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Experimental investigation of random loading sequence effect on fatigue crack growth

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ABSTRACT

An experimental study is proposed to investigate the effect of random loading sequence effect on the fatigue crack growth behavior of Al 7075-T6. The testing matrix includes different overload cycle percentage, overload ratios, and deterministic and random loading sequences in the current investigation. Multiple specimen tests and statistical data analysis are performed to show the effect of random loading sequence on the median and scatter behavior of fatigue crack growth. The proposed experimental study suggests that extreme value distribution is a good approximation of fatigue life distribution. It is observed that the effect of uncertain loading is different under different loading spectrums. For high overload cycle percentage spectrums, the random loading sequence has no major impact on the probabilistic crack growth behavior compared to the deterministic loading sequence with identical load cycle distributions. For low overload cycle percentage spectrums, the random loading sequence has huge impact on the probabilistic crack growth behavior compared to the deterministic loading sequence with identical load cycle distributions, for both the median and the scatter of the fatigue crack length curves. Finally, all experimental observations are reported in table format in Appendix A for future numerical model development and validation for interested readers.

1. Introduction

Fatigue crack growth process in engineering materials and structures is a complex stochastic process. It has been observed that huge scatter exists even for identical specimens under same loading conditions and environments [1–5]. This may be caused by the uncertainties of material properties, manufacturing process, and residual stresses, etc. More importantly, loadings for realistic structures have random/stochastic sequences, although the statistical distributions may be same. The loading uncertainties cause tremendous uncertainties under realistic working conditions and make the life prediction very difficult [6,7].

Many stochastic fatigue crack growth methods have been proposed to take into account uncertainties for accurate fatigue life predictions [4,5,7–10]. Most existing probabilistic analysis focused on the material variability and very few studies focused on the unknown/random loading uncertainties. Some studies have demonstrated that the random loading effect on fatigue is complex and needs significant additional study [2,7], especially the loading sequence effect under random loadings [7,11]. For the comprehensive statistical analysis of fatigue crack growth, multiple specimen testing under similar conditions are required. Due to the high time and budget cost associated with fatigue testing, very limited data have been reported in the open literature, especially for statistical analysis. Several data sets under constant amplitude loadings were reported [2,12]. In this study, experimental investigation under both deterministic and random variable amplitude loadings are designed and performed, which aims to provide a comprehensive data sets for the study of loading uncertainty effect on the fatigue crack growth and life prediction. Most reported experimental data in the literature is in the graphical format, which is not convenient for interested readers. In addition, a comprehensive report for multiple specimen testing under random loading spectrums is rarely found in the open literature, which makes it difficult for the community of statistical/probabilistic fatigue analysis. In addition, most existing data in the open literature are presented in figures and is not convenient for the readers to use. In view of this, all experimental observations are listed in the table format in Appendix A, which is beneficial for future numerical model development and validation for interested readers.

Random loading is a major source of uncertainty in fatigue crack growth analysis [1]. The quantification of random loading is a tough task itself. Several methods are available for this purpose [13], for example, the rain flow counting reconstruction method [14,15]. The measured loading history is transformed using the rain flow counting method [16] and the obtained rain flow counting matrix describes the statistical distribution of the stress range

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