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A Study on the Evaluation of Mterial Degradaion for 2.25Cr-1Mo Steel using Ultrasonic Attenuation Characterization

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ABSTRACT

In significant number of energy-related facilities for like thermal power plant or petro-chemical industry, CrMo steels are widely used energy conversion industries. However, these materials undergo precipitation of carbides or intermetallic compounds into grain boundary and change of internal microstructure such as coarsening of precipitation, decrease of solute elements and impurity segregation under more severe service conditions, which results in deterioration of inherent superior material characteristics.

In this study, it was verified experimentally the feasibility of the aging degradation evaluation for degraded 2.25Cr-1Mo steel specimens prepared by isothermal aging heat treatment at 630 ℃ by high frequency longitudinal ultrasonic and surface SH wave investigating the change of attenuation coefficient analyzed by spectral analysis. Attenuation coefficient had a tendency to increase as degradation proceeded.

Key words: Surface SH Wave, Material Degradation, Microstructure, Ultrasonic Attenuation Coefficient

INTRODUCTION

It is well known that NDE techniques are used extensively in industry owing to the versatility and inherent advantages of the method. Recently, the typical material degradation found in the atomic or turbine power plant is high temperature creep and aging degradation[1,2]. However, it is often impossible to get specimens for analysis without damaging the components in use. Degradation and damage of material can be evaluated in two ways: destructively and nondestructively. The destructive method such as impact testing, tension testing, and fracture toughness testing are reliable in the estimation of material degradation due to the prolonged service exposure in high temperature. It is widely used for the estimation of material degradation, but it have a time-consuming and a great difficulty in preparing specimens in-service industrial facilities. Therefore, the estimation of material degradation by nondestructive method such as electric resistance method, replica method, Barkhausen noise method, electro-chemical method and ultrasonic method is strongly desired[3].

Ultrasonic nondestructive evaluation method has been reported good to attain efficiency of measurement, high sensitivity of measurement, and rapidity and reliability of result interpretation.

For the evaluation of degradation with Ultrasonic NDE, it extracts parameters of all the characteristics that ultrasonic waveform has, derives correlation between strong feature parameters and material

degradation damage on the change of physical properties, expresses it numerically, and evaluates the degradation.

In this study, it was verified experimentally the feasibility of the evaluation of degraded 2.25Cr-1Mo steel specimens prepared by isothermal aging heat treatment at 630 ℃ by high frequency longitudinal ultrasonic and surface SH wave investigating the change of attenuation coefficient analyzed by spectral analysis. Attenuation coefficient had a tendency to increase as degradation proceeded. Most of all, frequency dependency of ultrasonic attenuation coefficient to aging degradation appeared prominently on the surface SH wave.

EXPERIMENTAL DETAILS

Test material is 2.25Cr-1Mo steel used as a material of turbine rotor at high-temperature and high-pressure power plant. The chemical composition of the material is given in Table 1.

Table 2 shows the accelerated aging time at 630℃ for equivalent microstructure served at 538℃. This is to simulate the microstructure of long term served materials at elevated temperature because of difficulty to sample the degraded materials on site[4]. All specimens were given homogeneous treatment to obtain uniform substructure. Surface roughness of the specimens were maintained within 1 ㎛ rms. The sheet type specimen of 90mm in length, 24mm in width and 10.6mm thickness was used for measuring ultrasonic characteristics. Table 3 shows the mechanical properties of test materials.

In order to investigate the change of carbide morphology and carbide to degradation steps, we observed the change of microstructure to increasing degradation time with field emission scanning electron microscope (FESEM) and quantitatively evaluate the internal microstructure with the change of area on the grain boundary carbides per unit grain boundary length. Fig. 1 represents the schematic diagram of experimental setup for measuring surface SH wave characteristics.

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 2. Accelerated aging time at 630℃ for equivalent microstructure served at 538℃

Time served at 538℃(h)	As-received	80,000	170,000	260,000
Aging time at 650℃(h)	0	1,500	3,100	4,800

Table 3. Mechanical properties of test material

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

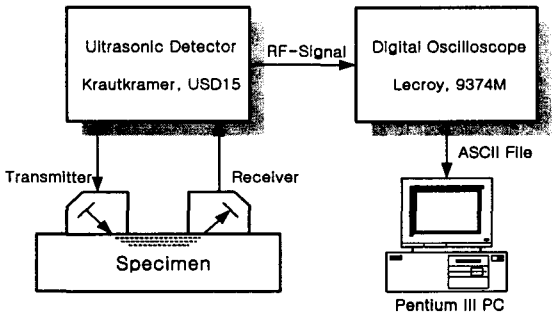


Fig. 1 A schematic diagram of experimental setup for surface SH wave

The present work takes the pulse-echo method as the basis for quantitative characterization of microstructure via attenuation measurement. Using ultrasonic detector(KrautKramer, USD15) and digital oscilloscope(Lecroy, 9374M), We varied propagation distance 12mm and 30mm with pitch-catch method. The probe used in the experiment was surface SH wave probe(5C10×10A90-SH) and SHN-30(Nichigou Acetylene Co., Ltd) was used as the couplant for shear wave exclusive use. We loaded 5kg for 15 minutes to stabilize signal.

Longitudinal wave measurements were made with 5MHz, 10MHz, and 50MHz broadband ultrasonic transducers, commercially available 0.25in. diameter using water immersion techniques.

Maximizing the first specimen back surface reflection and simultaneously monitoring the spectral content of the front surface reflection maintained alignment between transducer and specimens. Owing to the relatively large attenuation at 50MHz, specimens were machined to a thickness of 2.3 mm.

The ultrasonic attenuation measurements were made at room temperature by the ultrasonic pulse-echo reflection method for longitudinal wave and surface SH-wave. Both of the ultrasonic techniques are based on the applications of spectral analysis, FFT and wavelet transform.

RESULTS AND DISSCUSSION

Fig. 2 represents the results of FESEM micrographs showing coarsening of carbides with aging time in the as-received and artificially aged specimens. Carbides went on coarsening and spheroidization as degradation time increased. The needle-like acicular carbide decreased in number and was not observed and transformed other carbides in 1000 hours degradation.

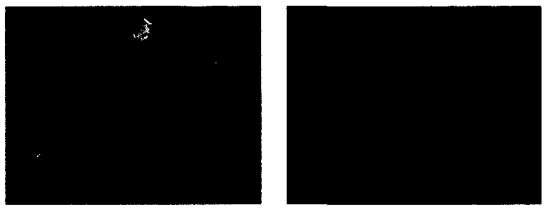
In this study, aging degradation did not make a measurable difference in grain size changes. At each stage of degradation, all the specimens had the same mean grain size about 20㎛. So, it was identified that grain didn't grow in size as degradation time increased.

It is very difficult to quantitatively evaluate the change of internal microstructure because of carbide coarsening and transforming other carbides. So we analyzed to change of area on the grain boundary carbides per unit grain boundary length showing in Fig. 3.

Fig. 4 shows the dependence of Vickers hardness value on aging time. We can tell that downfall of hardness value grew saturated as degradation time passed. The value of hardness decreases more rapidly in the short aging time and the change becomes slower in the long aging time. Since these change of hardness value is related to material degradation extent, we can predict indirectly and identify the possibility of evaluation of material degradation.

Fig. 5 shows frequency dependency of horizontally polarized shear wave and high frequency longitudinal wave attenuation coefficient to degradation. The shear wave shows higher frequency dependency of attenuation coefficient to degradation than that of high frequency longitudinal wave.

(a) as-received (b) 340 hr



(c) 1200 hr (d) 3700 hr

Fig. 2 FESEM micrographs showing morphology of carbide coarsened

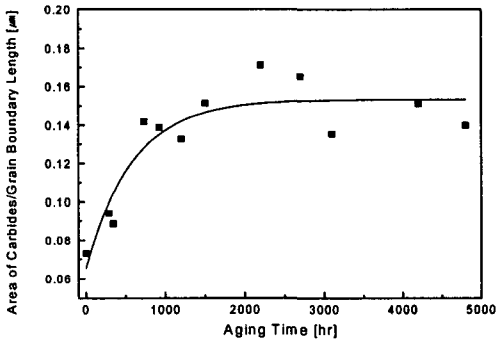


Fig. 3 Carbides area on grain boundary per unit grain boundary length

The slope of attenuation coefficient via frequency increased from 2.56 to 3.74 in surface SH wave.

But, in the longitudinal wave, it varies from 1.8 to 2.4 shown in Fig. 6.

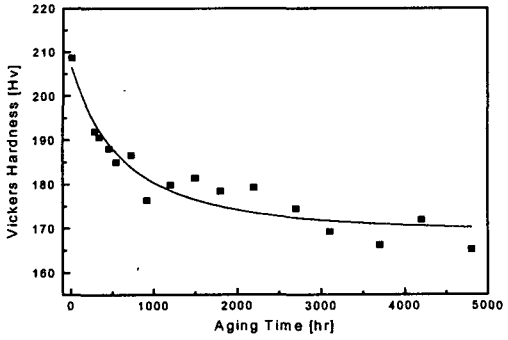
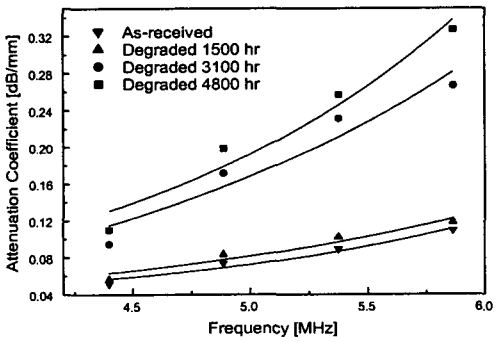
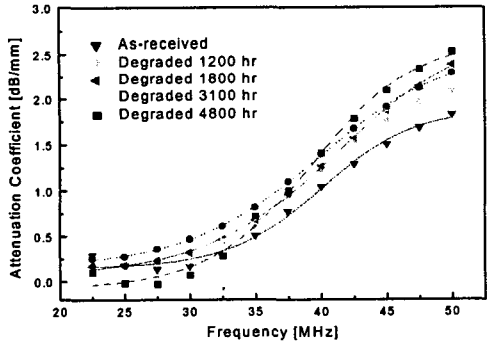


Fig. 4 Effect of degradation time on Vickers of 2.25Cr-1Mo steel hardness



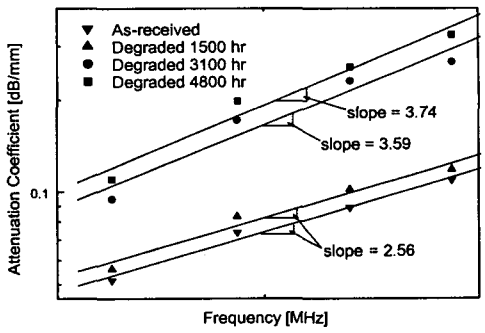
(a) surface SH wave



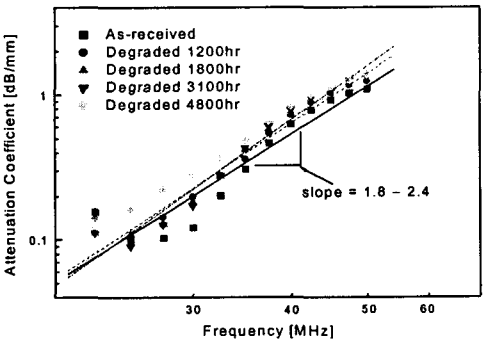
(b) longitudinal wave

Fig. 5 Attenuation coefficient as a function of frequency surface SH and longitudinal wave

The theoretical attenuation coefficient strongly depends on the type of matrix (isotropic, unisotropic, polycrystalline) and scatterer(gas, liquid, elastic) and volume content of scatterers.



(a) surface SH wave



(b) longitudinal wave

Fig. 6 The slope of attenuation coefficient via frequency

For quasiisotropic polycrystalline materials, scattering is proportional to the scatterer volume and to the fourth power of frequency[5].

But as-received consisted of two phase and very small carbides. As the aging time increased, coarsening of carbides along grain boundary and transforming other carbides results in deterioration of the materials. Owe to these changes of microstructure, the slope of attenuation coefficient via frequency shows lower than that of theoretical value.

Fig. 7 shows the change of attenuation coefficient at each frequency to degradation time. The measurements carried out in this study have shown

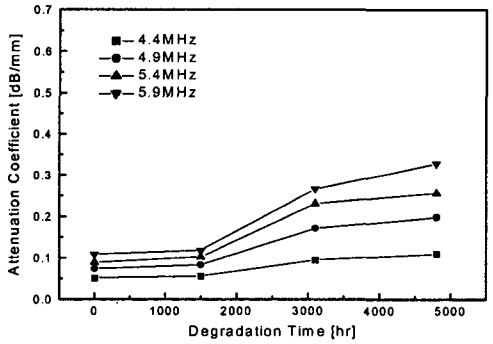
that attenuation of ultrasonic wave closely follows variation in the microstructure of degraded materials.

Attenuation coefficient prominently increases in 1000 hours degradation. The results indicate that the best agreement with change of carbide area on the grain boundary length shown in Fig. 3.

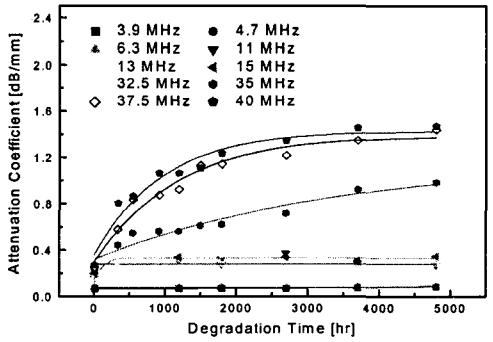
But, in surface SH wave, ultrasonic coefficient is increased after 1500 hours degradation. It is well agree with the time to transformation of needle-like carbide Mo_2C.

As for the result of longitudinal wave in Fig. 7(b), there is no measurable change of attenuation coefficient in low frequency.

Considering the grain size and precipitation of carbide, it is need to use broadband high frequency transducer for evaluating degradation.



(a) surface SH wave



(b) longitudinal wave

Fig. 7 Effect of degradation time on attenuation

CONCLUSIONS

We carried out experiments to verify the feasibility of material degradation evaluation using the change of microstructure and ultrasonic attenuation characteristics to simulated aging degradation of 2.25Cr-1Mo steel. And we made following conclusions; Because of carbide precipitation increase and spheroidization near grain boundary of microstructure to aging degradation, attenuation coefficient had a tendency to increase as aging time.

It was identified possible to evaluate degradation using the characteristics of surface SH wave.

ACKNOWLEDGEMENTS

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