Degradation Estimation Of Material by Barkhausen Noise Analysis

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(논문접수일 2005. 2. 25, 심사완료일 2005. 4. 8)

바크하우젠 노이즈 해석에 의한 재료의 열화도 평가

이명호*

Abstract

The destructive method is reliable and widely used for the estimation of material degradation but it have time-consuming and a great difficulty in preparing specimens from in-service industrial facilities. Therefore, the estimation of degraded structural materials used at high temperature by nondestructive evaluation such as electric resistance method, replica method, Barkhausen noise method, electro-chemical method and ultrasonic method are strongly desired. In this study, various nondestructive evaluation(NDE) parameters of the Barkhausen noise method, such as MPA(Maximum Peak Amplitude), RMS, IABNS(Internal Area of Barkhausen Noise on Signal) and average amplitude of frequency spectrum are investigated and correlated with thermal damage level of 2.25Cr-1.0Mo steel using wavelet analysis. Those parameters tend to increase while thermal degradation proceeds. It also turns out that the wavelet technique can help to reduce experimental false call in data analysis.

Key Words : Nondestructive evaluation, Barkhausen noise, Degradation evaluation, Aging time, Wavelet analysis

1. INTRODUCTION

A destructive mechanical testing is widely used to assess degradation level of thermally damaged materials. However, the conventional approaches appear to be not only time-consuming but also the technical difficulty in obtaining a specimen from structural integrities in operation. For this reason, there have been a high demand to employ non-destructive techniques for the evaluation of structures and materials of high temperature application like electrical resistance method, the replica test, electrical-chemical test, ultrasonic method and the Barkhausen noise method, etc.

Various Cr-Mo steels have been extensively used in

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the power and petrochemical industries due to their decent mechanical properties at high temperature environment. However, it is also well known that these materials can be weakened due to the micro-structure change induced by either granular or inter-granular carbides while they are being exposed to high temperature environment, say at 300-540 deg[1,2]. Since the material degradation can shorten life time of facilities and give rise to a catastrophic failure, regular in-service inspection(ISI) with a reliable technique can play a significant role to assess a current safety level of the structures and possibly provide a reasonable engineering guideline for maintenance and subsequent life prediction[3,4].

The best way for the in-service inspection of thermally damaged materials is to directly carry out various mechanical tests with the specimens extracted from real structures like impact, creep, tensile and fracture toughness tests. However, it is not realistic to easily obtain the specimens from real structures and furthermore the technique is very time consuming and costly. For example, it is not possible to evaluate entire facility only with the specimens from limited parts.In addition, the technique involves many subsequent procedures for data analysis and shows some inconsistency in the reliability. Consequently, there has been high demand of developing reliable quantitative in-situ techniques which can be applied in a nondestructive way[5~7]. Some of the well known examples are indentation hardness test[13], electric resistance technique[8], the replica test[9], the Barkhausen noise method[9], electric-chemical technique[10], ultrasonic technique[11], etc.

In this study, various NDE parameters of the Barkhausen noise method, such as MPA(Maximum Peak Amplitude), RMS(Root Mean Square), IABNS(Internal Area of Barkhausen Noise on Signal) and average amplitude of frequency spectrum are investigated and correlated with thermal damage level of 2.25Cr-1.0Mo steel using-wavelet analysis. The 2.25Cr-1Mo steels used in this study were prepared through the isothermal treatment at 630?. The micro-structure change of the specimens like the increase of carbide contents with respect to aging time were monitored by transmission electronic microscope (TEM) and scanning electronic microscope(SEM). In addition, the feasibility of wavelet denoising technique is presented to discuss reliability enhancement in data analysis

2. THEORETICAL BACKGROUND

The Barkhanusen noise method is a kind of NDE technique based on the usage of magnetic behavior change of strong ferroelectric materials. In such strong ferromagnetic materials as steel and nickel, internal magnetic domain occurs due to the driving force activated by the change in external magnetic fields and they gradually turn to show magnetic behavior through the movement of magnetic domain wall during the growth of magnetic domain. The movement of magnetic wall can be interfered by such retarding factors as materials granular boundary, carbide contents, nonmagnetic inclusions and defects and the interfering force is called "retarding force" on the growth of magnetic fields. The retarding force forces the magnetic wall to move discontinuously causing pulse-type

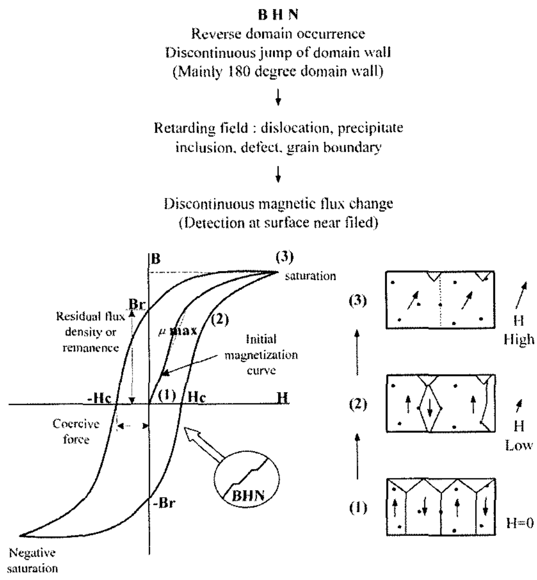


Fig. 1 Occurrence of magnetic Barkhausen noise(BHN) and domain wall motion in ferromagnetic material[8]

magnetic noises responding to a sudden magnetic change The Barkhausen effect is the phenomenon that a magnetic noise takes place due to the discontinuous movement of magnetic wall when a strong ferromagnetic material is magnetized and it was discovered in 1919 by a German physicist named "Barkhausen"[(14)]. The discontinuous magnetizing process can be detected by an induced voltage with a coil and the induced noise is called the Barkhausen noise(BHN)[(14)]. Fig. 1 represents the curve between applied magnetic field and BHN. It is well known that the BHN is very sensitive to microstructure change and stress level of metallic materials.

3. EXPERIMENT

3.1 Specimens

The material for experiment is the 2.25Cr-1.0Mo steel which is widely used for various turbine rotors and is prepared through the process of 1hr normalizing at 900? followed by 1hr tempering at 720 deg. The chemical and mechanical properties are presented in Tables 1 and 2, respectively. In this study, the high speed thermal treatment process consisting of the 15 sub-steps at between 630-538?was conducted to obtain specimens simulating the materials of real structures which experience corresponding thermal degradation at the same level over a longer time period in fields. Table 3 is a sample thermal aging time at different degradation level calculated based on the self-diffusion equation of steel[(15)].

Table 2 Mechanical properties of test materials

Mechanical Properties	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Hardness (Hv)
Value	480.2	630.14	24	203.8

Table 1 Chemical composition of 2.25Cr-1Mo steel

Element	C	Si	Mn	S
wt.%	0.138	0.142	0.46	0.004
Element	P	Cr	Mo	Fe
wt.%	0.014	2.27	0.97	Bal.

Table 3 Accelerated aging time at 630℃ for equivalent microstructure served at 538℃

Time served at 538℃(hr)	as-received	25,000	40,000	65,000	145,000	200,000	260,000
Aging time at 630℃(hr)	0	460	730	1,200	2,700	3,700	4,800

3.2 Observation of Micro-Structure Change and Quantification of Carbides

The micro structure changes of 2.25Cr-1.0Mo steel were observed at each different aging time by TEM and SEM to investigate the change in carbide content and shape depending on the level of thermal degradation 2.25 Cr-1Mo. For this procedure, specimen surface was maintained at the level of 1μm roughness by the emery papers of #200, #500 and #2000. The TEM and SEM observations were carried out in conventional standard procedures. The specimens for TEM were prepared with the mixed electrolytic liquid of 100ml asetic acid 100ml and 900ml methanol at -20 deg. under the conditions of 3 Volts electric input and the flow rate of 3.

3.3 Monitoring of Mechanical Properties

The specimens for hardness tests were prepared from the fracture toughness ones by polishing surface in the order of 0.5μm to remove the effect of surface roughness to experimenal hardness values. The distance between each indentation points was maintained more than 5 times to their diameter and the indentation test was repeated 10 times for the specimens at each different aging time. The indentation time and load are 15 seconds and 1kg, respectively. The test was conducted with the micro Vickers hardness tester, HMV-2000 by Shimizu Co.

3.4 Monitoring of the Barkhausen Noise Parameters

Fig. 2 is a schematic diagram of BHN experiment. First, specimens are magnetized by the coil to which magnified alternative current is applied through a funtion generator and an amplifier. During the process of mag-

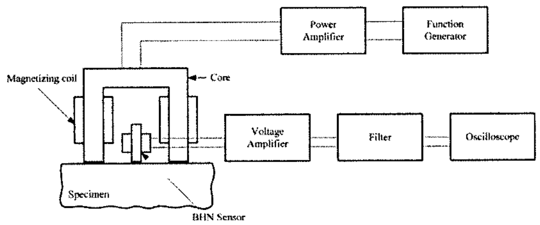


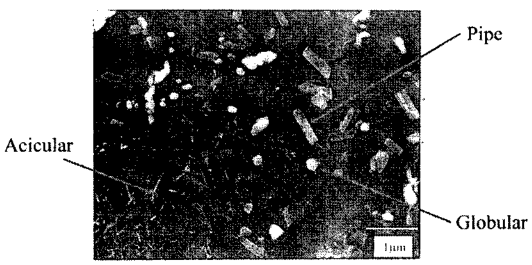
Fig. 2 A schematic diagram of experiment for BHN measurement system

netization, change of magnetic field in the specimens is monitored as the induced corresponding electric voltage by the coil equipped inside BHN sensor.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Changes of Micro-Structure and Carbide Contents

Fig. 3 is the FESEM(Field Emission Scanning Electron Microscopy) image of an as-received Cr-Mo steel specimen for zero aging time representing various initial carbides morphology. They appear to be the three unique morphologies such as globular, pipe and acicular ones. The carbide observed around grain boundary contains mainly elliptical ones and carbides of the different morphology independently exists not gathering with other carbides. With increase in aging time, the acicular carbide rapidly disappears and only the pipe and globular ones remain after 1000 hrs. In general, carbides contents tend to reduce with respect to aging time.



x 20,000

Fig. 3 Morphology of carbides in Cr-Mo steel(FESEM)

4.2 Mechanical Property Changes

Fig. 4 is the hardness change to aging time increase. It is shown that hardness descends significantly up to 1000 hrs and varys mildly beyond the point. This is because the morphology of pipe and globular carbides gradually become cluster shapes with aging time change and consequently the portion of thermally damaged region increases resulting in weakening materials mechanical characteristics.

Fig. 5 shows the variation in the number of carbides for different morphology with respect to aging time change. It is noted that the acicular carbide rapidly decrease and completely disappear after 1000 hrs.

4.3 The Change in Maximum Amplitude of the Barkhausen Noise(BN)

Fig. 6 is the change of maximum voltage amplitude of BHN containing electric noise signal with respect to aging time variation. The "Magn" denotes the intensity of magnetization. Although the trend is slightly different depending on the Magn value, overall the maximum voltage amplitude ascends with aging time up to 1000 hrs. The data for stronger magnetic intensity, say the Magn values of 70 and 80 present more analogous trend to material property change indicating the fact that the movement of magnetic flux is influenced by magnetic intensity.

Fig. 7 is the results of maximum amplitude variation

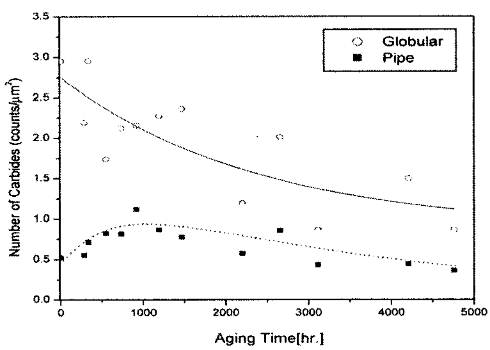
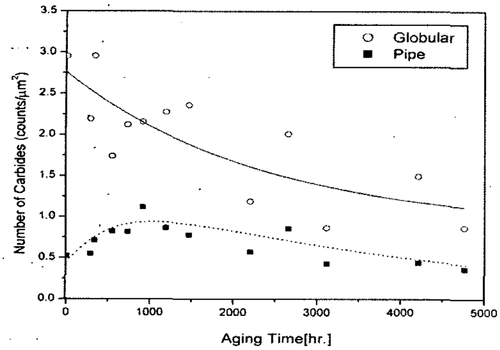
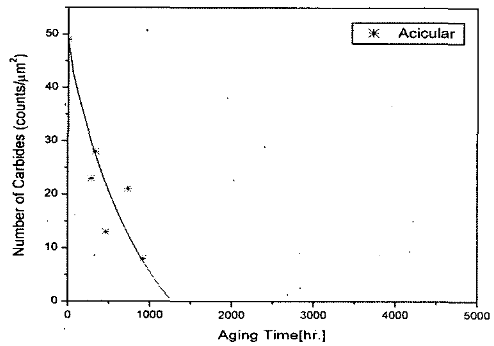


Fig. 4 The change of Vickers hardness versus degraded time



(A) globular, pipe type



(B) acicular type

Fig. 5 Change of number of carbides per unit area with aging time

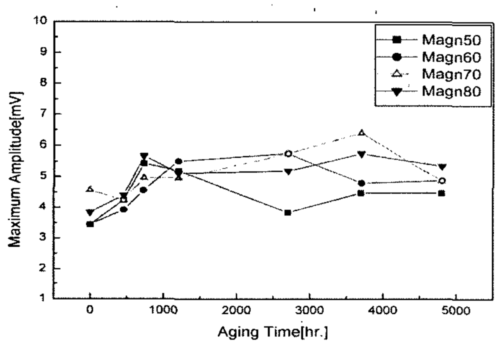


Fig. 6 Change of maximum voltage with aging time (original signal)

with aging time obtained through the wavelet denoising technique. Especially for the curve of the Magn value of 80, the wavelet technique helps to obtain smoother variation by depressing noise and consequently reducing the deviation of experimental data. As a result, the de-noised data of the Magn value of 80 shows a consistent tendency with one of material property change.

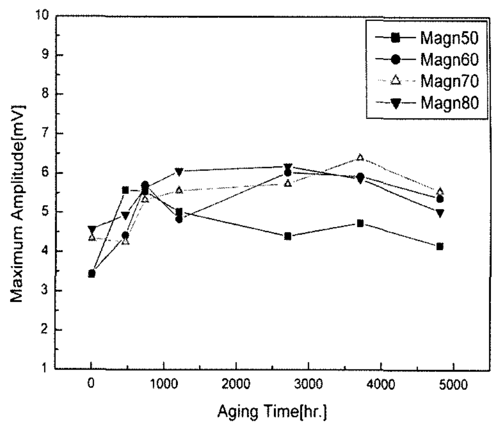


Fig. 7 Change of maximum voltage with aging time (de-noised signal)

4.4 Root Mean Square(RMS) Voltage Change

Fig. 8 represents the variation of RMS voltage with 10032 sampling points over 100ms time period. This result also shows a rapid increase with aging time up to 1000 hrs and a stable trend beyond the point. The consistent feature of various BHN parameters variation provides a clear picture of the fact that a significant microstructure change occurs at 1000 hrs aging time. The observation addresses that the present BHN technique can be successfully used as a promising tool for condition monitoring of thermally degraded materials. Fig. 9 is the RMS results of de-noised data.

After 1000 hrs aging time, the acicular carbides to interfere the movement of magnetic flux disappear as observed by the FESEM images. Consequently, the reduced retarding force induced by shrunken retarding field enables magnetic flux to diffuse faster leading to the increase of the voltage of BHN.

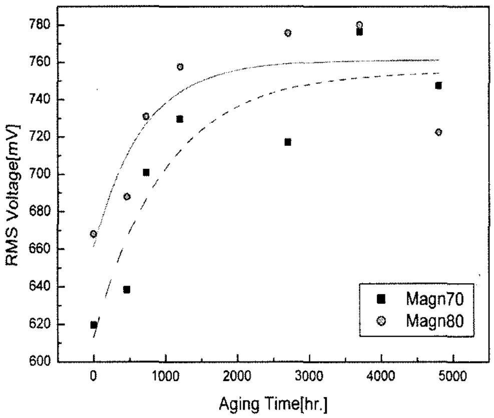


Fig. 8 Change of RMS voltage with aging time(original signal : 10032data point)

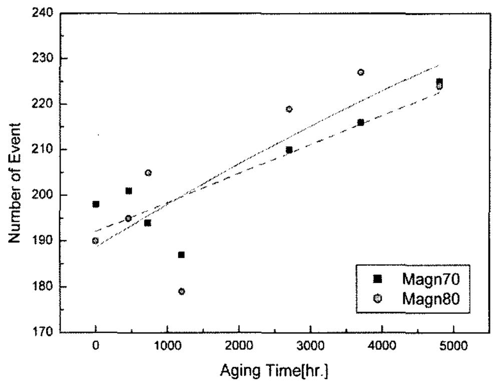


Fig. 10 Change of BNC with aging time(original signal, 1cycle)

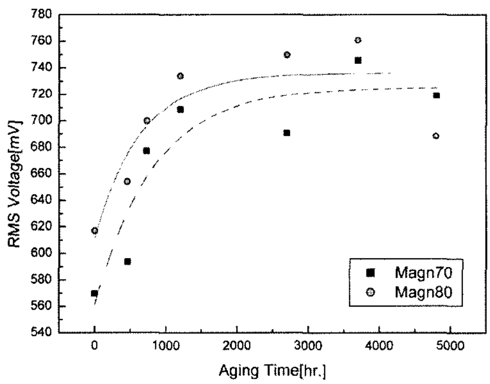


Fig. 9 Change of RMS voltage with aging time(de-noised signal : 10032data point)

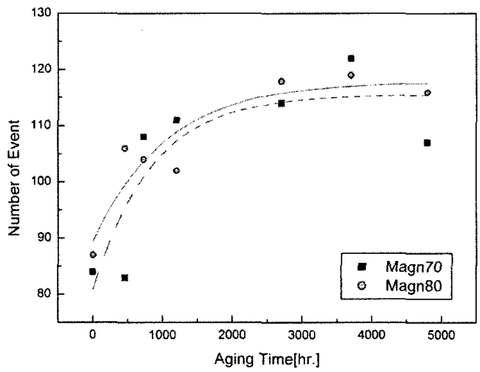


Fig. 11 Change of BNC with aging time(de-noised signal, 1 cycle)

4.5 Number of the Barkhausen Noise Counts (BNC)

Figs. 10 and 11 are the results of BNC with 10032 sampling points over one magnetized current cycle. The threshold voltage level for counting the Barkhausen events is set at 1mV. It turns out that BNC is proportional to aging time and the trend is affected a lot by both magnetized current period and threshold value. Further study might be needed for a more consistent data over a greater number of magnetized current cycles with higher threshold value. In Fig. 11, again the wavelet de-noising technique makes it possible to obtain the data with narrower deviation than ones of Fig. 10.

It is known that the occurrence of the pulse caused by the magnetic wall movement globally appears to be as a cluster rather than a single pulse at a certain point. This leads to the fact that BHN generation mechanism depends on distribution of retarding fields and their time correlation factors[9]. If the magnetizing condition is assumed to be uniform within the size of magnetic coil, the increase of BNC with aging time seems to be due to the disappearance of the acicular carbides to interfere the movement of magnetic flux.

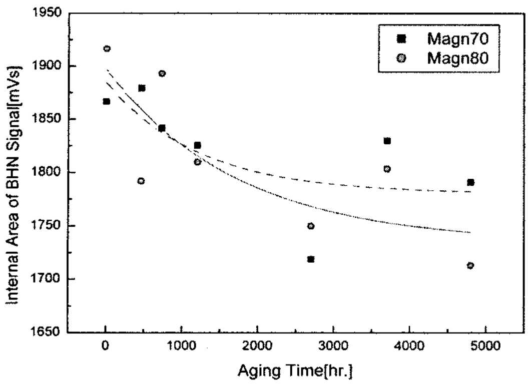


Fig. 12 Change of IABNS(area) with aging original signal, 1 cycle

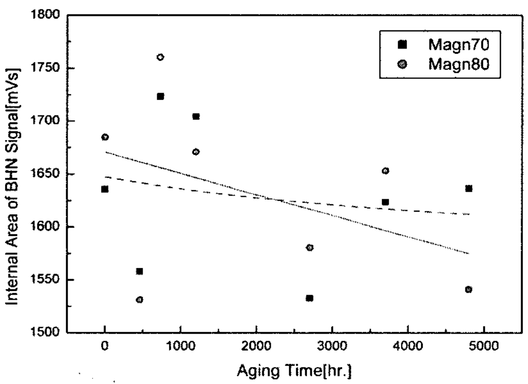


Fig. 13 Change of IABNS(area) with aging time(de-noised signal, 1cycle)

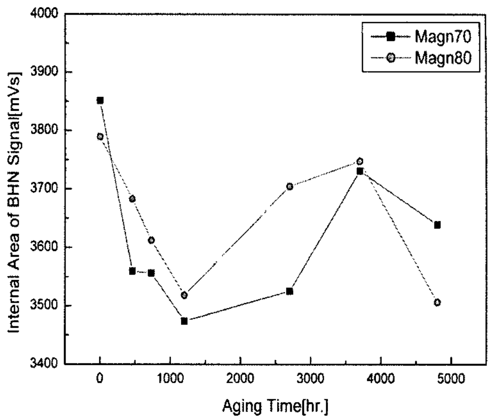


Fig. 14 Change of IABNS(area) with aging time (original signal, 1cycle)

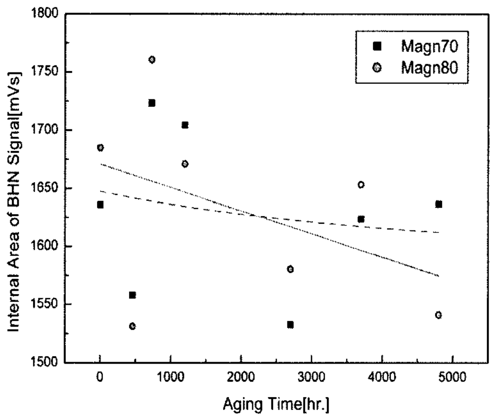


Fig. 15 Change of IABNS(area) with aging time(de-noised signal, 1cycle)

4.6 Internal Area of the Barkhausen Noise Signal(IABNS)

Figs. 12 and 13 illustrate the change of IABNS and de-noised IABNS, respectively over the half period of magnetized current. Figs. 14 and 15 show the change of IABNS and de-noised IABNS, respectively over one period of magnetized current. Unlike other three results, the de-noised IABNS data over one period of magnetized current tend to remarkably increase with aging time up to 1000 hrs in Fig. 15.

4.7 Power Spectrum Analysis and Mean Amplitude Change

In Fig. 16, the center frequency of Fourier transformed BHN is around 10kHz and the peaks A and B represent high frequency contents which would come from electrical noise contained in the BHN.

The high frequency electrical noises were filtered out by the FFT with wavelet denosing technique as shown in Fig. 17. In addition, the denosing process slightly shifts the signal to left, low frequency range reducing amplitude. This is because the denosing enhances the

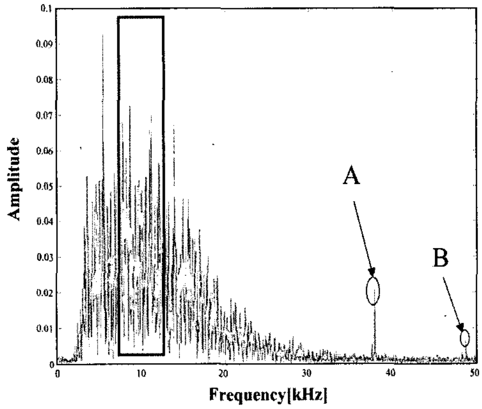


Fig. 16 FFT result of Barkhausen noise(original signal)

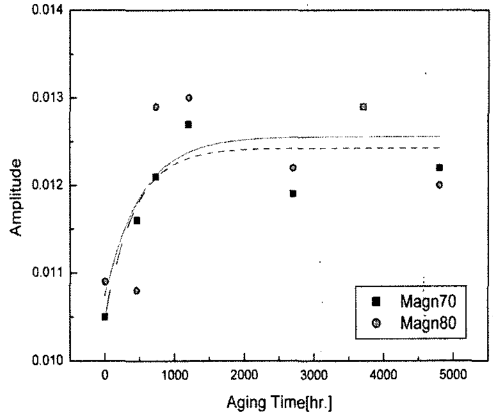


Fig. 18 Change of FFT amplitude mean value with aging time(original signal)

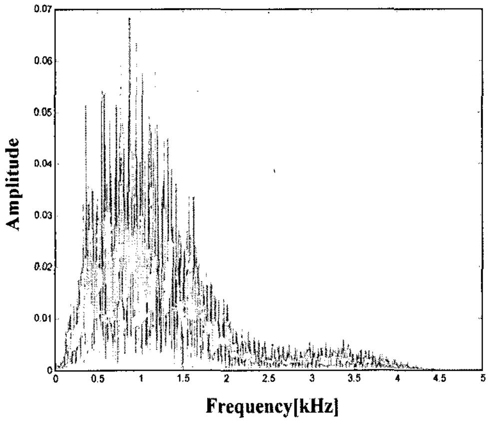


Fig. 17 FFT result of Barkhausen noise(de-noised signal)

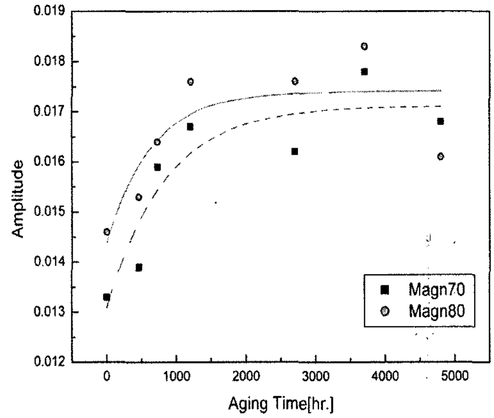


Fig. 19 Change of FFT amplitude mean value with aging time(de-noised signal)

resolution of low frequency contents in frequency domain, which is less effective while decreasing the resolution of time domain signal and consequently the entire shape of denoised signal appears to be in somewhat compressed toward low frequency range. A similar trend used to be found inultrasonic wave forms. Figs. 18 and 19 represent the variation of meanFFT amplitude with respect to aging time. It is observed that the denosing technique can help to improve the reliability in correlating the mechanical property variation due to thermal degradation with micro-structure change reducing deviation of experimental data.

5. Conclusion

In the present study on Barkhausen noise method for investigating thermal degradation of Cr-Mo alloys, the following conclusions were obtained

(1) Through the results of SEM and TEM, the number of carbides rather decreases with respect to the aging time increase up to 1000 hrs.

(2) It turns out that all those Barkhausen noise NDE

parameters like maximum amplitude, RMS, count number, internal area of BNS and mean FFT amplitude tend to be proportional to thermal degradation and consequently the present technique shows a promising feasibility for thermal damage evaluation.

(3) The wavelet denoising technique was successfully applied to enhance SN ratio and experimental data deviation of mean FFT amplitude, internal area of BNS and count number.

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