Magnetic Properties Studies on Thermal Aged Fe-Cu Alloys for The Simulation of Radiation Damage

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Abstract

We evaluated the changes in magnetic properties due to cold rolling and thermal ageing of a Fe-1%Cu model alloy in this study. Initially, the alloy was 10% cold rolled, and isothermally aged at 400oC for 1, 10, 100and 1000 hr. The samples were prepared at various thermal aging conditions and all the conditions were interpreted. The hysteresis loops, Magnetic Barkhausen noise (BN). The change of magnetic properties can be interpreted in terms of the domain wall motion and dislocation dynamics associated with copper rich precipitates (CRPs).The results were interpreted in terms of ageing time dependence of the precipitates evolution such as the volume fraction and size distribution.

Key words: Domain Wall, Barkhausen Noise, Hysteresis Loop, Thermal Ageing, Copper Rich Precipitates.

1. Introduction

Reactor Pressure Vessel (RPV) embrittlement is serious issue that needs to be evaluated periodically. There are numerous methods in existences in both destructive and nondestructive Techniques. Now days, magnetic techniques such as Hysteresis Loop (HL) and Barkhausen Noise (BN) became handy tools for the evaluation of reactor pressure vessel (RPV) embrittlement nondestructively. These micro magnetic methods have high sensitive characteristics to the microstructure and residual stresses that made it suitable candidate for the evaluation of RPV steel embrittlement due to radiation. Irradiation can enhances the copper rich precipitates (CRPs) which is a prime reason for the RPV embrittlement. Fe-Cu alloys are the most commonly used alloys for the simulation of radiation induced damage of RPV steel, because the neutron irradiation can enhances the copper rich precipitates (CRPs). Hence, an investigation of thermally aged Fe-Cu model alloy is a common and adequate alloy for this study. The investigation is focused mainly on the behavior of copper precipitates with aging time in 10% cold rolled Fe-Cu alloy. The hysteresis loop and BN were measured in cold rolled and thermal aged Fe-Cu alloys in order to know the mechanism of magnetic properties change. In this paper the selected annealing temperature is sufficiently low (500℃) compare with the solubility limit (i.e. 750℃ for Fe-1wt%Cu)[1]. The binary iron-copper system is quite often used as a model alloy to validate the precipitation model [2] due to its spherical nature of precipitation, and to the composition of CRPs, which is reported to be pure copper even in the earliest stages of a formation. The size of the CRPs is known to be a few nanometers. The behavioral magnetic properties and micro hardness under the annealed conditions were interpreted in terms of domain wall motion and the dislocation movement signifies by the CRPs. The configuration of hysteresis loop was not changed by cold rolling and thermal aging but the initial coercivity of strained sample is larger than that of pre strained sample the coercivity of pre strained sample increased by thermal annealing. The coercivity of strained sample is decreased by thermal annealing.

2. Experimental Setup

The alloy was made through a melting with pure Fe and pure Cu. After the samples were solution-treated at 1123K for5 Hrs in a vacuum condition, they were water-quenched. Initially, the alloy is 10% cold rolled, and then isothermally aged at 400°C for 1, 10, 100 and 1000Hr respectively.

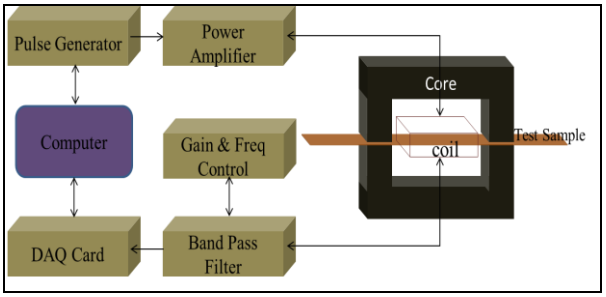

Fig. 1. Block diagram of Barkhausen noise and Hysteresis Loop measurement setup

Fig.1 shows the measurement setup of Barkhausen noise. The major blocks of the system are Pulse generator, Power amplifier, Band pass filter and DAQ with a computer. A rectangular shaped bobbin to hold the sample was first wounded by a thin sensing coil and over the sensing coil a thick exciting coil was wound. The Exciting coil was driven by a sin wave generated from Pulse generator and amplified using power amplifier; a band pass filter can extract the Barkhausen noise from the induced signal using the sensing coil.

And the results were displayed on the computer. To measure the hysteresis loop, band pass filter was replaced by a flux meter, the exciting coil is driven by same pulse generator and the induced signal was read from the sensing coil through flux meter which will directly give the induced flux in the test sample. All magnetic parameters such as coercivity, saturation magnetization, maximum permeability and BH energy were calculated and displayed.

3. Results

An inclusion is a region which has different spontaneous magnetization from the surrounding materials such as second phase, carbides and CRPs. In Fe-Cu alloy, probably two kinds of inclusions can impede the wall motion namely carbides and CRPs. The large sizes of inclusions such as carbides will act as a strong pinning point of domain wall by making a spike domain. But, considering the decrease of coercivity in the annealed sample, the role of carbides can be excluded in this sample. Inclusions are more effective when the inclusion diameter is above or equal to the wall thickness. The coercivity of Fe-Cu alloy tends to decreased with increasing ageing time. Fig.2 shows the changes of the hysteresis loop configurations for 10% strained Fe-Cu alloy with ageing time 1000Hrs at 400^{o}C and as-receive sample. It is clearly visible that the configuration of the hysteresis loop was not changed with increasing ageing time except decrease of coercivity. The saturation magnetization is not sensitive to micro structural change therefore the CRPs cannot affect the saturation magnetization. The change of saturation seems to be related with the electronic structure during thermal annealing at this point where as the decrease in coercivity is due to the impeded CRPs

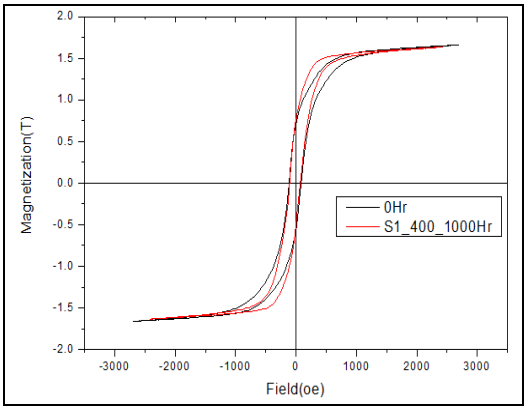

Fig. 2. Comparison of BH Loop configuration of AS Receive and annealed for 1000Hr sample.

Because of thermal annealing, the number of defects decreases, but the sizes of the defects will be increased. The decrease of coercivity with ageing time is attributed to the decrease of number density of CRPs. The BN is released as a result of a change in magnetization associated with the domain wall motion [3]. The induced voltage due to the domain wall displacement decreases with the presence of a retarding barrier [8].The CRPs will acts as a retarding barrier of the domain wall motion in the thermal aged Fe-Cu alloy, which results in a decrease of BN. According to a prior study [2],

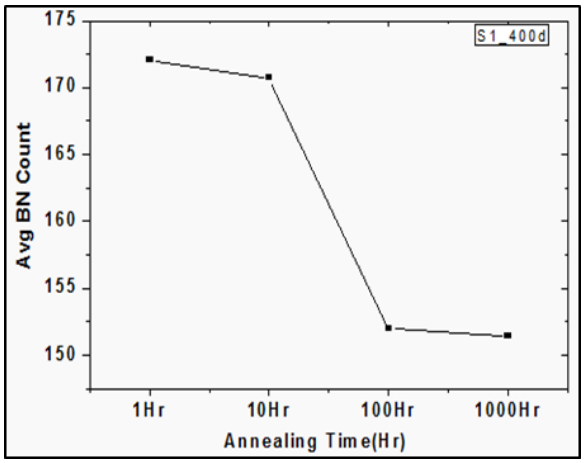

Fig.3. Average BN Count of Fe-Cu samples annealed at 400^{o}C for 1Hr, 10Hr, 100Hr, 1000Hr respectively.

4. Conclusion

In order to evaluate the radiation embrittlement of RPV steel, A Cold rolled Fe-Cu model Alloy was prepared, The prepared samples were thermally aged by annealing at 400^{o}C for various times, the magnetic properties of the annealed samples were measured, The Barkhausen noise and BH Loop shows a considerable trend corresponding to the Ageing time. The magnetic properties were interpreted and correlated to the CRPs formed through annealing process.

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