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Effect of vibration loading on the fatigue life of part-through notched pipe

Rahul Mittal [a], P.K. Singh [b,*], D.M. Pukazhendi [c], V. Bhasin [b], K.K. Vaze [b], A.K. Ghosh [b]

[a] Nuclear Power Corporation of India Limited, Mumbai, India
[b] Bhabha Atomic Research Centre, Mumbai, India
[c] Structural Engineering research Centre, Chennai, India

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ABSTRACT

A systematic experimental and analytical study has been carried out to investigate the effect of vibration loading on the fatigue life of the piping components. Three Point bend (TPB) specimens machined from the actual pipe have been used for the evaluation of Paris constants by carrying out the experiments under vibration + cyclic and cyclic loading as per the ASTM Standard E647. These constants have been used for the prediction of the fatigue life of the pipe having part-through notch of $a/t = 0.25$ and aspect ratio (2c/a) of 10. Predicted results have shown the reduction in fatigue life of the notched pipe subjected to vibration + cyclic loading by 50% compared to that of cyclic loading. Predicted results have been validated by carrying out the full-scale pipe (with part-through notch) tests. Notched pipes were subjected to loading conditions such that the initial stress-intensity factor remains same as that of TPB specimen. Experimental results of the full-scale pipe tests under vibration + cyclic loading has shown the reduction in fatigue life by 70% compared to that of cyclic loading. Fractographic examination of the fracture surface of the tested specimens subjected to vibration + cyclic loading have shown higher presence of brittle phases such as martensite (in the form of isolated planar facets) and secondary micro cracks. This could be the reason for the reduction of fatigue life in pipe subjected to vibration + cyclic loading.

1. Introduction

Piping components are subjected to vibration loading caused by rotary equipments viz. pumps, compressors etc in the piping system. These vibration loadings are of the low amplitudes but extend over the lifetime of plant operation and causes severe mechanical damage leading to reduction of the life of the piping components. Vibration induced fatigue may lead to excessive pipe vibration which can cause real problems like loosening of threaded connections, leakage through flanges, knocking off the pipes from their supports. S.N. Huang [1] brought out the procedure to assess the fatigue damage of the piping systems and explained the feasibility of the estimation of piping responses resulting from pump-induced vibration with the limited test data. ASME O&M design code [2] calls for qualification of piping system in terms of velocity and deflection of the piping system subjected to the vibration during plant operation. These piping components are also subjected to higher amplitude cyclic loading due to plant startup and shut down. The effect of simultaneous occurrence of cyclic loading along with the vibration loading on piping system has not been discussed in ASME.

Fatigue crack initiation has been studied in the past using notched small specimens by evaluating local stress or strain at the notch tip considering the stress or strain concentration, equivalent energy density method and low cycle fatigue curve [3]. Evaluation of fatigue crack initiation life using fracture mechanics approach has also been reported.

Austenite to martensite transformation has been observed in 300 series stainless steels, which results in a reduced fatigue life [4]. The extent of the martensite transformation depends on several factors such as the chemical composition of the steel and the temperature at which the deformation taking place [5,6]. Martensite can be induced in an austenitic stainless steel when the material is plastically deformed at certain temperature, which determine the stability of the austenite with respect to the formation of alpha martensite [7]. The formation of martensite during deformation at the room temperature in austenitic steel such as 304L and 304LN steel has been reported [8–11]. Strain induced martensite has a great influence on the mechanical properties of austenitic stainless steels. The presence of the martensite can produce significant changes in the tensile properties, strain hardening behavior and fracture toughness. There is no literature

* Corresponding author. Tel.: +91 22 25591522.
E-mail address: singh_pawank@yahoo.com (P.K. Singh).

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