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Grain size and magnetic properties of steel

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Abstract –The paper addresses the need for more accurate determination of the relations between coercive force or hysteresis area and grain size, in the search for more accurate mechanistic models of the interaction between magnetic domains and microstructure. The magnetic properties of eleven samples with different grain sizes were measured. An inverse proportionality describes well both the relation of coercive force and hysteresis loss with grain size, but while the angular coefficient is almost constant with increasing maximum induction, hysteresis area significantly increases. This suggests that the magnetic domain mechanisms that control coercive force and hysteresis area are not the same, contrary to assumptions widely used in this field.

Among the four microstructural factors that affect magnetic properties (grain size, inclusions, dislocation density and crystallographic texture), grain size is the most easily measured. The fact that increasing grain size decreases coercive force and energy dissipation per cycle on hysteresis is known for decades. There has been some discussion about the best fit for that relationship, either a simple inverse relationship ($Hc \propto 1/\ell$) or an inverse square root relationship ($Hc \propto 1/\sqrt{\ell}$) and the most cited model for the relation is Mager's, favouring the first (1). The value of the proportionality factor should be an important check on the validity of the model. Mager used Yensen's results (2) as a confirmation of its relation to the magnetic domain wall energy. As there is some scatter in the values presented by literature, and a poor description of the measurement methods, the subject is here readdressed.

A 0.54mm thick sheet of annealed 0,7%Si 0,3%Al steel, with grain size of 11µm, was used as a starting point to produce ten other samples with grain sizes raging from 23 to 133 µm, either by cold rolling and annealing or by long term annealing, always under the typical heat treatment atmosphere of 90% nitrogen, 8% hydrogen and 2% humidity. Grain size was measured by the intercept method, by the planimetric method and by averaging a grain size distribution, sized by semi-automatic means. Hysteresis plots were determined in quasistatic measurement in an Epstein frame using 8 strips per sample, from several maximum inductions. From the hysteresis plot, its total area (dissipated energy per cycle) and the coercive force were determined. 60Hz total losses were also determined in the same samples.

The results have shown that a simple inverse relationship is slightly favorable, in terms of R^2 evaluation, but the coercive force angular coefficient is 3 times lower than the ones seen by previous researchers, as shown in figure 1. The effect of maximum induction on the angular coefficient is very small on coercive force, but significant in the dissipated energy (by definition, linearly related to the hysteresis loss), as seen in figure 2. When Steinmetz law is fitted to the dissipated energy values, it was found that both the pre-exponential and the exponential constants are dependent on the grain size. There is a need to include texture in this correlation, as there is no way to maintain a constant texture when grain size is varied. These results also indicate that the usually made direct connection between coercive force and hysteresis area must be avoided when mechanistic modeling is attempted. Simple models for domain nucleation at high induction and for domain wall movement at coercive force will be described.

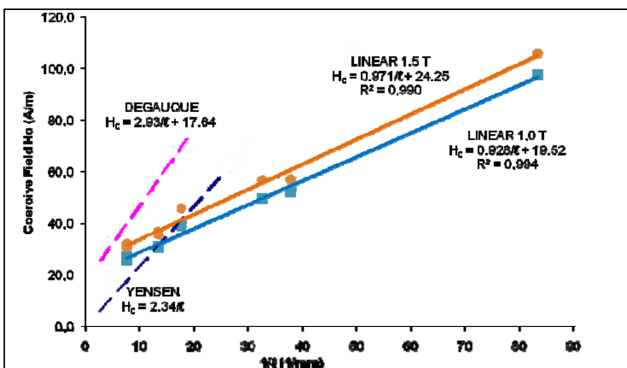

Fig. 1 Effect of grain size on coercive force

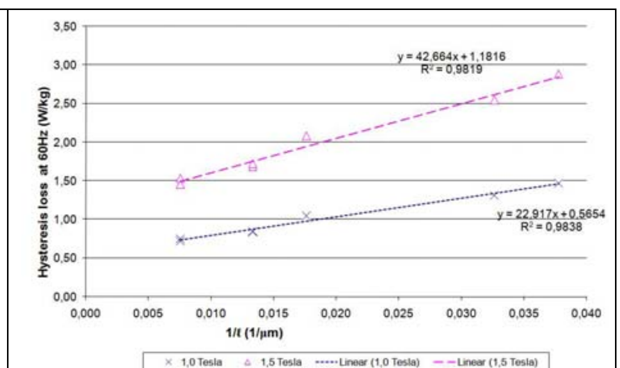

Fig. 2 Effect of grain size on hysteresis loss

References

[1] A. Mager, A . Ann. Phys. Leipzig, (1952) 11-15
[2] TD Yensen Trans. ASM (1939) 797-820.