PREDICTION OF FATIGUE CRACK PROPAGATION LIFE IN SINGLE EDGE NOTCHED BEAMS USING EXPONENTIAL MODEL

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ABSTRACT

Metal beams are extensively used in structures, automobile sectors and machine components. Some of their applications include connecting rod of IC engine, shafts, axles, and gears, structures members of bridges and also components of machines. Most of them experience fluctuating or cyclic load condition in their service life's such loading conditions may initiate a crack and cause fatigue crack growth. The monitoring and modelling of fatigue crack growth are necessary for the stability and safety of machines and structures. In the present investigation an attempt has been made to develop a fatigue life prediction methodology by using an Exponential Model in single edge notched (SEN) cracked beams. The predicted results are compared with experimental crack growth data. It has been observed that the results obtained from the models are in good agreement with experimental data.

Keywords: *-Beams, crack profile, fatigue crack propagation, constant amplitude loading, life prediction, exponential model.*

INTRODUCTION

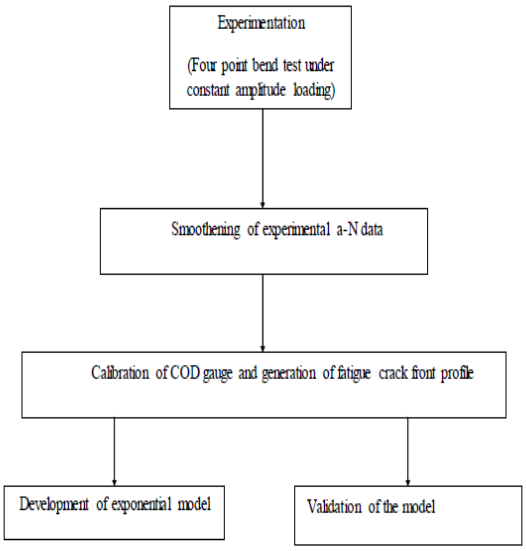
Failure due to repeated loading, that is fatigue, has accounts for at least half of this mechanical failure. No exact data is available, but many books and articles have suggested that between 50 to 90 per cent of all mechanical failures are due to fatigue, most of this is unexpected failures. In many situations a beam experiences fluctuating loading conditions. This may initiate and propagate a crack. The monitoring and modelling of fatigue crack growth is more significant for the stability and safety of machines components, bridges, aircraft and structures. In this project (EN8) medium carbon steel beam is used. In fatigue fracture the stress is generally below the yield stress. In general ductile material deforms before fracture and gives warning before failure of a component but in case of fatigue failure the ductile materials fails suddenly. This becomes more significant when failure is related to automobile sectors or machinery parts in which heavy loads or continuous work being done. In a dynamic world, however, failure occurs at stresses much below the materials ultimate strength or yield strength. This phenomenon, failing at relatively low stresses, came as quite a surprise to most engineers in the early years of metal component design and manufacturing. The other frustrating aspect is that the material exhibited no sign of its tiredness or fatigue and could fail without much warning. This could be more dangerous if proper selection of design criteria is not selected and validation of those criteria with experiment is not done. There are many areas where the fatigue criteria should be in mind before designing the component.

OBJECTIVES

The objective of present work is: To develop compliance correlation of *a-N* data and estimation of fatigue crack propagation life by using exponential model.

1. To conduct fatigue crack propagation test of supplied (EN8) medium carbon steel under constant amplitude loading condition with different stress ratios.

2. To propose an exponential model to predict fatigue crack propagation in single edge notched cracked beam.



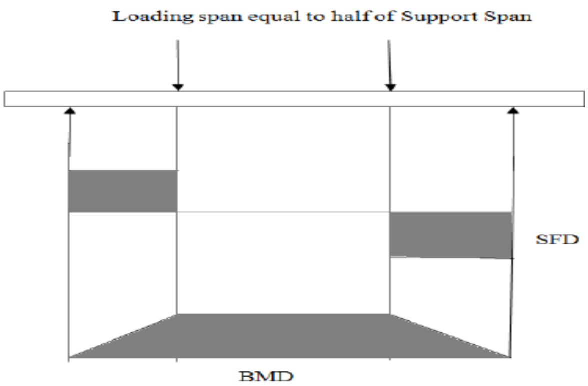
Plan of work

The crack initiation starts in a point where the stress concentration is high. This stress concentration may be due to abrupt change in cross section or due to defect present within the system. The change of the cross section can do in such a way that the stress concentration will be lower. But the defect due to manufacturing process cannot be eliminated completely because of the complex nature of manufacturing and human interference.

EXPERIMENTAL INVESTIGATION

The fatigue crack propagation tests were conducted on (EN-8) medium carbon steel beams. All the tests were conducted in a servo-hydraulic dynamic testing machine (Instron-8800) using through cross-sectional of cracked beam specimen under load control mode. A four point bend fixture was fabricated for conducting fatigue crack propagation tests. Before conducting the test, COD gauge was calibrated for single edge straight notched cracked beams specimens. All the tests were conducted in air and at room temperature.

Four Points bend Method: Four point bending (FPB) is a cornerstone element of the beam flexure portion of a sophomore level mechanics of materials course. The FPB lecture has traditionally developed the theory from body diagram through beam deflection, with related homework problems providing analytical practice. In FPB method Beam flexure represents one of the three most common loading categories for mechanical systems. As such, it is on the syllabi of nearly all sophomore- level mechanics of materials courses, including the mechanical engineering technology course under consideration here. Within the lecture setting, FPB theory is developed from free-body diagram through beam deflection. This theory is reinforced by analytical practice solving related homework problems. By this FPB the result to experimentally and analytically verify and Validated beam flexure theory. According to the convention specified in ASTM D6272-00 transverse vertical loads are applied to horizontal beams such that a constant bending moment results between the two inner load locations. Figure below shows the corresponding loading diagrams, from free-body to bending moment. The major difference between the three point and four point flexural tests is the location of bending moment. The four point bending method allows for uniform distribution between the two loading noses, while the three point bending method, stress is located under the loading nose. But in four point bending test, no shear force acts in between two inner spans, while in case of three point bending test maximum shear force act a loading nose.



Four points bend method

TENSILE TEST OF SPECIMEN

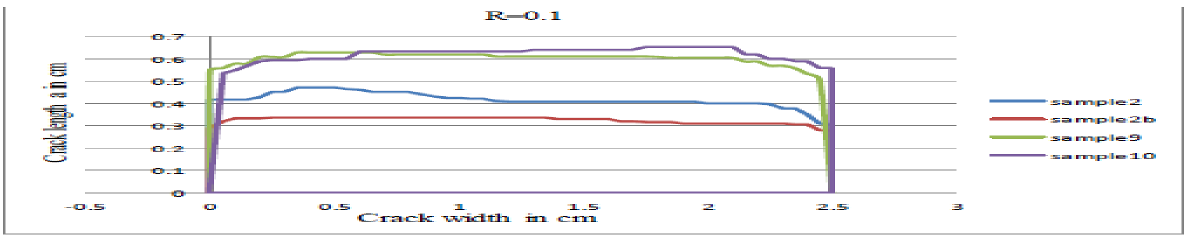
Tensile testing, in which a sample is subjected to controlled tension until failure. The Tensile properties of beam specimens were tested as per ASTM EN8 standards and EN8M (212A42) specifications. It is given in Table 3.1.2. The LLD (load- load line displacement) diagram is shown in fig. 3.4.3. Summarizes the average values of the mechanical properties data (e.g. stress strain diagram, yield stress, UTS, % elongation, % reduction in area and young's modulus, Poisson‟s ratio) measured, that were used in the fracture mechanics evaluation of the experiments results.

Dimension of tensile specimen of EN8 Test Specimen

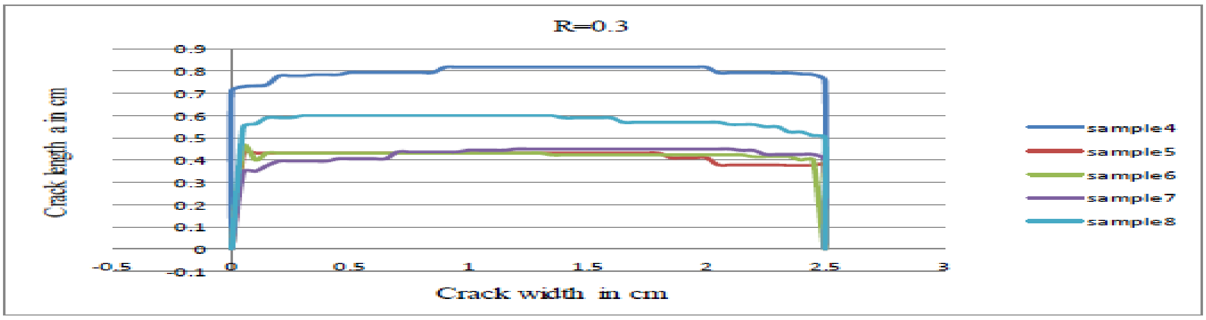
SL No.	Mean Diameter(mm)	Length(mm)
1	6.84	25
2	6.66	25

Generation of fatigue crack profile and calibration of cod gauge : The crack profile was measured and plotted with the help of optical travelling microscope and calibration of COD gauge was done using multiple specimen technique

Crack profile:

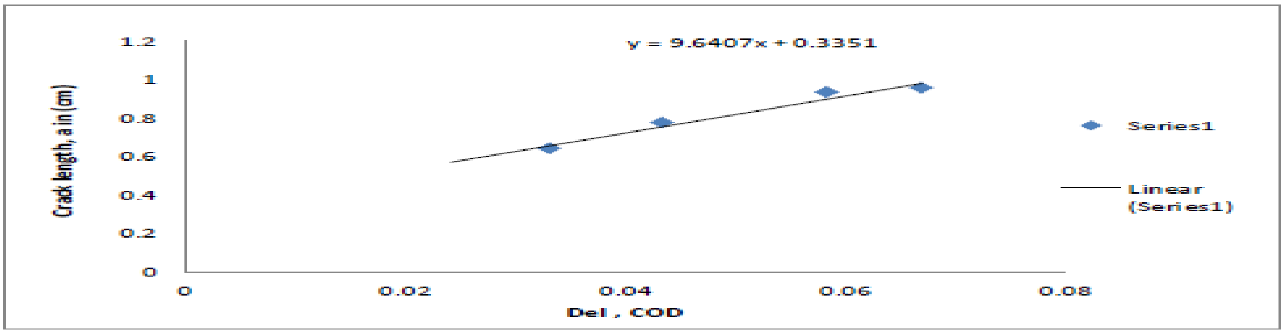


Crack profile with R=0.1



Crack profile with R=0.3

Calibration of COD gauge: Beams with straight notched at Centre were used for calibration of COD gauge. The COD calibration curve (Del. COD vs. measured crack length along the beam cross-section) is shown in



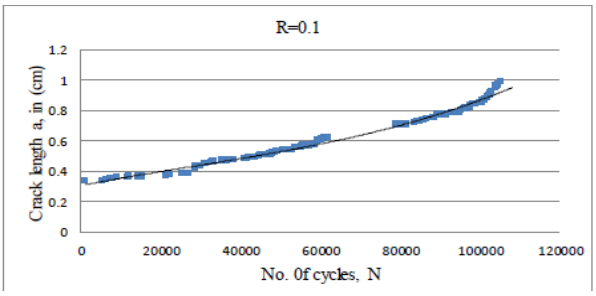
Calibration of COD gauge with R=0.1

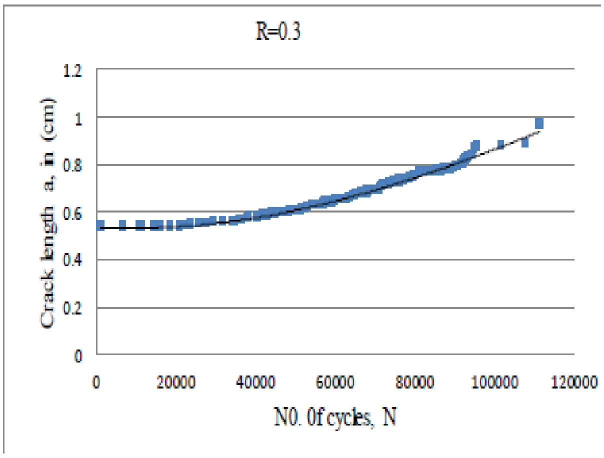
With constant loading of different R ratios such as R= 0.1 and R=0.3

Experimental Results of ENS beams

Sl no.	P_{max} In(N)	P_{min} In (N)	R	Max cod in mm	Min cod in mm	Del cod in mm	Crack length in cm	Total No.of cycles
1	8888.88	888.88	0.1	0.08147	0.0481	0.03337	0.637	78829
2	8888.88	888.88	0.1	0.07669	0.03308	0.04361	0.773	62203
3	8888.88	888.88	0.1	0.08577	0.02734	0.05843	0.928	108146
4	8888.88	888.88	0.1	0.08207	0.01494	0.06713	0.955	65685
5	11500	3451	0.3	0.18809	0.07785	0.11024	1.118	113799
6	11500	3451	0.3	0.07785	0.03894	0.03891	0.732	71410
7	11500	3451	0.3	0.06519	0.03376	0.03143	0.732	81174
8	11500	3451	0.3	0.010510	0.03789	0.06776	0.90	71863
9	11500	3451	0.3	0.09015	0.03991	0.05024	0.75	95825

Prediction of fatigue crack propagation using exponential model: Fatigue crack propagation, a natural physical process of material damage, is characterized by rate of increase of crack length (*a*) with number of cycles (*N*). It requires a discrete set of crack length vs. Number of cycle data generated experimentally. Unlike monotonic tests, fatigue test data are usually scattered. Therefore curve fitting of experimental *a*-*N* data was done which are usually scattered.



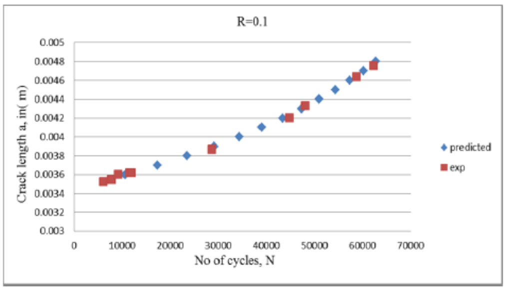


Curve fitting of experimental data (crack length vs. number of cycles)

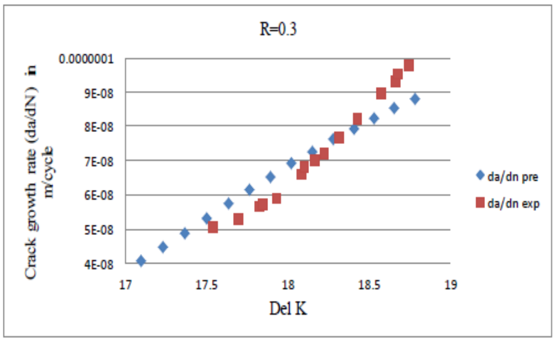
Introduction: The exponential model was developed by Mohanty *et. al.* [44-47] for prediction of fatigue crack growth in SENT specimen for constant amplitude loading as well as variable amplitude loading. However, this model was not developed for beams specimens. In the present investigation an attempt has been made to use the exponential model for fatigue crack propagation life in cracked beams subjected to constant amplitude loading. This model is based on the exponential nature of fatigue crack propagation with number of loading cycles. The exponent (known as specific growth rate) of the proposed exponential model has been correlated with various physical variables like crack driving parameters, crack resisting parameter, and material properties in non-dimensional forms. Finally the validation of the model has been done with experimental data in order to compare its accuracy in predicting fatigue life of cracked beams.

Value of coefficients for exponential model:

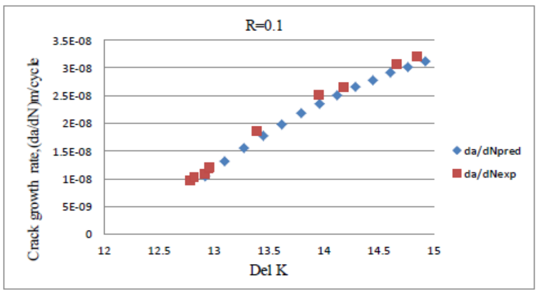
Material	A	B	C	D
EN8	7574.09	-8566.67	499.31	4.84



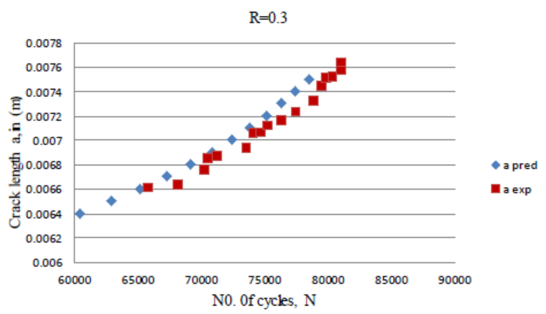
;(*a-N)* curve of EN8 medium carbon steel beam (exponential model)



(da/dN-ΔK) of EN8 medium carbon steel beam (exponential model)



(da/dN-ΔK) of EN8 medium carbon steel beam (exponential model)



(*a-N)* curve of EN8 medium carbon steel beam (exponential model)

RESULTS AND DISCUSSION

The basic aim of present work is to develop a fatigue crack propagation model for SEN beam without going through numerical integration process. The specific growth rate (*m*) is an important parameter of our model. The value of *m* is correlated with two crack driving forces (ΔK *and Kmax*), and with material parameters fracture toughness (*KC*), yield strength (σYS), stress ratio(R), and Young"s modulus (*E*) by curve fitting. The experimental *a-N* data of four specimens were used for formulation of model, and its validation has been checked for 5th and 6th specimens. The average value of curve fitting constants for beam has been given found out by using these constants fatigue life of a beam specimen can be predicted. The predicted result by using exponential model has been compared with the experimental result. The *a-N* curve obtained from proposed exponential model and that obtained from experimental data have been compared with other figure. The *da/dN* – ΔK curves are also compared also. It can be seen that the predicted results are in good with the experimental data.

CONCLUSIONS

1. The calibration curve of COD gauge is found to be straight line, which shows linear relationship between COD gauge and crack depth of straight notched beam.
2. The crack front profile is approximately thumbnail shape in nature as the crack depth increases.

3. Exponential model of the form has been used for other specimen geometries and can also be used to determine the fatigue life in beams without going through numerical integration.

4. Subsequently, to predict fatigue life, the exponent, *mij* (specific growth rate) has been judiciously correlated with crack driving parameters ΔK and *K*max and material properties *KC* (for specific specimen geometry) *E*, Ϭys and R in the form of dimensionless quantities.

5. The proposed exponential model may be used to predict fatigue crack propagation under constant amplitude loading condition with different stress ratios.

FUTURE WORK

1. The proposed models may be tested for other specimen geometries.
2. The soft computing methods may be used to determine the specific growth rate.

REFERENCES

[1] Suresh, S. (1991). *Fatigue of Materials*, Cambridge University Press, Cambridge.

[2] Johnson, H.H. and Paris, P.C. (1967). Subcritical flaw growth. *Engineering Fracture Mechanics* 1, 3.

[3] Wohler, A. (1860). Versuche über die festiykeit eisenbahnwagenuchsen. *Zeitschrift für Bauwesen* 10.

[4] Crack Growth Analysis of Wide Flange I-beam under Constant Amplitude Bending Loadings. Euro Journals Publishing, Inc. 2009 by J. Purbolaksono, A.A. Ali, A. Khinani, and A.Z. Rashid.

[5] M.L. Dunn, W. Suwito and B. Hunter, Stress Intensity Factors for Cracked I-Beams, Engineering Fracture Mechanics, 1997, 57, 609-615.

[6] H. GAO and G. Herrmann, On Estimates of Stress Intensity Factors for Cracked Beams. Engineering Fracture Mechanics, 1992, 41, 695-706.

[7] R.I. Stephens, A. Fatemi, R.R. Stephens and H.O. Fuchs, Metal Fatigue in Engineering, New York: Wiley Interscience, 2001

[8] M.H. Aliabadi, the Boundary Element Method, Chichester: John Wiley, 2002.

[9] M.H. Aliabadi and A.L. Saleh, Fracture Mechanics Analysis of Cracking in Plain and Reinforced Concrete Using the Boundary Element Method, Engineering Fracture Mechanics,2002, 69, 267-280.