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Evaluation of influence of cutting gap on the quality of the cutting surface when cutting of electrical steel

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ABSTRACT
This work deals with the evaluation of the influence of cutting gap on the quality of cutting surface in the ways of cutting electrical steel. The theoretical part of this work contains knowledge related to sheet metal cutting technology. In this part we also focused on the problem of electrical steel which is the part of electric motors. The effort to increase the effect of those devices is closely related to the quality of the process of cutting metal contact segments for electric motors. One of the most important parameters of the cutting technology is the cutting gap that has got an essential impact on the formation of the cutting surface, on its shape, on the layout the strip of the cut and on the strengthening of material. The experimental part of this work is focused on the cutting of electrical steel.

Keywords *– cutting, cutting gap, cutting surface, electrical steel*

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I. INTRODUCTION

At a time, when it is generally common trend to expand the use of electric cars on the market as much as possible, mainly due to declining stocks of non-renewable energy sources, as well as efforts to protect the environment more effectively, research and development in this area is extremely relevant. However, a significant part of the research in this area is devoted to sources of electricity, respectively development of batteries, which are subject to very high requirements. A significantly smaller part of the research is focused on improving the efficient use of stored energy, thus to reduce losses of electric motors. According to current knowledge, the quality of shear surfaces after cutting and assembling rotors and stators also influences the efficient use of stored energy.

Electrical steel is a soft magnetic material with enhanced electrical properties that is widely used across applications such as small relays, solenoids, electric motors, generators, and many other electromagnetic devices. Electrical steel is also referred to as silicon steel, transformer steel, or lamination steel. It is used mainly in electrical power distribution systems and in automotive industries. [1]

Silicon steels are the essence of electrical appliances and they provide the best combination for electricity distribution and transmission. Desired properties of these steels are low magnetic losses, high permeability and induction and low magnetostriction. Low magnetic losses reduce heat generation and power consumption, a high permeability and induction result in reduced size and mass of the parts, and low magnetostriction decreases the noise (manifested as buzzing) in transformers and large capacity machines. [2]

The silicon content increases the electrical resistance, reduces the electrical losses caused by eddy currents and magnetic hysteresis. Alloys of iron and silicon, characterized as magnetic hard, are used for transformer sheets, while for dynamo sheets, materials characterized as magnetic soft are used. These are characterized by a simple change in the direction of magnetization and low energy losses associated with remagnetization.

In rotating machines, for example motors or generators, where the induction flow takes place in different directions, hot-rolled sheets are preferred, due to their isotropic properties. In practice, a 25 % participation of the edge structure in the structure of the material is allowed, which makes them quasi-isotropic. Gradually changing the intensity and direction of the magnetic field, we get a closed loop of the hysteresis curve, which determines the delay of changes in induction or magnetization due to changes in the magnetizing field. The area of the hysteresis loop is equal to the energy required to remagnetize the material. Part of the energy is dissipated in the form of heat and represents losses. This loss is related (according to SI) per unit volume per magnetization cycle (J / m^3).

In the case where the machines are driven by alternating current, the magnetization takes place in rapidly changing fields, which causes the hysteresis loop to be distorted by the effect of eddy currents. Energy losses increase because the losses on hysteresis reach the losses of eddy currents, whose energy is also converted into heat. In general, the greater the maximum induction and frequency of changes in the direction of magnetization, the greater the losses. [3]

II. INFLUENCE OF SHEAR ON MAGNETISM OF PRODUCT MADE OF ELECTRICAL SHEETS

Rotating electrical machines are characterized by the variability of the magnetic induction flux. For this reason, the sheets used for their production must be isotropic. The material of stator and rotor made from electrical sheets should have an isotropic structure after final processing. However, the plastic deformation accompanying the cutting process worsens the magnetic properties of the finished electrical sheet products. The production of rotors by cutting electrical sheets is therefore always accompanied by the occurrence of an area with different magnetic properties. A burr is formed (Fig. 1), the formation of which cannot be prevented during the cutting of electrical sheets, therefore the plates for the rotors and stators are sometimes subjected to an additional deburring operation. The influence of burr on the blades of rotors and stators, on the output characteristics of the electric motor is unfavorable. During winding of the coil and during electric motor operation, the insulation may be broken, the winding may be short-circuited, and the rotor of the electric motor may burn out. Therefore, it is necessary to cut these sheets with the smallest possible burrs, of course, while maintaining the conditions of economy of production. At the same time, the requirements for electric motors specify that the size of the burr of the cut sheets, for stators and rotors, in small and medium-sized electric motors, should not exceed 10% of the nominal thickness of the sheet used. [3, 4, 5]

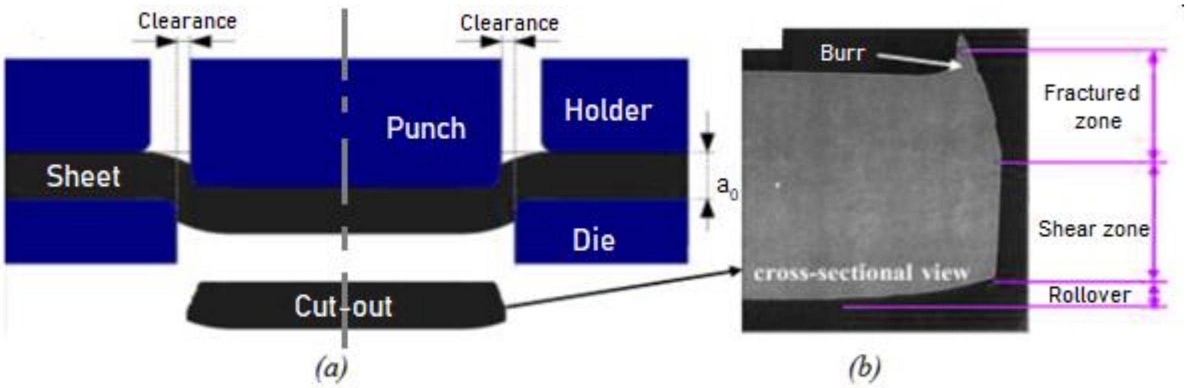

Fig. 1: Schematic of the cutting process and different zones of the cutting edge

The size and shape of the surface of the plastic deformation of the cut-outs from electrical sheets is influenced by the size of the cutting gap and by the wear of the cutting tool. Wear of the cutting edges of the tool causes the deterioration of the quality of the cut-outs and specifically causes:

- bending of cut-outs
- the formation of large burrs on the edges of the cut-outs
- deviations of the perpendicularity of the cut surface to the plane of the sheet
- large and extensive plastic deformations in the area of the shear curve

It is these mentioned shortcomings of the cutting process that impair the magnetic properties of electrical sheets. The shape and size of the plastic deformation area near the cut line can be determined indirectly by the method of measuring the microhardness of the material on the cross section of the blank. Changes in the hardness of the material in the cutting area, as well as deviations in the dimensions of the blank from the dimensions of the hole in the cut, can be different, depending on the different orientation, with respect to the rolling direction of the sheet. [6, 7, 8]

III. METHODOLOGY OF EXPERIMENT OF CUTTING SURFACE QUALITY EVALUATION

The subject of the experiment, which was performed in order to observe and evaluate the quality of the cutting surface, depending on the type of material used, as well as changes in the main parameter in the cutting process - cutting gap, were sheets made of electrical steel by U.S.Steel Košice.

Four types of structurally non-oriented Fe - Si electrical steels, designated in our case as A, B, C and D, were used in the experimental observation. Their chemical composition is given in the following table (tab.1). It is a new tested electric steel, with an effort to achieve the largest possible grain, in order to eliminate energy losses in electric motors. The electrical sheets from which the samples were taken for this experiment get a nominal thickness of 0.5 mm. [9]

Tab. 1: Chemical composition of the sample material

Chemical elements	*Sample A [%]*	*Sample B [%]*	*Sample C [%]*	*Sample D [%]*
Fe	92,330	93,530	95,080	95,600
C	<0,002	<0,002	<0,002	<0,002
Si	3,626	3,316	2,628	2,407
Mn	0,340	0,349	0,343	0,346
P	0,096	0,082	0,074	0,075
S	<0,002	<0,002	<0,002	<0,002
Cu	0,268	0,208	0,102	0,080
Al	1,705	1,437	1,064	0,950
Cr	0,055	0,058	0,037	0,038
Mo	0,302	0,203	0,128	0,099
Ni	0,558	0,320	0,226	0,158
V	0,119	0,087	0,051	0,039
Ti	0,010	0,010	0,006	0,006
Nb	0,239	0,158	0,092	0,070
Co	0,196	0,159	0,115	0,107

IV. CUTTING SAMPLES ON AN EXPERIMENTAL CUTTING TOOL

The next step of the experimental part of this experiment was the cutting of samples on an experimental cutting tool (Fig. 2) using a hydraulic press ZD 40, which has a nominal force of 400 kN (Fig. 3). A specific feature of this cutting tool is the difference in the size of the individual cutting gaps. (Tab. 2) Experimental blanks have the shape of a square with a dimension of 40 mm, but the individual sides of the blank are cut out, each with a different size of the cutting gap. The cutting tool was thus designed and manufactured in order to compare the effect of the size of the cutting gap on the quality of the cutting surface - the distribution and size ratio of parts of the cutting surface, monitoring the size of burrs, shape of the cutting surface and material reinforcement in the cutting area.

Fig. 2: Experimental cutting tool

Fig. 3: Hydraulic press ZD 40

Tab. 2: Cutting gaps of the experimental cutting tool

Cutting gaps [mm]			
n.1	**n.2**	**n.3**	**n.4**
0,20	0,10	0,05	0,02

V. EVALUATION OF CUTTING SURFACE QUALITY

1) Sample A with 4 sizes of cutting surface

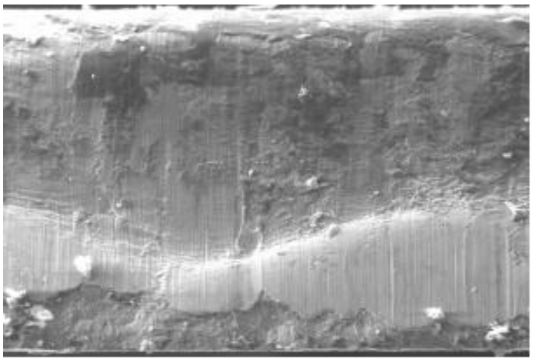

Fig. 4: Sample A cut with a 0,2 mm cutting gap

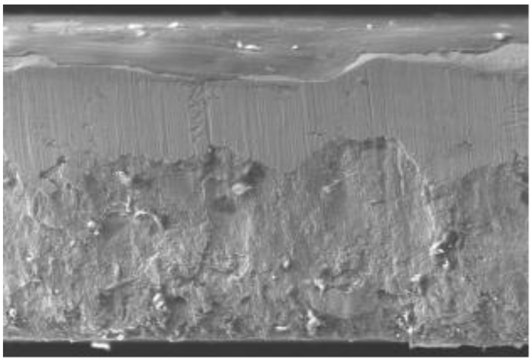

Fig. 5: Sample A cut with a 0,1 mm cutting gap

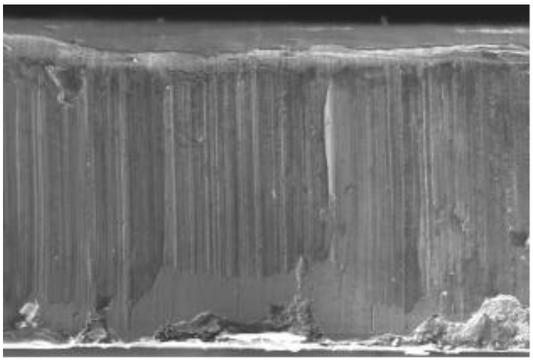

Fig. 6: Sample A cut with a 0,05 mm cutting gap

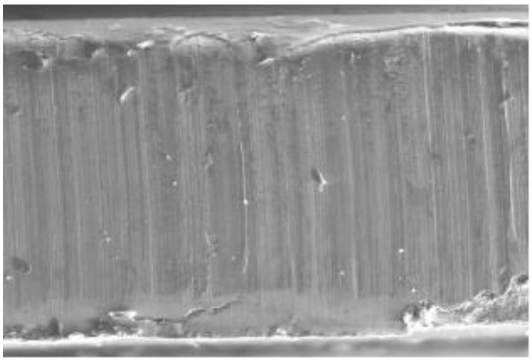

Fig. 7: Sample A cut with a 0,02 mm cutting gap

At the given outputs of observation of the appearance of the cutting surface, depending on the size of the cutting gap, the influence of the size of the cutting gap on the quality of the cutting surface is clearly demonstrable. The cutting surface resulting from the cutting with the largest cutting gap (0.2 mm) is uneven due to the material being drawn into the gap between a punch and a die, with a significantly predominant tearing area. The cutting zone is minimal. As the cutting gap decreases, the quality of the cutting surface improves. Gradually, the drawing of material into the cutting gap is eliminated and the cutting surface becomes more even and smoother. The size of the cutting band also increases. With the smallest cutting gap (0.02 mm), a very good cutting surface quality was achieved. The cutting surface is created by plastic deformation during the entire cutting zone, the presence of pressure and especially tearing is negligible.

2) Sample B with 4 sizes of cutting surface

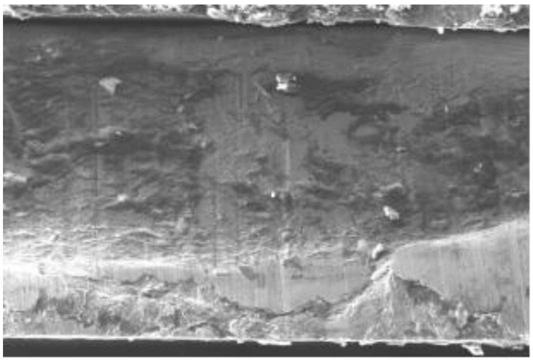

Fig. 8: Sample B cut with a 0,2 mm cutting gap

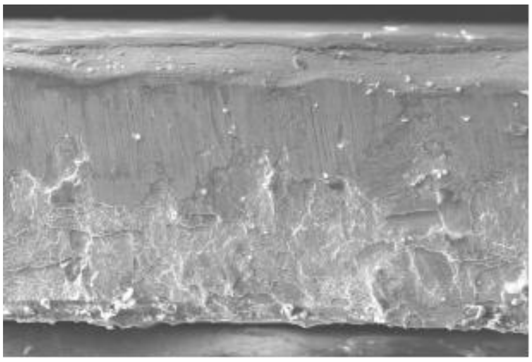

Fig. 9: Sample B cut with a 0,1 mm cutting gap

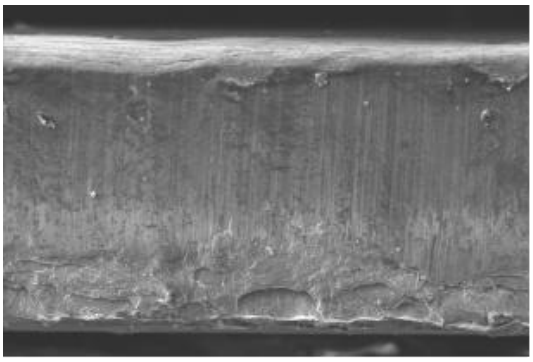

Fig. 10: Sample B cut with a 0,05 mm cutting gap

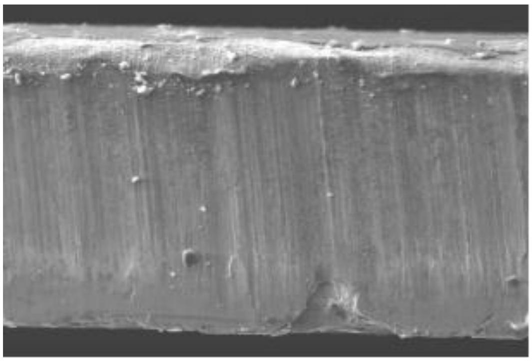

Fig. 11: Sample B cut with a 0,02 mm cutting gap

Sample B has a similar chemical composition, especially regarding the silicon-Si content, as sample A. At a cutting gap of 0.05 mm, whole grains were pulled out due to cutting stresses in the lower part of the cutting surface. Due to the lower ductility of these samples, brittle intracrystalline failure and subsequent tearing of the material in the fracture zone occurred at all cutting gaps - even at the smallest, due to shear stresses.

3) Sample C with 4 sizes of cutting surface

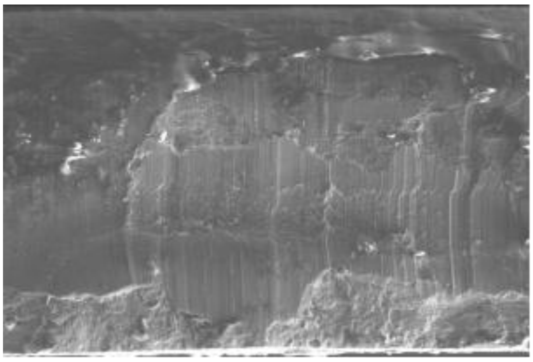

Fig. 12: Sample C cut with a 0,2 mm cutting gap

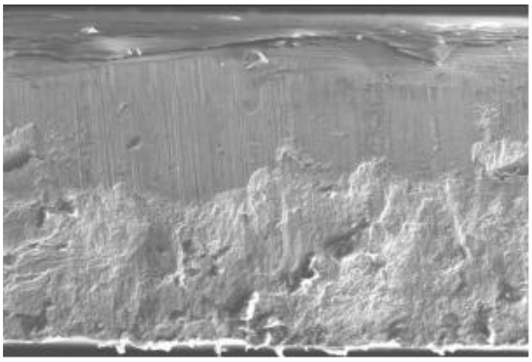

Fig. 13: Sample C cut with a 0,1 mm cutting gap

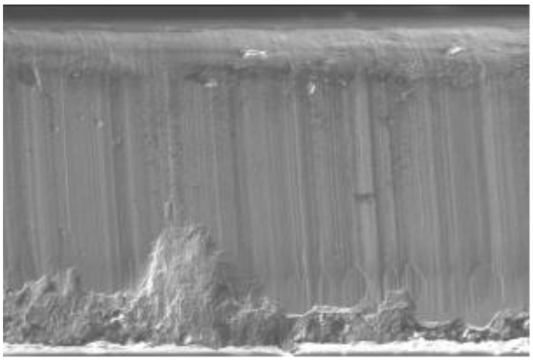

Fig. 14: Sample C cut with a 0,05 mm cutting gap

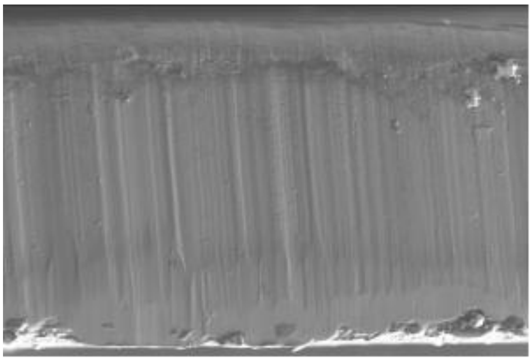

Fig. 15: Sample C cut with a 0,02 mm cutting gap

Compared to samples A and B, sample C has a significantly higher ductility due to the chemical composition. This fact was visibly reflected in all cutting gaps, especially in the rollover zone, where there was a more significant fillet of the cutting surface. Compared to the previous materials, this phenomenon is particularly observable in samples cut with a cutting gap of 0.05 and 0.02 mm. This is, of course, a negative manifestation of increased ductility, as a result of which, even when using a minimum cutting gap, an uneven cutting surface is formed.

4) Sample D with 4 sizes of cutting surface

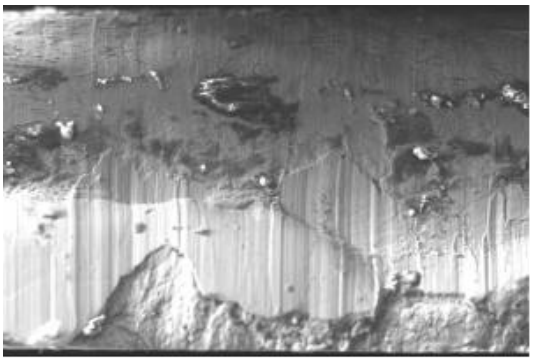

Fig. 16: Sample D cut with a 0,2 mm cutting gap

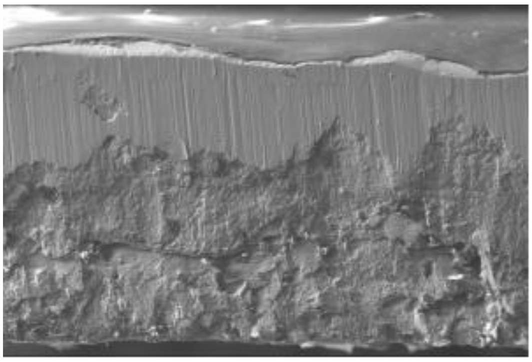

Fig. 17: Sample D cut with a 0,1 mm cutting gap

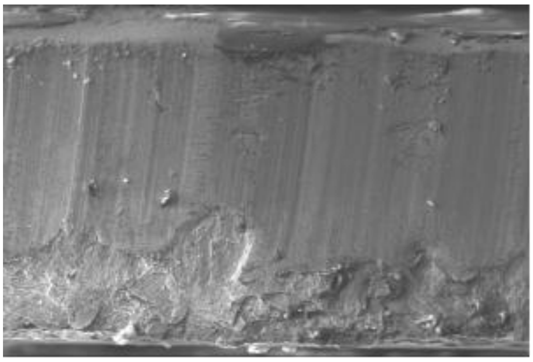

Fig. 18: Sample D cut with a 0,05 mm cutting gap

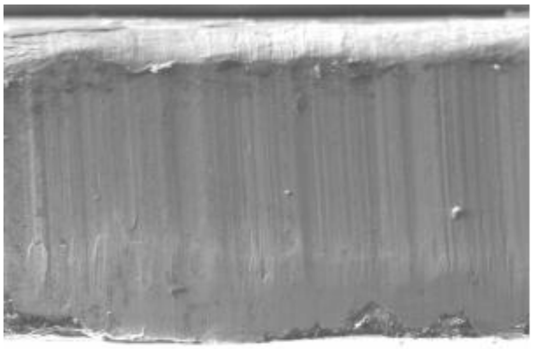

Fig. 19: Sample D cut with a 0,02 mm cutting gap

Due to the proportion of silicon content, sample D is very similar to sample C. It shows the same ductility and the formation of the cutting surface took place in a similar way. Even when using this sample, a larger fillet is visible in the rollover zone of the cutting surface. With the smallest cutting gap - 0.02 mm, similarly to material C, there was at the end of the cutting surface - in the fracture zone, the smallest tearing of the material, as a result of which the cutting surface is almost perfect.

When cutting experimental samples with use a small cutting gap (0.05 mm and 0.02 mm), the impact of cutting edge wear of the punch on the quality (flatness) of the cutting surface is visible on the surface of the cut-outs.

VI. CONCLUSION

In this work, evaluation of influence of cutting gap on the quality of the cutting surface when cutting of electrical steel is described. From the results it is possible to make a clear conclusion that at the smallest selected size of the cutting gap - 0.02 mm, the cutting surface is smooth, perpendicular and no torn grains are evident on it. Therefore, stators and rotors made of metal contact segments that have been cut with such a cutting gap should have minimal electrical losses due to eddy currents and subsequent overheating. These facts are currently the subject of further research.

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