Thermal elastic plastic analysis for welding problem of large scale models†

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1. Introduction

It has been more than three decades since the finite element method was first applied to the welding simulation. However, due to the poor performance of the computer, application of the FEM was limited to small scale laboratory models. On the other hand, the need for the theoretical prediction of the welding distortion and residual stress, especially in the industries, has kept growing. To meet this demand, authors developed an FE code which is specially designed for efficient computation so that complex and large welded structures or welded parts produced in industry can be simulated. In this paper, the idea of iterative substructure method (ISM) [1-5] and its advantage for large scale problems are discussed. Also, its potential capability is demonstrated through an example problem with more than million elements.

2. Concept of Iterative Substructure Method

If the problem can be separated into a large but constant stiffness problem and a small moving nonlinear problem, the computational time can be reduced by using an iterative substructure method. As schematically shown in **Fig. 1**, the region B which exhibits strong nonlinearity is limited in a small region compared to the whole model A to be analyzed. In ISM, the problem is reformulated as follow.

(1) The region B is the region with strong nonlinearity.
(2) The region (A-B) is the mostly linear region.
(3) The boundary Γ is the boundary between regions (A-B) and B.
(4) The virtual region A' is the model in the past. The difference from region A is that its stiffness is unchanged until updated.
(5) Solve the region (A-B) using the stiffness of A' and solve the region B using current stiffness.
(6) The continuity on the boundary Γ is maintained through the iterative procedure.

The detail of the iterative solution procedure is shown in the following and in **Fig. 2**.

(a)Solve A using the stiffness of A' and compute

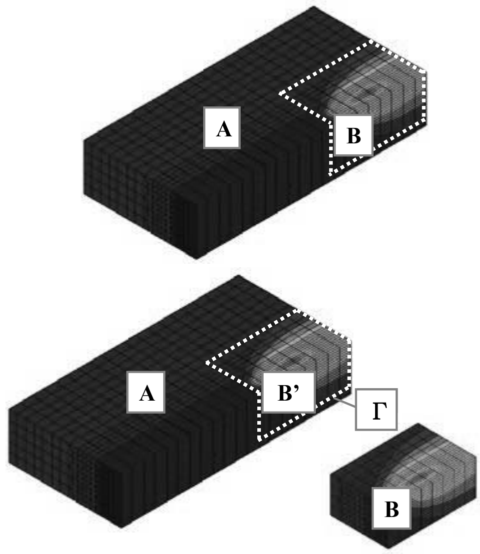

Fig. 1 Concept of Iterative Substructure Method.

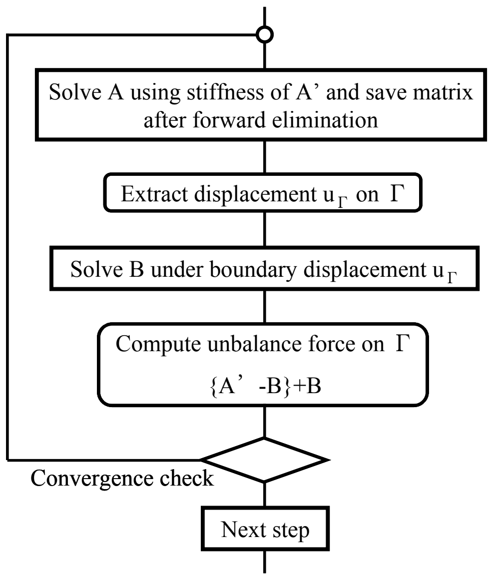

Fig. 2 Flow chart of iteration.

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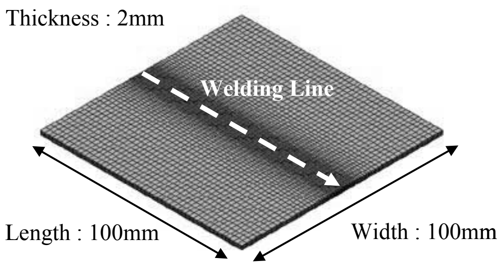

Fig. 3 Model for analysis.

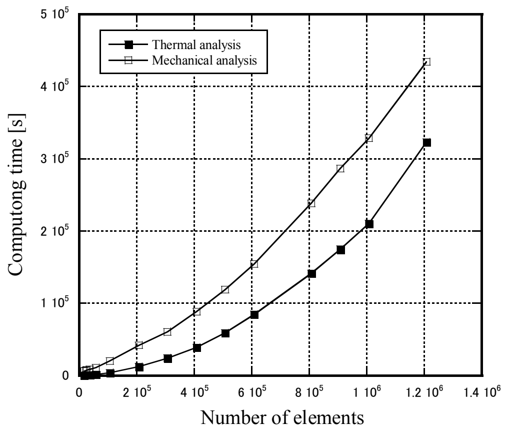

Fig. 4 Relation between computing time and number of elements for thermal and mechanical analysis.

displacements in the whole model. If the updated stiffness of A is used, save the stiffness matrix after the forward elimination.

(b) Solve B by using the displacement on Γ computed in step (a) as the boundary condition. In this way, the continuity of the displacement on the boundary Γ is maintained. This solution process is nonlinear and the Newton-Raphson iterative method is employed.

(c) Compute the unbalance force between the reaction forces from (A'-B) and B.

(d) To recover the continuity of the traction, feedback the above unbalance force to step (a) and compute the correction for the displacement on the boundary Γ.

(e) Repeat steps (a) through (d) until the convergence is reached.

3. Capability of ISM for Large Scale Welding Problems

The model is a simple bead on plate welding model with different width. In all cases, the thickness and the length of the plate is fixed as 2 mm and 100 mm, respectively. The width of the plate is increased from 100 mm to 12,000 mm so that the number of elements is increased from 18,000 to 1,208,000. An example for the case with 18,000 elements is shown in **Fig. 3.** The relations between computing time and the number of elements are shown in **Fig. 4**. For these computations, Intel Xeon W5590 (Quad Core 3.33GHz, 96GB) was used under single core mode. According to Fig.4, the mechanical analysis of the model with 18,000 elements can be completed in 6,542 seconds (1.8 hours), and the model with 1,208,000 elements can be computed in 434,010 seconds (120.5 hours).

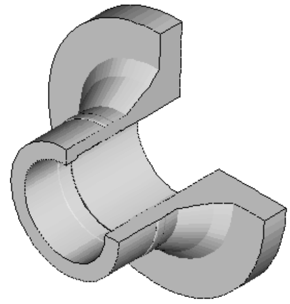

Fig. 5 Geometry of weld joint with cross-section.

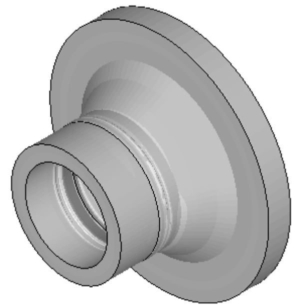

Fig. 6 Distribution of axial component of residual stress.

4. Preliminary Computed Results for NRC Round Robin

The second example is the preliminary computation of the welding residual stress in the nozzle shown in **Fig. 5**. This model is proposed by US Nuclear Regulatory Commission for International Weld Residual Stress Round Robin [6]. As a preliminary analysis, the residual stress produced by the welding between the nozzle and the safe end was computed. The outer and the inner diameter of the safe end are 381 mm and 284.5 mm, respectively. This model is divided into 63,000 elements. There are 40 and 27 passes on the outer and the inner sides. In the computation, only the welding passes on the outer and inner surfaces are computed using moving heat source and a stationary ring shape heat source (equivalent to axi-symmetric model) is used for the rest of the passes. For this computation, the total computing time for the mechanical analysis is 53.6 hours. The distribution of the axial component of the residual stress is shown in **Fig. 6**. Through this preliminary computation, it is found that the full computation using a moving heat source for all passes can be completed in about 8 days.

5. Conclusions

ISM was developed based on the idea to separate the nearly linear region and the nonlinear region in an efficient way. In order to examine the effectiveness of this method, the bead on plate welding was analyzed as example. From that computation, it is found that the computational time is drastically reduced by using ISM and its advantage becomes greater when the number of elements increases.

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