VFT COMPUTATIONAL WELD MODELING CODE ADAPTED TO WARP3D: PROBLEMS OF CRACK GROWTH AND FRACTURE IN RESIDUAL STRESS FIELDS

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Abstract

Residual stresses caused by the welding process can drive stress corrosion crack growth, affect fatigue crack growth, lead to reheat cracking issues if the components are operated in the creep regime, and can affect the fracture response of components. The Virtual Fabrication Technology (VFT™) computational weld modeling code, which can be used to predict the weld residual stresses (WRS) caused by the welding process, was adapted to the WARP3D open-source code recently. This effort describes the weld modeling process using VFT/WARP3D, provides predictions of WRS fields in several welded components, and provides crack growth predictions and fracture response in several example problems.

1. Introduction

The VFT/WARP3D weld modeling code was adapted to the Ohio Supercomputer (OSC) system for use 'on demand' to address residual stress issues and can be used subsequently to address crack growth and fracture response of components [1]. VFT consists of three modules: (i) Graphical User Interface which is used to define all weld passes in a component, define material properties, weld parameters, etc., (ii) Thermal Solution Code to predict the temperature time histories as each weld pass is deposited (since WARP3D does not have a thermal solver), and (iii) Structural solution using the temperature time histories of (ii) within the WARP3D open-source code. WARP3D was modified to permit robust convergence for the highly nonlinear computational weld modeling problem and accounts for weld material that has not yet been deposited. This effort briefly describes the VFT code and then provides examples of weld residual stresses developed for several components. Finally, crack growth within these WRS fields for several of these components is provided.

2. Results

Three example problems are discussed here: (1) weld analysis problem solution for a nuclear reactor vessel nozzle, (2) J-groove weld in a nuclear reactor head where stress corrosion crack growth was predicted, and (3) layered NASA pressure vessel with low toughness where residual stresses can contribute to fracture of the vessel. An example of the final WRS field produced from the 'on demand' VFT/WARP3D system on OSC for the nozzle weld problem is seen in Figure 1. The high level of tensile stresses (red) within the nozzle weld is a concern. Stress corrosion cracking (SCC) within this weld driven mainly be the weld residual stresses and the nuclear primary water reactor (PWR) coolant must be addressed. Procedures to reduce these tensile WRS fields or reduce them to compression in order to mitigate SCC are also discussed.

An example of crack growth shape, again driven by the WRS in the J-groove weld region of the reactor head, is shown in Figure 2 along with the computational model and WRS field. These results are normalized by the time to reach the triple point which is undesirable leakage. Such leakage can damage the ferritic head material and lead to dangerous loss of the head and containment. Additional details of this analysis and the ramifications on reactor safety are discussed. Finally, the NASA layered pressure vessel problem will be summarized. This is a case where the weld residual stresses were modeled. Since the toughness is low in these older NASA vessels the residual stresses can lead to abrupt fracture. The results showed that both the J-Integral along with the crack tip opening displacement illustrate that fracture is unlikely in these vessels.

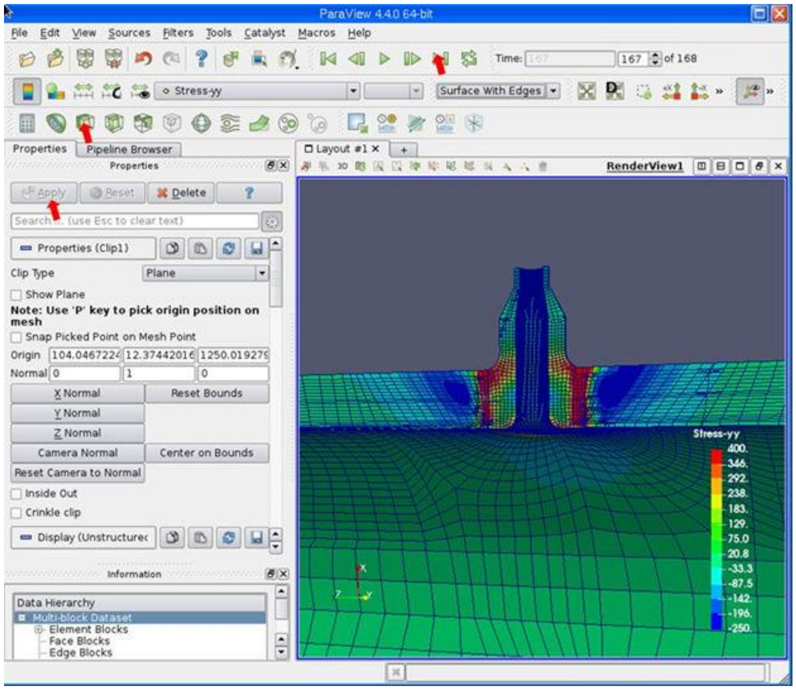

Fig.1 – Weld residual stress in nozzle predicted with VFT/WARP3D

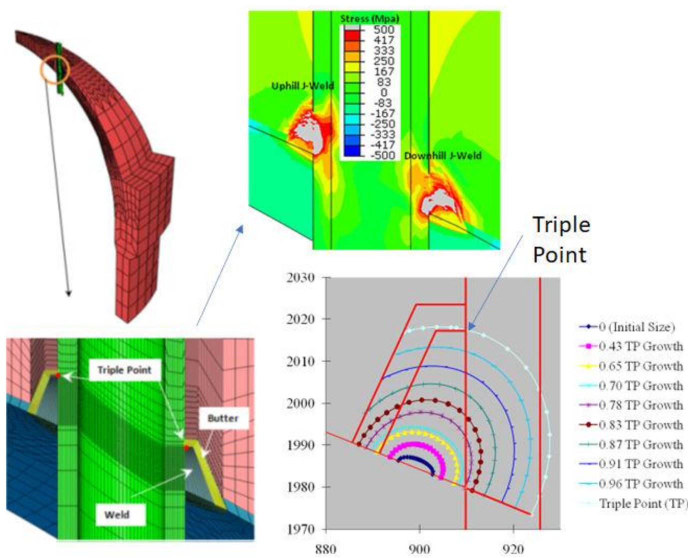

Fig.2 – WRS field and crack growth shape in nuclear J-groove weld

3. Conclusions

Weld residual stresses can drive both SCC crack growth and fracture in welded components. Here these issues are addressed using the VFT/WARP3D on demand computational weld tool which resides on the Ohio Supercomputer Center system.

References

[1] Brust, F. W., et. al., "Adoption of High Performance Computational (HPC) Modeling Software for Widespread Use in the Manufacture of Welded Structures", https://www.osti.gov/servlets/purl/1349722.