The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 11 || Series I || Pages || PP 29-35 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

The Effect of the Cutting Gap on the Microhardness in the Area of the Strain Hardened Cutting Surface

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ABSTRACT

This work deals with the effect of the cutting gap on the microhardness in the area of the strain hardened cutting surface. The aim of this study is to understand the relationship between the shear cutting process and the strain hardened cutting surface of an electrical steel sheet. Mechanical stress occurring during the manufacturing process of electrical machines detrimentally alters the magnetic properties (iron losses and magnetizability). This affects the efficiency and performance of the machine. The geometry of the shear cut edge as well as the depth and degree of work hardening in the shear affected zone can be adjusted by using specific shear cutting parameters, such as die clearance and cutting-edge radius.

Keywords *– microhardness, elongation, cutting gap, cutting surface, electrical steel, mechanical tensile test*

Date of Submission: 18-11-2020 Date of Acceptance: 03-12-2020

I. INTRODUCTION

Nowadays, 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 cutting surfaces after cutting and assembling rotors and stators also influences the efficient use of stored energy.

The results of the shear cutting process are changes in the surface of the base material. These changes not only affect their geometric properties, but also change the physical, chemical and mechanical properties of the surface (microstructural changes, cracks and microcracks, microhardness, corrosion resistance, etc.). All these changes are part of the concept of surface integrity, which is one of the basic aspects in terms of quality requirements, especially in structural elements for stator and rotor cores in electric motors, where these requirements are very high due to functionality and reliability. [1, 2]

The shear cutting process is one of the most economical separation processes, since it combines high production rates with low costs. The quality of the shear cut edge depends on the material properties, material thickness, die clearance, cutting edge radius, tool wear and shear cutting strategy. [3]

The variation of the influence factors can significantly affect the surface quality of a cut-outs. In addition to the four surface characteristics of rollover zone, clean shear zone, fracture zone and burrs zone, the cutting process causes an area affected by the shear that extends from the edge of the cut to the adjacent material. The shear affected zone represents the volume of material, which is subjected to plastic deformation during the shear cutting process and therefore experiences a strong work-hardening. Because the growth of the fatigue crack in the shear components usually starts from the cutting edge, the shear cutting surface, as well as the affected zone, has a significant effect on the fatigue behavior of the component. [4,5]

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. [6]

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. [7]

II. METHODOLOGY OF EXPERIMENT

The subject of the experiment, which was performed in order to observe the microhardness in the area of the strain hardened cutting surface, depending on the type of material used, as well as changes in the main parameter in the cutting process - cutting gap (tab.1), were sheets made of electrical steel by U.S.Steel Košice.

The experiment consisted of determining the mechanical properties of samples of individual types of materials, using a mechanical tensile test and evaluating the effect of the size of the cutting gap on the microhardness in the area of the strain hardened cutting surface.

Tab. 1: Cutting gaps of the experimental cutting tool

Cutting edge (mm)			
n.1	**n.2**	**n.3**	**n.4**
0,2	0,1	0,05	0,02

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.2). They are test-developed electric steels, 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 have a nominal thickness of 0.5 mm. [8]

Tab. 2: 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

III. MECHANICAL TENSILE TEST

In carrying out the experiment, a mechanical tensile test was performed. This test was performed in order to better analyze the mechanical properties of the material and their effect on the cutting process. To perform the test, two samples (Fig. 1) were prepared from all four types of material, made in a direction parallel to the rolling direction of the sheet.

The mechanical tensile test itself, on the TIRA test 2300 test tearing machine (Fig. 2), connected to the software, was preceded by the measurement of standard values - thickness (a_0) and width (b_0) on individual samples. These dimensions were measured at three locations on the scanned area of the test sample, and then the arithmetic mean was calculated, which was entered as an input value into the measurement program.

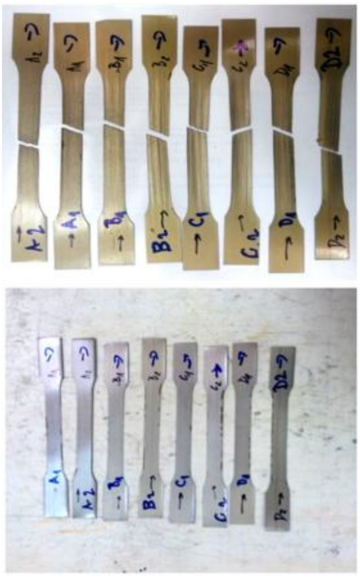

Fig. 1: Samples of electrical sheets for tensile test

Fig.2: Machine TIRA test 2300

The results of the mechanical tensile tests of the individual test specimens is the data recorded in the following table 3.

Tab. 3: Table of values recorded during tensile tests

Samples	**R_{eL}** (MPa)	**R_{eH}** (MPa)	**R_m** (MPa)	**A_{50}** (%)
A1	333	337	467	27,7
A2	331	334	462	27,1
B1	334	338	466	28,2
B2	331	336	462	29,0
C1	330	339	464	29,7
C2	329	339	461	29,2
D1	333	344	466	29,6
D2	333	336	461	29,5

With the help of graphical evaluation (Fig. 3), it is easier to compare the mechanical properties of samples of individual materials. The graphical evaluation of the tensile test is the following tensile diagrams (Fig. 4 - 11) of each tested sample. The diagrams express the magnitude of the elongation as a function of the magnitude of the loading force.

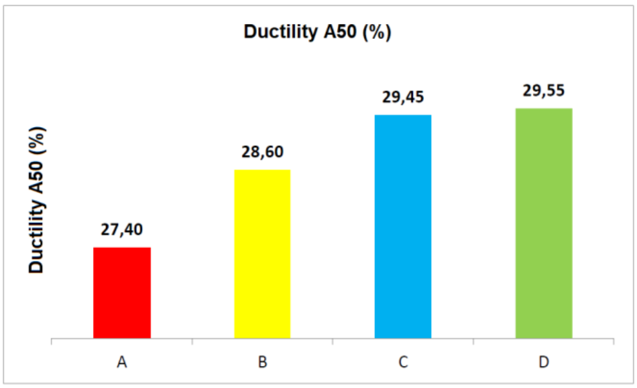

Fig. 3: Average ductility of the examined samples

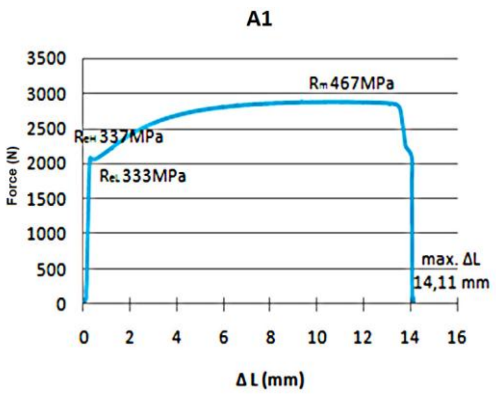

Fig. 4: Graphical dependence of force on elongation, in tensile test of sample A1

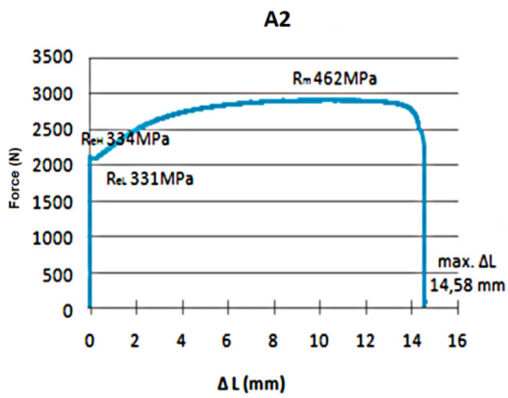

Fig.5: Graphical dependence of force on elongation, in tensile test of sample A2

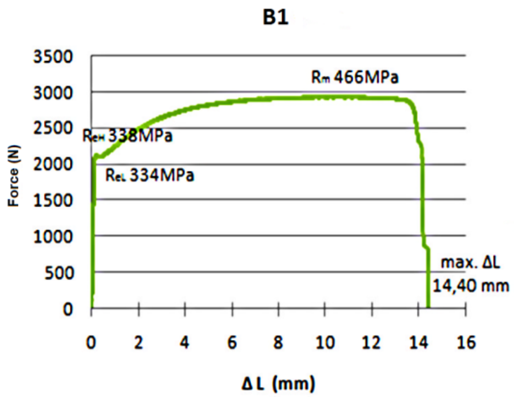

Fig. 6: Graphical dependence of force on elongation, in tensile test of sample B1

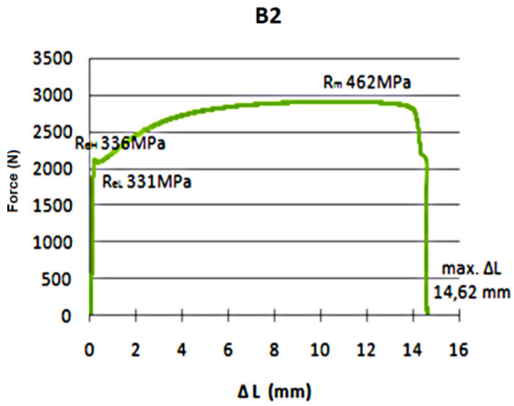

Fig. 7: Graphical dependence of force on elongation, in tensile test of sample B2

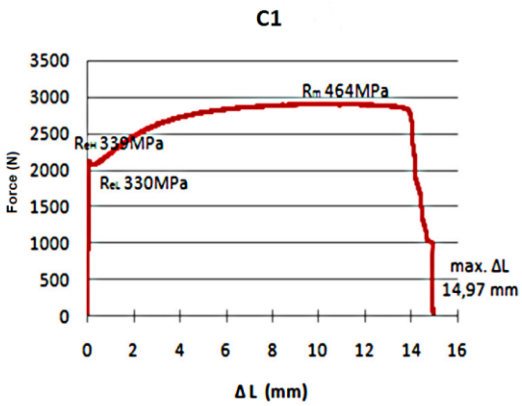

Fig. 8: Graphical dependence of force on elongation, in tensile test of sample C1

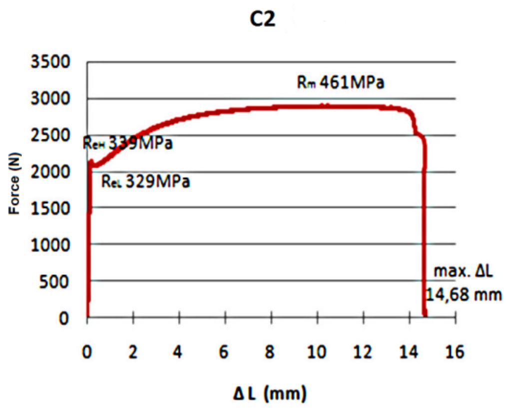

Fig. 9: Graphical dependence of force on elongation, in tensile test of sample C2

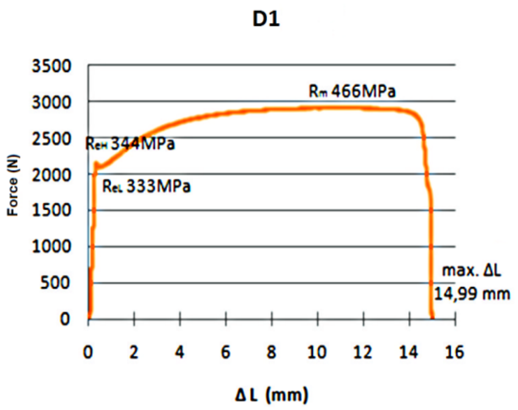

Fig. 10: Graphical dependence of force on elongation, in tensile test of sample D1

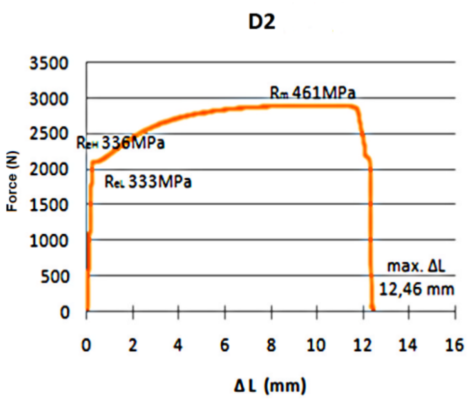

Fig. 11: Graphical dependence of force on elongation, in tensile test of sample D2

IV. METALLOGRAPHIC ANALYSIS

The next part of the experiment was taking and creating samples, in order to observe the microstructure and strengthening of the material in the cutting area. Samples of the material were embedded in dentacryl. Curing was followed by grinding, polishing and subsequent etching of the samples.

Microhardness was observed on selected samples on a stereoscopic microscope G11P (Fig. 12), in order to monitor the process of strengthening the material in the cutting area.

Fig. 12: Stereoscopic microscope G11P

V. EVALUATION OF MICROHARDNESS IN THE STRAIN HARDENED CUTTING SURFACE

In this part, the microhardness is compared, documenting the strengthening of the material and the deformation of the microstructure in the cutting area. Material D (which showed the highest elongation) with the largest - (0.2 mm) and the smallest - (0.02 mm) cutting gap is compared. Overall, a higher - undesirable strengthening of the material occurred at a cutting gap of 0.2 mm. (Fig. 13 - 14) It is uneven, but gradually decreases depending on the distance from the cutting curve. However, when cutting with this cutting gap, there is a very visible - undesired pulling out of the grains of material. The reason is the size of the cutting gap, the ratio of which is 2/5 (40%) compared to the thickness of the cut material.

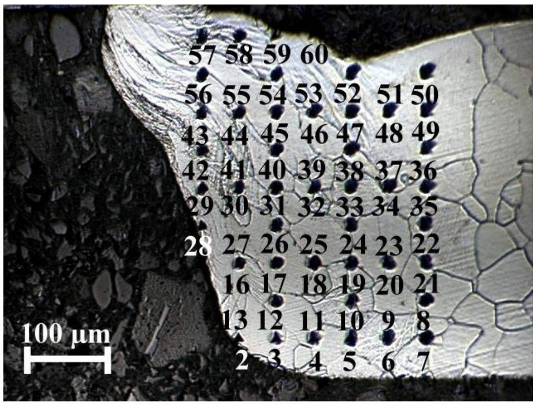

Fig. 13: Microhardness of sample D - cut with the largest cutting gap (0,2 mm)

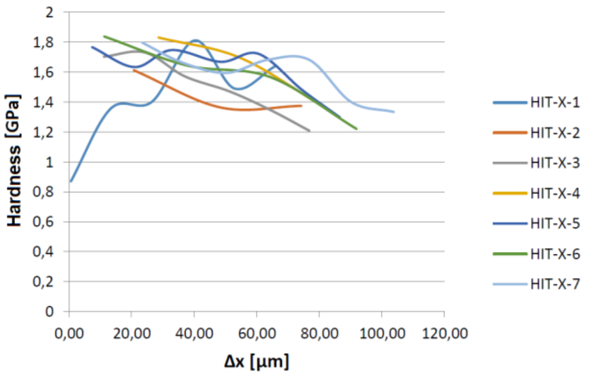

Fig. 14: Microhardness graph (sample D – 0,2 mm cutting gap)

Even when cutting with the smallest cutting gap - 0.02 mm (Fig. 15 - 16), the material was strengthened. It is a bit weaker and its decreasing course depending on the distance from the cutting curve is more even. However, the much better quality of the cutting surface, which is without torn grains, is clearly visible in the cross-sectional image.

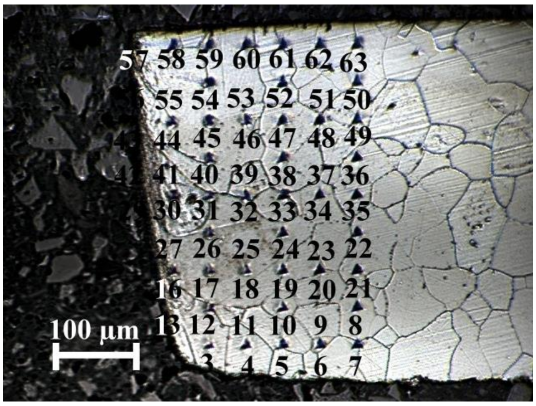

Fig. 15: Microhardness of sample D - cut with the largest cutting gap (0,02 mm)

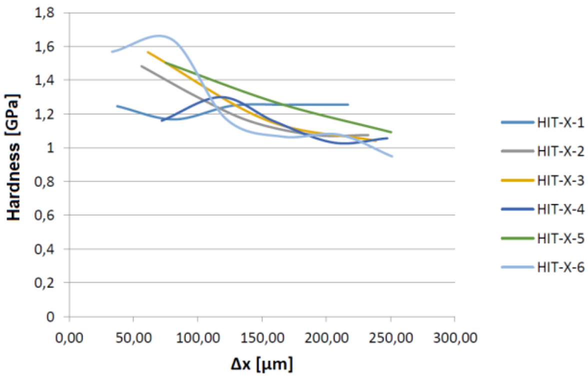

Fig. 16: Microhardness graph (sample D – 0,02 mm cutting gap)

VI. Conclusion

In this work, the effect of the cutting gap on the microhardness in the area of the strain hardened cutting surface is described. Four types of electrical steel were analyzed, using four different sizes of cutting gaps on an experimental cutting tool. After performing tensile tests on all samples, sample D showed the best elongation, and was then selected to compare the microhardness of the cutting process using the smallest (0.02 mm) and largest (0.2 mm) cutting gaps. The overall higher hardening of the material occurred when using a cutting gap of 0.2 mm. However, the hardening of the material is uneven and gradually decreases depending on the distance from the cutting surface. There is a very visible and undesirable pulling of grains from the material. The reason is the ratio between the size of the cutting gap and the thickness of the cut material. However, when the 0.02 mm cutting gap was used, there was less hardening of the material. It has a more even descending course depending on the distance from the cutting curve, which results in a much higher quality of the cutting surface, which is free of torn grains.

Acknowledgements

This paper was written with the financial support of the granting agency APVV within the project solution APVV-17-0381 and of the granting agency VEGA within the project solution VEGA 1/0384/20.

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Vladimír Rohaľ, et. al. "The Effect of the Cutting Gap on the Microhardness in the Area of the Strain Hardened Cutting Surface." *The International Journal of Engineering and Science (IJES)*, 9(11), (2020): pp. 29-35.