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Effect of bending stress on the magnetic properties of electrical steel using needle probe method

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The changes in magnetic hysteresis of electrical steel due to the effect of surface stress-induced magnetic flux leakage around bends is investigated. This paper deals with the bending angle impact on magnetic properties of electrical steels subjected to bending stress. Test samples are five equal strips extracted from a single wrought iron sheet, four of which subjected to bending stresses to create 130°, 150°, 160° and 170° bending angles respectively, and a reference strip at 180°. Hysteresis patterns of the test samples were compared for response to bending angles. Also, a graphical relation between magnetic flux leakage and bending angles at the top and bottom bending tips is deduced from the earlier pattern. Measurements of magnetic properties was carried out using the needle probe method. Bending stress results in significant magnetic flux leakage observed at the bottom bending tip of each sample due to uniform distribution of magnetic flux around tips. This effect was observed to increase with bending stress and angle.

Index Terms— Magneto-mechanical effects, Magnetic sensors, Nondestructive testing, Stress

I. INTRODUCTION

The understanding of the stresses induced in structural and electrical steel sheets by bending loads has long been of research priority for component functional performance and fatigue setback in sheet metal forming processing. This process aims at modifying the component's geometry by applying stresses beyond the material yield strength, causing the material to plastically deform without yielding.

Bending is a metal forming process in which a force is applied to a piece of metal sheet causing it to bend at an angle and forming the desired shape [1]. The major stresses induced during bending processes are normal stresses of tension and compression. The outside portion of the sheet will undergo tension and stretch to a greater length, while the inside portion with respect to the bending radius is subjected to compression and shortens [2].

Stress-induced magnetic behavior of ferromagnetic materials is a prime feature accounting for defects detection in materials and structures, either during manufacturing or while in service [3]-[4]. The piezomagnetic effect of this later has received more attention in the non-destructive testing (NDT) field, giving rise to electromagnetic nondestructive techniques [5]-[7] like the needle probe method.

Conceived by Werner in 1957 [8], the needle probe is a half search coil equivalent magnetic measuring method used to measure the surface flux density in the area in between a pair of needles in electrical contact with a magnetized material [9]. Although, unsatisfactory at its conception due to the technological limitations, its current applications in micromagnetic response of material properties such as microstructure and residual stress produce reliable results [10].

This paper investigates the bending stress effects on non-alloy structural steel strips subjected to different bending stresses yielding different bending angles. The changes in magnetic hysteresis of the sample strip due to the effect of

surface stress-induced magnetic flux leakage around bends were measured using the needle probe method.

II. EXPERIMENTATION

In this experiment, five oblong sample strips of equal dimensions (120 x 30 x 0.4) mm were extracted from a single wrought iron sheet. Four of these strips were set under bending stress via a manually operated V-bending machine to form 130°, 150°, 160° and 170° bending angles at their centres respectively, with the fifth strip acting as the reference strip (unstressed) at 180° (see Fig. 1).

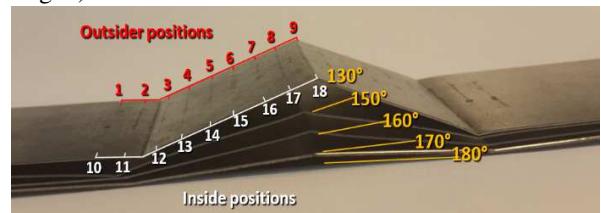


Fig. 1. Sample wrought iron strips subjected to bending stress

To allow for local measurement of flux density and magnetic field, sample lines of 4 mm intervals each were made on each sample strip. These sample lines were labelled from 1 to 9 (for outside surface measurements) and 10 to 18 (for inside surface measurements). Local magnetic measurements were carried out at the aforementioned sample points on the material using needle probe method. The experimental setup as well as the needle probe and hall sensors are shown in Fig. 2. The H-field

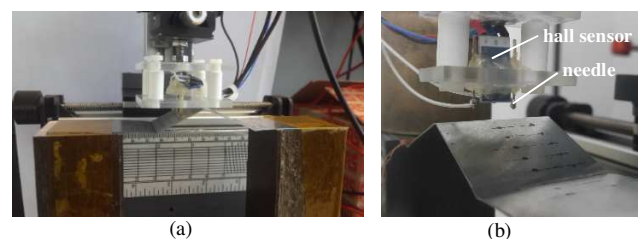


Fig. 2. (a) experimental setup (b) Needle probe and hall sensors setup

and B-field measurements along the incline plane were adjusted based on the sample strip bending angles. This is to maintain a perpendicular alignment between the fields and the sensors.

III. RESULTS AND DISCUSSION

The application of bending stress in the oblong strips of wrought iron steel was studied and micromagnetic responses were measured using the needle probe method. The outside and inside magnetic properties – relative permeability and coercivity, of the stressed sample strip with 130° bending angle is shown in Fig. 3. The permeability pattern shows extremums at positions 7 and 18, respectively referring to regions with maximum tensile stress (outside surface) and compressive stress (inside surface), see Fig. 3a. On the other hand, Fig. 3b shows minimum and maximum coercive fields at the strip outside (position 9) and inside (position 18) vertices respectively, accounting for the presence of leakage field at the inside surface under compressive stress.

This compressive stress causes an increase in magnetic field leakage outside the material in the immediate neighborhood of the inside vertex. This stress-induced leakage field is due mainly to shifts in the direction of the magnetic easy axis of the steel and changes in 180° domainwall population. Meanwhile, the outside surface shows least coercivity indicating increasing magnetic softness in the magnetizing direction since the bending stress develops tensile stress on the outside surface.

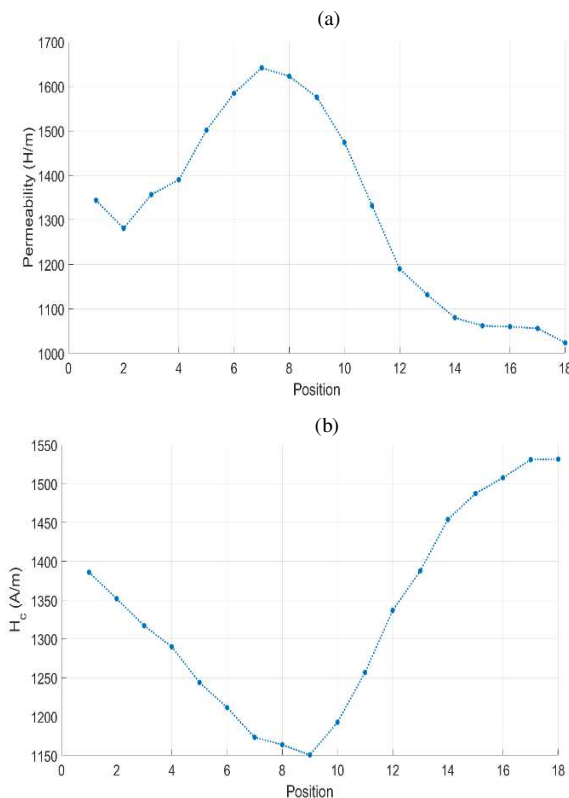


Fig. 3. Relative permeability and coercivity for the 130° bending angle strip.

A comparison of the relative permeability and hysteresis loss of all the sample strips at the outside vertex is shown in Fig. 4. Materials subject to bending stresses experience decrease in inside surface magnetic properties due to increasing leakage

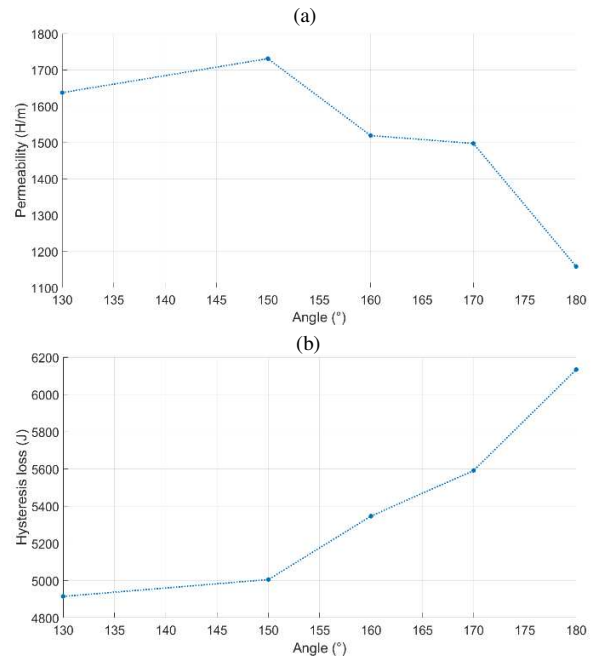


Fig. 4. Comparison of magnetic properties at the outer surface for different bending angles (a) relative permeability, (b) hysteresis loss.

field under compressive stress. This effect acruces with decreasing vertex angle. However, significant increase in permeability with decreasing vertex angle may be achieved at the outside surface of the material. An analysis of the outside surface relation permeability of the test strips shows that the application of bending stress increases the material's permeability by 41.5%. A similar analysis of the hysteresis loss on the same surface shows a drop of 19.9% compared to the reference strip.

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