Impact of guillotine cutting on losses in silicon steel

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An experimental study of the impact of cutting processes on the magnetic properties of electrical steel sheets is presented. Cuttings by guillotine and electric discharge machining, with and without heat treatment, are considered. Microstructural observations confirm the presence of a very high level of deformation at the cutting edge. Recrystallization leads to new grains whose reduced size leads to a level of losses higher than the nominal losses.

Keywords: magneto-mechanical coupling; magnetic behaviour; magnetic measurements and instrumentation

1. Introduction

Electrical machines are constituted of laminated steel sheets that are cut into the desired design. This process introduces residual stress and defects in the material which impact magnetic properties [1] and increase losses [2]. To properly model the machine's losses taking manufacturing into account a correction factor is usually applied [3]. Phenomenological approaches are also chosen which apply different magnetic properties to areas of a machine depending on the width of the yokes or teeth [4]. In this study losses are measured on Epstein strips, wire-cut or guillotine cut, raw and annealed. Microstructure observations of the cutting edges help to interpret magnetic measurements results.

2. Results and discussion

Fe-3.2wt%Si sheets are wire-cut by means of electric discharge machining into Epstein strips (300 mm x 30 mm – samples **E**) and wider ones (300 mm x 40 mm) along the rolling (RD) and transverse (TD) directions. The 40 mm wide strips are next guillotine cut on both sides to reach the 30 mm Epstein standard width (samples **G**). A stress relief annealing is conducted on a set of **E** and **G** samples at 760°C for two hours in vacuum. As-received samples tags are followed with "R" for raw and with "A" for annealed ones. **E**R samples (along RD and TD) are the reference samples. Losses are assessed at levels of induction from 0.1 T to 1.5 T. Relative losses are expressed as a relative percentage of the losses in **E**R. Only RD results are plotted in figure 1 for better readability showing the effect of cutting method and annealing. **E**A and **E**R exhibit very similar properties justifying the choice of **E**R as a reference. As expected, losses in guillotine cut samples are most impacted by the process. It is observed on the other hand that annealing does not completely restore the initial properties. Samples cut along TD (not presented) show higher losses than samples cut along RD whatever the process. Relative losses variations are lower for TD than for RD which can be explained by the initial anisotropy. Microstructure of the cutting edges is revealed using electron back-scattered diffraction (EBSD) on a Gemini 560 scanning electron microscope. Figure 2 shows grain orientations at the cutting edge of the guillotine sample before and after annealing. Cutting leads to a very high grain distortion and multiple shear bands. Annealing leads to recrystallisation with small grain size in accordance with high plastic strain levels [5]. Small grain size and remaining residual stress could explain why **G**A samples lead to higher losses than **E**A samples.

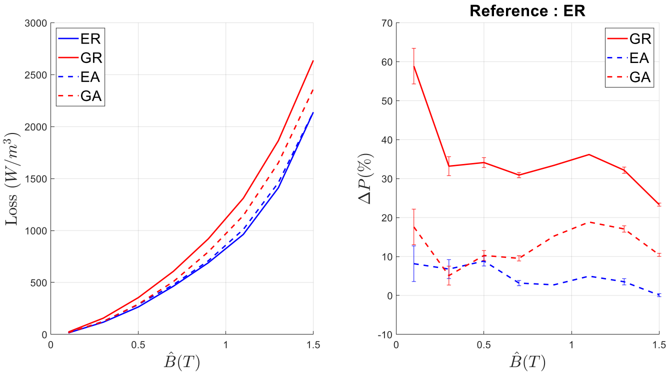

Figure 1: Left: losses of wire-cut samples, guillotine cut and guillotine cut and annealed. Right: relative variation of losses compared to the reference wire-cut sample.

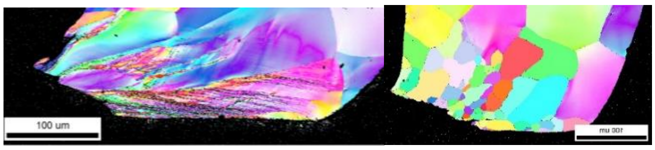

Figure 2: Grain orientations obtained with EBSD. Left: Guillotine cut raw **G**R. Right: Guillotine cut and annealed **G**A.

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