Prediction of Grain Orientation in Dissimilar Metal Welds Based on FEA and Optimization

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1. Introduction

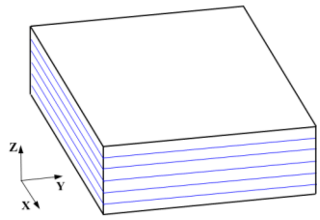
Primary water stress corrosion cracks have been found in dissimilar metal welds used in major components in nuclear power plants. Ultrasonic nondestructive testing plays an important role in structural integrity monitoring of dissimilar metal welds (DMWs) in pressure vessels and piping in nuclear power plants. Inspection of dissimilar metal welds using ultrasonic wave, however, has a relatively low probability of detection of cracks, because the grain structures (grain orientations) of weld area leads to distortion and splitting of the ultrasonic beam propagating in anisotropic media. To overcome this matter, the grain orientation and a precise ultrasonic wave simulation technique in anisotropic media is required so as to accurately model the distortion and splitting of the waves. This paper provides how to nondestructively predict the grain orientations of DMWs for the accurate simulation of ultrasonic wave propagation behavior in weld area. Ultrasonic wave propagation behavior in anisotropic media are simulated by finite element analysis when plane waves are propagating in a transversely isotropic material. Also, a new methodology to predict grain orientation of DMWs was proposed using simulation technique for ultrasonic wave propagation behavior calculation and optimization technique. The simulated ultrasonic wave behaviors with the grain orientations predicted through the proposed method show the usefulness of the proposed grain orientation prediction method. The proposed method could be used for the determination of the focal law in DMWs.

2. Simulation of Ultrasonic Wave Propagation Behavior in Transversely Isotropic Material

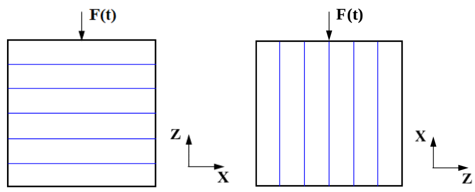
2.1 Finite Element Analysis

The ultrasonic wave propagation behavior in the transversely isotropic material was calculated through elastic finite element analysis (FEA), and the velocity was then compared with the theoretical solution for the validation. The FEA was performed with an implicit solver in the ABAQUS Version 6.14 package. Fig. 1 shows a configuration of a transversely isotropic plate and the loading condition. Within *x-y* plane, the medium appears isotropic but in any direction outside the plane the medium exhibits an anisotropic feature. The mesh was constructed with 25600 8-node plane strain elements, CPE8R (8-node biquadratic, reduced integration) in ABAQUS. Force was loaded at the center of the top surface as shown in Fig. 1 to simulate the stress induced by the piezoelectric transducer and to generate ultrasonic excitation. The force was applied in the form of one cycle sine wave with a frequency of 2 MHz. The force was loaded in *x* and *z* direction to investigate the anisotropic effect.

In isotropic material the material properties are the same throughout the material and in all direction so the velocity of ultrasonic beam is independent of the propagation direction. However, anisotropic material has the direction dependent material properties so the velocity is also dependent on the wave propagation direction. In *z-x* plane, the longitudinal wave velocity in *x* direction and *z* direction is expressed by this equation; $V_{xx} = \sqrt{C_{11}/\rho}$ and $V_{zz} = \sqrt{C_{331}/\rho}$. Table 1 shows the ultrasonic wave velocity calculated by theoretical and FEA methods, and the FEA results shows a good agreement with the theoretical solution within 1% difference. Thus, Thus, the FEA method was considered to be validated.



(a) Transversely isotropic plate



(b) Loading direction

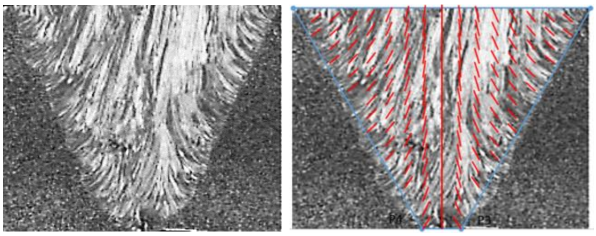
Fig. 1 Schematic diagram for transversely isotropic plate and loading condition for FEA

Table 1: Wave velocity in *x* and *y* direction

	V_{xx} (m/s)	V_{zz} (m/s)
Theoretical Solution	5542	6306
FEA	5510	6270

2.2 Ultrasonic Wave Propagation Response in DMW

A precise description of ultrasonic wave propagation behavior in austenitic stainless steel welds is difficult because complex grain structure cause skewing and splitting of the ultrasonic wave. For the ultrasonic wave propagation simulation, the grain orientation from the micrograph generally is used. In this paper, the grain orientation of the real austenitic weld of Fig. 2a [1] was further simplified by meshing the region and measuring the grain orientation in each meshed area to get the measured grain orientation as shown in Figure 2b. The measured grain orientation was used for simulation input material describing grain structures (anisotropy) in austenitic steel weldment. The ultrasonic wave propagation simulation was performed according to the FEA method described in Section 2.1, and the finite element mesh was shown in Fig. 3. Fig. 4 shows the ultrasonic wave responses measured at the sensing points (in Fig. 3) at the top surface.



(a) Macrograph (b) Measured grain orientation

Fig. 2 An example of macrograph of a V-weld and its measured grain orientation

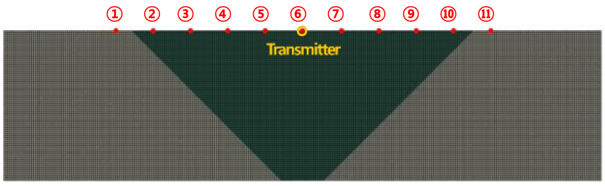
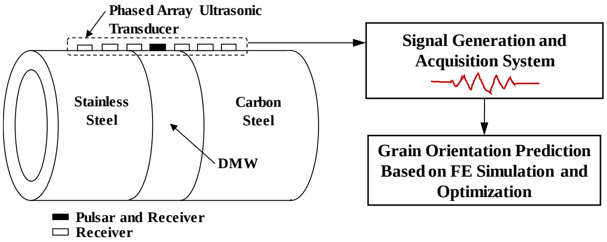


Fig. 3 Finite element mesh for DMW and schematic representation for transducer position

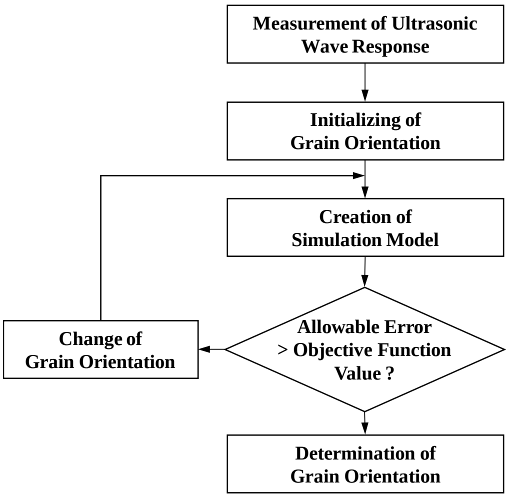
Fig. 4 Ultrasonic wave response in receiver

3. Optimization of Grain Orientation in Dissimilar Metal Welds

To obtain the grain orientation in austenitic weldment, most of the researches have been used the macrograph which is a kind of destructive method. This paper proposes how to nondestructively predict the grain orientation of DMWs. The key idea is to measure the elastic wave responses, which are generated by one transducer, with the others of phased array ultrasonic transducers, and then to find out the grain orientation of DMW by formulating as an inverse problem. Fig. 5 represents the schematic drawing of grain orientation prediction process in DMW using phased array ultrasonic testing, finite element simulation, and optimization techniques.



(a) Schematic representation of prediction of grain orientation of DMW



(b) Flow chart for determination of grain orientation of weldment

Fig. 5 DMW grain orientation prediction process

3. Conclusions

In this study, a novel methodology, which is based on FEA and optimization techniques, was proposed to nondestructively predict the grain orientation of dissimilar metal welds (DMWs) for the accurate simulation or ultrasonic wave propagation behavior in the weldment. Ultrasonic wave propagation in anisotropic media are simulated by finite element analysis and are validated by comparing with the theoretical solution when plane waves are propagating in a transversely isotropic material. Also, a new methodology to predict grain orientation of DMWs was proposed using simulation technique of ultrasonic beam propagation behavior and optimization technique. The proposed method could be used for the determination of the focal law in DMWs in order to use ultrasonic phased array testing technique.

REFERENCES

[1] A. Apfel, J. Moysan, G. Corneloup and B. Chassignole, Simulations of the Influence of the Grains Orientations on Ultrasounds Propagation, 16th World Conference on Nondestructive Testing (WCNDT 2004), Montreal (Canada), September 2004.