INFLUENCE OF LASER CUTTING AND PUNCHING ON MAGNETIC PROPERTIES OF ELECTRICAL STEEL M470-50A

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Abstract

Electrical steel M470-50A belongs to the most often used materials in electrical machines. Due to this fact, it is desirable to know the magnetic parameters after processing raw sheets into the required shape. Basic parameters of mechanical, electrical, and magnetic properties of the sheets are usually obtained from the producer but the magnetic properties are changing in dependence on additional machining processes. The aim of this study is to describe changes in parameters of magnetic behavior after punching, laser and spark cutting of the original sheets. The basic information of structure was obtained by optical and scanning electron microscopy. The magnetic parameters were acquired from the measuring of magnetic hysteresis loops in dependence on saturation fields and frequencies. The results are discussed from the point of view of applied cutting technology with the aim to obtain the best magnetic parameters and consequently a higher efficiency of the final product. Results can be used as input parameters in simulation of the electrical machine.

Keywords: Magnetic properties, M470-50A steel, laser cutting, punching, spark cutting

1. INTRODUCTION

Non-oriented Si steel is an appropriate material for applications in magnetic circuits especially in electrical machines. Worldwide trend aims to save energy and environmental protection requests the reduction of electrical consumption. Electrical machines can be found in a range of electrical equipment for industrial and home applications and therefore it is important to reduce their energy loss levels [1]. Magnetic properties of Si steels which are used in magnetic cores are known to be influenced by manufacturing conditions, e.g., punching or welding [2-6]. Therefore, it is useful to evaluate magnetic properties of electrical steel sheets under various flux condition in direct (DC) and alternating (AC) magnetic fields. Several important parameters can be obtained by these measurements for example magnetic flux density, magnetic field strength, coercivity, permeability and magnetic losses. They can be change with dependence on sheet processing.

The goal of this paper is to describe changes in parameters of magnetic properties due to application of different cutting techniques for preparation toroid shaped sample. The main attention will be given to the deterioration of permeability and total core losses.

2. EXPERIMENTAL

The investigated samples are commercially produced from non-oriented Si steel M470-50A with thickness of 0.5 mm [7]. This steel is composed of iron with 1.7 wt. % silicon. The samples in shape of rings were prepared by mechanical, laser, and spark erosion cutting.

The punching of the rings was carried out using NK 8 from Müller Weingarten for punching stator and rotor steel sheets with rated force 80 kN.

Laser cutting was done by Byspeed 3015 (maximum power 3000W) instrument with following parameters for cutting: actual power 2200 W, auxiliary gas nitrogen, pressure of the gas 12 bar and the speed of the cutting head higher than 13000 m / s. Time for creating annulus laser burning was approximately 3 s. Of course quality of final product can be affected by the quality of raw material. If this material is undulated so the distance between cutting head and material is changing and laser cutting is not so effective. The best results reach this device when the distance is constant and focus is exactly in the middle of thickness of the workpiece. During laser cutting rapid heating and cooling cause thermal stresses, which are considered as harmful on the magnetic properties.

The spark cutting was performed on the rest of material after punching and laser cutting on machine using 0.3 mm brass or brass coated copper wire. The cut samples were cooled in liquid hydrocarbon baths. The samples prepared by this method were used for comparison with those manufactured by punching and laser cutting. The distance from the influenced edges by punching or laser cutting was approximately 12 mm and that guarantees a removing of changed material after these processing.

The basic information of structure was obtained by optical microscopy (OM) and scanning electron microscopy (SEM).

The magnetic parameters were acquired from the measuring of magnetic hysteresis loops in dependence on saturation fields and frequencies. For AC measurements and quasistatic measurements of saturation magnetization and hysteresis losses equipment Remagraph - Remacomp C - 710 (Magnet-Physik Dr.Steingroever GmbH) was used with the ring core samples. This device is measuring the magnetic flux through the coil and it is based on the principle of Faraday law of electromagnetic induction. Outer diameter of first type of samples was 120 mm, inner diameter was 105 mm, height of this sample was 7.5 mm and weight was 158 g. Number of turns of primary winding was 243 and secondary winding had 50 turns. The second type of samples had outer radius 80 mm and inner radius 70 mm, height of this samples was 5 mm and weight was 45.5 g. Number of turns of primary winding was 162 and secondary winding had 40 turns. The properties were measured in frequency range 0 - 2000 Hz at room temperature. For the measurement without frequency was used part Remagraph and Remacomp was used for the other measurements (frequency range, which can this device use is approximately 10 Hz to 10 kHz). Larger samples were created by punching or laser cutting while smaller samples were created by spark cutting. The aspect ratio of these samples was 1.14 and it is close to ideal ratio for toroid sample which should be less than 1.1. The main advantage of this measurement is proximity of influenced edges in tested toroid samples.

Chemical composition was tested using Energy-Dispersive X-ray analysis EDX and by Glow Discharge Optical Emission Spectrometry (GDOES). Contents of iron and silicon were confirmed between these analysis and they are in good agreement with data given by the producer. Besides these main elements impurities - carbon, copper, aluminum, sulphur and nitrogen - were detected from the surface layer where is the isolation coating. EDX analysis was performed for individual points and made analysis on an area of several micrometers. Due to this fact content of elements at each point was different. For example percentage weight of silicon was changing from 1.35 % to 2.22 %. The disadvantage of this method is that it cannot properly detect the weight percentage of light elements like oxygen, phosphorus, sodium or carbon. GDOES detected much more elements because it does not have a problem with detecting light elements, due to the different method of determining chemical content. Identified extra elements in tested samples are however mostly only impurities due to insulation coating with percentage weight under 0.002 %, except aluminum, which has percentage weight 0.022 %.

3. RESULTS

Information on structure from OM and SEM are shown in **Figures 1 - 7**. To highlight the grains the samples were etched by 2% Nital solution. Changes in grain sizes were not observed in any sample. Optical microscopy showed plastic deformation near the cut line after punching process **Figure 1**. Changes can be seen in the bottom part of tested steel and influenced layer is approximately 50 µm. Laser cutting does not caused plastic deformation of grains (**Figure 2**) but due to high temperatures during processing the thermal stress can appear. This can lead to deterioration of magnetic properties near the cutting edge. Spark cutting (**Figure 3**) showed similar process edges as laser but the principle of this cutting process is different and samples are not influenced. But on optical microscopy is possible to see impurities in form of weld deposits (**Figure 4**) caused by cutting wire. The spark cutter with copper wire was used for the samples for optical microscopy and vibrating sample magnetometer (VSM). The toroid samples were manufactured by spark cutting with brass wire.

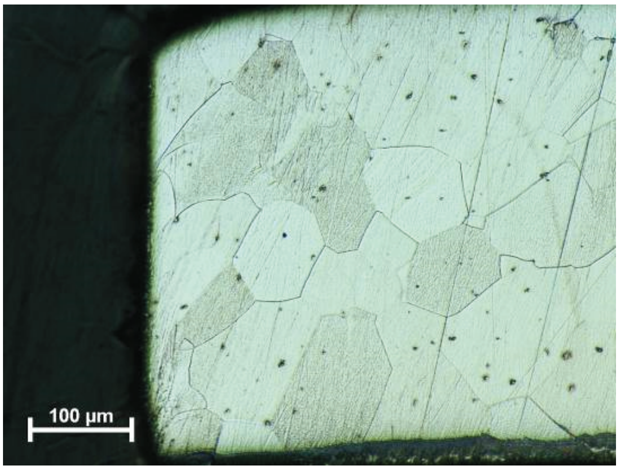

Figure 1 OM sheet, punching, etching

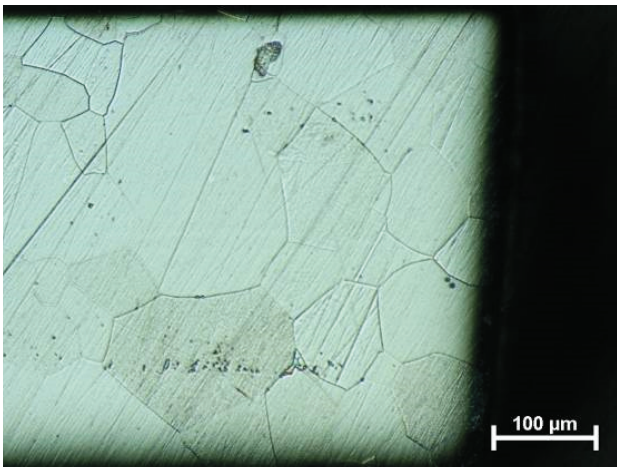

Figure 2 OM sheet, laser cutting, etching

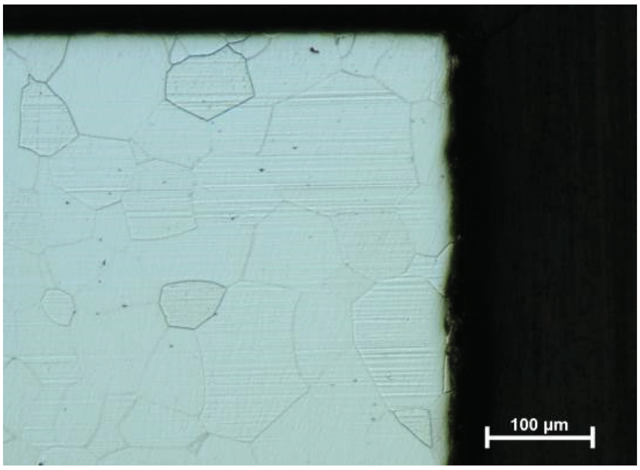

Figure 3 OM sheet, spark cutting 1, etching

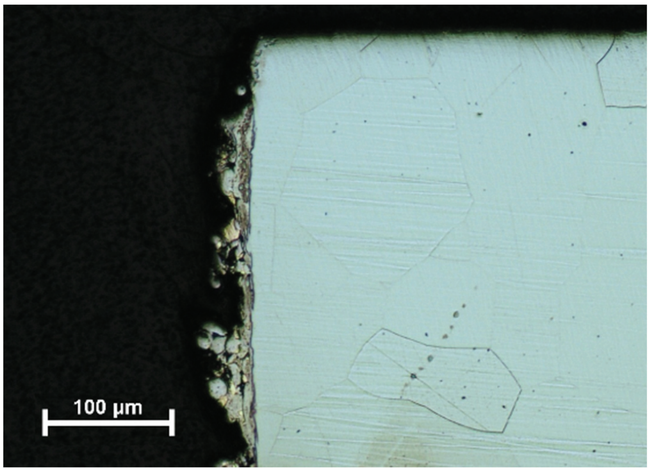

Figure 4 OM sheet, spark cutting 2, etching

The sample after laser cutting was examined by SEM (**Figure 5**). A thin layer of a modified material at upper side of picture can be seen. The same effect can be observed in **Figure 6** and **Figure 7**. The influenced edge after laser cutting was subjected to melting in comparison to punching where material is separated mechanically and it causes a grain deformation.

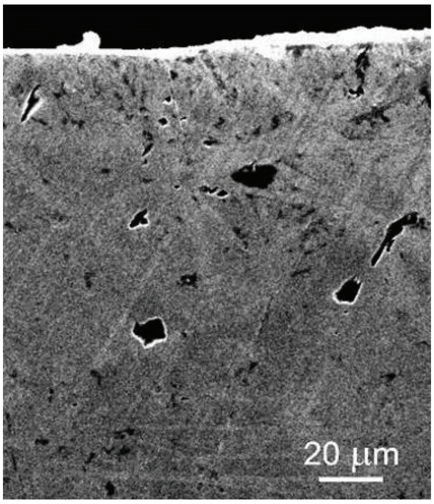

Figure 5 SEM sheet after laser cutting (upper edge influenced)

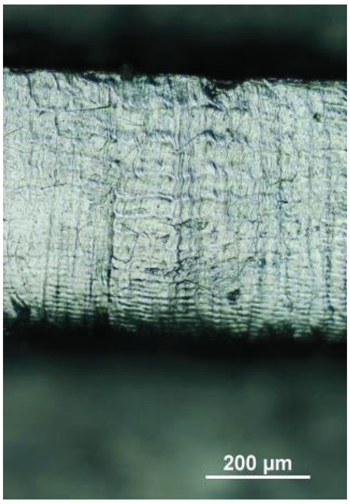

Figure 6 OM detail of edge sheet after laser cutting

Figure 7 OM detail of edge sheet after punching

The investigations of structure show no change in the size of the grains in tested samples after different kinds of processing. Just mechanical punching deformed grains near the cutting edge. Significant changes of parameters used material was observed in magnetic measurements. The most noticeable change can be observed for the measurement of hysteresis curves. The shape BH curves of sample after laser cutting is markedly different compared to other tested samples. The comparison of hysteresis curves for different processing and excitation is in **Figure 8**, **Figure 9** and **Figure 10**. The main difference can be seen in remanence B_r, which decreases with higher influence of processing itself. The worst values B_r was obtain on sample after laser cutting. Laser cut sample has the biggest differences for small value of magnetic flux density. This sample shows that even for small excitation there is a little bit saturation of the material and greater values of magnetic field strength.

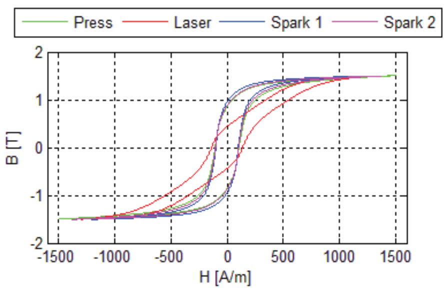

Figure 8 Hysteresis curves for different processing at 1.5 T and 50 Hz

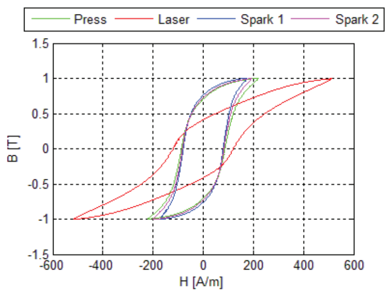

Figure 9 Hysteresis curves for different processing at 1.0 T and 50 Hz

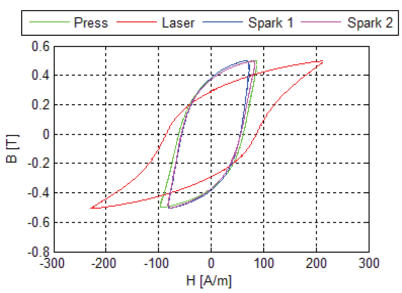

Figure 10 Hysteresis curves for different processing at 0.5 T and 50 Hz

As it is shown in graphs (**Figures 11-13**) permeability of laser cut sample almost does not increase at all. To reaching a certain value of B is necessary to increase magnetizing current from the beginning. Usually at the beginning of every measurement there is an increase of permeability in linear region and after reaching saturation of material it decreases again with higher excitation, but laser cut samples reach saturation early. Maximum value of permeability for commutation curves for example at 15 Hz is two times smaller value for laser cut sample than other samples.

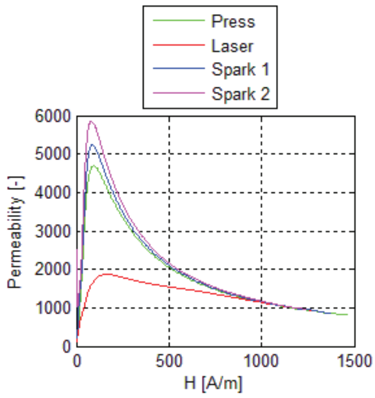

Figure 11 Dependency of permeability on magnetic field strength H measured at RemaGRAPH

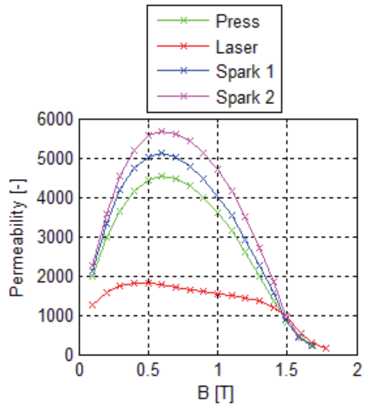

Figure 12 Dependency of permeability on magnetic flux density at 15 Hz

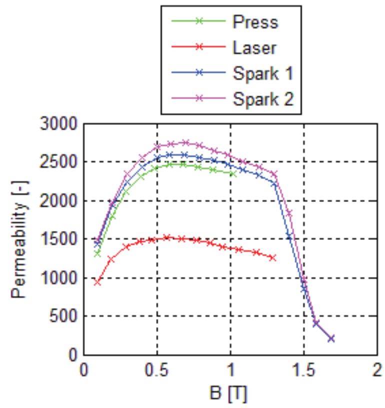

Figure 13 Dependency of permeability on magnetic flux density at 400 Hz

The next comparison of total magnetic losses for all samples shows exponentially increase of these losses. Exception was laser cut sample, where this dependence is more linear than exponential for small magnetic flux density **(Figure 14**). Samples after influenced by laser have higher magnetic losses for smaller magnetic flux density due to deterioration of permeability for small excitation. At higher values of excitation value magnetic losses and permeability become the same among compared samples.

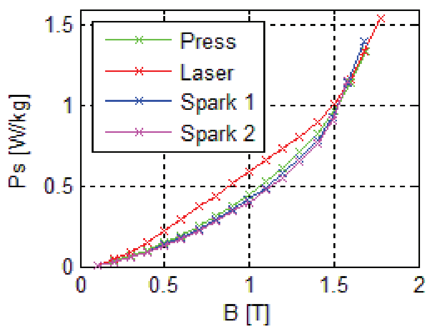

Figure 14 Dependency of total magnetic losses Ps on magnetic flux density B at 15 Hz

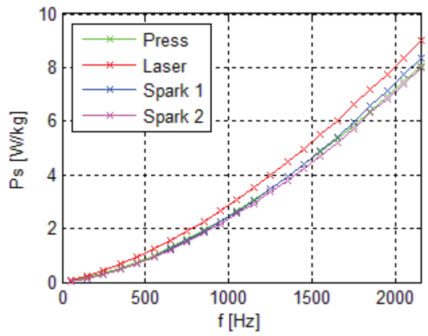

Figure 15 Comparison total magnetic losses Ps on frequencies

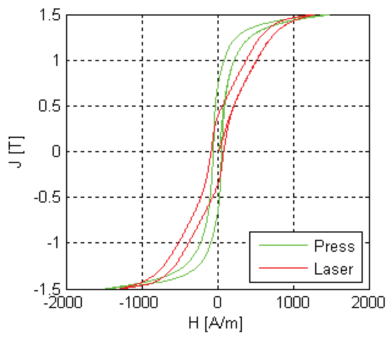

Figure 16 Hysteresis curves measured at RemaGRAPH

Total core losses with increasing frequency (**Figure 15**) are almost the same but the laser sample has a little bit higher losses. Probably at higher magnetic flux density this difference would be greater but the device limits do not enable to measure at higher magnetic field strengths as 10 000 A / m.

Samples were tested on change of magnetic properties by DC measurements too. The same deterioration of magnetic parameters can be seen for toroid sample without frequency on RemaGraph (**Figure 16**). Second DC measurement was performed on VSM but there were not detected any relevant differences between curves of tested samples. The reason is probably in the differences in geometrical dimension of the sample. Tested samples were really small 1 mm x 3 mm and probably these small dimensions caused that influence of processing electrical steel sheets did not show at all.

The significant change of magnetic parameters cause laser cutting instead of punching, which deforms grains near the cut edges. As it has been shown, the problem is the residual stress after rapid and large change in temperature of sample.

4. CONCLUSION

We have measured magnetic parameters of electrical steel sheets M470-50A. Three methods of processing have been used: laser cutting, spark cutting and punching. OM showed that size of the grains of material between these samples did not change at all. Punching of the samples can induce deformation near the processed edge. The AC measurements show that the power losses are increasing exponentially with frequency or magnetic flux density. Shape of the hysteresis curve after laser cutting is deformed and for small excitation reaches higher values of magnetic field strengths than for other methods of sample preparation. Permeability of sample after laser cutting is extremely deteriorated for small magnetic flux density. DC measurements confirmed deteriorated magnetic parameters on same toroid sample. The best magnetic parameters reach sample made by spark cutting. It proved that thickness of influenced layer near the processed edge was smaller than 12 mm. Measurement on VSM did not show any change between sample cuttings by laser and punching.

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