Spectrum analysis of acoustic Barkhausen noise on neutron irradiated material

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Abstract

In relation to a non-destructive evaluation of irradiation damage of micro-structure of interstitial, void and dislocation, the changes in the hysteresis loop and Barkhausen noise amplitude and the harmonics frequency due to neutron irradiation were measured and evaluated. The Mn-Mo-Ni low alloy steel of reactor pressure vessel was irradiated to a neutron fluence of 2.3×10^{19} n/㎠ (E≥1 MeV) at 288 ℃. The saturation magnetization of neutron irradiated metal did not change. Neutron irradiation caused the coercivity to increase, whereas susceptibility to decrease. The amplitude of Barkhausen noise parameters associated with the domain wall motion were decreased by neutron irradiation. The spectrum of Barkhausen noise was analyzed with an applied frequency of 4 Hz and 8 Hz, and a sampling time of 50 μ sec and 20 μ sec. The harmonic frequency of Joule effect shows 4 Hz, 8 Hz, 12 Hz and 16 Hz reflected from an unirradiated specimen. On the contrary, the harmonic frequency disappeared for the irradiated specimen. Harmonic frequency of induced voltage of sinusoidal magnetic field And Spectrum of Barkhausen noise on material is determined.

1. Introduction

•Irradiation induced degradation of light water reactor pressure vessel known as irradiation embrittlement, is of primary concern to operating nuclear power plants facing the possibility of being shut down before their license expiration date. Mechanical tests, such as Charpy impact and tensile tests, used to establish the level of embrittlement is time consuming and costly. Nondestructive evaluation(NDE) options dependent on intrinsic material properties are being explored to determine if nonintrusive methods can be used to assesses embrittlement in reactor pressure vessel.

Monitoring the irradiation induced degradation of a light water RPV is of primary concern to operating nuclear reactors in relation to the safety and life time prediction. The degradation known as embrittlement has long been evaluated by using approved models and guidelines together with mechanical tests, such as Charpy impact tests and tensile tests through reactor surveillance programs[1,2]. Results from the models and surveillance program, however, do not always provide enough accurate information regarding the exact material conditions about reactors. A further problem regarding the current surveillance program can be realized in limited number for the basis of life extension. Recently, several attempts have been made to utilize the measurements of magnetic parameters as a nondestructive testing method for examining the material state of the reactor under operation [3,4,5,6,7].

These investigations are based on the idea that microstructure changes due to irradiation inherently affect the magnetic domain wall movement and consequently affect the nature and magnitude of the magnetic parameters [8]. Until now, most of these examinations have been performed to explore the interrelationship among the changes in the material and mechanical parameters such as grain size, microstructure, hardness, tensile properties, fracture toughness, etc., and magnetic parameters like Barkhausen noise and hysteresis loop due to irradiation.[9] In the present work, the changes and magnetic parameters related to Barkhausen noise amplitude, Barkhausen noise harmonics frequency and hysteresis loop parameters due to neutron irradiation were measured and analyzed to investigate the interrelationship between these parameters on RPV steel.

2. Experiment

The materials used in the present study were obtained from a surveillance test of an operating reactor. The total accumulated fluence was 2.3×10^{19}

n/㎠(E≥1 MeV). The saturation magnetization, coercivity and susceptibility were measured by a vibrating sample magnetometer. To minimize the demagnetizing field effect, specimens were made in a 3mm diameter disk. The block diagram for the Barkhausen noise parameters is shown in figure 1. A U-shaped ferrite magnet core was used to magnetize the specimen. An electromagnet was placed along the length of the specimen. A magnetic field was applied to the specimen by supplying a sinusoidal current of 4 Hz and 8 Hz to the electromagnet. An encircling sensing coil wound around the specimen was used to measure the magnetic induction in the specimen. The Barkhausen noise signal detected by the pick-up coil was amplified. The data were processed by a computer via a storage digital oscilloscope..

3 Results and Discussion

3.1 Effect of neutron irradiation on magnetic properties

Figure 2 shows the comparison of the hysteresis loop of base and weld metal before and after the irradiation. After neutron irradiation, the specimen's hysteresis loop showed a clockwise rotation relative to that of the unirradiated specimen. This means a reduction of relative susceptibility. The susceptibility of a base metal decreases 50%. It is believed that the decrease of susceptibility is attributed to the interference of domain walls with the defects, such as strain, inclusions, lattice imperfections, or a small amount of impurities. Saturation magnetization is known to be insensitive to structure in the sense that it does not depend on the details of a fine structure[10). Therefore, saturation magnetization did not show any change due to neutron irradiation in a compliance with a constant saturation magnetization of about 208 emu/g. The coercivity of the base metal showed an increase from 8.8 Oe to 11.9 Oe. The coercivity can be explained by using the equation of Gyorgy *et al* [11). According to the equation, the coercivity can be expressed as :

$$H_c = \left(4S(AK)^{\frac{1}{2}} \Big/ (M_s t) \right) \text{-------} (1)$$

where S is a function of the size and density of the precipitates, A is the exchange constant, K is the anisotropy constant, M_s is the saturation magnetization and t is the thickness. When A, K, M_s and t are known to be variables in the equation above, coercivity can to be determined from the size and density of the precipitates. Therefore, the formation of a defect and the second phase due to neutron irradiation brings in an increase of coercivity. The same results were revealed in the work of Narayan[11) in that the size and shape of the second phase grain affect the magnetic field and, in particular, the coercivity in high strength and low alloy iron.

The Barkhausen noise amplitude is in comparison between the irradiation and un-irradiation for base metal with a magnetic field of 45 Oe. The Barkhausen noise signals reflect the statistical nature of both the number of the event and the individual pulse height via the degree of overlapping in the detector coil, in which the individual pulse is signified by irreversible wall motion. Generally, it is known that Barkhausen noise amplitude decreases when the motion of domain wall is impeded by a retarding force. Therefore, the decrease of Barkhausen noise amplitude in neutron irradiated specimens is attributed to the hindrance of the domain wall induced by defect clusters. Figure 3 show a comparison of the Barkhausen noise waveform for both the pre-irradiation and post – irradiation of base metal with a magnetic field of 4Hz.

3.2 Spectrum analysis of Barkhausen noise[12,14)

In order to observe the harmonics frequency of the applied AC current, the spectrum analysis of the BN signal of the specimen is analysed. This method enables to supply the characteristic of the harmonics frequency as well as the fundamental frequency. The spectrum of the input signals is represented as equation (2).

$$\Phi(e^{jw}) = \sum_{-\infty}^{\infty} \phi(n) e^{-jnw} \text{-------------------------------} (2)$$

where $\phi(n)$ is the signal of the time domain. ϕ is represented as the AC signal.

$$V_{in} = A\cos wt \text{ ---------} \quad (3)$$

where $\omega = 2\pi f$. In the experiment, a frequency of 4Hz and 8Hz and a magnetic force of 45 Oe is adopted to meet the impedance-match. In the case of the order of 3 model of harmonics, the output is depicted as below.

$$V_{out} = k_0 + k_2 \frac{A^2}{2} + (k_1 A + \frac{3k_3 A^3}{4})\cos\omega t \text{ ....} + (\frac{k_2 A^2}{2})\cos 2\omega t + (\frac{k_3 A^3}{4})\cos 3\omega t \text{ ------------} (4)$$

Where $k_0 - k_3$ is the harmonic parameter, $A^1 - A^3$ is an amplitude. The output spectrum involves the DC components, fundamental frequency and harmonics frequency. If ω_1, ω_2 the input signals exist, the equation is expressed as the below.

$$\omega_{nm} = | n\omega_1 \pm m\omega_2 | \text{------------------------------}(5)$$

where n and m result in $n + m \leq 3$.

The spectrum of Barkhausen noise is analyzed with an applied frequency of 4 Hz and 8 Hz of a sampling time 50 μ sec, 20 μ sec. Spectrum involved three characteristics signal result in distortion due to irradiation

–Induced voltage of sinusoidal magnetic field

–Harmonic of elastic sound

–Barkhausen noise spectrum

The spectrum of an applied magnetic field, 4 Hz, is plotted with the leakage phenomenon. The leakage phenomenon results from a finite computation different from equations 3-4 [13)]. In the case of 4 Hz, the harmonic frequency of elastic shows at 4 Hz, 8 Hz and 12 Hz, dominantly reflected from a pre-irradiation specimen in figure 4. In the case of 8 Hz, the harmonic frequencies are shown at 8 Hz and 16 Hz dominantly echoed from the pre-irradiation specimens. The harmonic frequency, however, disappeared for the irradiated specimens possibly due to the embrittlement induced by the defect clusters in figure 5, [8,9)]. Harmonic frequency of induced voltage of sinusoidal magnetic field on irradiated material is shown in figures 6,. Spectrum of Barkhausen noise is shown in fig 7.The analysis of the harmonic frequency is a useful tool for monitoring the degradation induced by irradiation.

4. Conclusions

The irradiation effects of neutron irradiated Mn-Mo-Ni low alloy steel were measured and compared using magnetic measurements. The saturation magnetization of neutron irradiated samples did not change. The neutron irradiation caused the coercivity to increase, whereas susceptibility to decrease. Barkhausen noise parameters associated with the domain wall motion were decreased by neutron irradiation. Barkhausen noise energy and susceptibility increased while coercivity have decreased. The harmonic frequency of Joule effect shown at 4 Hz, 8 Hz and 12 Hz was reflected from unirradiated specimens. The harmonic frequencies, however, disappeared on irradiated specimens due to the embrittlement induced by the defect clusters. Harmonic frequency of induced voltage of sinusoidal magnetic field And Spectrum of Barkhausen noise on irradiated material is analyzed. The harmonic frequency can be a useful tool for the monitoring degradation induced by the irradiation. Further, the magnetic measurements may be used as a promising nondestructive evaluation method in monitoring the degradation of reactor material such as SA-508 of PWR-RPV steel

This work was supported by the neutron beam utilization research as a part of a long term nuclear project of MOST

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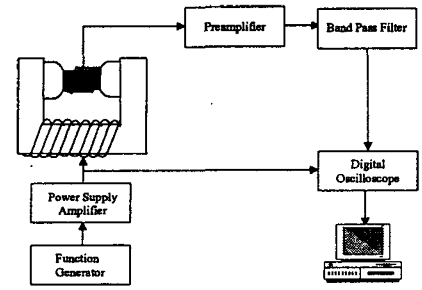

Fig.1 Block diagram of Barkhausen noise measurement equipment

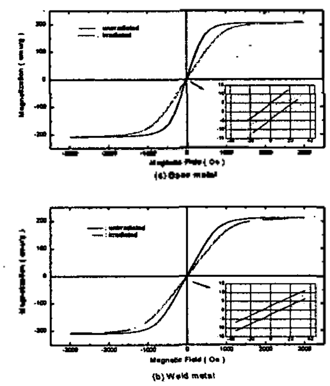

Fig. 2 Comparison of hysteresis loops for base and weld metal with dose of 2.3 X 10^{19} n/cm^2.

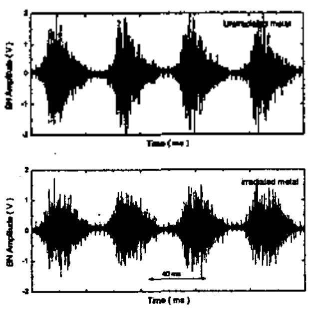

Fig. 3 Magnetic Barkhausen waveforms of base metals at a magnetizing field of amplitude of 45 Oe.

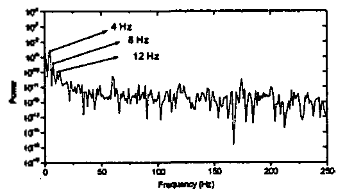

Fig. 4. The harmonics frequency of an applied current 4 Hz on the unirradiated base metal

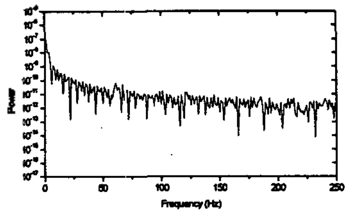

Fig. 5. The non-harmonics frequency of an applied current 4Hz on the irradiated base metal

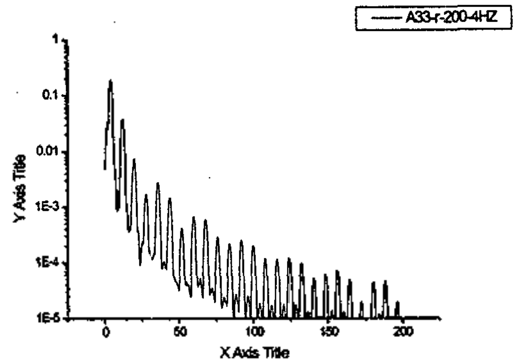

Fig 6. Harmonic frequency of Induced voltage of sinusoidal magnetic field on irradiated material

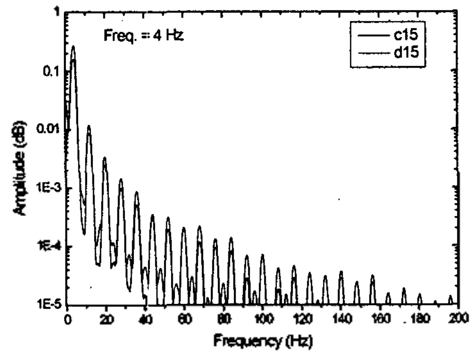

Fig 7. Spectrum frequency of Induced voltage of sinusoidal magnetic field on unirradiated material