Finite element simulation of multi-pass welding process with rezoning technique†

—Fast prediction for welding deformation and residual stress—

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KEY WORDS: (Finite element simulation) (Multi-pass welding) (Rezoning technique) (Welding Deformation) (Residual Stress) (Computational efficiency)

1. Introduction

Finite element simulation of welding process has been widely employed in engineering where welding deformation and residual stress are considered. One big problem during thermal elastic-plastic simulation is the severe demands of hard disk capacity and computation time, especially for large structures with long weld length or multi-pass welding. Lindgren proposed an automatic rezoning procedure in simulation of welding based on a graded hexahedral element [1]. Murakawa developed an iterative substructure method to perform analysis on large scale welding problems [2]. To minimize the number of unknowns in finite element model, a rezoning technique is developed to simulate the multi-pass welding process. The local nonlinear zone around the pass close to the heat source is modeled with a dense finite element mesh, while the region of other passes is modeled with a coarser mesh. Then the model is redefined pass by pass to represent the filling of the metal and the motion of the weld arc. Three-dimensional finite element simulations with and without rezoning technique are performed to obtain transient temperature, welding deformation and residual stress. By comparing the results of the model, computational efficiency and accuracy of the proposed method is confirmed.

2. Analysis Procedure and Rezoning Technique

In the rezoning model, the deformed geometry after one welding pass is rebuilt by different nodes and elements, and exact locations of the new nodes are determined by a large number of high order simultaneous equations [3]. The Newton-Raphson method is employed to solve the equations and just several iterations are needed to achieve convergence. Variables such as temperature, strain and stress are mapped from the old mesh to the new mesh after obtaining the equivalent solving space. The multi-pass welding process is then simulated pass by pass, with the FE model changed in the mesh density and the filling of metal. Thermal and mechanical analyses are implemented by three-dimensional FEM. The welding joint is also simulated by thermal elastic-plastic analysis in full model. The computational results with and without rezoning technique are compared.

3. Results and Discussion

Figure 1 shows the shape and size of a multi-pass welded butt joint. Thermal-mechanical sequentially coupled analysis procedure is employed in this study. Heat input is simulated by surface and body combined heat source. It is significant to accurately evaluate temperature distribution in prediction of reliable welding deformation and residual stress. **Figure 2** shows temperature history at two specific points in the full model and rezoning model. The results agree well for the two points in transient time.

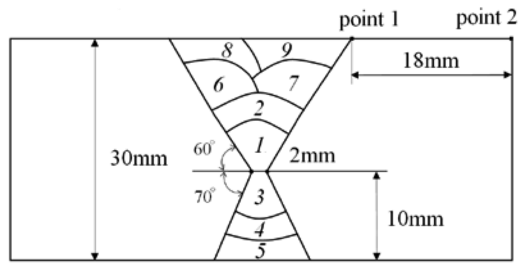

Fig. 1 Shape and size of the multi-pass welding joint

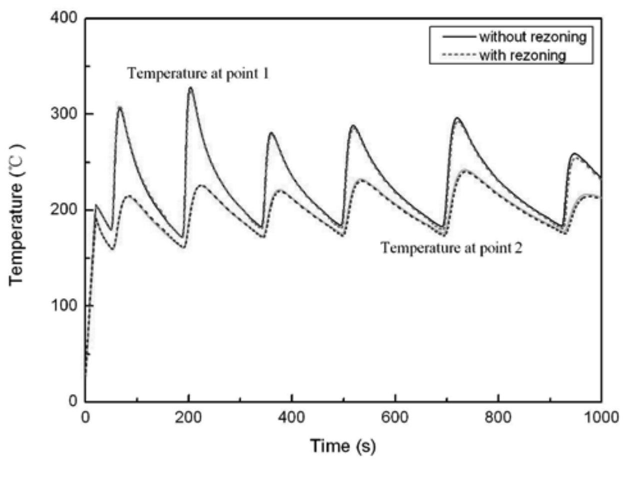

Fig. 2 Temperature history of two points

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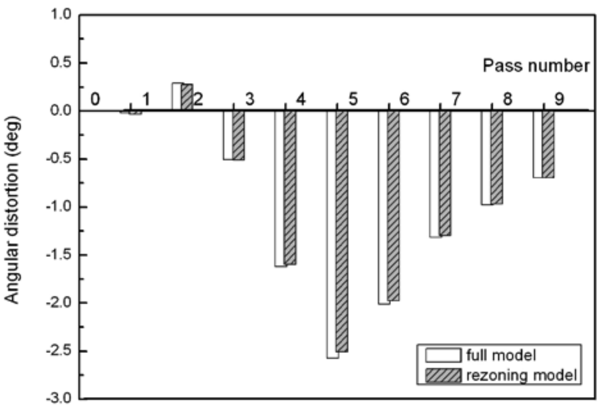


Fig. 3 Angular distortion in each welding pass

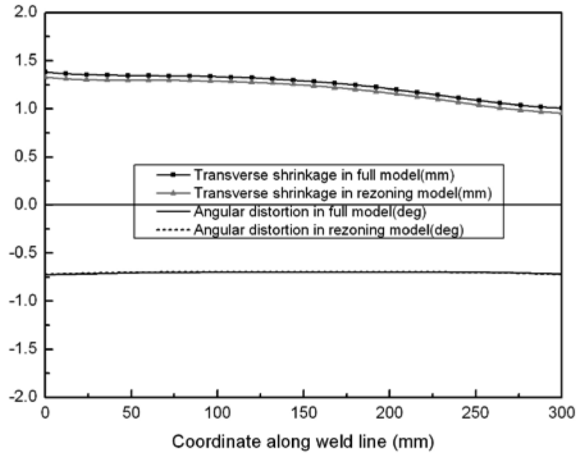
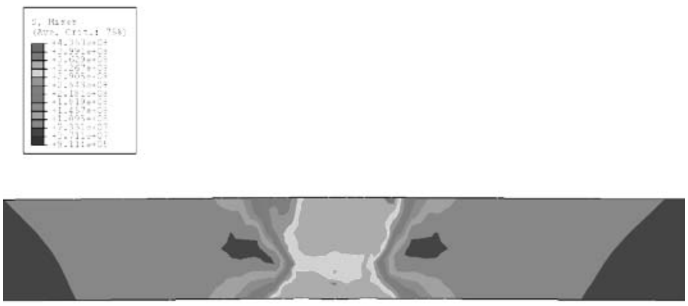
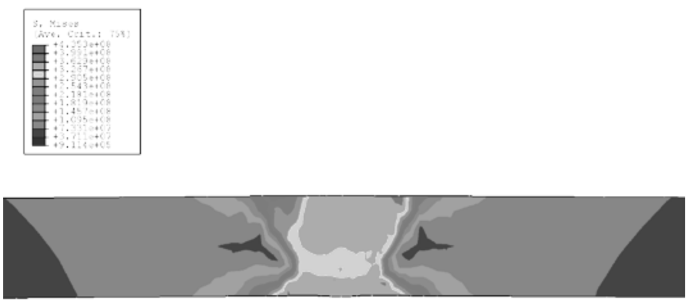


Fig. 4 Welding deformation of the multi-pass welding joint



(a)



(b)

Fig. 5 Comparison of Mises stress field on middle cross-section: (a) without rezoning (b) with rezoning

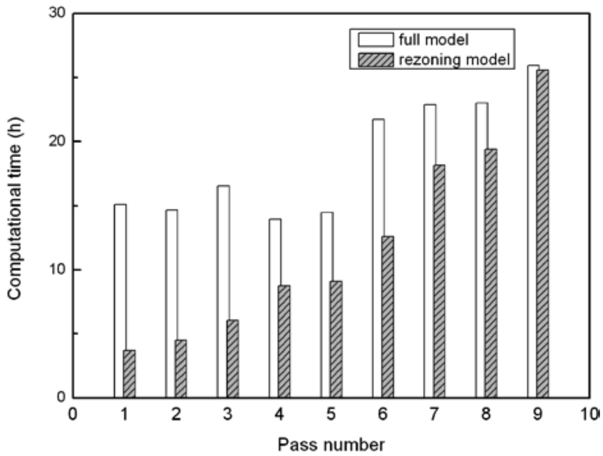


Fig. 6 Comparison of simulation time for each welding pass

Angular distortion at the middle cross section of the plate normal to the weld line after each welding pass is shown in **Fig. 3**. Transverse shrinkage and angular distortion of the two different models after cooling are shown in **Fig. 4**. It can be seen that the simulated results of rezoning model agree very well with the full model.

Figure 5 shows Mises stress field on the middle cross-section of the model with and without rezoning technique. The material in the fusion zone exhibits high stress level and most of the points have reached the initial yield strength. The difference of residual stress distributions between full model and rezoning model is very small. Computational time for each welding pass is shown in **Fig. 6**. The full model requires almost the same time for each pass since the mesh is not changed during the simulation. It can be found that computational time increases by pass in the rezoning model. This can be explained by the fact that the mesh scale becomes larger as the pass number increases. The mesh of the rezoning model for the last welding pass is the same with that of the full model. Total simulation time of the model with and without rezoning is listed in **Table 1**.

Table 1 Total simulation time

	Simulation time (h)
With rezoning	107.8
Without rezoning	168.3

It should be noted that, the first five welding pass can be simulated in half a model due to the symmet of the problem. Then the full model can be obtained by reflecting the half model to fulfill the consecutive passes. It can be expected that more computational time will be saved without loss in accuracy. In the present study, mesh coarsening has not been implemented. The relationship between coarsening criterion and solution accuracy is under investigation to gain more reduction in solution time.

4. Conclusions

Multi-pass butt joint welding process is simulated by three dimensional FEM in both rezoning model and full models. Transient temperature, welding deformation and residual stress calculated in rezoning model agree well with that of full model. Computational time of the simulation is reduced by 36% with a rezoning technique for the studied model. Effectiveness and efficiency of the proposed method is confirmed.

References

[1] L. E. Lindgren, H. A. Haggblad, J. M. McDillb: a.s.oddy, Comput. Methods Appl. Mech. Engrg. 143(3)(1997), pp.401-409.

[2] H. Murakawa, I. Oda, S. Ito, H. Serizawa, M. Shibahara and H. Nishikawa: J. Kansai Soc. N. A. Japan, 243(2005), pp.67-7 0 .

[3] S. B. Brown and H. Song: ASME J. Engrg Industry, 155(1993), pp.415-423.