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Using the Barkhausen Effect to Determine the Internal Stress Distribution of S335 Ferromagnetic Steel

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The paper presents the results of measurements of stresses and strains of joined steel sheets with various microstructures. The MagStress5d device is used for the research. This device allows for effective and quick measurements of strains and stresses using the Barkhausen effect. It is a phenomenon of inducing voltage pulses in a coil in contact with a ferromagnet subjected to variable stress. This is the result of the reorganization of the magnetic structure under the influence of stress. The obtained results constitute the basis for verifying numerical models for stress state and deformation testing of real constructions.

topics: Barkhausen effect, stress distribution, welding, magnetic anisotropy

1. Introduction

The Barkhausen effect, discovered by German physicist Heinrich Barkhausen in 1919, is a magnetic phenomenon that involves a sudden increase in the magnetization of a ferromagnetic material under the influence of an external magnetic field. This phenomenon is the result of the inhomogeneity of the material structure and the presence of defects that affect the movement of magnetic domains. In recent years, the Barkhausen effect has found wide application in non-destructive testing [1, 2], especially in the context of assessing the stress and condition of metallic materials. S355 steel, one of the most commonly used structural steel grades, is characterized by high strength and good weldability, making it an ideal material for applications in construction and mechanical engineering. Proper monitoring of stress in S355 steel is crucial to ensuring the safety and durability of the structure. Traditional stress measurement methods, such as extensometry or ultrasound, have their limitations, so the search for new, more effective techniques is constantly relevant. This paper presents the application of the Barkhausen effect as a non-destructive method for determining stresses in S355 steel [3, 4]. Analysis of the results allows for the assessment of the potential of the Barkhausen effect in practical engineering applications and indicates directions for further research in this field.

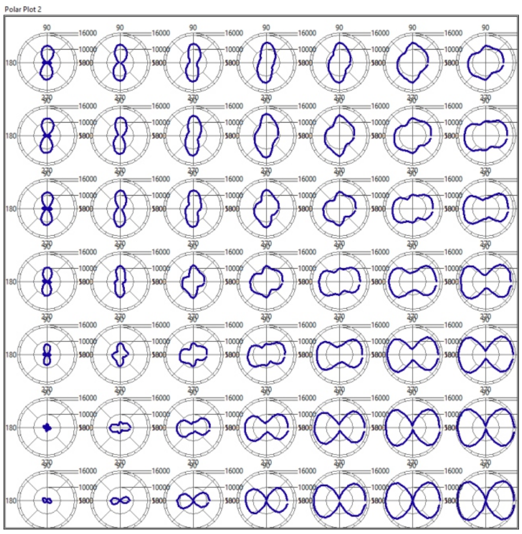

Fig. 1. Angular distributions of the Barhausen effect obtained during calibration at 49 positions.

2. Calibration, results and discussion

During the calibration process, 49 measurement points were assumed. Based on the experimental tests performed, calibration curves and two-dimensional (2D) calibration maps were obtained. The intensity of the effect in the individual

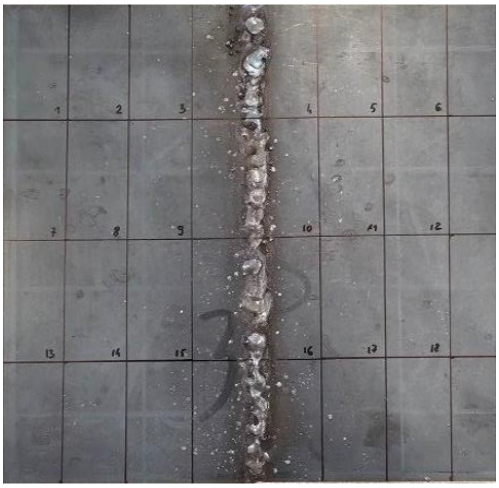

Fig. 2. The measuring sample with the marked points for stress measurements.

Fig. 3. The measuring head while taking measurements at the indicated points.

calibration stages is shown in Fig. 1. The intensity of the Barkhausen effect depends on the various physical properties of the materials tested.

The experiment was carried out on plates made of S355 steel. Two manual metal arc (MMA) welded sheets measuring 200×100 mm^2 had a thickness of 6 mm (Fig. 2).

Then, 18 measurement points were marked on the welded sheets. Characteristic points were placed at intervals of 25 mm along the X axis and 50 mm along the Y axis. Subsequently, measurements were taken at the designated points by applying a measuring head (Fig. 3).

Figures 4–6 show example results obtained at selected points 3, 9, and 15. Strains were measured along the X and Y axes and were then used to determine the values of principal stresses.

In calculating the principal stress components σ_1 and σ_2, Hooke's laws are used, assuming a 2D (in-plane) strain distribution [5, 6]. Young's modulus and Poisson's ratio are taken as values $E = 200$ GPa and $\nu = 0.3$. The relations used are as follows

$$\sigma_1 = \frac{\sigma_x \cos^2(\alpha) - \sigma_y \sin^2(\alpha)}{\cos(2\alpha)} \tag{1}$$

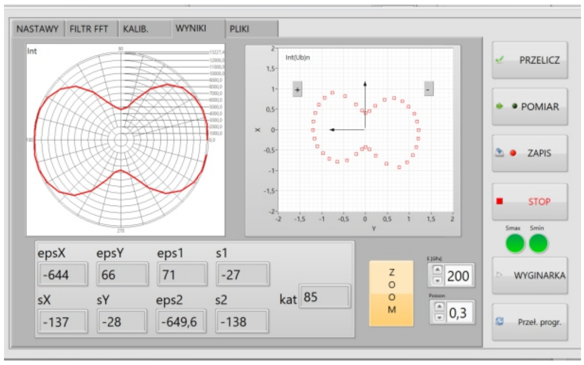

Fig. 4. Microdeformation and principal stress results obtained for point 3.

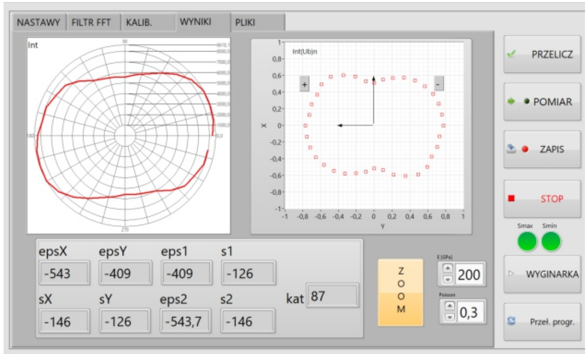

Fig. 5. Microdeformation and principal stress results obtained for point 9.

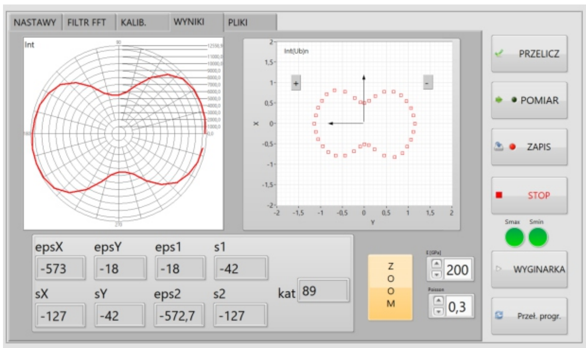

Fig. 6. Microdeformation and principal stress results obtained for point 15.

and

$$\sigma_2 = \frac{\sigma_y \cos^2(\alpha) - \sigma_x \sin^2(\alpha)}{\cos(2\alpha)}, \tag{2}$$

where α is main strain axis orientation, σ_x and σ_y represent stress components, while the symbols x and y refer to the orientation relative to the weld, with x denoting perpendicular orientation and y parallel orientation.

Figure 7 (see also [7, 8]) shows the considered coordinate system and the notation of angle α.

TABLE I

Values of principal stresses at all measurement points.

No. point	σ_1	σ_2	α
	[MPa]		[°]
1	−113	−119	85
2	−127	−158	78
3	−27	−138	85
4	−47	−122	−87
5	−97	−127	−88
6	−98	−140	86
7	−98	−148	86
8	−65	−124	89
9	−126	−146	87
10	−109	−148	86
11	−69	−134	89
12	−65	−131	90
13	−92	−145	87
14	−69	−139	88
15	−42	−127	89
16	−120	−152	88
17	−85	−141	87
18	−65	−133	89

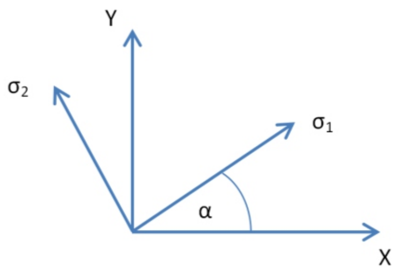

Fig. 7. Sketch of the geometry used to determine the principal strains for the X and Y axes orientation [7, 8].

Table I presents the collective values of the principal stresses σ_1 and σ_2 and the angle α of the stress vector deviation from the X axis for all measurement points.

3. Conclusions

The Barkhausen effect is used to measure stress in S355 steel after welding by analyzing changes in the magnetic properties of the material. The welding process introduces residual stresses that can affect the strength and durability of the structure. By analyzing the Barkhausen signals, it is possible to assess the level of these stresses and identify potential problems. This method is non-invasive and allows for quick and accurate measurements, which is especially useful in industry, where monitoring the condition of materials after welding is crucial to ensure safety and efficiency.

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