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Fracture Mechanics-Based Fatigue Predictions for HPHT Equipment

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Abstract

A methodology covering fatigue life predictions for high pressure high temperature (HPHT) equipment is presented. HPHT equipment is generally thick-walled and by a common definition involves pressure ratings of 15,000 psi and above and temperature ratings of 350ºF and above. A fracture mechanics-based approach is described including the crack growth methodology and the determination of the design life. The approach is similar to that used in the ASME Boiler and Pressure Vessel Code and discussion is presented including a comparison to engineering criticality assessments (ECAs) covered in API recommended practices and in British Standards. The application of safety factors through input variables and through the analysis methodology is discussed. The limitations of S-N fatigue analysis for the evaluation of thick-walled high pressure equipment are also discussed.

Example problems are presented to display the application of the method to subsea equipment. The stresses are examined on a series of cylinders with several wall thickness to diameter ratios. This includes a cylindrical vessel with dimensions similar to a wellhead housing. The finite element method is used to determine the appropriate stress profiles through the thickness for the extreme loading and the cyclic loading.

Several sensitivity studies are performed to display the influence of the inputs. The relative importance of material toughness (i.e. CTOD or K_{IC}) and residual stress are discussed. While their values are generally important, they can vary widely without influencing the fatigue life prediction. The influence of other material properties, such as the crack growth constants, and residual stresses are also discussed.

Introduction

The design verification of equipment for high pressure high temperature (HPHT) applications, typically defined as those requiring pressure ratings of 15,000 psi and above and temperature ratings of 350ºF and above, will require thinking beyond the “tried and true” analysis methodologies used in the oil industry for the past couple of decades. Recent changes in and continued development of relevant codes and standards will surely impact the oil field equipment industry in the near future.

The material selection for HPHT components is critical to ensure adequate life. Deep reservoirs can bring about high partial pressures of H_2S and corrosive by-products. High temperatures can alter material properties, behavior, and failure mechanisms. While these problems are significant, they are further complicated in that many HPHT components have additional functional requirements. In many cases, factors other than internal pressure (such as excessive deformation, sealability, functionality, fatigue) may limit the design pressure or require wall thicknesses beyond that needed for internal pressure alone.

Notable discussions and work has begun to better define the difficulties associated with understanding all aspects of HPHT problems. A discussion on material selection for HPHT wells has been given by Brownlee, et al [1]. Several papers have described the design methods for HPHT equipment [2,3]. In these papers it is discussed that the high pressure rules of ASME’s Boiler and Pressure Vessel Code (BPVC) Section VIII, Division 3 are best suited for carrying over to HPHT applications. The Division 2 assumptions include the primary failure mode to be deformation resulting in leakage before failure, something that is not likely with HPHT components. In Division 3, the failure process is one of cyclic loading, crack propagation, and eventual fracture. A fatigue analysis using conventional S-N methods is not sufficient for thick-wall pressure equipment. HPHT components are susceptible to crack growth-based fatigue. The presence of a flaw or crack and