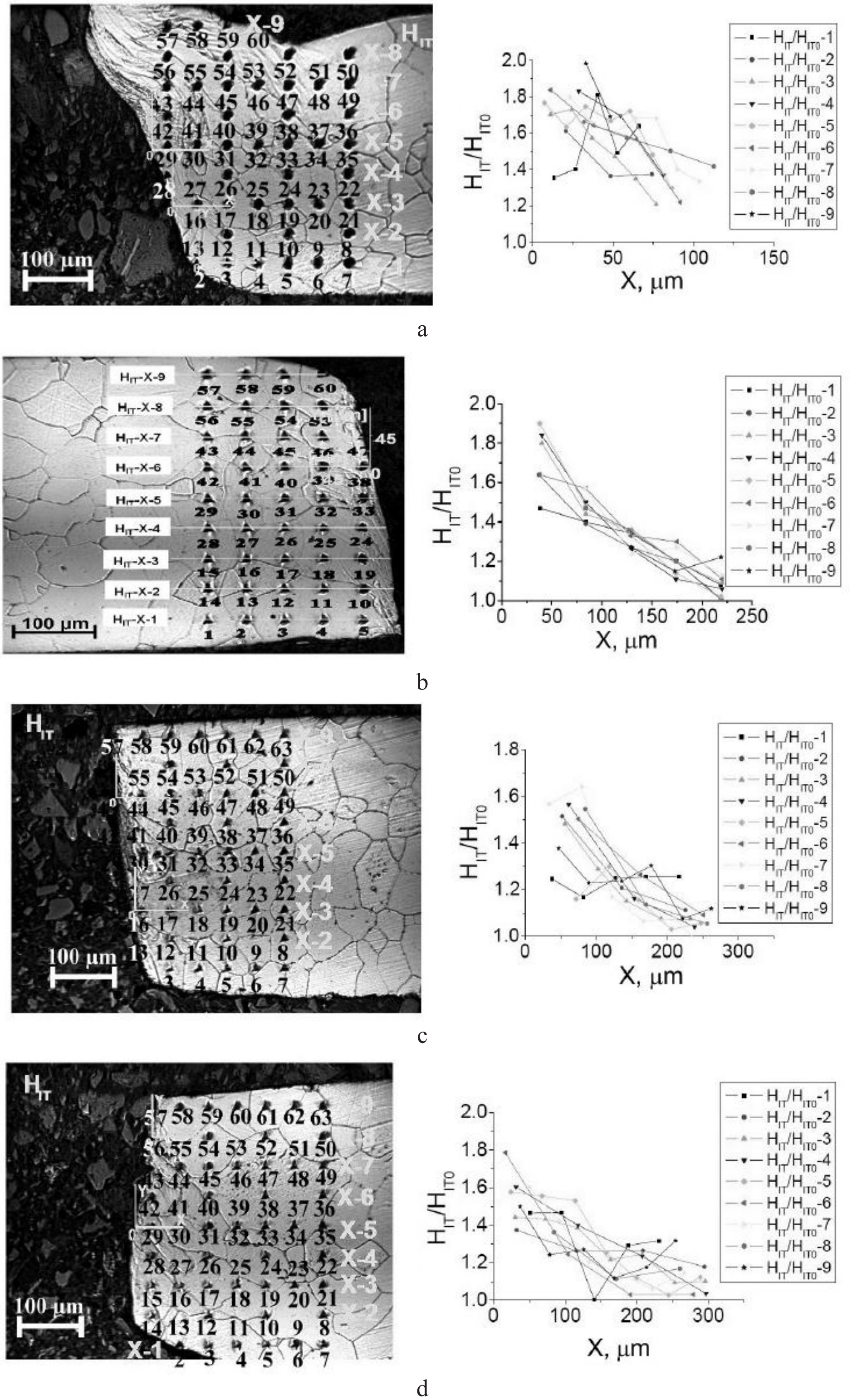


Fig. 10. Measurement of the hardening around the area of cutting line for FH material, cutting gaps 0.2 mm (a), 0.1 mm (b), 0.05 mm (c), and 0.02 mm (d).

hardness are not highest. During the cutting of steel sheets with the larger grain structure, the smallest cutting gap corresponded to the grains being extracted.

Conclusions. This contribution evaluated the influence of the cutting gap size on the quality of the cutting surface during cutting of the electric sheets. Four types of electric sheets were evaluated. Experimental sheets varied in silicon content and processing method. Used sheets possessed different mechanical properties. The nominal thickness of examined sheets was 0.65 and 0.5 mm.

To prove the influence of the cutting gap on the quality of the cutting surface, 4 sizes of cutting gap were chosen: 0.02, 0.05, 0.1, and 0.2 mm. Quality of cutting surface was evaluated by the ratio of the area of plastic cut to the total thickness of the material. Results show us that with the smallest cutting gap (0.02 mm), cutting surface is smooth and perpendicular. There are visible extracted grains in the lower part of the cutting surface. Quality of cutting surface during the cutting with the cutting gap of 0.2 mm is not appropriate and it cannot be used during cutting.

Measurement of hardness in the area of cutting surface was also realized for the examined materials. Highest values of hardening were measured out with the largest cutting gap. The largest area of hardening was measured out with the smallest cutting gap.

From the results, we can understand that it is necessary to observe and control the size of cutting gap and the quality of the cutting edges of a tool during the whole durability of the cutting tool.

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