STUDIES OF CRACK GROWTH AND FRACTURE DRIVEN BY WELD RESIDUAL STRESS FIELDS

F. W. Brust[1]*

[1]Engineering Mechanics Corporation of Columbus (EMC[2]), Columbus, OH, USA
** Presenting Author email: asaxena@uark.edu*

Abstract
Subcritical crack growth of nuclear components is a current concern in operating light water nuclear reactors. Weld residual stresses (WRS) 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. This paper provides several examples where crack growth, driven by weld residual stress fields, has led to safety concerns in several nuclear components. This is especially true for the dissimilar metal welds that are present in most PWR reactors. Mechanical mitigation examples are also discussed which are used to reduce the WRS fields or alter them to compression which can mitigate stress corrosion cracking.

1. Introduction

Flaw indications have been found in some dissimilar metal (DM) nozzle to stainless steel piping welds and reactor pressure vessel heads (RPVH) in pressurized water reactors (PWR) throughout the world. The nozzle welds usually involve welding ferritic (often A508) nozzles to 304/316 stainless steel pipe) using Alloy 182/82 weld metal. The welds may become susceptible to a form of corrosion cracking referred to as primary water stress corrosion cracking (PWSCC). It can occur if the temperature is high enough (usually >300C) and the water chemistry in the PWR is typical of operating plants. The weld residual stresses (WRS) induced by the welds are a main driver of PWSCC. The effect of WRS on PWSCC is shown with three examples that are relevant to the nuclear industry. These problems are the effect of inlay on crack growth, the effect of crack growth in a steam generator replacement weld, and crack growth in a nuclear containment head.

2. Results

One proposed method for mitigating PWSCC in nozzles is to apply a thin layer of Alloy 152/52 overtop the Alloy 182/82 weld material as seen in the upper right of Figure 1. The Alloy 152/52 has at least an order of magnitude less PWSCC growth rate compared to Alloy 182. The application of the inlay leads to the WRS field shown in the upper left of Figure 1 which were calculated using a computational weld modeling procedure. The crack shapes versus time predicted using a well established PWSCC crack growth law is seen to be of a ‘balloon’ type as seen in Figure 1. These crack growth shapes were calculated using a ‘natural crack growth’ procedure using a finite element-based procedure (see [1] for details). This type of balloon crack growth is undesirable since a large underlying crack might be present but the restricted flow on the ID may lead to a situation where, once the crack reaches the OD of the nozzle, the leakage may be too small to detect. This can compromise leak before break (LBB) desires of nuclear piping systems.

The second example illustrates PWSCC axial growth in a steam generator replacement weld which is driven by high hoop weld induced residual stresses. Figure 2 shows the nozzle, the corresponding hoop WRS field that was predicted using computational weld modeling (middle illustration), and the crack shape evolution using a natural crack growth finite element-based procedure discussed in [1]. The time in the crack growth evolution plots is normalized by the time it takes for the crack to leak water. It turned out that the time for leakage is very short due to the high hoop WRS fields which indicated that the replacement steam generator welding process needs to be modified.

The final example is of crack growth that occurs in the J-groove welds in a RPV head penetration. The penetrations are used to insert rods to control the reaction. The cracks were grown using a natural crack growth procedure and indicated that such PWSCC growth could be quite fast if the residual stresses in the J-groove welds are not managed properly. Methods for managing WRS will be discussed in presentation.

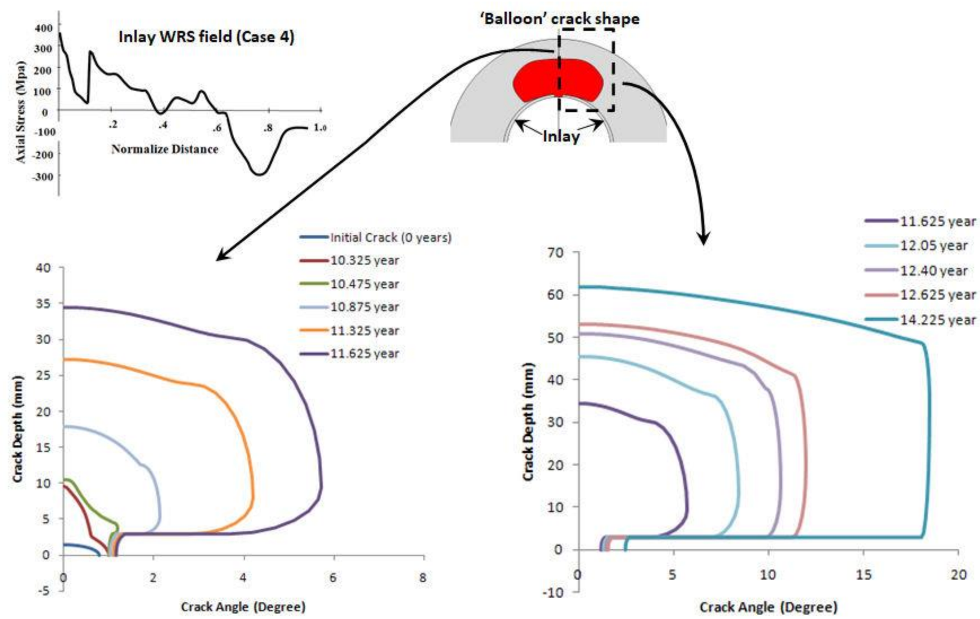

Fig.1 – Crack growth shapes predicted in nozzle treated with Alloy 52/152 inlay

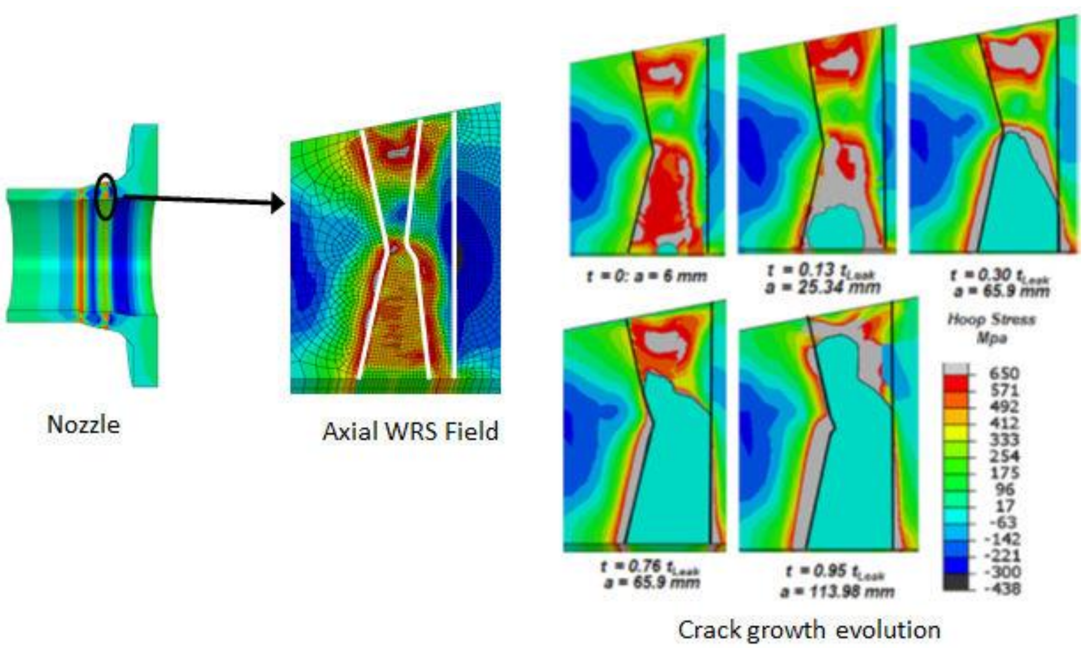

Fig.2 – WRS field and crack growth shape in nuclear J-groove weld

3. Conclusions

Weld residual stresses can drive both SCC crack growth and fracture in welded components. Here several examples are shown which illustrate the potential rapid crack growth that can occur due to PWSCC and the corresponding need to mitigate tensile WRS fields on the ID of nuclear nozzles.

References

[1] Brust, F. W., Shim, DJ, Wilkowski, G, Rudland, D., "PWSCC Crack Growth Modeling Approaches", paper PVP2011-57974, Proc. AMSE 2011 PVP Conference, Baltimore, MD, July 2011.