MODELLING OF PLASTICITY AND DUCTILE FRACTURE FOR LOW TO MEDIUM INDIAN STRUCTURAL STEEL GRADES

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Abstract

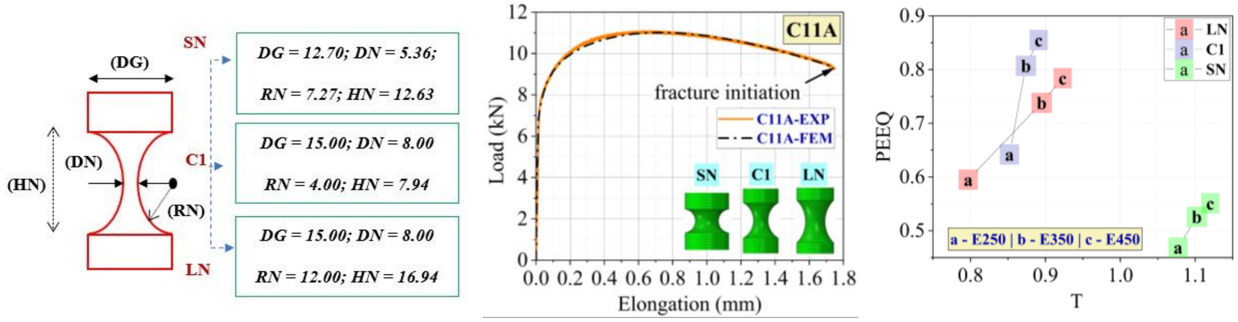
The data points available for developing a Fracture Locus (FL) database for structural steel used in the Indian construction industry are extremely limited. The current study is conducted to determine the FL data points for three different grades of Indian structural steel, namely E250, E350, and E450. Uniaxial tests on notched dog bone specimens of three different specimen configurations are performed. The selected configuration is used to determine points for plotting FL corresponding to high-stress triaxiality (0.7 < T >1) and Lode angle (L) almost equal to 1. With the help of numerical simulation, the FL points are obtained and reported. The accuracy of numerical simulation is checked by precisely matching the load versus displacement obtained from the experiment. Six fracture prediction models are chosen for the present study. These six models are chosen using the following criteria, (1) only depends on stress triaxiality (b) depends on both stress triaxiality and Lode angle and (c) the number of coefficients used. The effectiveness of all the selected models in predicting fracture initiation across all three steel grades is compared, and the findings are reported.

1. Introduction

The selection of the structural steel grade used in the construction industry in designing the fuse element of any earthquake-resistant steel structure is very critical. The selected grade determines the strength and ductility of the fuse element. The above-mentioned fuse element is the structural element designed to undergo excessive plastic deformation to dissipate the seismic energy safeguarding other structural and non-structural members. FL is generally plotted using three parameters namely T, L, and equivalent plastic strain (PEEQ). With the help of FL, the designer can accurately determine the critical fracture PEEQ of the component subjected to specified T and L. From the past experimental studies, the PEEQ corresponding to the fracture initiation point of the fuse element occurs only under the domain of positive T and $0 < L \geq 1$. For the most common steel grades produced in the United States, Europe, and Japan, data points for plotting FL are widely available. However, very few or no studies have been conducted to generate data points for plotting FL for structural steel used in the Indian construction industry. Thus, the purpose of this research is to generate data points to plot the FL for low to medium (E250, E350, and E450) structural steel grades used in the Indian construction industry. Several studies have recently been conducted to calibrate parameters of fracture-predicting models corresponding to their steel grades. Four fracture models based solely on T namely, (a) Void Growth Model (VGM), (b) Kiran and Khandelwal Model (KKM), (c) Johnson-Cooke Model (JCM), and (d) Xue and Wierzbicki Model Without L (XWM WL), as well as, two fracture models employing both T and L namely, (e) Stress Weighted Damage Fracture Model (SWDFM) and (f) Xue and Wierzbicki Model (XWM) are studied and compared on the basis of the average error in predicting the fracture strain for all the three steel grades.

2. Experiment and Results

Fig. 1(a) provides the dimensions of the selected study specimens to cover the study range of T and L. Uniaxial tests with all these study specimens until fracture have been carried out at a loading rate of 0.2 mm/min. Finite element (FE) analyses replicating the exact experimental conditions are simulated using C38DR solid elements in ABAQUS CAE. The in-built combined hardening model is used to capture both isotropic-kinematic hardening behavior and the calibrated parameters (Q, b, C_1, γ_1, C_2 and γ_2) are tabulated in Table 1. The load versus elongation behavior is obtained from the loading and digital image correlation (DIC) equipment. The representative comparison plot of load versus elongation curves obtained via simulation and experiment is shown in Fig. 1(b). The sudden loss in the slope of these curves is assumed as the fracture initiation point. T, L, and PEEQ corresponding to this point is obtained from numerical simulation and the plot between T and PEEQ is shown in Fig. 1(c). The parameters for all six models have been calibrated using the obtained values of T, L, and PEEQ and are tabulated in Table 2 along with their average error.



(a) (b) (c)

Fig.1 – (a) Dimension detailing of considered study specimens (b) Comparison of load versus elongation curves obtained from the Experiment (EXP) and FE Modelling (FEM) and (c) FL (T vs PEEQ) of all the study specimens segregated according to their structural steel grade.

(DG) – diameter of the grip; (RN), (HN), and (DN) – curvature radius, height, and diameter of the notch respectively. (All the dimensions are in mm); C11A, C1 – specimen configuration; 1 – replicate number and A – E250 steel grade.

Table 1. Calibrated parameters of combined hardening model

Grades	Q (MPa)	b	C_1 (MPa)	γ_1	C_2 (MPa)	γ_2
E250 (A)	60 - 86	90 - 110	1400 - 1700	6.45 – 8.20	195 - 205	0.75-4
E350 (B)	130 -145	60 - 84	1440 - 1500	3.25 – 8.65	130 - 200	0.5 - 4
E450 (C)	75 - 150	80 - 100	1375 – 1500	2.80 – 8.65	135 - 225	0.25 - 4

Table 2. Calibrated parameters and average error of six considered fracture-predicting models

Grades	*VGM – #0.31		*KKM – #1.37			*JCM – #0.52		*XWM WL – #0.57			
	C1	C2	Dcr	C1	C2	C1	C2	C1	C2	C3	C4
E250 (A)	0.45		0.34	0.63	0.49	0.49	0.34	1.06	0.24	1.24	0.17
E350 (B)	0.35	1.5	0.39	0.58	0.50	0.44	0.25	0.87	0.31	1.27	0.14
E450 (C)	0.32		0.40	0.57	0.51	0.43	0.22	0.81	0.34	1.26	0.13

Grades	*SWDFM – #0.28				*XWM – #0.046			
	C1	C2	C3		C1	C2	C3	C4
E250 (A)	0.46	0.50	1.50		1.23	0.16	0.59	0.46
E350 (B)	0.35	0.50	1.50		1.25	0.14	0.64	0.44
E450 (C)	0.33	0.50	1.50		1.25	0.13	0.64	0.44

**Fracture model name, #average error on predicting fracture initiation in specimens of all three steel grades*

3. Conclusions

The fracture prediction accuracy error decreases with the inclusion of the Lode angle and increases with the number of parameters. The considered test data points are limited and only include the high-stress triaxiality region, however, all the models are giving fairly accurate results. Further experiments have to be carried out to determine the data points covering the entire range of T and L that corresponds to the fracture initiation point of fuse elements. Future studies can also focus on developing generalized prediction models for low to high carbon structural steels.