Low Cycle Fatigue Crack Initiation in Notched Wide Plates

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1. Introduction

Since the investigation by Crews et al., very few researches have been made on the correlation between low cycle fatigue crack initiation life of a notched wide plate and that of a small size specimen which was subjected to strain cycling simulated cyclic behaviour of peak strain at the tip of a notch in wide plate. The present test was carried out for the purpose of confirming the possibility of estimation of crack life of a notched wide plate from fatigue properties of small size specimens.

2. Experimental Methods and Test Results

2.1 Cyclic Characteristics of Peak Strain at the Tip of a Notch in Wide Plate

Wide plate specimens with the geometry and dimensions illustrated in Fig. 1 were machined out from 13 mm thick steel plates: a mild steel and a 50 kg/mm^2 high strength steel. A notch was machined at the center of a specimen so as to make the theoretical stress concentration factor K_t approximately 5, 10 and 14.

Controlled repeated axial load was applied to the specimen till the initiation of a fatigue crack, and after the crack initiation the specimen was loaded under the condition of constant net section stress amplitude.

Strain distributions on front and rear surfaces of the notched section were measured at maximum and minimum loads by using strain gauges and Moiré method, in which gratings of 150 lines/inch were photoengraved on specimen surface.

Examples of cyclic characteristics of peak longitudinal strain at the tip of a notch in a specimen subjected to repeated load are illustrated in Figs. 2 and 3. The

symbol S_n and N_c mean the net section stress in the notched section and visible crack initiation life, respectively. In case of the mild steel, maximum and residual strains increased greatly in the range of imposed cycles less than one tenth of N_c, and then showed nearly constant increase. This tendency was generally true for the mild steel specimens. On the contrary, nearly linear increasing tendency was observed for the 50 kg/mm^2 strength steel specimens. However, it should be mentioned in all cases of tested specimens that the strain range at the tip of a notch was found to be approximately constant untill the crack initiation.

Close observation about crack initiation behaviour and cyclic strain characteristics proved that the crack initiation life of a notched plate would be affected mainly by four factors: (1) the maximum peak strain at the first half cycle, (2) amplitude of peak strain (3) increasing mean strain at the tip of a notch and (4) the degree of restraint in thickness direction.

2.2 Correlation of Crack Initiation Lives

Hour-glass shaped specimens with the configuration of 8 mm in diameter and 1.06 in shape factor were machined out from the same materials as used for notched plate specimens. Strain cycling tests were carried out on hour-glass shaped specimens, and visible crack initiation life N_c^* was defined as number of cycles to formation of a surface crack 0.2 to 0.5 mm long. In the test, cyclic strain against cycle history at the tip of notch in a plate specimen that had been previously obtained by load cycling the notched specimen was duplicated in a hour-glass shaped specimen.

In Fig. 4, number of cycles to visible crack initiation in a notched plate specimen N_c is plotted against N_c^* obtainted by a hour-glass specimen. Good agreement is observed especially for the mild steel specimen with 10 of K_t value, while the increasing tendency of N_c^* is also found with increase of K_t value. Plotting was also made for the relation between N_c and crack initiation life of hour-glass specimen which was subjected to zero mean strain and constant strain amplitude corresponding to that at the

tip of a notch in plate specimen, and poor agreement was observed between both lives.

2.3 Strain Cycling Test with Linear-Increase Mean Strain

After prestraining in 15% tensile strain, hour-glass specimens were tested by strain cycling with 2% in total strain range and with increasing mean strain at the linear increase rate ranging from 0.005 to 0.5% per cycle. As a result of the test the following formulae expressing a cumulative damage law were derived:

$$D = N_c \left(\frac{\epsilon_{tR}}{\epsilon_f - \epsilon_{mo}} \right)^p$$

$$p = a \left(1 - \frac{\Delta \epsilon_m}{\epsilon_{tR}} \right)^4 + 1 \qquad (1)$$

where a is equal to 0.92 for the mild steel, and 0.82 for the 50kg/mm^2 steel. ϵ_{tR} is total strain range, ϵ_f static fracture ductility, ϵ_{mo} tensile prestrain, and $\Delta \epsilon_m$ increment of mean strain per cycle. Analysis of the results of plate specimens by applying Eq.(1) showed D values ranging from 0.4 to 1.3. Application of cumulative damage formulae proposed by other investigators proved that Eq. (1) gave the most safety side estimation.

3. Conclusions

(1) The main factors affecting the crack initiation life of a notched plate are the maximum peak strain at the first half cycle, amplitude of peak strain, increasing mean strain at the tip of a notch, and the degree of restraint in thickness direction.

(2) Good correlation was found between visible crack initiation life of a notched plate and that of a hour-glass shaped specimen which was subjected to duplicated straining of strain-against-cycle history at the tip of notch in the plate specimen.

(3) An expression of cumulative damage was proposed. This expression gives more safety side estimation of crack initiation life of a notched plate as compared with those proposed previously by other investigators.

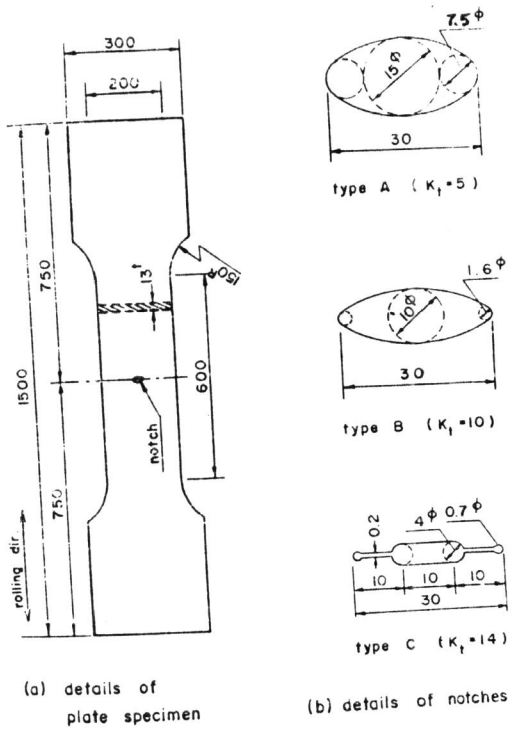

Fig. 1 Details of notched plate specimens

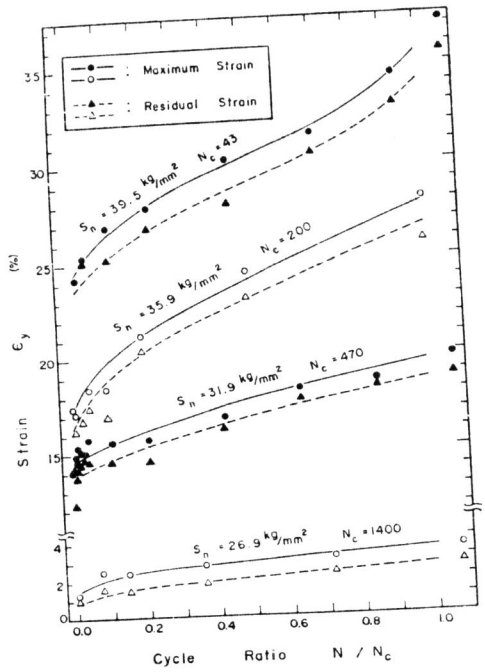

Fig. 2 Cyclic behaviours of longitudinal strain at the tip of notch (K_t = 10) in plate specimen of mild steel

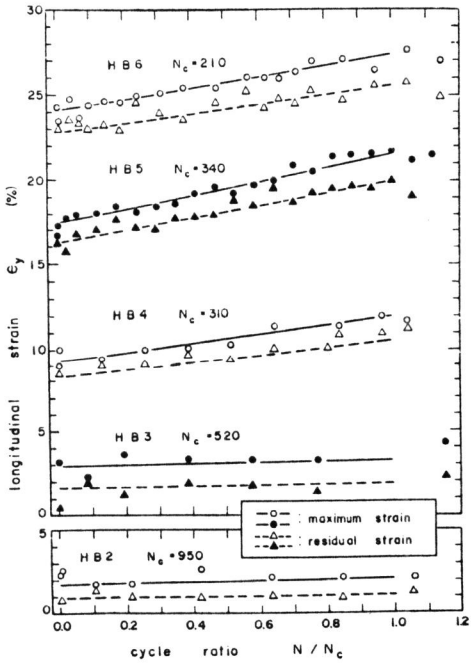

Fig. 3 Cyclic behaviours of longitudinal strain at the tip of notch (K_t = 10) in plate specimen of 50 kg/mm² high strength steel

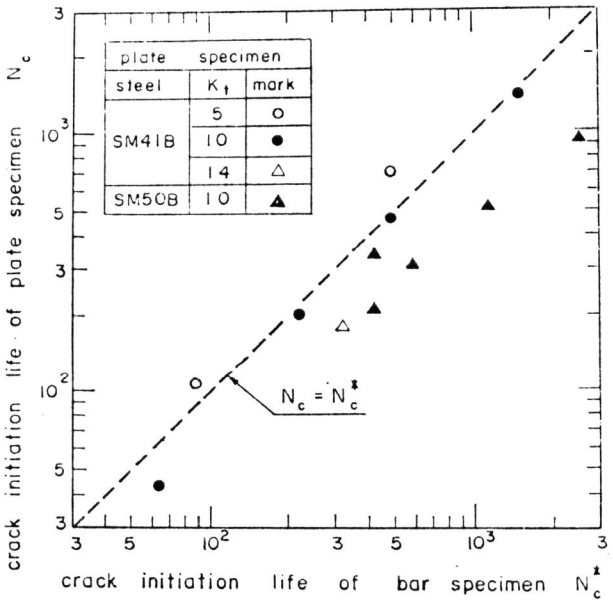

Fig. 4 Correlation between crack initiation life of notched plate specimen and that of hour-glass specimen fatigued by simulated strain cycling