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DETECTION OF MICROSTRUCTURE ANISOTROPY USING INDUCED MAGNETIC FIELDS

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Abstract. *Conventional manufacturing processes cause plastic deformation that leads to microstructural anisotropy in processed materials. The production of these materials involves many rolling steps and recrystallization thermal treatments, which can cause anisotropy. In the microstructures formed by ferrite and pearlite, the magnetic flux lines tend to pass more easily through the ferrite phase than the pearlite phase due to their differences in magnetic permeability. In the present work, samples of rolled SAE 1045 steel were submitted to different induced magnetic fields to detect the microstructural anisotropy. The magnetic fields were applied to circular samples with different thicknesses and angles varying from 0° to 360° with steps of 45°. The average ferrite grain size was determined in function of the used rotation angles. The results detected a microstructural anisotropy of ferrite phase in the 45° angle.*

Keywords: *microstructure anisotropy, induced magnetic field, permeability.*

1. INTRODUCTION

The magnetic properties of electrical steels such as core loss and magnetic induction depend on the microstructure and texture, which result from thermo-mechanical processes like slab reheating, hot and cold rolling and final recrystallization annealing (CLAPHAM 1999, CHERNENKOV 2007, FRYSKOWSKI 2008, ELMASSALAMI 2011). These processes can also generate magnetic anisotropy due to microstructural changes in the material because the magnetic behavior of steels strongly depends on their stress and strain states. When testing polycrystalline ferromagnetic materials, the magnetic properties are often found to depend on the direction in which the properties were measured, and that there are certain macroscopic orientations, depending on the material that are easier to magnetize (CLAPHAM 1999, ORTIZ 2015).

The angular magnetic Barkhausen noise technique has been applied to characterize the magnetic anisotropy in pipeline steels (CLAPHAM 1999, ORTIZ 2015). Clapham et al. showed the difficulty to find a correlation between the crystallographic texture of an API5L-X70 pipeline steel and the angular dependence of the MBN energy, and their results suggested that the plastic deformation and residual stress are responsible for the magnetic easy axis. Martínez-Ortiz et al. (ORTIZ 2015) proposed a method to determine the magnetic easy axis of Roll Magnetic Anisotropy in API-5L steels. The method took into account the fact that the angular dependence of the energy corresponding to the main peak of the Magnetic Barkhausen signal presents uniaxial anisotropy, independently of the angular dependence of the magnetocrystalline energy in the material.

In this study, measurements of an induced magnetic field generated by direct current obtained in the reversibility region of magnetic domains are used to study the microstructural anisotropy in a rolled steel.

2. EXPERIMENTAL PROCEDURE

As-received rolled and annealed SAE 1045 steel samples were submitted to a magnetic field of 188 A/m. These samples have a diameter of 24 mm and thicknesses of 2, 4, 8 and 12 mm. The measurements were done at the center of the samples according to the following angles: 0, 45, 90, 135, 180, 225, 270, 315 and 360°. The testing surface was perpendicular to the rolling direction, Figure 1. The external magnetic H field is generated by a solenoid and then applied to the disk face; note that the face and H are perpendicular. The Hall sensor is placed on the disk surface, at the center, according Figure 1.

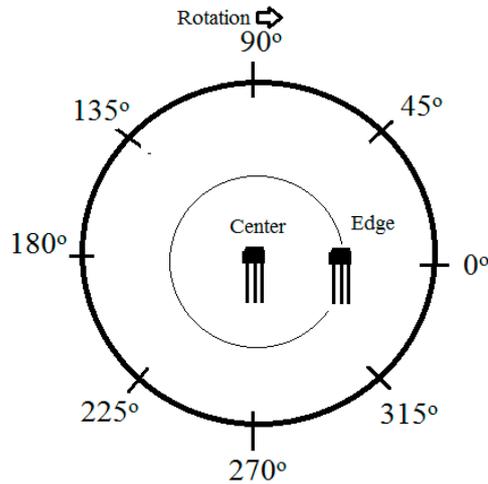


Figure 1. The measures were performed at the center of the samples.

The experimental setup showed in Figure 2 was used to study the samples under analysis based on the application and assessment of induced fields. In this setup, a solenoid is responsible for generating the external magnetic field, and a Hall Effect sensor (from Honeywell, USA, model SS495A) is used to determine the magnetic flux density. External magnetic fields up to 188 A/m were applied to generate the induced fields in the region of reversibility of the magnetic domain, leaving no permanent magnetization in the sample under test. The external magnetic field was produced by direct current. One hundred and fifty signals were acquired from each sample.

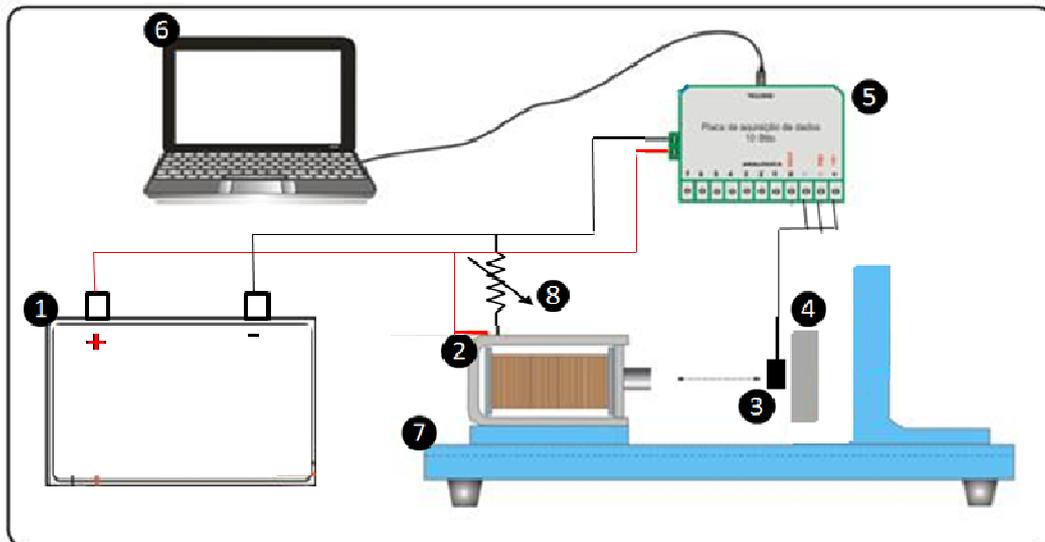


Figure 2. Experimental setup used: (1) Power supply, (2) Solenoid, (3) Hall sensor, (4) Material sample, (5) Data acquisition board, (6) Computer, (7) Bench test and (8) Potentiometer.

The as-received rolled and annealed SAE 1045 steel samples were submitted to metallographic analysis both longitudinally and transversally.

3. RESULTS AND DISCUSSION

This work tried to observe the magnetic anisotropy of the steel here studied. Several studies were developed for this purpose (CHEN 2014, EMURA 2001, GRÖSSINGER 2008, GURRUCHAGA 2010, KUMAR 2005), but some used destructive tests and others nondestructive test but with specimens of higher dimensions as compared with the ones of the present work, as already showed. They have shown that magnetic properties of ferromagnetic materials suffer interference from the microstructure and from the stress conditions which come from the plastic deformation. This is caused by the conventional manufacturing processes, leading to an anisotropic behavior of the variables just mentioned.

Figure 3 shows the microstructure of the studied surface and it shows the ferrite grain, iron α and perlite (cementite + ferrite lamellar) phases. The production of these materials evolves many rolling steps and recrystallization (recovery and grain growth) thermal treatments, which cause anisotropy. In microstructure formed by ferrite and perlite, the magnetic flux line density tends to pass more easily through ferrite phase than to the perlite phase due to the difference of permeability between them. The perlite has a lamellar structure that difficulty the domain movements (Figure 3). Martínez-Ortiz (2015) studied the interaction between magnetic flux line and ferrite and perlite microstructure and showed that higher coercive field of the perlite difficult the direction of the magnetic flux vectors which change near the region corresponding to the pearlite bands and follow the ferrite microstructure. Martínez found a coercive field of 8 A/m to ferrite and 160 A/m to perlite.

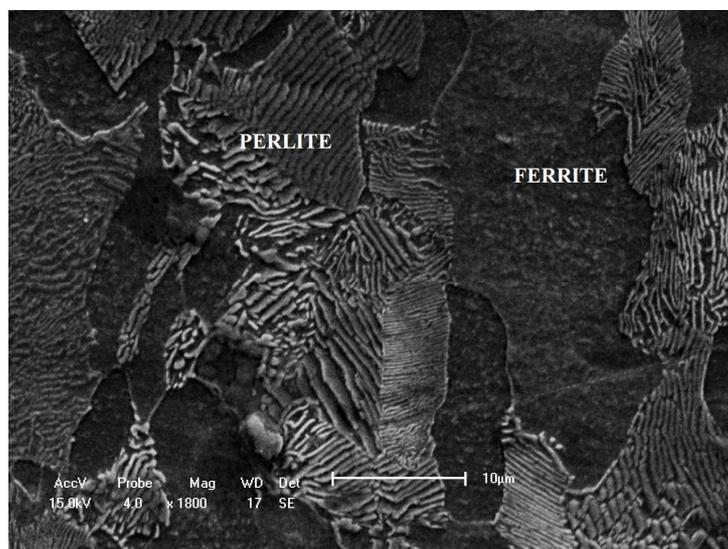
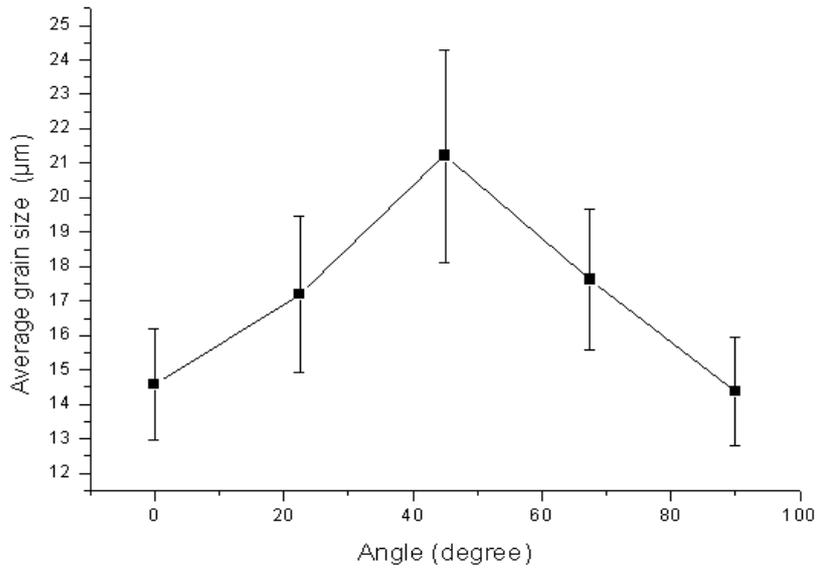
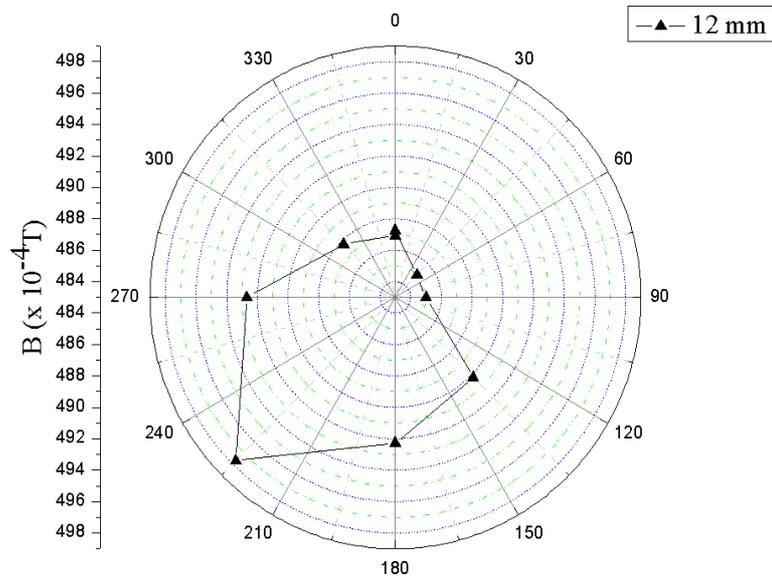


Figure 3. Microstructure of the studied material.

The average grain size of the ferrite was determined from the rotational angles between 0 and 90° in order to analyze the existence of residual deformation, (see figure 4a). Figure 4a shows that the ferrite has the largest average grain size in the 45° direction, which corresponds to the easy magnetization direction. Although the materials undergo a thermal annealing treatment at the final stage of production after rolling, in the studied case, there is still a preferred direction for grain orientation. The variation of induced magnetic field with the rotation angle is related to this plastic deformation, generating enough magnetic anisotropy to be detected. Figure 2b shows the magnetic easy direction at 225°. The present work was performed with a direct current and fixed pole; however, if the pole was changed, the polar graph would show higher values of induced magnetic field around the angle of 45°, since the angles of 45 and 225° are opposites along the direction of easy magnetization.



a) Change in the ferrite dimension according to the rotation angle.



b) Induced magnetic field for 12 mm thick sample, versus the rotation angle

Figure 2: (a) Average ferrite grain size and (b) Induced magnetic field for 12 mm thick sample, versus the rotation angle.

4. CONCLUSIONS

The proposed approach can be successfully applied for experimental evaluation of microstructural anisotropy in steels. This approach was also able to determine the easiest magnetization direction of steel, even in samples with different dimensions and even different geometries

5. ACKNOWLEDGEMENTS

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