

Failure Mechanisms of Pressure Vessels Under Thermo-mechanical Cycling

by J. Penso, Petroleos de Venezuela and C.L.Tsai, The Ohio State University

Cracking and bulging in welded and internally lined pressure vessels that work in thermal-mechanical cycling services have been well known problems in the petrochemical, power and nuclear industries. Published literature and industry surveys show that similar problems have been occurring during the last 50 years. Understanding the causes of cracking and bulging would lead to improvements in the reliability of these pressure vessels. This study attempts to add information required for improving the knowledge and fundamental understanding of these problems.

The results from previous work based on a field survey lead to elaborate different hypothesis for cracking and bulging. Later metallurgical analysis permitted to analyze some in these hypotheses. In this work, some hypotheses previously not studied are assessed with the aid of finite element analysis FEA. Previous published FEA has not been able to capture the axial and radial thermal gradients occurring in the pressure vessel wall due to process conditions. Also, the analysis of the mismatch in mechanical and physical properties in the highly dissimilar welds has not been studied. This work includes both analyses.

Mismatch in material properties and operating variables have been found to have a very important impact on the lives of these pressure vessels. These problems cause severe economical losses to oil refineries.

The FEA procedure selected to evaluate this coking process is a sequentially coupled heat transfer-mechanical model. The user-subroutines developed in this work were capable to simulate the internal heat transfer process across the pressure vessel wall and the variations of internal pressure along the entire thermo-mechanical cycle. For model calibration, temperature and strain predictions from FEA were compared against field data.

In this work it was found that differences in materials properties lead to strain accumulation in all interfaces between dissimilar materials large enough to produce HAZ and shallow clad cracks. Axial and radial thermal gradients are high enough at the interface between the liquid and vapor phase during heating and quenching to produce plastic strains leading to cracking and bulging. Bending stress reversals lead to shell-skirt attachment weld cracking due to fatigue. The strain rate observed were below to those required for dynamic loading.

Some recommendations for new design based in the analysis conducted in this work include the use of higher yield strength Cr-Mo materials will reduce substantially the amount of plastic strain observed in the backing plate. As far as the notch toughness is not impaired, the use of higher yield strength material should permit longer low cycle fatigue live for the Cr-Mo alloys considered. Clad with Alloy 625 LCF should perform better than with 405 SS.