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Ultra Large Scale FE Computation Using Idealized Explicit FEM Accelerated by GPU

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1. Introduction

Due to the recent advances of numerical simulation in science and technology, finite element method (FEM) are widely used for mechanical analyses of actual structures. In particular, FEM is widely applied to design and production. However, for welding problems, the application of FEM is limited to the level of joint welding and is rarely applied to large-scale welding problems. The reason is that; the welding is transient and strongly nonlinear problem and static implicit FEM must be used for accurate simulation of 3D stress and deformation. Static implicit FEM requires large computer memory and computation time when large scale structures are solved. Then, we developed idealized explicit FEM (IE-FEM) for utilization in high-speed small-memory analyses.

As IE-FEM is based on a dynamic explicit FEM, it can be analyzed by independent sequential computation of each element and each analytical degree of freedom (DOF). Then, we develop new parallelized idealized explicit FEM (PIE-FEM) using graphics processing units (GPUs), which have become the focus of widespread interest in recent years. We evaluated this method for 3D moving heat source problems in multi-pass welding and found that it enables large-scale analysis involving approximately 1,300,000 DOFs on a single commercially available PC. Such an analysis is extremely difficult with commercial FEM software.

2. Application of GPU-accelerated parallelized idealized explicit FEM (GPIE-FEM) to large-scale analysis of multi-pass welding

Fig. 1 shows the analytical flow for GPIE-FEM. In the present study, we investigated the application of this method to a large-scale problem of multi-pass welding.

2.1 Analytical model

Fig. 2 shows the mesh division used in this study in the overall (a) and weld metal (b) regions of analysis. The analysis was performed using 1,283,205 analytical DoFs, 427,735 nodes, and 412,400 elements. The welding conditions consisted of 17 V welding voltage, 120 A welding current, 6.66 mm/s welding speed, with a thermal efficiency of 0.5 and an assumed interpass temperature of

250°C. The 33-pass welding sequence is shown in Fig. 3. The computer used for this analysis was a Core i7 2.66 GHz CPU, 12 GB RAM memory, with three GeForce GTX 285 GPUs, each having 240 computing cores.

We performed an all-step sequential analysis by the GPIE-FEM for 56,320 temperature steps, as determined by a thermal conduction analysis.

2.2 Results of analysis

Fig. 4 shows the distribution of stress in the direction of y (σ_y) in the central cross section and on the surfaces from the central cross section to the terminal edge. Fig. 4(a) shows the distribution on the completion of 1st welding pass. The distribution on the completion of 8, 15, 22, 29, and 33 welding passes is shown in Fig. 4(b) to (f). The figure clearly shows the overlays formed by consecutive

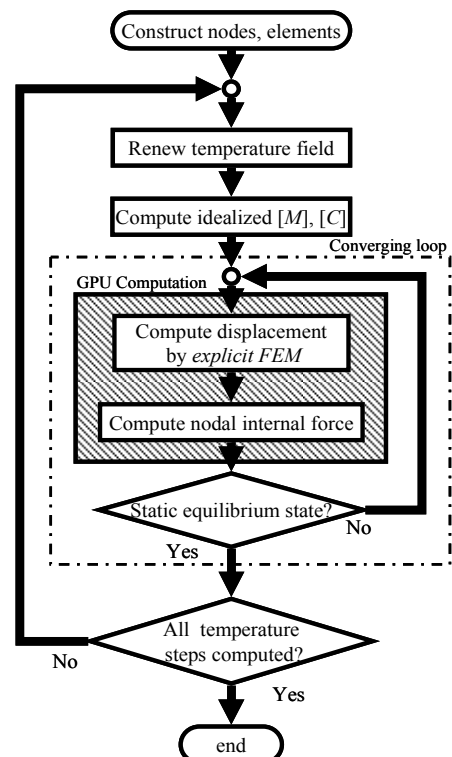
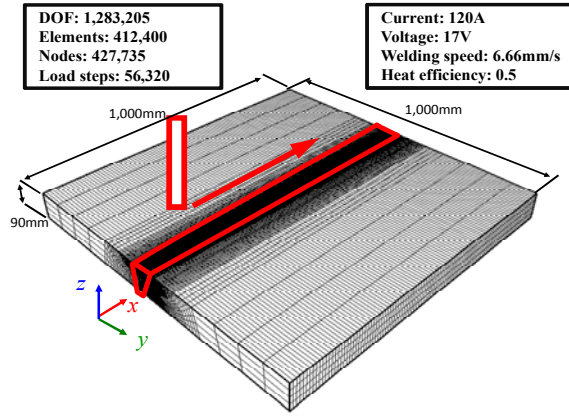
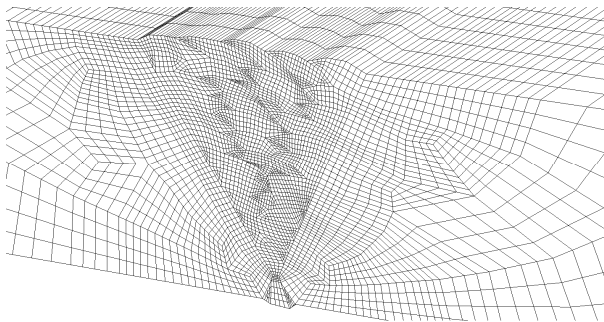


Fig. 1 Computing flow of Parallelized Idealized Explicit FEM using GPU.

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(a) Overall mesh division



(b) Zoomed mesh division

Fig. 2 FE mesh division of multi-pass welding model.

passes. The finely detailed stress distribution can be seen and the relatively high stress occurs near the pass overlays just after welding. The computing time for the deformation and stress analysis was approximately 108 hours, which is considered to be within the practical computing time.

The results of this analysis indicate that the proposed method will be highly useful, because the analyses of transient stress behavior of each welding pass are extremely important for the avoidance of stress corrosion cracking and fatigue cracking in various type of structures. Therefore, this method is promising for the extension to not only general structural problems, but also thermal elastic plastic

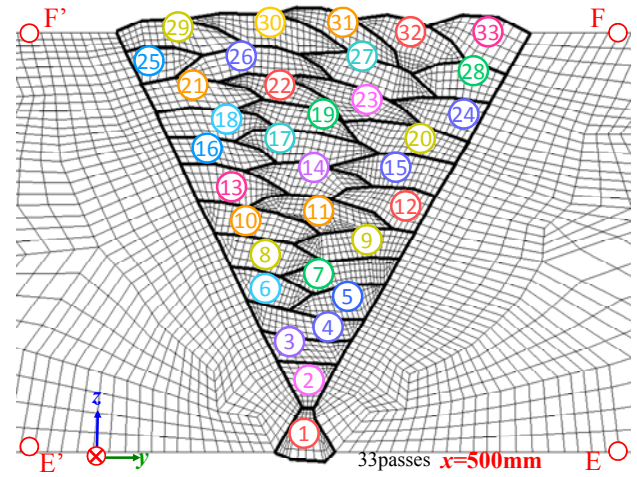


Fig. 3 Welding sequence of multi-pass welding.

problems, creep problems, geometric nonlinearity, and other problems.

3. Conclusions

In this study, parallelized idealized explicit FEM with GPU (GPIE-FEM) acceleration is developed for the purpose of large-scale high-speed analysis of problems in welding mechanics. This method was applied to a T-joint welding problem to verify its usefulness and validity and following conclusions are obtained.

- 1) The proposed GPIE-FEM enables analysis of problems involving phenomena of long duration, such as those of the cooling process in welding problems, which are generally difficult to be analyzed by dynamic explicit FEM.
- 2) By using the proposed method for the analysis of the large-scale multi-pass welding problem with 1,283,205 analytical DOFs, 427,735 nodes, 412,400 elements, and 33 passes, it was possible to complete the transient stress and deformation analysis for all of the welding passes in a computing time of approximately 108 hours.

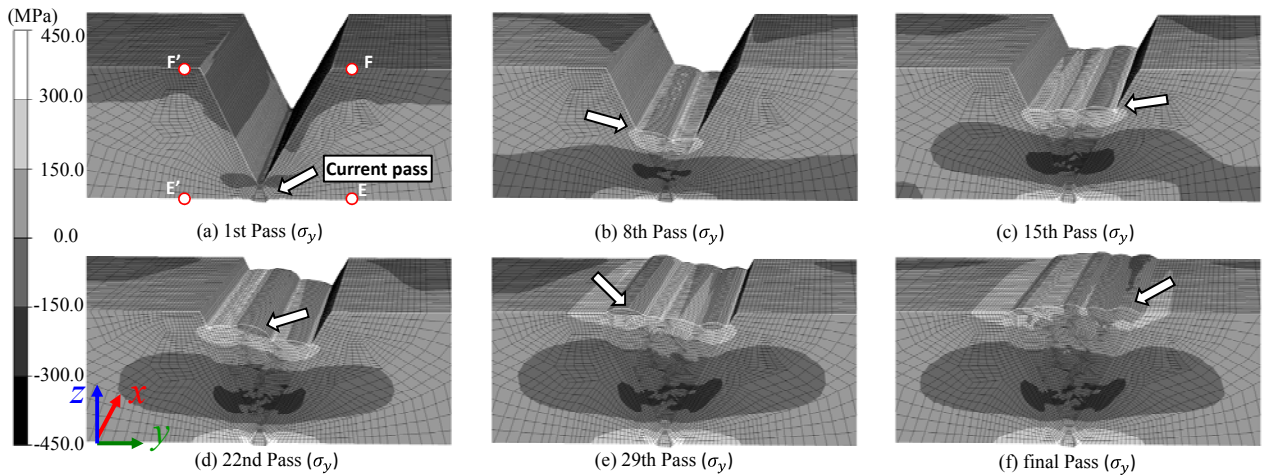


Fig. 4 Distribution of stress σ_y at interpass temperature on transverse cross section.