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Experimental analysis of dishing deformation in multi-layer blanking of electrical steel sheets

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----------ABSTRACT----------
Multilayered blanking is a novel innovation in the blanking process, allowing for an increase in productivity, particularly in the production of rotor and stator iron core sheets. This innovation increases the productivity of the process, but it leads to a decrease in the quality of the produced sheets when compared with sheets produced by conventional blanking. One of the available potential improvements in quality is the blanking of layers with different strength properties, specifically, the use of the same material but from opposite ends of the strength property range specified by manufacturer. This analysis explores impact of this innovation on dishing deformation of blanks, which greatly affects stacking factor of produced iron cores, by conducting a series of blanking operations on two layers of material, with each layer selected from material with different strength. After blanking, dishing deformation was observed on the produced samples and the results were compared. The setup where the material with higher tensile strength was positioned as top layer had deformation similar to configuration of two same materials. Configuration where material with higher tensile strength was positioned as bottom layer had greater deformation when compared to the previous two configurations. Based on these results, the use of layers with different strength properties does not appear to be an effective approach for reducing dishing deformation in multilayer blanking.

KEYWORDS;-*Multi-layer, Blanking, Punching, Dishing*

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I. INTRODUCTION

Iron cores of the rotors and stators used as the drive units in the electrical vehicles are generally made by vertical stacking of great amounts of individual layers of electrical steel sheets [1]. These steel sheets can be produced by several technologies but based on the comprehensive research of Paltanea et. al., blanking is preferred method because of the required production volumes. This technology is capable of much higher production output, which is critical as it is a bottleneck of the electric motor production [2,3].

Even though the blanking technology provides the highest productivity, there are still limits to the output of a single press. To push these limitations, the double-layer configuration blanking was introduced. In this type of blanking there are two sheets of the material blanked at the single position with one stroke of the press. These steel sheets are placed on each other designated as the top layer and the bottom layer. For each of these layers the deformation induced by the blanking process is different from conventional process, and each of the deformations for the respective layers are different from each other. This is the result of partial replacement of the geometry of the tool in the process by the material itself. For the top layer, the die is replaced by the bottom layer and for the bottom layer, the punch is replaced by the top layer. These replacements are fluidly deforming during the process which means that the cutting forces are distributed differently.

Deformation process of the double layer blanking simulated in Simufact Forming software can be seen in Figure 1 [4].

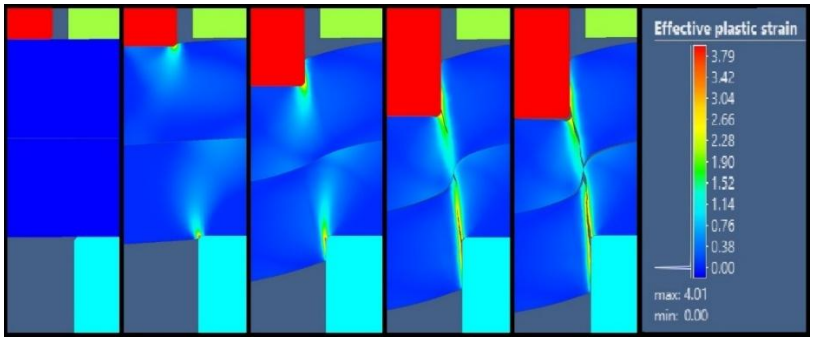


Figure 1. Double layer blanking process (contact with punch/elastic phase/plastic phase/fracture initiation/break) [4]

One of the possible optimizations of this process may be based on using materials with slight difference in the material properties for each respective layer.

II. MULTI-LAYER BLANKING OF LAYERS WITH VARIABLE STRENGTH PROPERTIES

While the double-layer is based on blanking of two layers of steel sheets which are made of the same material, it is not a rule for them to have perfectly equal material properties. Material supplier can't make two batches of material with perfectly aligned properties, instead, the material is produced in certain tolerance ranges with nominal value and main strength properties which are measured after production and these parameters are included in the cover letter that the buyer receives with the material delivery.

Thanks to this there is possibility to choose two different batches of material produced with the strength properties from the opposite limits of the tolerance range and put them into the double-layer configuration.Two possible variations of the configuration can be created:

-Stronger punch- Material from the upper limit of the strength tolerance range is placed in configuration as the top layer. Material from the bottom limit of the tolerance is placed as bottom layer.

-Stronger matrix- Material from the bottom limit of the strength tolerance range is placed in configuration as the top layer while the material from the upper limit of the tolerance is placed as bottom layer.

Position of the material with higher tensile strength layer will influence the results of these experiments in greater value because of its higher material strength and lower ductility. We can predict that variant where the layer with higher tensile strength is placed as bottom layer is expected to potentially have the dishing of the part lower in comparison to other configurations because of the layer with higher tensile strength acting partly as the counterpunch.

III. MATERIALS AND METHODS

Materials and Methods

Two types of thin electrical steel sheets with 0.5 mm thickness were used in the experiment. Most important differences of these materials are their different mechanical properties. Material „H´´ is characterized by its high silicone content, high material strength and low ductility. Material „S´´ is characterized by its lower silicone content, lower material strength but higher ductility.

Chemical composition of these materials is shown in Table 1 and Table 2. Mechanical properties were acquired by uniaxial tensile test on five samples per material on standardized specimens. Important mechanical properties in the rolling direction are shown in Table 3.

Table 1Chemical composition of electrical steel sheet H (weight %)

Fe	C	Si	Mn	P	S	Cu	Al
94.13	< 0.002	2.806	0.267	0.038	< 0.002	0.037	2.422
Cr	Mo	Ni	V	Ti	Nb	Co	
0.027	0.069	0.035	0.019	0.004	0.048	0.099	

Table 2Chemical composition of electrical steel sheet S (weight %)

Fe	C	Si	Mn	P	S	Cu	Al
98.29	< 0.002	0.744	0.329	0.071	0.004	0.036	0.182
Cr	Mo	Ni	V	Ti	Nb	Co	
0.033	0.037	0.034	0.012	< 0.002	0.031	0.086	

Table 3 Mechanical properties of electrical steel sheet S and H

	$R_{p0.2}$ [MPa]	R_m [MPa]	A_g [%]	A_t [%]	A80 [%]
Material H	406 ±5.3	516 ±5.8	13.8 ±1.76	19.2 ±0.9	19.1 ±0.9
Material S	321 ± 2.5	434 ±2.6	23.4 ±3.3	35.6 ±0.5	35.6 ±0.5

Experimental setup and equipment

Experiment was conducted with the progressive experimental blanking tool. Diameters of the punches are Ø25.003 mm and Ø15.039 mm. Diameters of the dies were Ø25.013 mm and Ø15.049 mm. Shear gap of the tool was 0.01 mm and nominal blanked thickness tn was 1 mm because each of the two layers is 0.5 mm. Simplified sketch of this experimental tool with the dimensions can be seen on Figure 2.

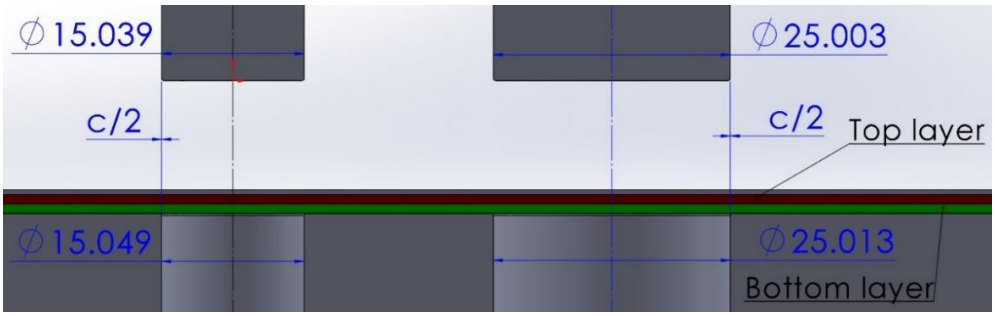


Figure 2 Layout of double-layer configuration (top layer is red and bottom layer is green)

Produced blanks are of the toroid shape as it is possible to use this shape in the Epstein Frame device for research into the influence of deformation on the electro-magnetic properties of the blanks.

Hydraulic press with the nominal force of 200kN was used for this experiment.

Sheets were blanked in two configurations:

-Configuration A- material Hwith higher tensile strength was used as the top layer, while the material S with lower tensile strength was used as the bottom layer.

-Configuration B- Material S with lower tensile strength was used as the top layer while the material H with higher tensile strength was used as the bottom layer.

IV. EXPERIMENT RESULT AND ANALYSIS

To quantify the results of the experiments we followed methodology of previous experiments [5] and the dishing deformation was measured on each of the layers produced by the blanking operation, concretely in our case top and bottom layer. Results were then compared to the previous experiments where blanking was conducted on two layers of the same material.

Four types of blanks were produced by the experiment and each sample was measured at 4 points with the calibrated caliper. From these four measurements per blank average value was calculated. The deformation is equal to difference between the measurement and the nominal thickness value tn of the metal sheet. Downside of this measurement is that its value can be influenced by the burr on the blanks. Measurements of the dishing along with measurements from previous experiment with layers of same material properties are in Table 4.

Table 4 Dishing values of samples

Configuration	Layer	Average measurement (mm)	Dishing increment t_i (mm)	Layer dishing deviation (mm)
S+S	Top = S	1.26 ±0.04	0.76	0.04
	Bottom - S	1.22 ±0.02	0.72	
S+H	Top = S	1.62 ±0.05	1.12	0.29
	Bottom = H	1.33 ±0.04	0.83	
H+S	Top = H	1.24 ±0.04	0.74	0.07
	Bottom = S	1.31 ±0.03	0.81	

Measurements have shown less dishing deformation for the configuration where top layer consists of material with higher tensile strength and bottom layer with lower tensile strength in comparison to the opposite

configuration. Even though this configuration was superior, it still had slightly bigger dishing than the configuration consisting of both layers with weaker strength material properties.

V. CONCLUSION

The analysis of the available data regarding dishing deformation of the blanked samples forms the basis to the following conclussions:

- The dishing deformation produced by the configuration in which the higher tensile strength material was used as the lower layer resulted in the worst quality of the three configuration options. The sample positioned as the top layer exhibited higher dishing deformation and it deviated from the bottom layer by nearly 0.3mm.
- The configuration in which the higher tensile strength material was placed as the top layer exhibited lower dishing deformation, which was close to the deformation produced by the configuration in which both layers had material with the same strength properties. The deviation between the top and bottom layer was only 0.07mm.

Based on these conclusions, we can conclude that the configuration with the higher tensile strength material acting as the top layer and lower tensile strength material acting as the bottom layer provides better quality compared with the configuration in which the top layer consists of the lower tensile strength material and bottom layer consist of the higher tensile strength material.

Further experiments analyzing the sheared edge of these samples need to be conducted to explore potential of this innovation, especially experiments in which the layers consist of the same material but with strength properties from the upper and lower ends of the tolerance range. If these experiments will show improvement, innovation can be used in industrial applications where the material flow from the supplier is monitored and material certificates containing information on strength properties are available for every batch.

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Conflicts of Interest: The authors declare no conflict of interest.

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