MICROVOID CHARACTERISTICS AT FRACTURE IN ASTM A992 STEEL UNDER MONOTONIC AND ULTRA-LOW CYCLE FATIGUE LOADING

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Abstract

Ductile fracture is the fracture initiating mechanism in steel structures subjected to both overloading and ultra-low cycle fatigue (ULCF) loading. This paper aims to characterize the statistical distribution of microvoids on the fracture surface of structural steel specimens subjected to monotonic and ULCF loading by employing advanced microscopy techniques. Furthermore, the relationship between the experimentally inferred mean microvoid size and the state of stress and strain is investigated.

1. Introduction

The ductile fracture mechanism is a multi-step process involving three stages: (a) void nucleation from the secondary non-metallic inclusions, and metallurgical phase boundaries; (b) void dilation, elongation, and rotation of the voids under the influence of stress state and evolving plastic strain; and (c) coalescence of the microvoids to form cracks resulting in the initiation of ductile fracture in steel. Although microvoids are known to be responsible for initiating fracture in structural steels, there is a dearth of experimental studies characterizing the microvoids at the instance of fracture. In the present study, axisymmetric ASTM A992 structural steel notched specimens were subjected to monotonic and ULCF loading. Various notch geometries were used to capture a wide range of stress triaxialities [1]. The fracture surfaces of the test specimens were separated into three distinct fracture zones based on the stress states and were studied using a digital microscope. Two square areas of size 75µm × 75µm were randomly drawn on the micrographs of each of the fracture locations, and 25 microvoid areas were extracted from each of the square areas. The extracted microvoid sizes from the fracture surface of the steel specimens were characterized using statistical analysis. Non-linear finite element analyses of the notched steel test specimens were performed to obtain the stress triaxiality and equivalent plastic strain variation across the cross-section of the fracture surface. Furthermore, equivalent plastic strain-averaged stress triaxiality was computed to capture the evolution of stress triaxiality throughout the straining process. Finally, the relationship between the experimentally extracted microvoid size, stress triaxiality, and equivalent plastic strain was investigated.

2. Results

The microvoid areas were extracted from the fracture surface using the image analysis software ImageJ [2] and were used to compute the equivalent spherical radii of the microvoids. The histograms of the void size (equivalent spherical radii) distributions of the distinct fracture zones of the test specimens subjected to monotonic loading were studied. The void size distributions were found to be approximately normal with slight deviations near the tail of the histogram plots. Furthermore, normal probability plots consisting of equivalent spherical void radii and theoretical Z-score were also used to capture the normality in the data. The normal probability plots were found to follow an approximately linear pattern with slight deviations at the ends. The minor deviations in both the histogram and normal probability plots indicate a slightly right-skewed normal distribution with the mean equivalent spherical void radius greater than the median void size for the majority of the void size distributions. The right-skewed normal void size distributions further indicate that the larger microvoids on the fracture surface of the steel test specimens influence the mean equivalent void radius of the fractured specimens. The typical micrographs of different locations on the fracture surface of a reference unnotched (RU) ASTM A992 structural steel specimen subjected to monotonic loading are presented in Figure 1. The histogram and normal probability plots for the equivalent spherical void radii distributions corresponding to fracture zones 1 and 3 of the unnotched specimen are shown in Figure 2.

Figure 1. Typical micrographs of fracture zones 1 and 3 in unnotched (RU) ASTM A992 structural steel specimen under monotonic loading

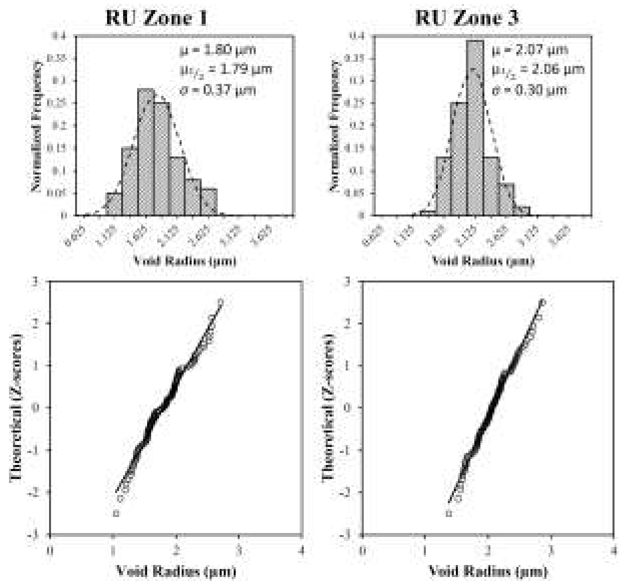

Figure 2. Histograms and normal probability plots of equivalent void radii distributions for fracture zones 1 and 3 of unnotched (RU) ASTM A992 structural steel specimen under monotonic loading

3. Conclusions

The void size distributions of the ASTM A992 structural steel specimens subjected to monotonic loading were observed to be approximately normal with majority of the distributions being slightly right-skewed. The mirovoid radii on the fracture surface of the monotonically loaded test specimens were found to range between 1.04 µm and 3.45 µm. The relationship between the stress states and experimentally obtained microvoid sizes was investigated and will be presented in the talk.

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