Abstract

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Title of the thesis: Characterization of Tearing Resistance of Automotive Grade Steel Sheets

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The present study aims at a comprehensive characterization of tearing resistance of a 1 mm thick automotive grade interstitial free (IF) steel sheet, a material with a very high strain hardening exponent. The tests comprise of deforming at chosen quasi-static strain rate notched (tip radius 0.1 mm) or fatigue pre-cracked double edge notched tensile (DENT) or single edge notched tensile (SENT) specimens clamped on both edges.

In this study, the crack initiation parameters examined are the initiation energy per unit ligament area (w_i), in addition to the critical values for the J-integral and CTOD (respectively J_c and δ_c). For determining the initiation parameters, it is first necessary to identify the crack initiation event with sufficient accuracy, a non-trivial problem for a ductile thin sheet with large plasticity, crack tip necking and tunneling. In the present study a new method based upon comparing test data with those from 3-D finite element analysis (FEA) for non-growing crack has been adopted for detecting the crack initiation event. Notwithstanding the extensive plasticity and the related effects, the use of J_c has been validated for the SENT specimens of the present test material from the 3-D FEA computed path independent line integral values of J, in addition to determining the η_p factor for these specimens. The crack growth parameters examined are the CTOA (φ) and its critical value for stable crack growth (φ_c), the δ_5 parameter, and also the energy dissipation rate parameter (R) and its value for stable crack growth (R_∞). The R parameter has hitherto been used almost exclusively for thick specimens. An attempt has been made to search for normalized energy dissipation rate (R_N) to be determined from R_∞ such that R_N would be independent of specimen geometry. Of these parameters, only CTOA determination has been standardized for sheet metals (ASTM E 2472); however, the testing and measurement procedures prescribed by this standard require both experimental resources and skill, and are as such not very attractive for routine industrial applications. Optical measurements of CTOA and δ_5 for SENT and DENT specimens reported here adopted an experimental procedure developed in the course of the present study. The values for the crack initiation and growth parameters thus determined are compared with the corresponding parameters from the Essential Work of Fracture (EWF)

method determined using DENT specimens as is widely practiced, and also SENT specimens, ramp loaded to (near) fracture. The EWF test yields three parameters pertaining to tearing resistance of sheets: (i) the essential work of fracture, w_e, (ii) the opening across the fracture process zone (FPZ), δ_c^e, and (iii) the flank angle of the FPZ, ψ^e. Dependence of the values of these various parameters determines on specimen geometry has also been examined. Additionally, notched SENT specimens have been used for exploring the use of the EWF method for the initial mixed mode regime of crack growth.

Results from the present investigation show that among all the possible tearing resistance parameters examined in the present study, four crack initiation parameters namely J_C, δ_c, w_e and w_{ie} (the value of w_i data back extrapolated to zero ligament length) determined with fatigue pre-cracked specimens, and the three crack growth parameters (φ_c, ψ^e and δ_5) appear to be material parameters independent of specimen geometry. Therefore, these parameters can be used for tearing resistance characterization of the present test material. In particular, it is confirmed that the ψ^e parameter, determined by the very simple experimental EWF procedure, is an actual measure of the stable CTOA φ_c optically measured in the present study. Use of SENT specimens is advantageous when determining the initiation based parameters that require fatigue pre-cracking the specimens.

Cohesive zone modelling (CZM) considering Mode I crack growth proved successful in simulating crack growth in notched or fatigue pre-cracked SENT and DENT specimens; also, the corresponding CZM parameters values are consistent with specimen geometry independence of crack growth parameters in sheet specimens. These studies need to be extended to other automotive grade steels, particularly with higher strengths and lower strain hardening indices.

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