High Performance Computing Tools For Advancing Materials Joining Technology

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Need

Integrated computational weld engineering (ICWE) simulation tools are increasingly needed in nearly all industry sectors to optimize process and performance of welded structures. However, welding simulation is very time consuming with today's computers. It can take weeks or months to perform a detailed simulation with sufficient fidelity to achieve design and manufacturing optimization of a vehicle structure welding process or welding of nuclear reactor components shown in Fig. 1.

This project aims to create new HPC-based ICWE modeling tools to reduce the computational time to days or hours which is essential in order to create value by optimization of welding technology and proactive mitigation of the detrimental welding-induced residual stresses/distortion.

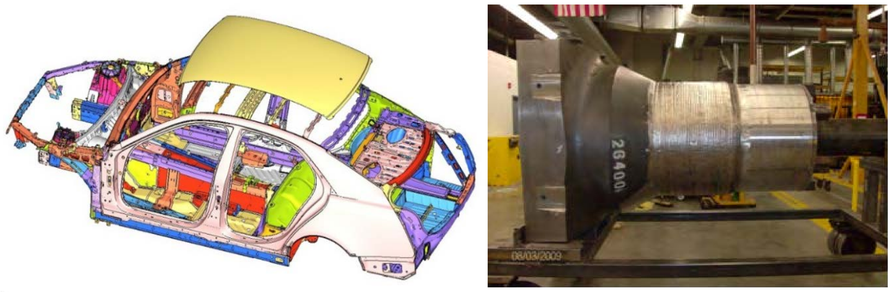

Fig. 1 Illustrative targeted industrial welding simulation: (a) laser seam welding of large roof panels in auto assemblies and (b) repair welding of a 36-in diameter pipe to a nuclear reactor vessel with several hundreds of passes and over 1500 lbs of weld filler metal.

Approach

Develop an HPC based ICWE simulation tool with an approximate 100X order of magnitude increase in computational performance, compared to today's commercial welding process simulation tools

- Apply explicit FEM based solver with a novel acceleration scheme to drastically speed up welding simulation (formulated based on insight of unique physical features of welding processes).
- Effective use of massive parallel computers (with sufficient performance scalability on cluster type HPC having 500 to 2000 processing cores)

Results and Status

- New project from the 2016 Spring call. CRADA completed in Feb, 2017
- Initial code development has already demonstrated the potential for major computational time reductions with the newly developed novel acceleration scheme (under patent filing) for stress analysis:
  - Laser welding: initial speed-up was in the range of 20-100X (Fig 2)
  - Arc welding: initial speed-up was in the range of 15-50X (Fig 3)
  - Refinement of acceleration scheme to control errors *a priori* is ongoing (Fig 4)
- Implementation of the new welding simulation code in HPC cluster is ongoing.

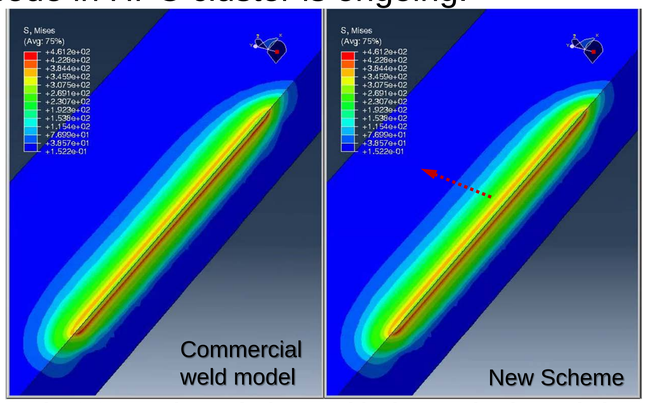

Fig. 2 Comparison of Mises residual stress in short stitch laser welding of thin-gage steel (auto-body welding scenario)

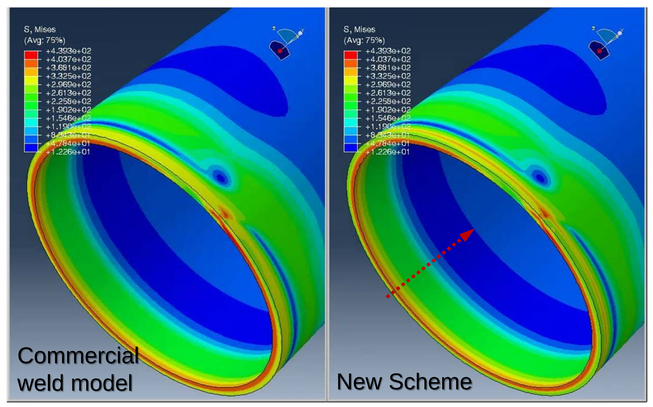

Fig. 3 Comparison of Mises residual stress in arc welding of steel pipe girth weld (nuclear reactor repair scenario)

Table 1 Speed up of computational performance - initial results

Testing Cases	A	B	C	D
Welding processes	Laser	Laser	Arc	Arc
# of elements	~126,000	~126,000	~95,000	~95,000
Baseline CPU time, sec	49,329	51,831	58,217	61,048
Speed-up factor	115.9x	28.7x	44.8x	30.1x

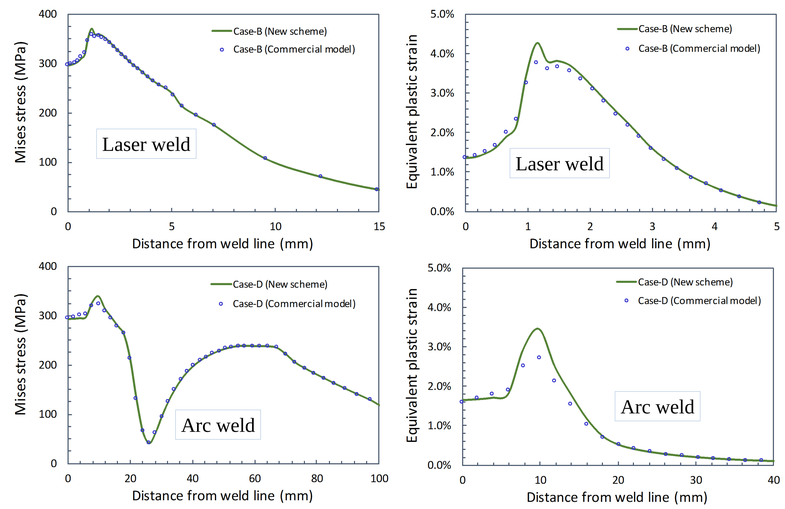

Fig. 4 Comparison of Mises stress and equivalent plastic strain distribution along transverse lines as depicted in Figs. 2&3

Benefits

The HPC based ICWE modeling tools allow for advanced CAE of welding fabrication options or scenarios in a practical timeframe. This project aims to reduce the time for a welding simulation from 12-15 weeks on today's workstation computer to less than 24 hours. The value add for our industrial team members would be the ability to realistically evaluate welding innovations numerically rather than rely on expensive and time consuming iterative physical trial and error methods.

HPC based ICWE simulation tools would have significant impact on energy savings, productivity, manufacturing cost reduction, reducing product development cycle, and the overall competitiveness of US welding industry. They will accelerate welding technology development across a broad spectrum of industries from automotive to nuclear energy.

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