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Welding Models and Simulation for the Perfect Weld

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Abstract:

Welding models, simulation algorithms, and computational welding mechanics (CWM) are now mature and can predict thermal, microstructural and mechanical aspects of welding with a good level of reliability. In addition, the fast-growing power of computation helps make the use of large and complex welding models much more feasible in terms of time and cost for actual structures. In other words, welding Engineers are now capable of using modern high power computing methods for designer-driven optimization of welded structures and related welding procedures for all levels of application. Using such a capability supports welding engineers allowing them to apply their creativity, expertise and skill to be optimal, more productive, and innovative when developing solutions to welding problems. The author will demonstrate projects performed and present the benefits of using welding models and simulation; and more importantly the synergy of combined welding modeling capability with extensive practical experience of welding engineers. This enables them to design and deliver complex methods for control of distortion, residual stress, sequence planning, microstructure control, fracture, and repair welding on high value assets.

Introduction

Welding models, simulation algorithms, and computational welding mechanics (CWM) deal with high performance computer algorithms, and software to predict the behavior of welds in the welded structures. CWM started developing early 1970s for practical weld engineering [1] and it is now maturing with a good level of reliability including complex physics of welding, material modeling, and stress–strain dependency on temperature and evolution of microstructure [2]. From 1980 to 2000, CWM capability evolved rapidly and, then after 2000, CWM is being adopted quickly by industry. Recent activities further has focused on computational strategies and how they are integrated with other approaches to facilitate the use of simulations in industrial scale engineering with sizeable geometry and real-world complexity [3,4]. Increasing power of computation provide a platform for performing more complex CWM algorithm for achieving a perfect weld including interactive integration of CWM framework with other packages and robots.

Welding Engineering companies are now capable of using modern high power computing methods for the designer-driven optimization of the design of welded structures and related welding procedures for all levels of application. Using the state of the art CWM platform for weld modeling combined with practical experience, their welding engineers apply their creativity, expertise and skill to be optimal, more productive, and innovative when developing solutions to welding problems.

Looking at a big picture from strategic planning document for welding industry around the globe, the general trend is walking in the same path of conducive environment for using weld modeling and simulation as part of welding engineering. American Welding Society (AWS) vision of 2020 indicates that *"welding moves from being an art to being a manufacturing science with the help of computers"* [5]. AWS vision 2020 introduced the term *"virtual factory where modeling and simulation tools become commonplace in welding operations"*. Technology Road Map for the Canadian Welding and Joining Industry vision of 2016 highlighted that *"Incorporate welding and joining considerations early in product-design stage [using computer models]"* [6]. European Federation for Welding, Joining and Cutting (EWF) used the term *"Smart Factories where advanced computer modeling, automation and control are key technologies to help welding become more competitive, energy-efficient and innovative as part of manufacturing"* [7]. If you look at similar documents around the world including Japanese Welding Engineering Society (JWES), Asian Welding Society (AWS) objectives, and the annual report of the International Institute of Welding (IIW), they encourage incorporating welding simulation as part of our welding engineering routine. One can conclude that it is fostering and eventually coming to every fabrication that remains serving in the welding industry. In this paper, authors share few examples of their industrial work conducted by the mean of CWM.

Residual Stress Quantification

Born of CWM can be tracked down into the need for calculation of residual stress as an alternative to limited and expensive experimental measurement. Residual stress affects the service life and condition of weldment during course of service if it doesn't introduce immediate problems during the manufacturing process. Weld modeling is the most cost effective method to generate a 3D map of all stress components during and after welding as well as interaction with operation loading condition for fatigue and creep analysis. This leads to optimal design for enhancing service life and can avoid further cost of rejected parts from service. Figure 1 shows 3D map of final residual stress after welding computed as part of a repair engineering project on a cracked drum. A drum 3.6 [m] OD made of 1 in thick A36 steel was cracked in service along the fillet weld connecting thrust ring and stiffener web to the drum plate. The cause of crack was reported fatigue loading and therefore the effect of residual stress was asked to be quantified on the remaining life of structure while our team of engineers was developing a repair solution and plan.

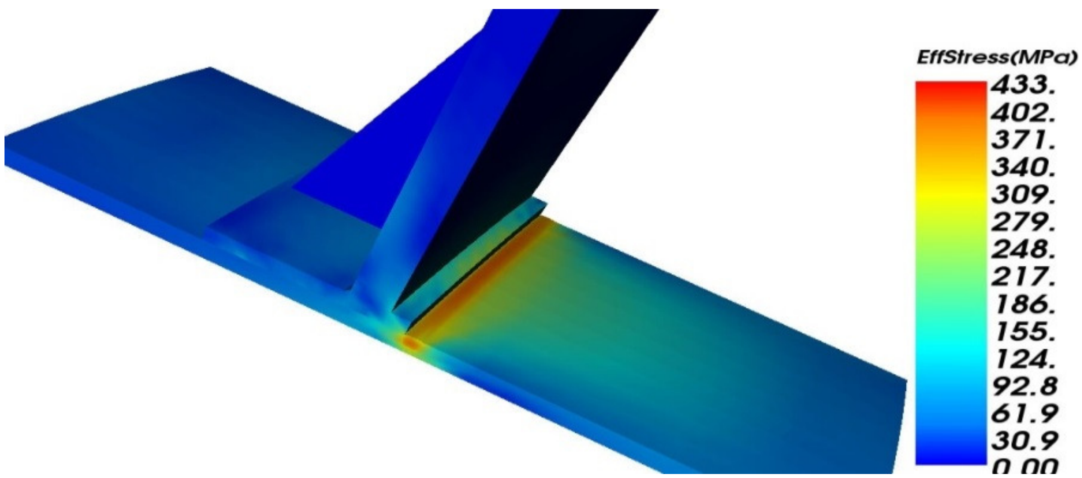

Figure 1 Residual stress computed as part of a repair engineering project on a cracked drum

Weld Distortion Control

Weld distortion is the most frequent problem in welding and many techniques have been developed over time to mitigate the distortion or in some case achieve zero distortion. Simulation and modeling enables the designer to optimize complex methods and techniques including adaptive clamping and process control.

In multiple welding, weld sequence planning provides an opportunity to manage the plastic strains and stress condition by counter balancing and/or locking effect on one weld from another. Over many years, this has been employed for reducing distortion in panels and bars; however routine industrial practice of welding engineering in weld sequence planning is generally limited to intuition-based designs that are mainly based on the recommendation or similar practices. This approach becomes difficult to be effective in large scale multiple welding involving several welds on a complex geometry. A general recommendation is to use a simulation code to predict the distortion of different weld sequence scenarios. Figure 2 shows 3D welding distortion after welding is completed as part of a repair engineering project on a cracked drum. The transient distortion was computed during and after all weld passes.

Many techniques have been developed since 1960s to mitigate the welding distortion. The concept of these techniques were well understood; however, practical implementation of them depends mainly on the power of running large-scale optimizations. It is often difficult or very expensive to experimentally determine the best configuration of design parameters for the techniques. CWM has enabled studying the weld mitigation optimization with extended scope beyond the limit of experimental optimization. In the past decades, several mitigation methods have been studied using CWM such as pre-bending, pre-offset, thermal tensioning, or by using optimized weld prep.

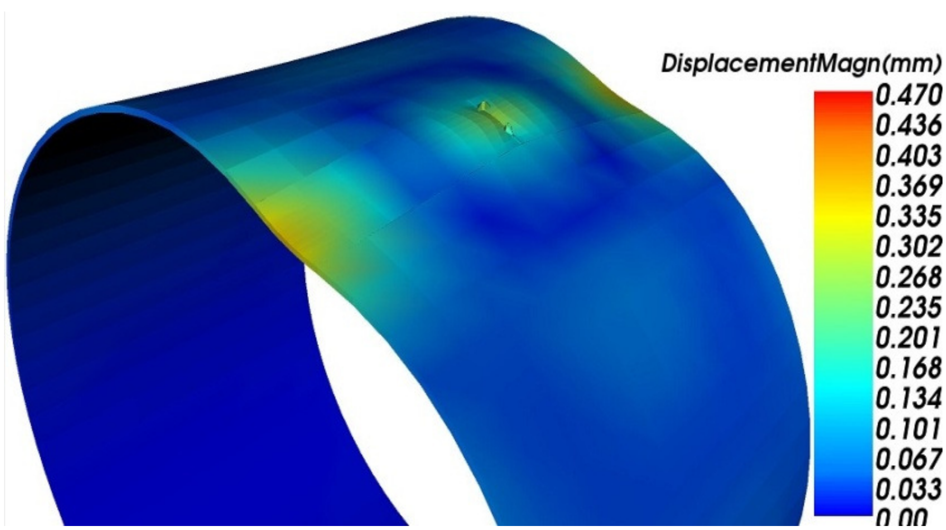

Figure 2 Welding distortion computed as part of a repair engineering project on a cracked drum

Microstructure Evolution

Microstructure evolves inevitably through rapid heating and cooling cycle from welding and this evolution differs from point to point in the weld and Heat Affected Zone (HAZ). CWM models predict the 3D evolution-map of different materials' microstructure e.g. steel's microstructure for Ferrite, Pearlite, Bainite, and Martensite. The essential idea is that a pseudo-Iron-Carbon phase diagram in which all lines and points are functions of the alloy composition is used to estimate the equilibrium microstructure of the alloy at any time and temperature. Then the kinetics of the transformation of the austenite or gamma phase to ferrite, pearlite, bainite, and/or martensite phases, which try to drive the microstructure toward an equilibrium state, is considered. Hardness of the alloy can also be computed by rules of mixtures. Figure 3 and Figure 4 show the microstructure map computed for different repair phases as part of a repair engineering project on a cracked drum. The electrode was E 7018 which was considered in microstructure model as different weld metal and base metal. The high hardness and martensite formed in start and end locations of welding beads suggested performing either additional temper bead, specific PWHT, or grinding on start and end welding locations to avoid forming new fatigue crack in the course of service.

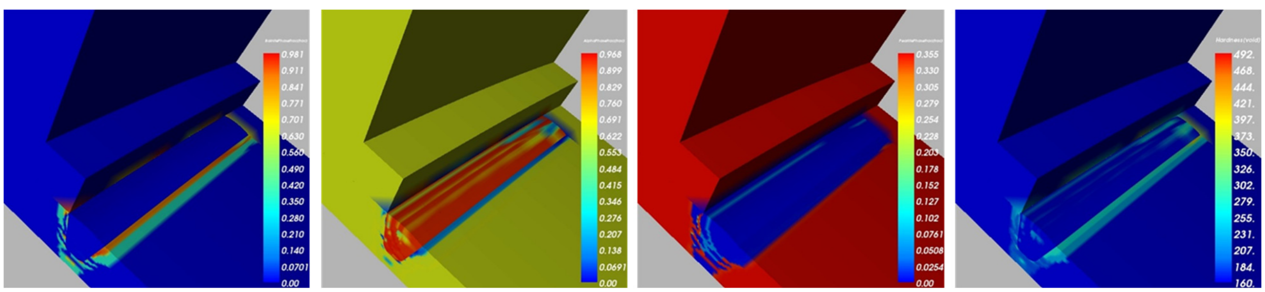

Figure 3 Microstructure map computed for first repair phase as part of a repair engineering project on a cracked drum. From left to right; Bainite, Pearlite, Ferrite, & Hardness.

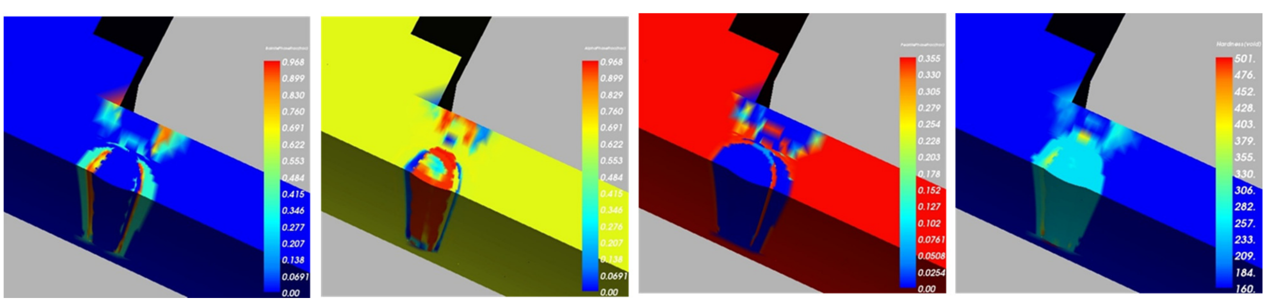

Figure 4 Microstructure map computed for first repair phase as part of a repair engineering project on a cracked drum. From left to right; Bainite, Pearlite, Ferrite, & Hardness.

Conclusion

Repair welding is among the most challenging welding engineering since 1) it is usually for high value assets, 2) operational down-time is critical, 3) generally there is no past experience or similar case, 4) no risk of mistake is acceptable, 5) repair procedures are not directly dictated from standards, 6) the condition of weldments has changed over time, and 7) limited available information on older structures & welds. Using CWM enables weld engineers to model weld and welding procedures on existing old structures for an optimal repair process. That should be validated through experimental lab and mock-up tests to assure delivery of high quality and risk-free repair procedure.

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