L3 Milestone
Use Computational Model to Design and Optimize Welding Conditions to Suppress Helium Cracking during Welding

June 2012
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Background and Objectives

Today, welding is widely used for repair, maintenance and upgrade of nuclear reactor components. As a critical technology to extend the service life of nuclear power plants beyond 60 years, weld technology must be further developed to meet new challenges associated with the aging of the plants, such as control and mitigation of the detrimental effects of weld residual stresses and repair of highly irradiated materials. To meet this goal, fundamental understanding of the “welding” effect is necessary for development of new and improved welding technologies.

Welding repair of irradiated nuclear reactor materials (such as austenitic stainless steels used for the reactor internals) is very challenging because the existence of helium in the steel, even at very low levels (i.e. parts per million), would cause cracking during repair welding. Helium is a product of the boron and nickel transmutation process under intense neutron irradiation. As the service life of nuclear reactors in the US prolongs, the amount of helium in the structural materials in certain highly irradiated areas will continue to increase, potentially to a level that the current welding repair technologies cannot be used reliably.

Under the influence of high temperatures and high tensile stresses during welding, rapid formation and growth of helium bubbles can occur at grain boundaries, resulting in intergranular cracking in the heat-affected zone (HAZ). Over the past decades, a basic understanding has been established for the detrimental effects of weld stresses on the helium induced cracking. However, practical methods for weld repair of irradiated materials are still evolving.

The **overall objective** of this task was to develop advanced welding technologies that can be used to repair highly irradiated reactor internals without helium induced cracking. Toward this goal, we have developed a computational model that can be used to gain a fundamental understanding of the effect of welding stress and temperature on the formation helium induced cracking during welding. The computational model was then used to design and optimize a novel welding approach to suppress helium induced cracking reported herein.

Methodology and Results

Recognizing the critical role of tensile stresses, we conceptualized an approach to suppress helium induced cracking by means of in-situ stress alternation through proactive thermo-mechanical management during welding. Extensive computational modeling was conducted to derive the specific welding conditions that can suppress the formation of helium cracking during welding. As it is under consideration for patent application [1], the specific details of the approach are not disclosed here. Nevertheless, the effectiveness of the approach is illustrated below.

Figure 1 shows a snap shot of the temperature distribution during welding of an AISI 304 stainless steel plate under the typical welding conditions used by the industry. Figure 2 shows the corresponding evolution of temperature and stresses as function of time at two selected locations in the vicinity of the weld where helium induced cracking is most likely to occur. It can be seen in Figure 2 that the stresses quickly become tensile upon cooling. The tensile stress reaches approximately 200MPa as the weld temperature drops to 1000K. Such high tensile stresses result in the formation of helium induced cracking.

With the new in-situ stress alternation approach, the tensile stresses at elevated temperatures during welding cooling cycle can be effectively suppressed. This is shown in Figure 3. Further calculations using ONRL's integrated weld process and performance model suggests that the suppression of the tensile stresses above 1000K would greatly expand the repair welding process window so that some high helium concentration situations can be successfully repaired without helium cracking.

In addition to the modeling work reported here, ORNL and EPRI are working together as part of the LWRSP and LTO project to produce helium containing materials and to build the one-of-kind weld hot cell at ORNL to experimentally demonstrate the in-situ stress alternation technique and other advanced repair welding techniques for highly irradiated reactor internal materials. These experimental activities are progressing well according to the project schedule.

References

[1] W. Zhang, Z. Feng and E. Willis, In-situ Stress Alteration during Welding, ORNL Invention Disclosure No. 201102565.

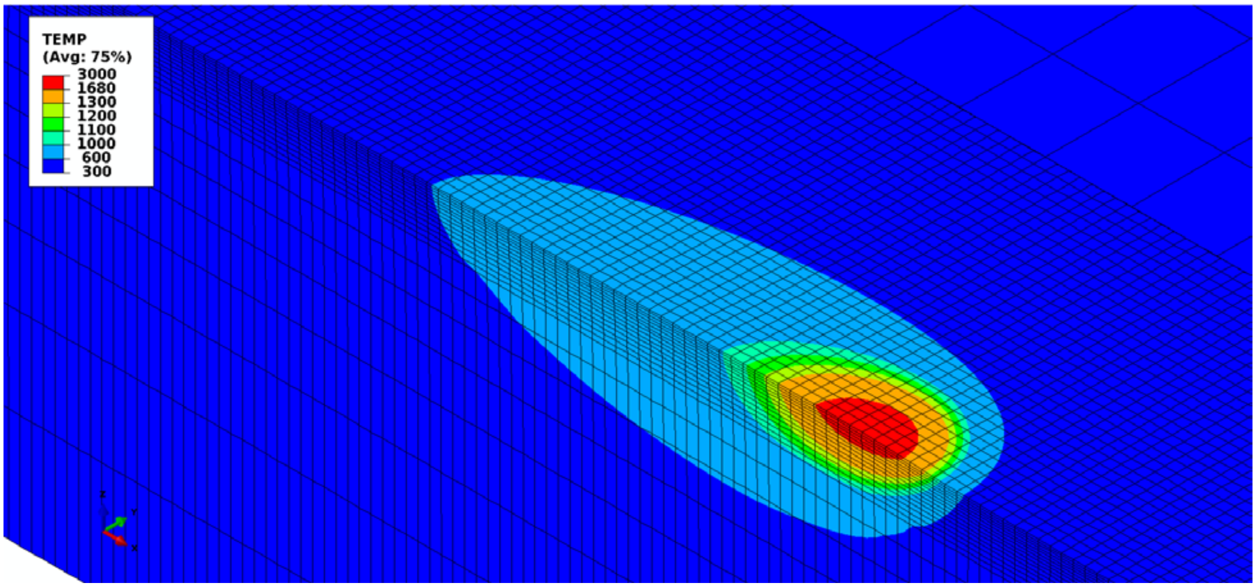

Figure 1. Snapshot of temperature distribution during welding. The temperature is given in Kelvin. Only a half of plate is shown to reveal the temperature distribution on the weld central plane.

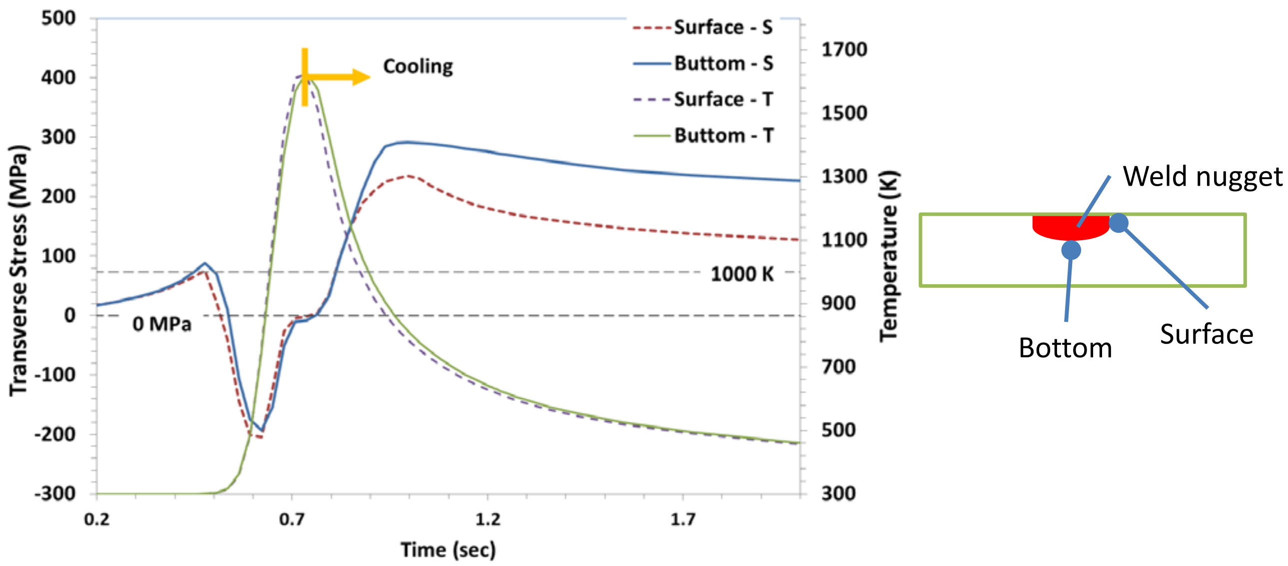

Figure 2. Evolution of transverse stress and temperature during welding at two monitoring locations in the heat-affected zone (HAZ) adjacent to the weld pool. T and S designate two different normal stress components causing cracking.

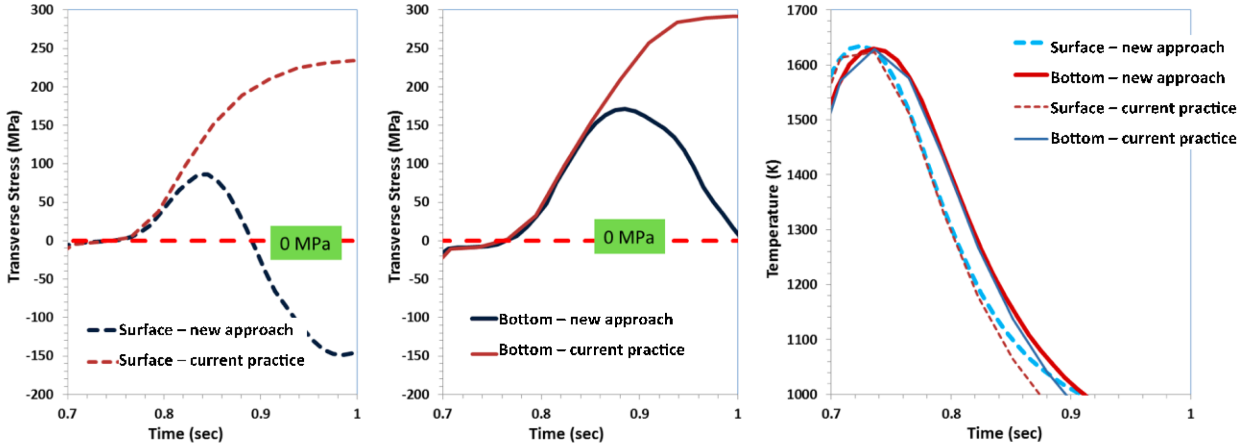

Figure 3. Evolution of temperature and stress during welding: current welding practice vs. the new in-situ stress alternation approach.