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Evaluation of the influence of material properties of electrical sheets on the quality of the shearing edge

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ABSTRACT
The article deals with the evaluation of the influence of the material properties of electrical sheets on the quality of the shearing edge. Electrical sheets are used mainly in the electrical industry due to their magnetic properties. Due to their sensitive magnetic properties, the quality of processing of these materials plays a fundamental role in achieving high performance and low energy losses. One of the decisive technological processes of their processing is shearing, during which a shearing edge with certain geometric and qualitative characteristics is created. The aim of this article is to analyze the influence of the material properties of electrical sheets on the quality of shearing at different punch-die gap sizes. The cutting surfaces cut with a punch-die gap of 1% and 10% of the thickness of the cut material were investigated.

Keywords *– electrical sheets, shearing, punch-die gap, shearing edge*

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I. INTRODUCTION

Electrical steel is an ultra-low carbon alloy of silicon and iron, with a silicon content of 0.5% ~ 6.5%, which belongs to soft magnetic materials. Cold-rolled electrical steel can be divided into non-oriented electrical steel and oriented electrical steel according to the direction of grain arrangement. The main task of electrical sheets is to conduct magnetic flux with minimal losses. Depending on the grain orientation, electrical sheets are mainly used in power transformers (electrical sheets with a directionally oriented structure), where the magnetic flux runs in one direction, and in rotating machines such as motors and generators (electrical sheets where the grains are not directionally arranged).

Several factors have a significant impact on the quality of cutting, including the punch-die gap, i.e. the distance between the cutting edges of the shearing punch and the shearing die in the shear cutting tool. The size of the punch-die gap depends mainly on the thickness of the material being cut and its mechanical properties. The optimal punch-die gap can be considered a gap that is uniform along the entire length of the shear curve and achieves the required quality of the shear surface with minimal force and work. The size of the punch-die gap affects the stress-strain state of the material during shearing, the distribution of the plastic zone, as well as the resulting characteristics of the shear surface, including the angle of separation.

The aim of this paper was to assess the quality of the shearing edge at different punch-die gaps for three types of electrical sheets used to produce rotary machines. Samples from experimental materials were therefore cut at 1% and 10% punch-die gaps.

II. MATERIAL USED IN THE EXPERIMENTS

The paper evaluates 3 types of isotropic electrical steel: material A with a thickness of 0.5mm, material B with a thickness of 0.35mm, material C with a thickness of 0.5mm. The influence of the size of the punch-die gap of 1% and 10% of the thickness of the material on the quality of the sheared edge was investigated. The influence of the mechanical properties of the investigated materials (index R_e/R_m) on the ratio of the plastic shear zone to the thickness of the sheared material (h_v/a_0) at different punch-die gaps was verified.
Tab. 1 shows the chemical composition of the investigated materials.

Tab. 1 Chemical composition of the investigated materials A, B a C [%]

Material	Fe	C	Si	Mn	P	S	Cu	Al	Cr	Mo	Ni	V	Ti	Nb	Co
A	96.25	<0.002	2.637	0.294	0.014	<0.002	0.014	0.676	0.02	0.028	0.017	0.006	<0.002	0.017	0.026

B	96.28	<0.002	2.651	0.266	0.016	<0.002	0.018	0.646	0.024	0.03	0.018	0.006	<0.002	0.015	0.025
C	98.220	<0.002	0.892	0.385	0.095	<0.002	0.018	0.195	0.029	0.024	0.029	0.008	<0.002	0.018	0.038

III. EXPERIMENTAL METHODOLOGY

Uniaxial tensile test

The uniaxial tensile test was performed according to STN EN ISO 6892-1:2020. The test was performed using the electromechanical machine TIRAtest2300. To measure the mechanical properties of the materials under study, five samples were produced and tested from each material in the directions of 0°, 45° and 90° with respect to the rolling direction.

The dimensions of the test samples for the uniaxial tensile test are shown in Fig. 1.

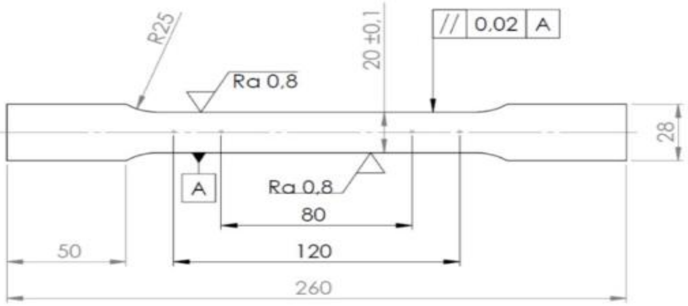

Fig. 1 Dimensions of the tested samples for the uniaxial tensile test

Cutting of experimental samples

The experimental blank (Fig. 2), on which individual measurements are performed, is circular in shape (pad). The inner diameter of the blank is 15 mm, and the outer diameter is 25 mm. The blanks were cut from a strip cut that was cut to the required length of 400 mm ± 0.05 mm.

To assess the quality of the cut surface, the blanks were cut with a 1% and 10% punch-die gap - for all investigated materials. For both punch-die gaps, 5 samples were cut, in the direction of 0°, 45° and 90° with respect to the rolling direction.

The blanks were cut on a progressive shear cutting tool (Fig. 3), which was designed and constructed at our workplace.

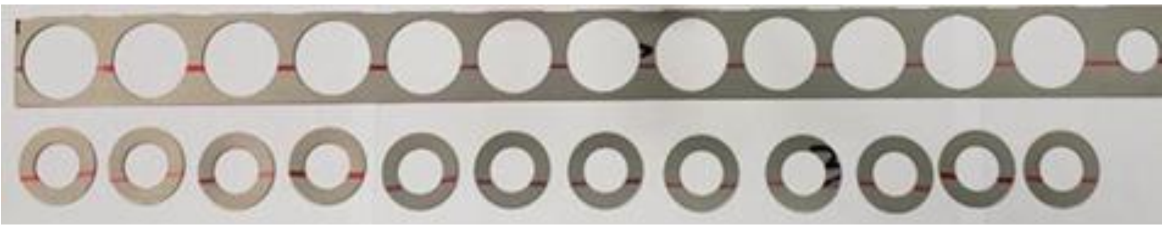

Fig. 2 Experimental blanks

Fig. 3 Progressive shear cutting tool

The average values of the mechanical properties of the tested materials obtained by uniaxial tensile testing are shown in Table 2-4.

Tab. 2 Mechanical properties of the material A, a_0 = 0.5 mm

Direction [°]	R_e [MPa]	R_m [MPa]	A_{80} [%]	r [-]	n [-]
0	366	492	24.1	0.741	0.186
45	373	494	24.4	1.260	0.178
90	385	505	18.3	1.006	0.173

Tab. 3 Mechanical properties of the material B, a_0 = 0.35 mm

Direction [°]	R_e [MPa]	R_m [MPa]	A_{80} [%]	r [-]	n [-]
0	373	486	19.5	0.955	0.182
45	377	489	19.3	1.204	0.177
90	397	508	18.1	1.313	0.170

Tab. 4 Mechanical properties of the material C, a_0 = 0.5 mm

Direction [°]	R_e [MPa]	R_m [MPa]	A_{80} [%]	r [-]	n [-]
0	280	428	35.6	1.112	0.253
45	309	449	33.6	0.906	0.245
90	300	437	34.4	1.493	0.247

Microscopic analysis of the shear edge

Experimental verification of the shear edge by microscopic analysis was performed on a Keyence VHX-5000 digital microscope. All shear edges of the tested samples were examined in the same position with respect to the rolling direction (0°, 45° and 90°) to observe the formed zones on the shear edge. The samples were observed after the shearing process without any microstructural preparation to preserve the resulting edges.

Tab. 5 shows the average values of the measured plastic zone height and tear zone of sample A in the 0°, 45° and 90° directions at different punch-die clearances.

Tab. 5 Values of shear edge areas of sample A in the direction of 0°, 45° and 90° with respect to the rolling direction

Clearance - specimen (%) orientation (°)	Sample thickness (mm)	Plastic zone height (mm)	Tear zone (mm)	Plastic zone height (%)	Tear zone (%)
1 - 0	0.5	0.465	0.035	93.00	7.00
10- 0	0.5	0.224	0.276	44.80	52.20
1 - 45	0.5	0.402	0.098	80.40	19.60
10 - 45	0.5	0.238	0.262	47.60	52.40
1 - 90	0.5	0.392	0.108	78.40	21.60
10 - 90	0.5	0.243	0.257	48.60	51.40

Tab. 6 shows the average values of the measured plastic zone height and tear zone of sample B in the 0°, 45° and 90° directions at different punch-die clearances.

Tab. 6 Values of shear edge areas of sample B in the direction of 0°, 45° and 90° with respect to the rolling direction

Clearance - specimen (%) orientation (°)	Sample thickness (mm)	Plastic zone height (mm)	Tear zone area (mm)	Plastic zone height (%)	Tear zone (%)
1 – 0	0.35	0.315	0.035	90.00	10.00
10- 0	0.35	0.194	0.156	55.43	44.57
1 – 45	0.35	0.295	0.055	84.28	15.72
10 – 45	0.35	0.176	0.174	50.28	49.72
1 – 90	0.35	0.328	0.022	93.71	6.29
10 - 90	0.35	0.205	0.145	58.57	41.43

Tab. 7 shows the average values of the measured plastic zone height and tear zone of sample C in the 0°, 45° and 90° directions at different punch-die clearances.

Tab. 1 Values of shear edge areas of sample C in the direction of 0°, 45° and 90° with respect to the rolling direction

Clearance - specimen (%) orientation (°)	Sample thickness (mm)	Plastic zone height (mm)	Tear zone area (mm)	Plastic zone height (%)	Tear zone (%)
1 - 0	0.5	0.425	0.074	85.00	15.00
10- 0	0.5	0.232	0.268	46.40	53.60
1 – 45	0.5	0.373	0.127	74.60	25.40
10 – 45	0.5	0.200	0.300	40.00	60.00
1 – 90	0.5	0.370	0.130	74.00	26.00
10 – 90	0.5	0.243	0.257	48.60	51.40

Fig. 4 shows a microscopic analysis of a sample produced in a direction of 90° with respect to the rolling direction.

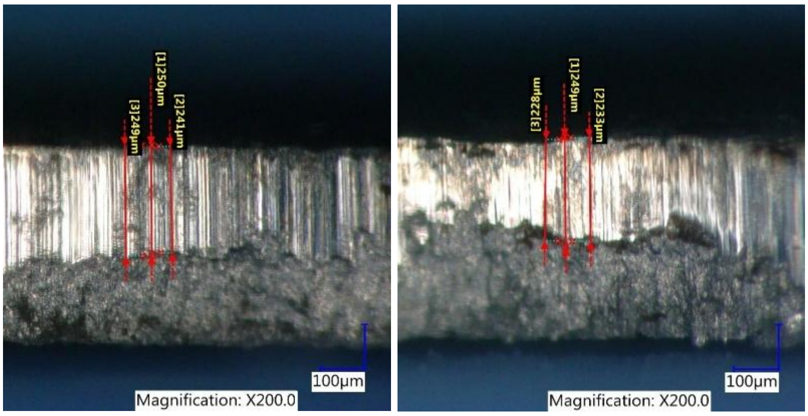

Fig. 4 Microscopic analysis of samples C1 and C10, in the direction of 90° with respect to the rolling direction

According to the results of the plastic phase depth measurement, the area of the plastic phase decreases proportionally with the increasing gap between the punch and the die, which was confirmed in all tested materials. Tab. 8 shows the ratio of the plastic phase depth (average values from five tested samples) to the material thickness.

Tab. 8 Relative plastic zone height h_v/a_0 dependence on sheet material index R_e/R_m

Material	Sheet thickness a_0 (mm)	Re / Rm index	Clearance (%)	Plastic zone height - h_v (mm)	h_v / a_0
A	0.5	0.754	1	0.420	0.84
	0.5		10	0.235	0.47
B	0.35	0.773	1	0.313	0.89
	0.35		10	0.192	0.55
C	0.5	0.676	1	0.389	0.78
	0.5		10	0.225	0.45

Fig. 5 shows the dependence of relative plastic zone height h_v/a_0 on sheet material index R_e/R_m for the tested materials at different punch-die gap sizes.

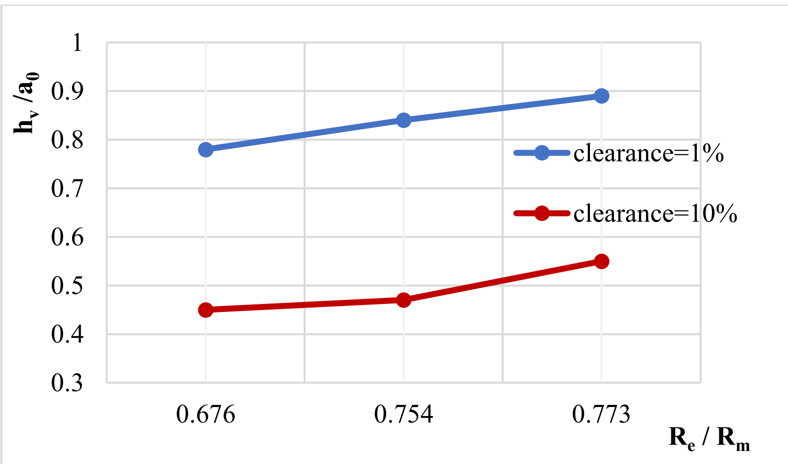

Fig. 5. Relative plastic zone height h_v/a_0 dependence on sheet material index R_e/R_m

IV. RESULTS

The experiments were aimed at evaluating the quality of the shear edge of electrical sheets. When cutting the samples, two different sizes of punch-die gaps of 1% and 10% of the thickness of the cut materials were used. Samples from all investigated materials were cut in three directions (0°, 45° and 90°) with respect to the rolling direction. Experimental verification of the shear edge by microscopic analysis was performed on a Keyence VHX-5000 digital microscope. The plastic zone height and the tear zone were measured.

Tab. 5 shows that for sample material A in all three directions (0°, 45° and 90°) the measured plastic zone height was larger at a 1% punch-die gap (78.40 – 93.00%).

Tab. 6 shows that for the sample from material B in all three directions (0°, 45° and 90°) the measured plastic zone height was larger at a 1% punch-die gap (84.28 – 93.71%).

Tab. 7 shows that for the sample from material C in all three directions (0°, 45° and 90°) the measured plastic zone height was larger at a 1% punch-die gap (74.00 – 85.00%).

Experimental measurements show that in the case of shearing, the relative plastic zone height h_v/a_0 differs significantly from the different material properties characterized by the ratio of the yield strength to the tensile strength (Tab. 8). The value of the h_v/a_0 index increases with the increasing value of the R_e/R_m ratio for both values of the used gap between the punch and die (Fig. 5).

V. CONCLUSION

The results of the experiment indicate that when shearing electrical sheets with a thickness of 0.5 and 0.35 mm, the gap between the punch and die clearly affects the quality of the shearing edge. This was evaluated by the ratio of the plastic zone height to the thickness of the cut material. In all three types of electrical sheets, the h_v/a_0 values were higher at a 10% punch-die gap than at a 1% punch-die gap.

The experiment showed that in the case of the tested electrical sheet thickness, with an increasing value of the ratio of the yield strength to the tensile strength, the value of the ratio of the plastic zone height to the thickness of the cut material increases.

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