α"-martensite detection in 316L austenitic steel from Magnetic Barkhausen Noise measurement

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This work assesses the feasibility of using Magnetic Barkhausen Noise (MBN) as a way to detect α”-martensite in a 316L austenitic steel.

Keywords: Barkhausen noise spectrum analysis, hydrogen storage, magnetic signals

1. Introduction

Hydrogen is a promising alternative energy carrier due to its clean and versatile nature [1]. Storage is essential for integrating hydrogen into the energy landscape. Hydrogen tanks are classified into four types, each catering to specific needs: Type I (metal), Type II (metal with partial composite reinforcement), Type III (metallic liner with full composite wrap), and Type IV (polymer liner with full composite wrap).

A key concern in Type I and II tanks is hydrogen embrittlement, where hydrogen diffusion into metal weakens atomic bonds, leading to microstructural degradation such as cracking and loss of ductility. This phenomenon compromises mechanical integrity, particularly under cyclic loading and high-pressure conditions. 316L austenitic steel is widely used for Type I and II tanks due to its resistance to hydrogen embrittlement and favorable mechanical properties. Its high chromium and nickel content stabilizes the austenitic phase, reducing susceptibility to hydrogen-induced cracking, while its low carbon content enhances weldability and mechanical stability. However, prolonged exposure to hydrogen can still induce embrittlement, often initiated by stress-induced transformation of austenite to α'-martensite. This phase transformation lowers ductility, as martensitic regions act as hydrogen traps, exacerbating local embrittlement.

Traditional detection methods for α”-martensite in 316L include X-ray diffraction (XRD), electron backscatter diffraction (EBSD), transmission electron microscopy (TEM), and optical microscopy with chemical etching. While effective, these techniques are destructive, requiring sample extraction and preparation.

Pure 316L is paramagnetic due to its face-centered cubic (FCC) structure, whereas α”-martensite is ferromagnetic, adopting a body-centered cubic (BCC) or body-centered tetragonal (BCT) structure. This magnetic contrast enables non-destructive detection of α'-martensite through magneto-sensitive methods. Previous techniques, such as magnetic hysteresis loop measurements and magnetic balances [2], have demonstrated sensitivity to phase transformations but are impractical for large-scale applications due to limitations in sensor design and detection sensitivity. To overcome these limitations, this study explores the characterization of the Magnetic Barkhausen Noise (MBN). MBN is a characteristic phenomenon observed in ferromagnetic regions, resulting from the dynamics of magnetic domains during the magnetization process [2, 3, 4].

During magnetization, magnetic domains change their size through the movement of domain walls within the crystal lattice in response to variations in the magnetic field. Each wall displacement induces a sudden, local change in magnetization and magnetic flux. In bulk materials, these micro-flux variations superimpose, becoming strong enough to be detected by magnetic flux sensors. The resulting raw signal is known as MBN. MBN is a direct manifestation of ferromagnetism, it is the ideal candidate for the α'-martensite detection in 316L steel.

2. Experimental setup, results and discussion

A dedicated experimental setup was built to acquire MBN signals. The magnetic inductor consisted of two U-shaped FeSi 3 wt.% yokes. A 1000-turn excitation coil was wound around each yoke. These coils were connected in series and supplied by a power amplifier (HSA 4014, NF Corporation, Japan), driven by a frequency generator (Agilent 33220A, USA) with a f = 0.1 Hz sinusoidal waveform. The MBN signal was detected using a 500-turn surface coil. This coil was wrapped around a Ø = 500 µm diameter ferrite core.

Figure 1 provides an example of MBN measurement in a 316L steel specimen treated with tensile stress.

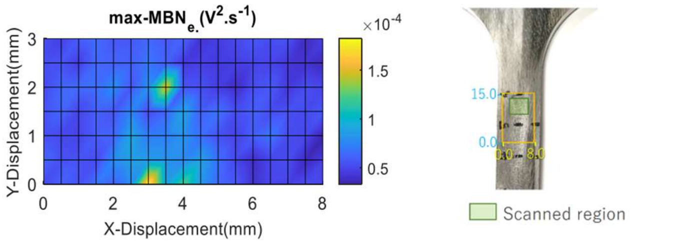

Figure 1: Right side: max(MBN) measurement, Left side: tested specimen.

The extended version of this study will provide large quantities of experimental results and will conclude regarding the feasibility of the MBN characterization as a way to detect the α”-martensite in 316L austenitic steel.

References

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