Residual Stress Analysis of Multi-pass Welding Using Idealized Explicit FEM with GPU

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1. Introduction

Residual stress inevitably occurs in the multi-pass weld regions of thick plates used for the construction of pressure vessels, large ships and other steel structures. It may lead to stress corrosion cracking, fatigue cracking and other defects. Accurate prediction of the residual stress in these weld regions is important for assessment of the welded joint.

Dissimilar weld joints such as those of nozzle stubs are highly complex in formation and structure. Although they are reportedly susceptible to stress corrosion cracking [1], experimental determination of their residual stress is extremely difficult, costly, and time consuming.

In their manufacturing, stainless steel is firstly clad-welded to the inner side of the low-alloy steel nozzle, which is then butter-welded. After those process, post-welding heat treatment (PWHT) is done to improve the material characteristics of the low-alloy steel. The dissimilar low-alloy steel nozzle and the stainless steel are then joined by multi-pass welding. Assessment of the residual stress in the welded joint is complex, and experimental stress measurement is extremely time consuming and costly. It is therefore highly desirable to establish an effective numerical simulation method for residual stress prediction. In the numerical simulation of welding [2], however, it is necessary to perform a sequential analysis that follows the occurrence of stress and deformation throughout the entire process from beginning of welding to complete cooling. For multi-pass welding, in particular, the number of analytical steps and elements becomes extremely large and the computation tends to become prohibitively difficult.

In the present study, we investigated the application of our previously developed GPU-accelerated parallelized idealized explicit FEM (GPIE-FEM) method [3] to the analytically difficult problem of 3D thermal elastic plastic analysis of a cylindrical multi-pass dissimilar weld joint. And the validity of our method is verified by comparing the results with those of deep hole drilling (DHD) and other methods of residual stress measurement.

2. 3D analysis of residual stress in 50-pass cylindrical dissimilar weld joint

2.1 Analytical model and conditions

GPIE-FEM is applied to the analysis of the cylindrical dissimilar multi-pass welding problem. As shown schematically in Fig. 1, the joint consisted of SUS316 and SFVQ1A as the base metals Alloy 132 as the buttering and the weld metal and SUS308 as the cladding inside the SFVQ1A cylinder. Figure 2 shows the dimensions and meshing in the analytical model: a welded joint of 735 mm in inner diameter, 883 mm in outer diameters and 1020 mm in length, with 72,576 elements and 77,976 nodes. The annealing temperature was 800˚C, and the initial and inter-pass temperatures were 20˚C and 100˚C, respectively. Full-circumference multi-pass welding was assumed. The position of weld starting is at 0˚ and the weld direction is the same in all passes as also indicated in Fig. 2.

We assumed 25 passes on the inner side and 25 passes on the outer side for a total of 50 passes, alternating between the inner and outer sides every two or three passes. In all of the overlaying, the passes progressed from the base-metal SUS316 side to the base-metal SFVQ1A side. The pass conditions are shown in Table 1. The moving heat source analysis was performed with the heat input conditions shown in the same table. To investigate the effect of the weld metal overlay, we disregarded the influence of the initial residual stress in the clad and the buttering and the

Table 1 Welding condition.

Inside or Outside	Layer	Pass	Current (A)	Voltage (V)	speed (mm/s)	Thermal efficiency	Heat input (kJ/mm)
Inside	1	2	343	27	3.16	0.7	2.05
	2	2	514				3.07
	3	2	600				3.58
	4,5,6	3	600				3.58
	7,8,9	3,4	714				4.26
Outside	1,2,3	2	514	27	3.16	0.7	3.07
	4,5,6	3	600				3.58
	7,8,9	3,4	714				4.26

Fig. 1 Material location of multi-pass weld joint.

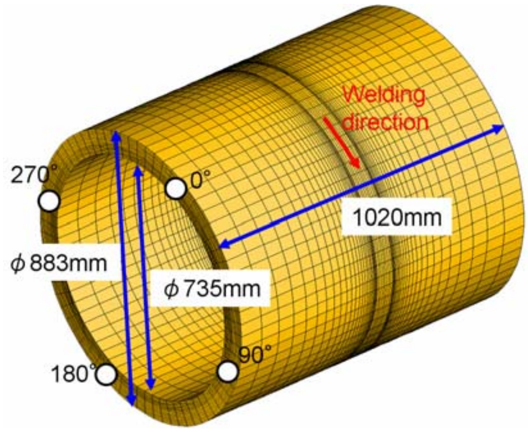
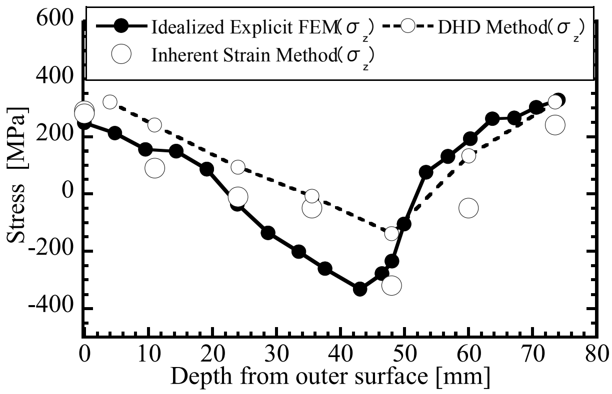
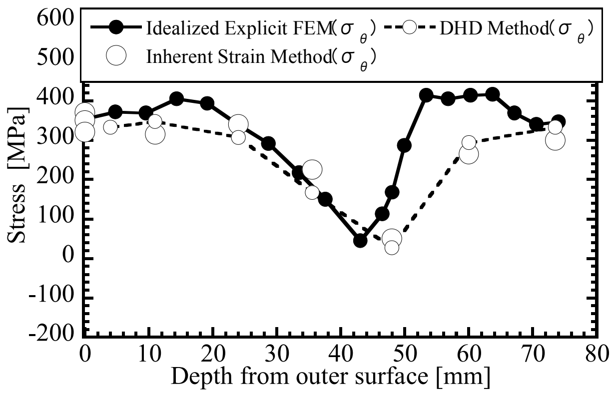


Fig.2 FE mesh division.



(α) Axial stress σ_z



(b) Hoop stress σ_θ

Fig.3 Comparison of stress distribution between measurement and FE analysis

residual stress in the weld metals is investigated.

2.2 Comparison of GPIE-FEM with experimental measurements

To verify the validity of the GPIE-FEM as applied in this study, we compared the analytical results with those obtained by inherent strain method and DHD method [4]. Figures 3(a) and (b) show the comparison of these results in terms of the axial (perpendicular to the welding line) and hoop stress distributions, respectively. Thus, it was shown that good analytical accuracy is possible using GPIE-FEM technique for the analysis of residual stress in multi-pass welded joints.

3. Conclusions

Using GPIE-FEM method, we performed a residual stress analysis of a cylindrical multi-pass dissimilar weld joint. The conclusions obtained in this study is as follows;

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1) The use of GPIE-FEM enables analysis of the residual stress in 50-pass cylindrical dissimilar joints with practical computing time, which is difficult with general-purpose FEM analytical codes.
2) The analytical results obtained by the proposed method were in good quantitative agreement with the measurements obtained by the inherent strain method and DHD method and thus indicate the capability of this method to attain good practical accuracy.

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