Abstract

A series of elastic and elastic-plastic stress analyses have been carried out on single edge notched tension, center cracked tension, compact tension and single edge notched bend specimens using finite element method (FEM). The magnitudes of J-integral, crack-tip opening displacement (CTOD), extent of the elastic-plastic boundary from the crack-tip along the crack-plane (r_p) and rotation factor (r_o) in these specimens have been computed. Emphasis was laid on the examination of the nature of plane stress plastic zone and its size along the crack-plane in small scale yielding (SSY) and large scale yielding (LSY) conditions. The geometry and size of plastic zones were also computed using existing analytical formulations proposed by Irwin, Dugdale, Hutchinson-Rice-Rosengren (HRR) and Kujwaski and Ellyin. The theoretical results were substantiated by experimental measurements of plastic zone size in two types of specimen geometry. The materials selected for experimental studies were interstitial free steel and 316 stainless steel; their composition, microstructure and tensile behaviour have been characterized.

The present results lead to the following major conclusions: (a) the variations of normalized plastic zone size (r_p/a) versus normalized applied stress (σ/σ_y) estimated by FE elastic and elastic-plastic analyses are in good agreement with the similar results estimated by available analytical formulations only in SSY condition. In large scale yielding condition, the deviations between the results of r_p/a obtained by the numerical and analytical methods are significant, (b) a reference standard based on J-integral has been considered for comparing plastic zones estimated in different specimen geometry. This new reference standard ($J/a\sigma_y$) is more powerful to delineate the difference in plastic zone characterizing parameters than the conventional one (σ/σ_y), (c) the magnitude of r_p is independent of specimen geometry at SSY condition but is dependent on specimen geometry in the LSY condition under identical loading state, (d) the magnitudes of r_p are in decreasing order in CCT, SENT, CT and SENB specimens, for identical J-integral values ahead of a crack-tip for $J/a\sigma_y > 0.0025$, (e) the growth of plastic zone at a crack-tip gets hindered by the simultaneous development of another plastically deformed zone growing from the end of the ligament of SENT, CT and SENB specimens, (f) a simple procedure has been suggested for the estimation of plastic zone size by micro-hardness technique, (g) experimental results of r_p for interstitial free steel and 316 stainless steel are in excellent agreement with the elastic-plastic FE analysis, unlike those predicted by analytical formulations, (h) the rotation factor used for estimating CTOD is proportional to plastic zone size up to a critical value of the latter and beyond this value, rotation factor is independent of plastic zone size and its magnitude is equal to that proposed by ASTM standard and (i) 3D elastic-plastic FE analysis has shown that the estimated size of a plastic zone is always higher on the surface than that at the center of a specimen, in agreement with natural expectation. All the conclusions derived from this investigation have been substantiated by appropriate discussion.