Ultrasonic Examination by Frequency Analysis for Creep Damage Detection of Boiler Piping

By Hiroaki Hatanaka*, Nobukazu Ido*, Minoru Tagami, Ishikawajima-Harima Heavy Industries Co, Production Engineering Center, Yokohama, Japan
Takuya Ito†, Hirokatsu Nakagawa, Ishikawajima-Harima Heavy Industries Co, Power Plant Division, Tokyo, Japan
Ryota Uemichi, Ishikawajima-Harima Heavy Industries Co, Power Plant Division, Hyogo, Japan

Abstract. Boiler piping of fossil-fuel combustion power generation plants are exposed to high-temperature and high-pressure environments and failure of piping due to creep damage has been a concern. Therefore, a precise creep damage assessment method has been needed. This paper proposes a nondestructive method for creep damage detection of piping in fossil-fuel combustion power generation plants by ultrasonic testing. Ultrasonic signals are transformed to signals in frequency domain by Fourier transform and a specific frequency band is chosen. To determine the creep damage, the spectrum intensities are calculated. Calculated intensities have good correlation to life consumption of the weld joints and this method is able to predict the remaining life of high-temperature piping, which have been already installed.

Introduction

Piping of fossil-fuel combustion power generation plants such as main steam and hot reheat piping are exposed to high-temperature and high-pressure environments. Furthermore, design temperature and pressure are increasing for effective electric power generation. Therefore, failure of the piping due to creep damage in Heat Affected Zone (HAZ) of the welds has been a concern and development of a precise creep damage assessment method permits repair, or replacement decisions. The initial stage of creep generates voids at the grain boundaries. The next stage is generated voids connect to each other and finally develop into cracks.

Ultrasonic testing is very useful to detect cracks, flaws, and inclusions inside materials. However, it is difficult to detect small voids by the conventional testing. Hence, replication methods [1, 2] and hardness testing and so forth have been utilized to determine the creep damage of the piping.

In this paper, specimens made with modified 9Cr-1Mo steel, which is employed for real boiler piping, were prepared and a nondestructive method for creep damage detection by ultrasonic testing was established. This method uses a normal beam method and ultrasonic signals between an initial pulse and a back-wall reflection were recorded. The signals were then transformed into signals in frequency domain by Fourier transform and the spectrum intensities at a specific frequency band are calculated to determine the creep damage. The spectrum intensities at a chosen frequency band have good correlation to life consumption of the HAZ.

Principle

Figure 1 shows the schematic image of scattering of the ultrasound inside materials. When the material is not damaged, small scattering from grains are observed between the initial pulse and the back-wall reflection. When the material is damaged, scattering from voids or micro cracks are observed, as well as the scattering from the grains. To evaluate the scattered wave quantitatively, Fourier transform [3] is applied to the signals under the time gate.

When the frequency of the ultrasound is 15MHz, the wavelength is found to be 0.4mm. A creep void is much smaller than the wavelength. To detect the small object inside materials, high frequency ultrasound is necessary because of a small wavelength. It is considered that the higher frequency components should be sensitive to the voids in the initial stage of the creep damage process. When the creep damage proceeds, voids are connected to each other and voids become bigger and the lower frequency components will also be sensitive to them. In this method, the spectral intensities of the specific frequency band were calculated as a scattered ultrasound parameter P_S.

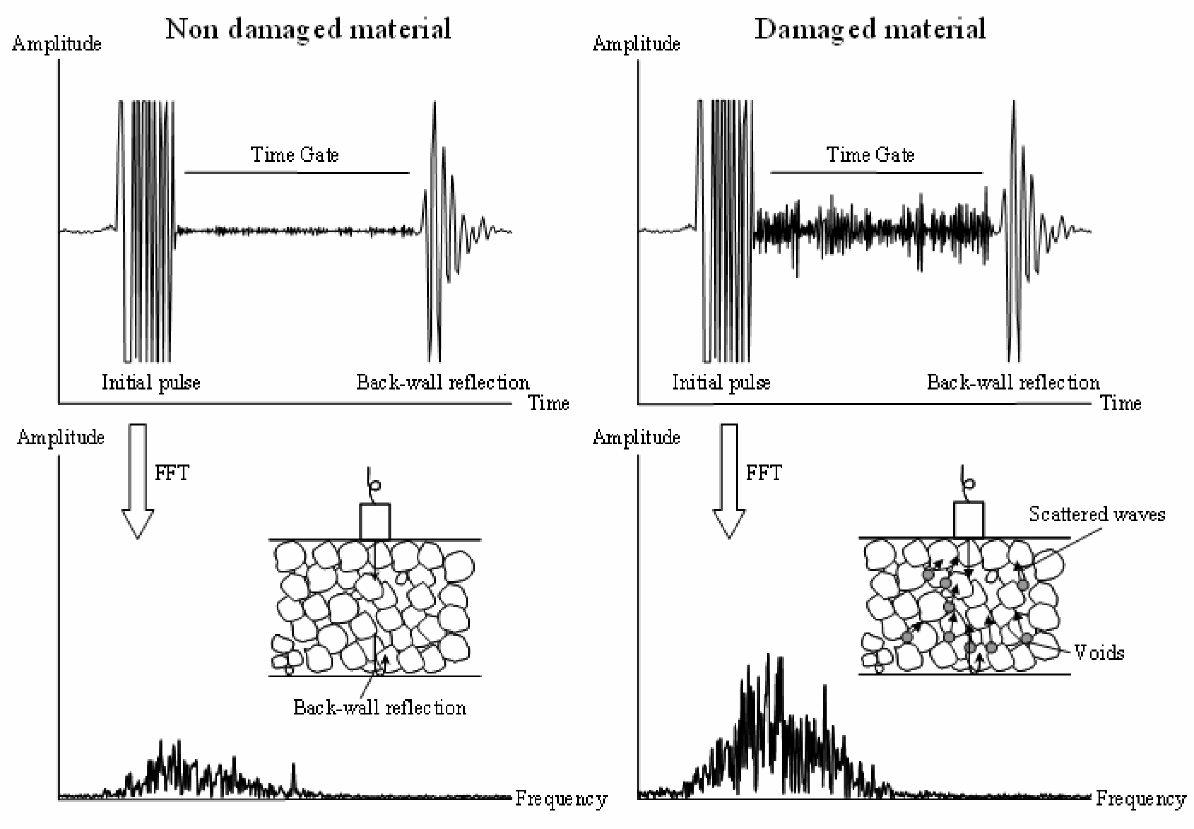

Figure 1. Schematic image of the scattering inside materials

Experimental Procedures and Specimens

To obtain the ultrasonic data, a normal longitudinal wave probe, which has a frequency broadband of 15MHz, was employed and a contact method was applied. To locate the creep damage, the time gate was divided into 1mm-long time gates and a probe was scanned perpendicular to the weld joint (i.e. B-scan). Figure 2 shows the schematic illustration of the experiment. It is thus possible to obtain 2-dimensional color maps. Colors of the color map (Figure 2(b)) indicate the scattered ultrasound parameter at each position.

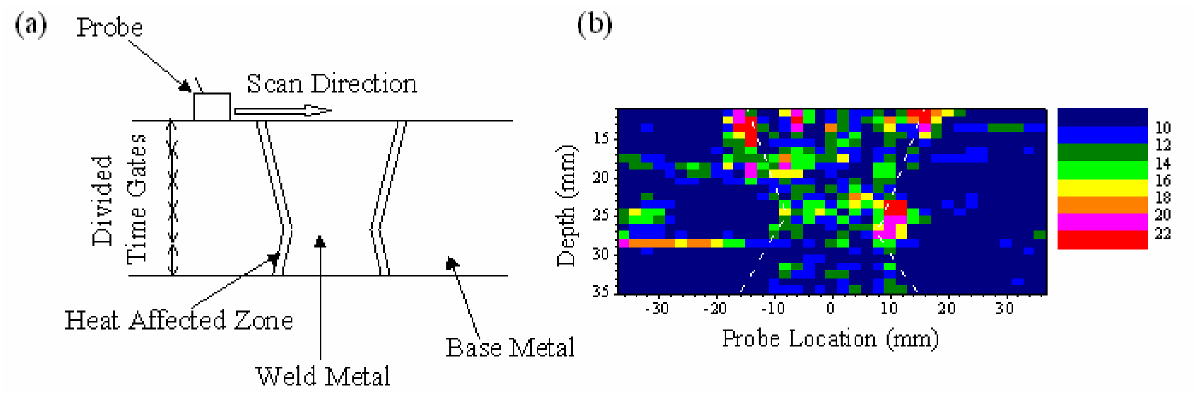

Figure 2. (a)Schematic illustration of the probe scanning and (b) an example of the image data

A 9Cr steel, equivalent to ASME A387 Gr. 91, was used as the base metal for the specimens. Table 1 shows the chemical components of the base metal and the filler metal. The dimension of the specimens was 36mm in thickness and 18mm in width. The creep tests were carried out and ultrasonic data were obtained after aborting the test before failure. The continuous creep rupture tests with interruptions were also carried out and data acquired at each interruption.

Table 1. Chemical components of the base metal and filler metal

(Weight %)	C	Si	Mn	Ni	V	Nb	Cr	Mo
Base Metal	0.09	0.36	0.46	0.13	0.20	0.08	8.45	0.99
Filler Metal	0.08	0.13	1.73	0.60	0.23	0.05	8.91	0.90

Experimental Results

Measurement of Aborted Creep Test Specimens

Prior to the creep test, time to rupture time was estimated by the creep test condition such as uni-axial stress and test temperature. The creep tests were aborted at 40, 60 and 80% of the estimated rupture time and the ultrasonic data was acquired from the specimens. Figure 3 shows the ultrasonic data from a specimen tested in 58.8MPa and 650°C with the test aborted at 60% of the estimated rupture time. The colors in Figure 3 indicate the normalized P_S at each position. After the measurement, the specimens were cut and the high-P_S areas were observed by an optical microscope. As shown in figure 3(c), micro cracks were found at the high-P_S areas.

Measurement of Continuous Creep Test Specimens

Figure 4 shows the experimental data of a continuous creep test specimen. The test stress and temperature were 66MPa and 650°C, respectively. Before the creep test, the initial data were acquired. Periodically the tests were interrupted to allow ultrasonic data to be acquired. At the region A and B, scattered ultrasound parameters increased notably.

Finally this specimen was ruptured from the HAZ on the left hand side. The origin of the creep rupture should be the damage at region B. Figure 5 shows a cross sectional picture of the ruptured specimen and the magnified pictures at the high-P_S area A. This method is thus able to locate and detect the creep damage.

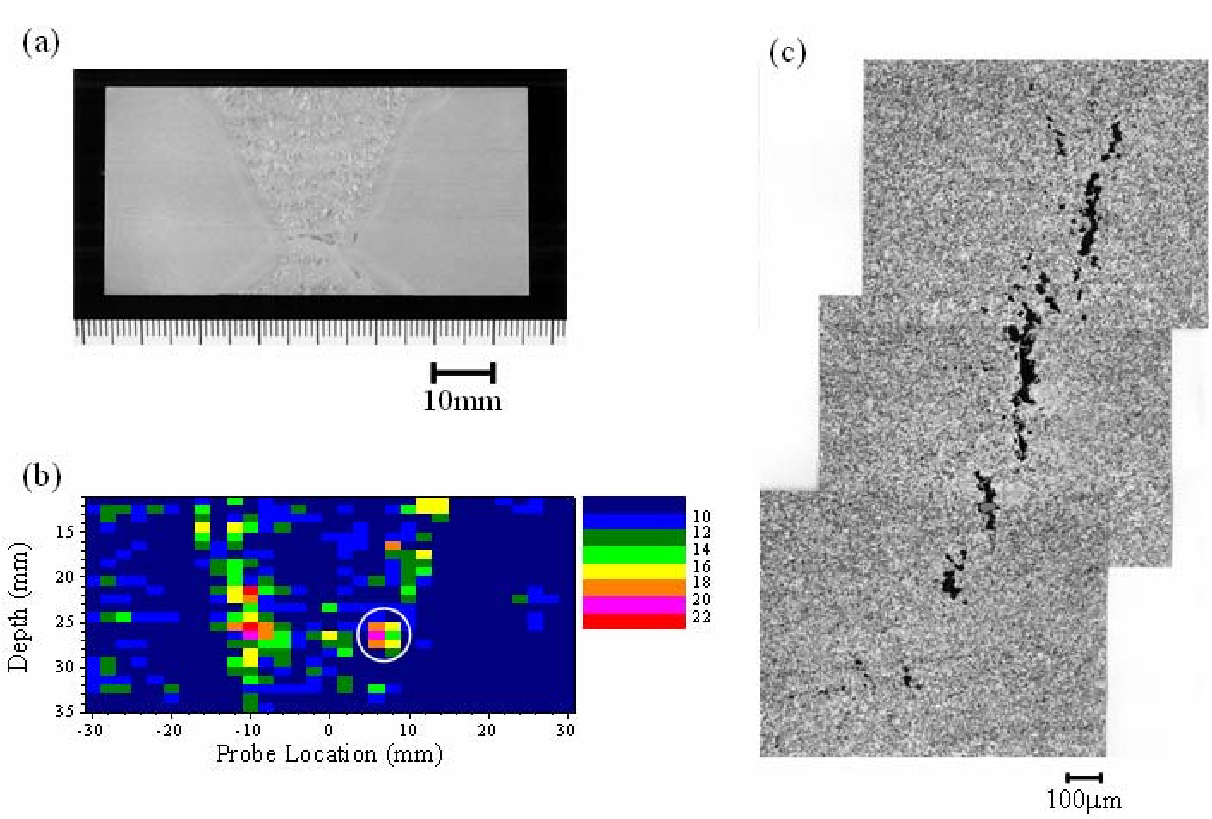

Figure 3. The result for the aborted specimen (650ºC, 58.8MPa, 3449hrs., 60.1%) (a) a cross sectional picture, (b) an ultrasonic test result and (c) a magnified picture of the circled region

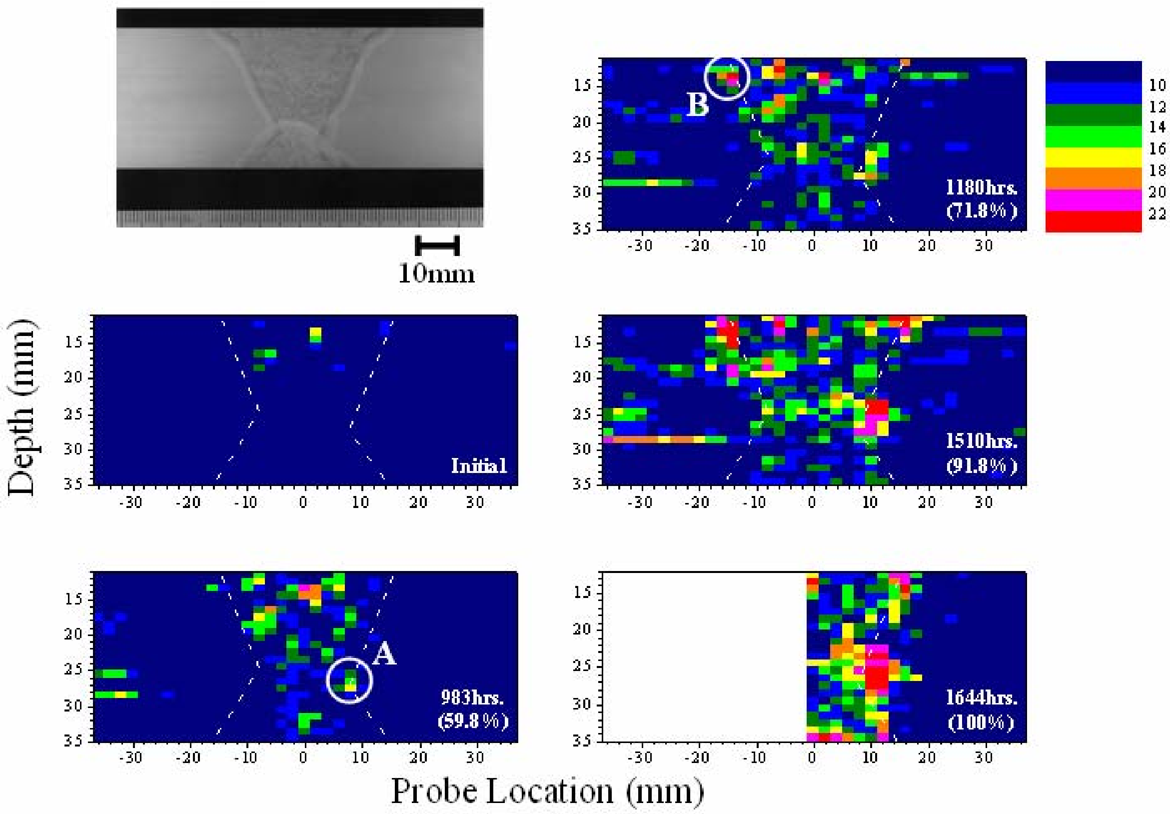

Figure 4. The result by B-scan method for the continuous creep test specimen (650ºC, 66MPa)

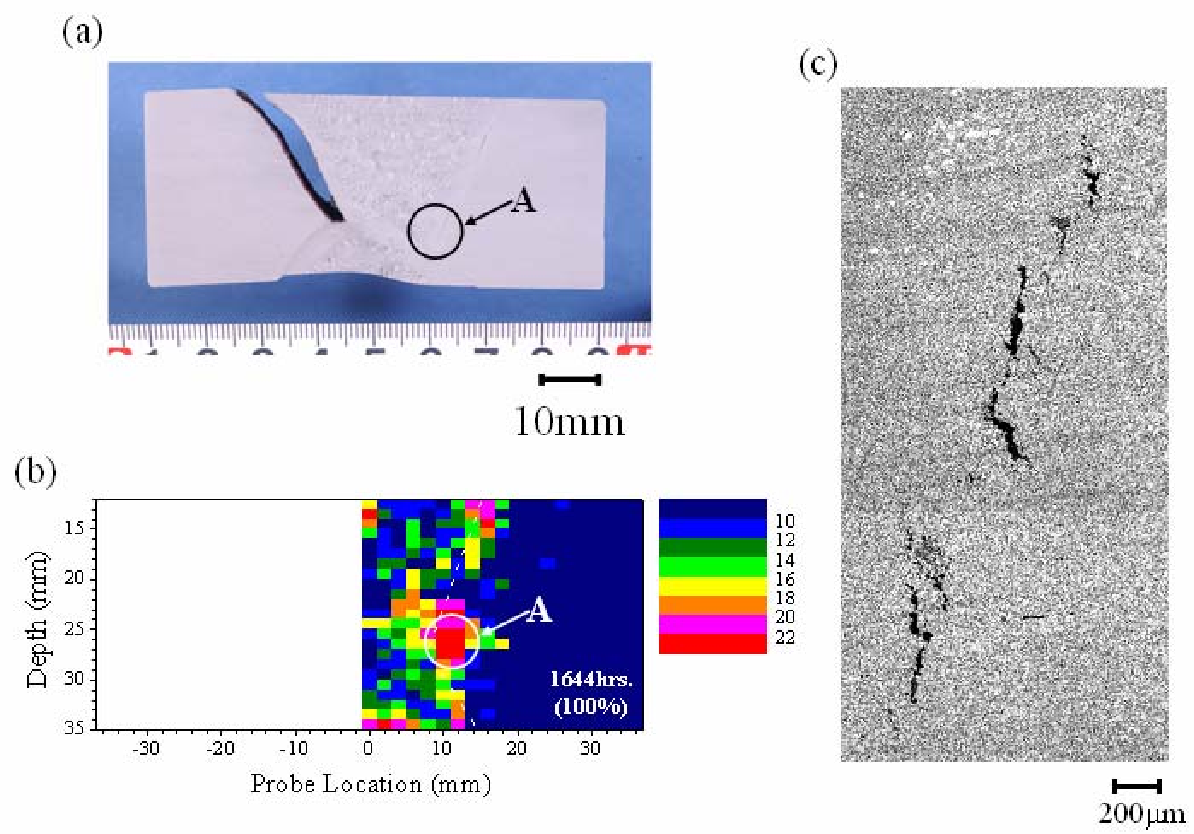

Figure 5. (a) A cross sectional picture of the ruptured specimen, (b) ultrasonic test result after rupturing and (c) a magnified picture at region A

Discussion

Void generation causes the change of the sound velocity and attenuation. To measure the sound velocity and the attenuation, back-wall reflections are needed. For the real boiler components, back-walls may not be consistent because of corrosion or erosion.

Figure 6 shows the correlation between scattered ultrasound parameter and the life consumption. It was found that the averaged parameters have a good correlation with life consumption.

The P_S value at 36% in the life consumption is the same level as the P_S value at 0%. It is considered that the error of this measurement might be bigger in the early stage of the creep damage process because of the existence of the material noise (scattered waves from grains). If there are minute flaws such as blowholes in the weld metal, this causes error of the measurement. And when the material noise would be large, this also might cause the error. So it is necessary to have the initial information of the weld joints when applying to the real piping and predicting the creep damage.

The parameter fluctuation becomes small or after the middle stage of the creep damage process. It is considered that the creep damage becomes dominant indication compared to the minute flaw indications and the material noise in this stage. So it will be possible to assess creep damage only after the middle stage of the creep damage process.

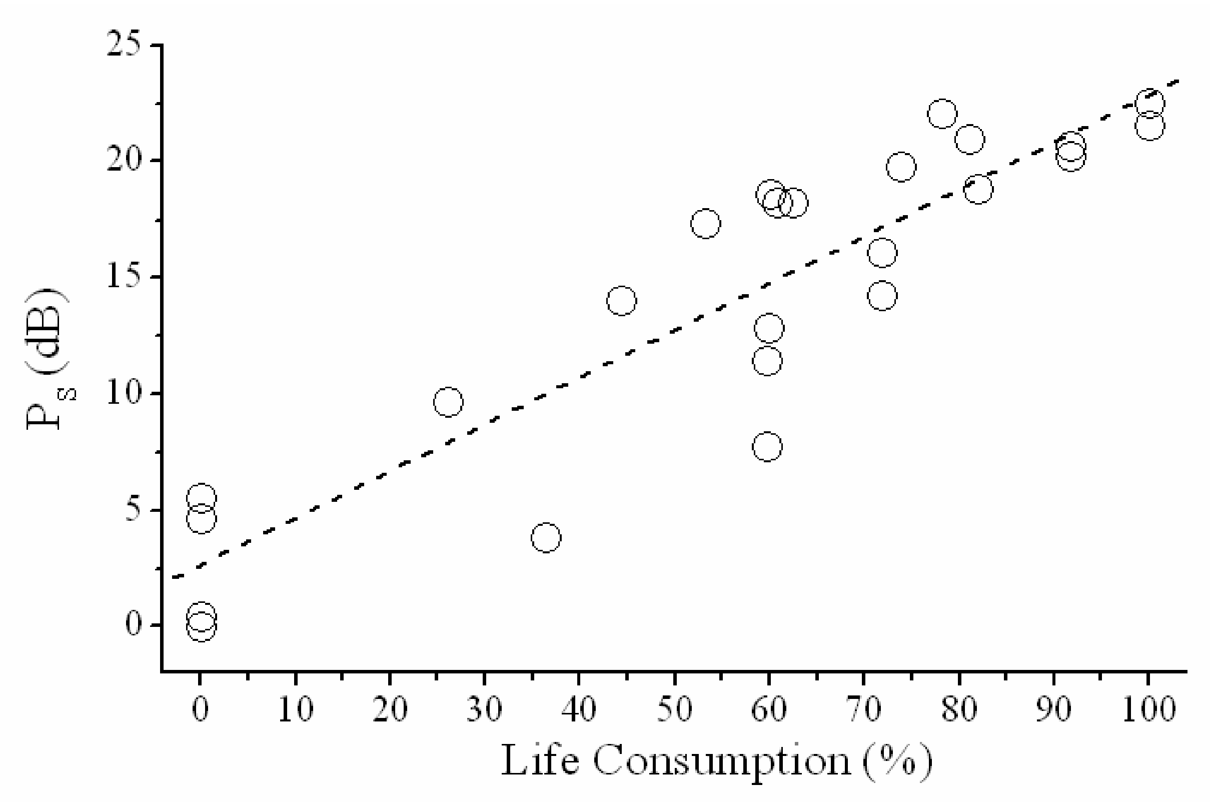

Figure 6. Correlation between averaged scattered ultrasound parameters and life consumption

Summary and future work

This paper proposed a nondestructive ultrasonic method to assess the creep damage of HAZ for modified 9Cr-1Mo steel weld joints. Creep damage is determined based on the spectral intensity at a specific frequency band of ultrasonic signals. Specific frequency components increase in good correlation to life consumption of weld joints.

As the future work, it is necessary to know the quantitative correlation between scattered ultrasound parameters and voids such as the void volume ratio. And it is also important to understand quantitatively what causes unexpected noise, for instance, what kinds of precipitates coarsen due to aging and how they cause noise for the creep damage assessment.

References

[1] Neubauer B. and U. Wedel, 1983, Advances in Life Prediction Methods, ASME, pp.307.

[2] Cane B. J. and R. D. Townsend, 1983, Proc. ASME Materials Seminar, Flaw and Fracture at Elevated Temperature, ASME, pp. 279.

[3] Arfken, G., 1985, “Mathematical Methods for Physicists”, 3rd edition, Acad. Press, NY. NY. pp. 794-864.