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Time-History Measurement of Welding Deformation Using Digital Image Correlation Technique

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In this study, a measurement method for welding deformation based on DIC is proposed. In addition, the sub-pixel estimation is also introduced to the proposed method to improve the accuracy of measurement. The measurement accuracy of the proposed method is discussed through the application to bead-on-plate welding. As a result, it is found that the measured results by the proposed method have the same tendency as the results obtained by thermal-elastic-plastic FE analysis in transverse shrinkage and longitudinal shrinkage. And it is found that the proposed method can measure transverse shrinkage with high accuracy in comparison with measurements using a vernier caliper or laser distance meter. While the methods using a vernier caliper and laser distance meter can measure only a few points at a time, the proposed method can measure the full field in a short time. This shows that the proposed method has many great advantages.

INTRODUCTION

The displacement behavior during welding provides important information for understanding the welding deformation and mechanism by which the welding residual stress is formed. Thus, the displacement behavior has been generally predicted by numerical analyses such as the finite element method (FEM) based on thermal-elastic-plastic theory. As a direct measurement method, the existing Electronic Speckle Pattern Interferometry (ESPI) has been reported by Meguro and Muramatsu (2006). By a technique using the ESPI system, the displacement increment can be measured with high accuracy. However, it is expensive because a laser light source and a precise optical system are necessary, and there are some restrictions on the measurement conditions, such as measurement range. In addition, it is necessary to irradiate the laser light to the measurement target and accurately receive the reflected light. Hence, it is considered that measurement under the influence of a welding arc is difficult.

On the other hand, many digital image correlation (DIC) methods, which use the images taken by the digital camera, are proposed, and DIC is applied to the measurement of deformation such as measurement of 2D deformation with lens distortion correction (Yoneyama et al., 2006), measurement of 2D deformation of a tension testing (Tung et al., 2009), and measurement of 3D vibration (Helfrick et al., 2011). Thus, DIC is well applied to the measurement of deformation, and it is assumed possible to apply it to the measurement of welding deformation. By so doing, full-field measurement of welding deformation can be achieved. In addition, the measurement of time-series deformation of welding will be also achieved by constructing the measurement system that applies DIC from the beginning of welding to the complete cooling. The application of DIC to the measurement of welding deformation is thus very effective for the understanding of mechanisms by which the residual stress and deformation are formed. However, there are few applications of DIC to the measurement of welding deformation.

So, in this study, we established our own practical and easily implemented method for measuring displacement. The method is inexpensive and requires no special equipment. Only a digital camera is necessary. An image of the entire area can be taken, and the time-dependent displacement behavior can be measured without contact. In addition, the atmospheric fluctuation during welding due to the temperature increase has only a small influence, but the measuring equipment is very simple and a special light source such as a laser is not required. Measurement of a large deformation is also possible because the image analysis is based on image-matching technology (Hasegawa and Shimizu, 1992; Ryugo et al., 2001; Machida and Hirano, 2001; Murata et al., 1999). Plus, the number of measurement points attainable at a time is more than 10 million, which is the number of effective pixels in the camera image, that is, all the pixels can be used as measurement points. The proposed method is promising since the precision of the measurement depends on the pixel resolution of digital cameras, and new high-performance digital cameras are frequently released these days.

In this study, the established measurement method is applied to the measurement of time-dependent displacement behavior in intense arc light. The validity of the obtained time history of the distribution of transverse shrinkage is examined by the thermal-elastic-plastic finite element method (FEM). In addition, the residual deformation is also measured by another method, and the measurement precision and usefulness of the proposed method is verified.

DEVELOPMENT OF IN-SITU FULL-FIELD MEASUREMENT SYSTEM OF WELDING DEFORMATION USING DIGITAL CAMERA

Continuous, multiple digital images along the time history are recorded in the in-situ full-field deformation measurement system using a digital camera. Small movement or displacement in the obtained image is calculated in pixel orders by the image correlation method. To improve the precision of measured displacements to less than a pixel order, curve approximation is performed for distribution of the brightness correlation values at pixel locations. The position of the maximum value of the obtained correlation

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