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The influence of cutting technique on the magnetic properties of electrical steels

M. Emura[a], F.J.G. Landgraf[b,*], W. Ross[c], J.R. Barreta[c]

[a] *Globalmag Transdutores Magnéticos Ind. Com. Ltda, Brazil*

[b] *IPT, Technological Research Institute, Av. Prof. Almeida Prado 532, 5508-901 Sao Paulo, Brazil*

[c] *Instituto de Pesquisas Energéticas e Nucleares –IPEN, Brazil*

Abstract

Magnetic permeability and losses at 1.5 T of a 2% Si non-oriented fully processed electrical steel Epstein strip, cut by different techniques (punching, guillotine, laser and photocorrosion), have lower values at the as-cut condition, when compared to after annealing. Permeability at 1.5 T showed to be more affected by cutting than the losses. Photocorrosion is slightly less harmful, but annealing did not improve it as much as it did to samples cut with guillotine.

Keywords: Electrical steels; Punching; Permeability; Magnetic loss

Cutting operations induce stresses in electrical steels and consequently magnetic properties are partially deteriorated. The magnetic losses increase and permeability decreases. The magnetic properties deterioration seems to depend on the amount of cutting per unit volume and on the angle of cutting relative to the rolling direction [1] and also on the silicon content of the steel [2]. When cutting by punching, Schmidt [3] identified a stressed region up to 0.35 mm from the cut edge. Recently, Moses et al. [4] stated that the degraded volume may extend to more than 10 mm from the cut edge.

Motor laminations are produced by punching while frequently single sheet and Epstein strips are prepared by guillotine. Both methods are known to bring about plastic deformation in the area adjacent to the cut edge. Laser has been used to prototype different lamination shapes. Laser cut edges undergo very high temperatures which can cause permanent damage to the magnetic properties [5]. Photocorrosion could be a less deleterious process in which no mechanical deformation should occur.

A 2% Si non-oriented fully processed steel lamination, with resistivity of 38 $\mu\Omega$ cm and 0.485 mm thick was cut in Esptein strips by different techniques: punching, guillotine, laser and photocorrosion. Laser cutting was performed with a Nd:YAG laser at 300 mm/min, with 0.5 J/pulse, 0.2 ms, repetition frequency of 165 Hz, using oxygen as the assistance gas. Strips parallel (RD) and transverse (TD) to the rolling direction were cut. These samples were characterized into four conditions: (i) just after cut (JCUT), (ii) cut and annealed (CUT + A), (iii) annealed and cut (A + CUT) and (iv) annealed, cut and annealed again (A + CUT + A). The annealings were performed under N_2 and H_2 (90/10) at 750°C during 1 h.

Magnetic losses and permeability at 1.5 T/60 Hz were measured under sinusoidal magnetic induction using the Wattmeter procedure of IEC and ASTM standards. The quasi-static loss was determined as the internal area of a hysteresis loop traced with 5 mHz.

The edge profiles of the samples cut by the four methods are shown in Fig. 1. Plastic deformation can be observed for guillotine and punching and the deformed area seems to extend for about 0.3 mm. The deformed grains recrystallize after annealing. The laser technique

*Corresponding author. Tel.: +55-11-37674211; fax: +55-11-37674037.

E-mail address: landgraf@ipt.br (F.J.G. Landgraf).

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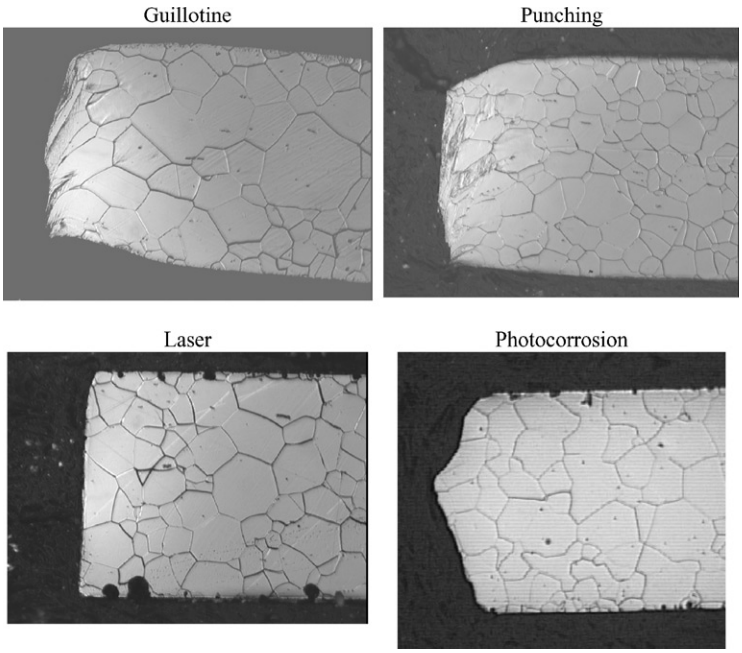

Fig. 1. Edge profiles before annealing.

Table 1
Magnetic properties of the samples cut in Rolling Direction

	Guillotine			Punching			Laser			Photocorrosion		
	P_{tot}	P_h	μ_{15}	P_{tot}	P_h	μ_{15}	P_{tot}	P_h	μ_{15}	P_{tot}	P_h	μ_{15}
JCUT	4.28	2.52	1954	4.08	2.34	2305	4.31	2.54	2138	4.01	2.30	2568
CUTA	4.06	2.35	3552	3.77	2.00	3657	4.27	2.37	2621	4.08	2.19	2716
ACUT	4.62	2.66	2036	4.25	2.35	2478	4.64	2.76	2226	4.25	2.38	2490
ACUTA	4.19	2.35	2501	3.86	2.06	3165	4.16	2.32	2557	4.44	2.53	2388

P_{tot} and P_h in W/kg.

caused no deformation on the grains. The samples cut by photocorrosion had a sharp edge of approximately 0.2 mm and grain deformation is not observed either.

The main conclusions about the influence of the cutting technique are similar to RD and TD samples. Table 1 synthesizes the results for RD samples. Differences in losses are small, less than 10%, but significant for the motor makers. Differences in permeability are much larger, above 20%. Considering the JCUT data, photocorrosion and punching are the least detrimental cutting techniques. Annealing the JCUT samples reduced losses and increased permeabilities, except for photocorrosion, which resulted in higher losses. This might be attributed to higher nitrogen and oxygen penetration through the corrosion opened grain boundaries during annealing. A + CUT data present a similar variation of the magnetic properties among the different cutting techniques to the JCUT samples, with higher losses and lower permeabilities. The A + CUT + A had the magnetic properties improved as compared to A + CUT samples, again except for the photocorrosion technique. Annealing the cut samples recovers the magnetic properties as can be observed in CUT + A and A + CUT + A data. Besides, the recovering is more effective in the CUT + A samples. Losses data of A + CUT + A samples are similar to the CUT + A, but do not reach the high values of permeability of CUT + A samples. It suggests that the each annealing, besides eliminating stresses, may also introduce other defects due to the formation of subsurface oxides and nitrides, leaving the A + CUT + A samples with more subsurface inclusions than the CUT + A.

Fig. 2 shows the quasi-static hysteresis curves for the samples cut by laser in the four different conditions.

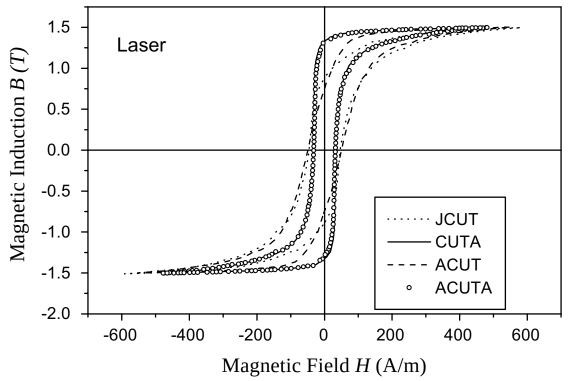

Fig. 2. JCUT, CUT + A, A + CUT, A + CUT + A quasi-static hysteresis curves of samples cut by laser.

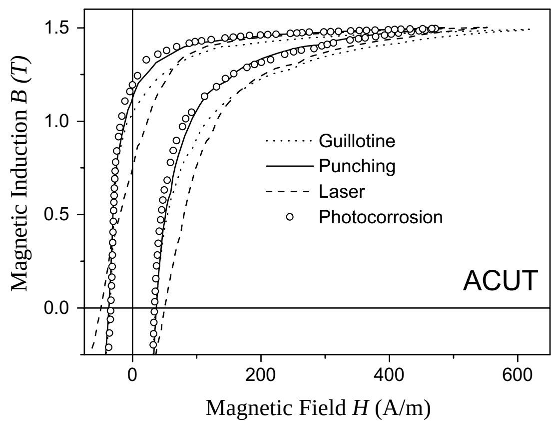

Fig. 3. Quasi-static hysteresis curves of samples cut by different techniques, in the annealed + cut condition.

Cutting has the effect of "shearing" the hysteresis curves, resulting in lower remanence and permeability. A similar shearing of the as-cut sample was mentioned by Dickmann [5]. JCUT curve is more sheared than A + CUT curve in the low-induction region, indicating that other effects, besides cutting, like residual stresses from coiling, might have an influence on the magnetic properties of JCUT samples. CUT + A and ACUT + A curves are very similar with almost the same remanence and coercive force values. Punching, guillotine, and photocorrosion samples showed a similar behavior, although less evident than in laser cut samples.

Fig. 3 compares the quasi-static hysteresis curves of the A + CUT samples cut by the four different techniques. Photocorrosion and punching curves are very similar. Remanence and permeability (Table 1) are higher for photocorrosion cut samples, though. The laser-cut sample presents low remanence and higher coercive force.

Although photocorrosion results in a less aggressive cut in the JCUT samples, allowing for the lowest loss and highest permeability, it seems to produce a harmful consequence, which becomes more severe as annealing is performed.

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