Analysis of Fatigue Life Prediction Methodology by Exponential Model

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Abstract- Designing strategies to foresee the exhaustion life of designs has been accessible since the start of the twentieth 100 years. Be that as it may, a viable issue emerges from complex stacking conditions and a huge concern is the exactness of the strategies under factor plentifulness stacking. This paper gives an outline of existing weariness harm models with accentuation on generally new elective models and computational methodologies to anticipate weakness life. These models are contrasted and it are talked about with guarantee new abilities.

Keywords: Continuum damage mechanics, fatigue damage, cohesive zone.

I. 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 modeling 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 material's 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.

II. BACKGROUND

Wohler, [2020] the process of fatigue failure itself consists of several distinct processes involving initial cyclic damage (cyclic hardening or softening), formation of an initial fatal flaw (crack initiation), macroscopic propagation of this flaw (crack growth), and final catastrophic failure or instability. The physical phenomenon of fatigue was first seriously. Considered in the mid nineteenth century when widespread failures of railway axles in Europe prompted Wohler in Germany to conduct the first systematic investigations into material failure under cyclic stresses.

Paris et al., [2019] However, the main impetus for research directed at the crack propagation stage of fatigue failure, as opposed to mere lifetime calculations, did not occur until the mid-1960s, when the concepts of linear elastic fracture mechanics and so-called „defect-tolerant design" were first applied to the problem of subcritical flaw growth.

GAO and Herman [2017] the detailed geometries according to the size and weight have been standardized such as ASTM, ISO etc. Since I-beam has a significant contribution in building and other structural constructions, careful considerations has to be taken if defects or cracks are present in the beams. Many researchers have reported the behaviors of beam. Introduced closed-form expressions for stress intensity factors for cracked square -beams subjected to a bending moment.

Stephens et al.[2016] Most structural components are often subjected to cyclic loading, and fatigue fracture is the most common form of failure. In general, fatigue process consists of three stages: initiation and early Crack propagation, subsequent crack growth, and final fracture. The fatigue crack growth rate, d*a*/d*N*, which determines the fatigue life of the cracked components.

Aliabadi [2014] extensively been investigated experimentally and theoretically. BEM has emerged as a powerful alternative to Finite Element Method (FEM) for cases where better accuracy is required due to situations such as stress concentration (as in the case of a crack), or an infinite domain problem. Since BEM only requires discretization of surfaces (in case of 3D problems) and discretization of lines (in case of 2D problems), it allows modeling of the problem becoming simpler.

Irwin et. al. [2013] The results of the constant-amplitude crack growth tests by Paris were expressed in terms of da/dN (where N is the number of fatigue cycles) as a function of ΔK (which is Kmax - Kmin) on a double log scale. Plotting such data shows a region of growth where a linear relation between log (da/dN) and log (ΔK) appears to exist. This paper examines the Compliance crack length relations for the four-point bend specimen geometry in the laboratory.

Chen Wen-Hwa [2011]The predicted results are compared with experimental crack growth data obtained for 7020-T7 and 2024-T3 aluminum alloy specimens under constant amplitude loading. It is observed that the results obtained from this model are in good agreement with experimental data and cover both stage-II and stage-III of fatigue crack growth curve.

Fang Huei-Lu [2009] The service life of a structure/machine component under cyclic loading can be estimated by integrating the rate equation of the Paris type. However, direct integration becomes robust and complicated as the geometrical factor f (g) in the expression of ΔK varies with crack length.

T.L Anderson [2008]To overcome this difficulty, the authors have attempted to introduce a life prediction procedure by adopting an „Exponential Model". The model can predict the fundamental a–N curve to calculate life without integration of FCGR curve. It is worth mentioning that an exponential model is often used for the calculation of the growth of population/bacteria, etc. In this paper, the fatigue cracks propagate in longitudinally reinforced concrete beams without stirrups.

Hertzberg RW [2005] The experimental program has been designed to investigate the influence of the shear span-to-depth ratio on diagonal crack propagation and load carrying capacity of tested beams under four-point bend test. The obtained test results were compared with numerical results made on the basis of Finite Element Method.

Marta Słowik [2006] In this paper, Fatigue crack growth tests were conducted on double cantilever beam bonded specimens with the aim to characterize an adhesive for structural applications. The tests were conducted in lab air at two different load ratios, and at two different loading frequencies, Crack propagation was monitored using the compliance method by three point bend test and FE model was used also.

III. PROBLEM IDENTIFICATION

1. The total plastic strain energy density absorbed by the material is a constant prior to reaching its ultimate state. This constant is a parameter that can be determined by tests.

2. The elastic strain energy density stored by the material does not cause damage and is released upon unloading.

IV. 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.

V. METHODOLOGY

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.

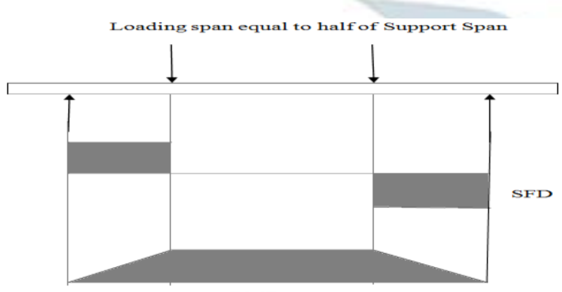


Figure 4: Four Points Bend Method

VI. RESULTS AND ANALYSIS

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

The crack profiles obtained by using multiple specimens are shown in Fig. 2 and Fig. 3 From the crack profile it is clear that the crack propagates in lateral direction and parallel to the loading. From the profile it is also clear that the crack front profile is approximately thumb nail shape in nature. In case of nail shape, the difference of maximum to minimum value of y-axis is taken as the crack length of a specimen with help of travelling microscope. Crack front shape strongly depends on initial flaw shape, size and loading situations. But the actual shape of the crack front is complex in nature. In the present investigation the crack front shape is experimentally evaluated also.

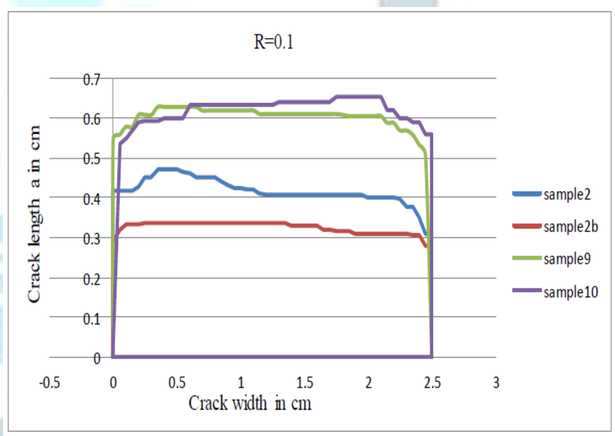


Figure 2: CRACK PROFILE WITH R=0.1

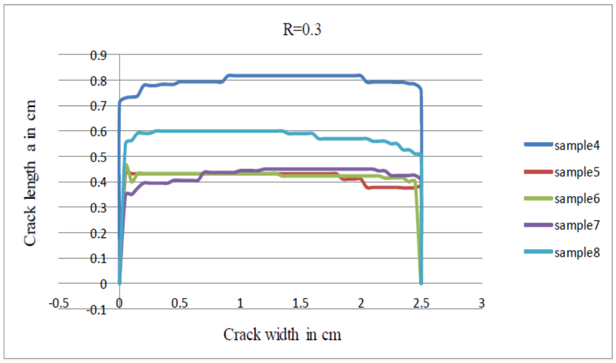


Figure 3: CRACK PROFILE WITH R=0.3

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 Fig. 2. With constant loading of different R ratios such as R= 0.1 and R=0.3

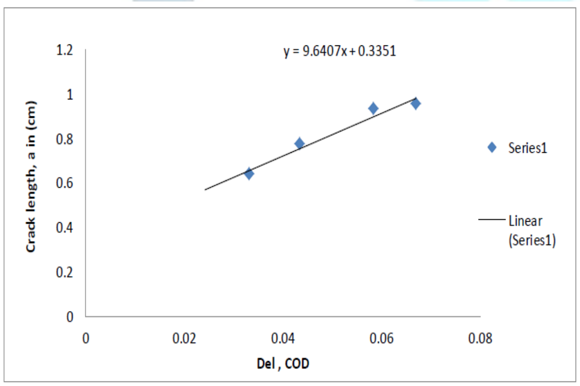


Figure 4: CALIBRATION OF COD GAUGE WITH R=0.1

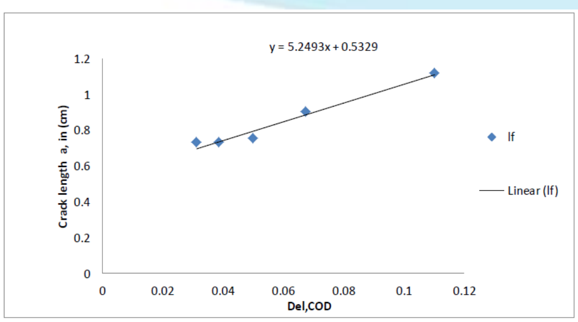
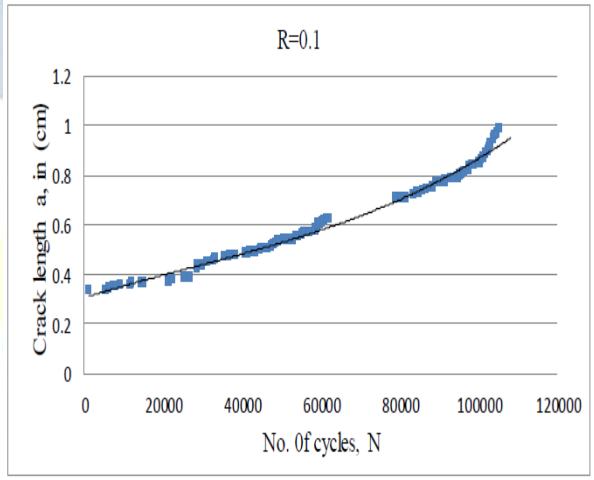


Figure 5: CALIBRATION OF COD GAUGE WITH R=0.3

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 (Fig. 6).



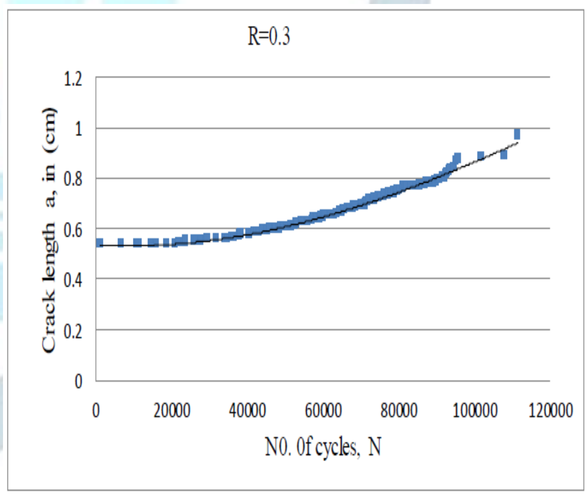


Figure 6: Curve Fitting Of Experimental Data (Crack Length Vs. Number Of Cycles)

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.

VII. 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 Kmax 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.

SCOPE OF 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.

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