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Measurement of In-situ Measurement System for 3D Welding Deformation Using Digital Camera

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1. Introduction

The displacement behavior during welding can provide very important information for understanding the mechanisms that cause welding deformation and residual stress. Specifically, if time-series welding deformation can be measured and the displacement distribution can be obtained over an entire measured area, the transition of deformation during welding can be evaluated and the mechanisms of welding deformation and residual stress may be better understood.

Therefore, we constructed an in situ three-dimensional deformation measurement method using digital cameras, which are simple to use and inexpensive. With this technique, it is possible to measure three-dimensional displacement behavior, that is, in-plane deformation and out-of-plane deformation, over an entire photographed image area along a time sequence and without physical contact. Since the measurement equipment is extremely simple and does not require a special light source, such as a laser, it is robust against atmospheric fluctuations, etc., which are generated as the temperature increases during welding.

2. Full-field measurement of three-dimensional deformation during welding

Images taken by the left camera during and after welding are shown in Fig. 1(a). The displacement distributions in the x-, y-, and z-direction components are shown in Figs. 1(b)–(d). In these figures, (i), (ii), and (iii) show the images captured and the displacement distributions at 30, 50, and 70 seconds after the start of welding, respectively. Additionally, (iv) shows the distributions after cooling is complete. The images in Fig. 1(a) show that an area of intense light is associated with the arc light surrounding the welding torch. Additionally, in Fig. 1(b), which is the x-direction displacement distribution during welding, it is confirmed that a distribution of negative displacement is seen at the start point of the weld [1] (the bracketed numbers are shown in the figure) and a distribution of positive displacement is seen at the end point of the weld [2]. These distributions are caused by thermal expansion in the vicinity of the weld. It is also confirmed from the displacement distribution in the final deformation, shown in (iv) of Fig. 1(b), that the heat transfer into the air is nearly complete and the thermal expansion on the weld line during welding has nearly disappeared.

It can be seen from the y-direction displacement distribution at 30 seconds after the start of welding, shown in (i) of Fig. 1(c), the upper portion of the test specimen was displaced in the positive direction [3], while the lower portion of the test specimen was displaced in the negative direction [4]. This displacement is caused by thermal expansion in the y-direction at the start point of the weld. The displacement distribution at 50 seconds after the start of welding, shown in (ii), confirms that negative displacement was produced in area [5] at the back of the torch, while positive displacement was produced in area [6]. It can be understood from this that localized thermal shrinkage occurs on the weld line in the transverse direction of the test specimen immediately after the welding torch passes. Local transverse thermal shrinkage [7] [8], shown in (iii), immediately after passage of the welding torch, is similarly confirmed from the displacement distribution at 70 seconds after the start of welding. In addition, the residual deformation, shown in (iv), confirms that the difference in displacement between the upper and lower portions of the test specimen, that is, the amount of transverse shrinkage, is greater at the end point than at the start point. Furthermore, from the distribution of displacement in the z-direction, shown in (d)(i) and (d)(ii), angular distortion gradually forms from the location where the torch has passed. It can also be confirmed from the displacement distribution in (iii) and (iv) that virtually no change occurs in the resulting angular distortion after the completion of welding, even with the passage of time.

3. Conclusion

The following was concluded for the full-field three-dimensional welding deformation measurement method based on stereoscopic imaging of the time-series measurements of displacement behavior under the intense light of a welding arc.

1. The proposed technique can measure the displacement distribution in the direction of the weld line, the displacement distribution in the transverse direction of the plate, and the displacement distribution in the

out-of-plane direction during the welding and during the cooling process.

2. The proposed technique can measure the amount of longitudinal shrinkage, transverse shrinkage, and angular distortion along a time series.
3. Three-dimensional deformation during welding showed good qualitative agreement between the measurements using the proposed technique and those of the FEM thermo-plastic-elastic analysis.
4. The amounts of transverse shrinkage and angular distortion measured from the residual deformation by the proposed method agreed well with the measurements by the laser displacement meter, and digital caliper measurements confirmed that high quantitative accuracy was also possible with the proposed method.

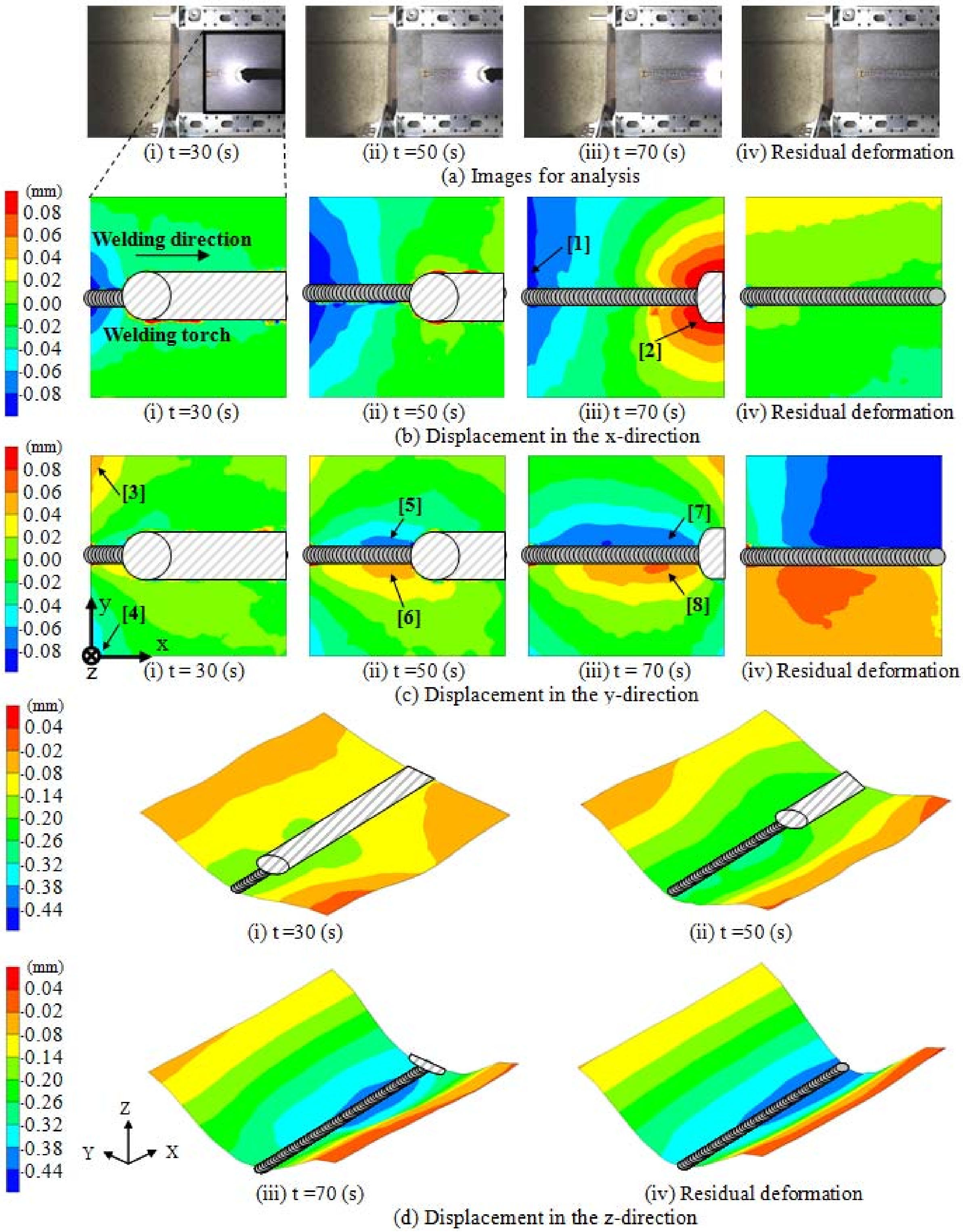

Fig. 1 Distribution of displacements during welding, as measured by the proposed method.