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EXPRIMENTAL AND THEORETICAL INVESTIGATION ON NOTCHED SPECIMENS UNDER BENDING LOADING

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Abstract*:* Fatigue is an important parameter to be considered in the behavior of mechanical components subjected to constant and variable amplitude loading. Mechanical, metallurgical and environmental variables can influence the fatigue resistance of a structural component. The number of cycles that a metal can endure before it breaks is a complex function of the static and cyclic stress values, the alloy, heat-treatment and surface condition of the material, the hardness profile of the material, impurities in the material, the type of load applied, the operating temperature, and several other factors.

Various materials are subjected to different notch sizes and tested under bending loading for their endurance limit. These results obtained are then compared with their respective theoretical values obtained by The Modified Manson Coffin Curve Method.[2]

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Key words: fatigue life, Mason-Caffin method, notched specimen, stress-life curve.

I. INTRODUCTION

Most of structures and engineering components have notches of various geometries such as the v-shape threads on nut-bolt connections, the square-shape key washer's grooves on shafts, scratches, nonmetallic inclusions and corners, fillets and geometry discontinuities, surface cracks I smooth structural components such as round bars, pipes and shells. It is well recognized that notches cause locally high stresses. A sudden fracture will occur if the alloy cannot stretch to relieve such high stresses. The components are often subjected to dynamic loading which gives rise to reduction of fatigue life of the components. Tremendous efforts to study the effect of notches of various shapes and dimensions on fatigue life of engineering components under dynamic loading (axial, bending…) have been made [2].

There are numerous evidences in the literature that the presence of notch can reduce the fatigue life of components dramatically in some circumstances. The fatigue life of V-shape notch specimens under rotating bending by analytical method was examined [6] Reference [7] also shows some rotating bending test results and a comparison between analytical and experimental results. The experimental evaluation of fatigue life of notched engineering components is a cumbersome task and the results are always controversial and disputable. Reference [8] has proposed a new method in which the fatigue life of notched specimens is estimated from the fatigue life of plain specimens of the same material and geometry. The method, however, has been used only for U-shape notches This notch shape along with two other shapes including V-shape and square-shape notches are studied in this work and the applicability of the method to the two forgoing notch shapes is investigated. In this work, the theoretical Manson-Caffin method [8] is used for prediction of fatigue life of notched specimens with three notch geometries, (U-shape, V-shape and C-shape). The results are then compared with those reported in the literature [5].

II. LITERATURE SURVEY

It is well recognized that notches cause locally high stresses. A sudden fracture will occur if the alloy cannot stretch to relieve such high stresses. The components are often subjected to dynamic loading which gives rise to reduction of fatigue life of the components. Tremendous efforts to study the effect of notches of various shapes and dimensions on fatigue life of engineering components under dynamic loading[1]

The term "notch" in a broad sense is used to refer to any discontinuity in shape or non uniformity in material. A notch is frequently called a "stress raiser" because it develops localized stresses that may serve to initiate a fatigue crack (or reduce the load-carrying capacity). Notches are hardly avoidable in engineering practice Previous analyses were primarily qualitative and based only on a single concept of basic material behavior, such as plasticity, damping capacity, cohesive strength, work-hardening capacity, elementary structural unit, or statistical theories of fatigue.[5]

Some attempts at rationalization have been based on the stress conditions as affected by the geometry of the notch, such as state of stress, shear energy theory, stress gradient and extent of stress concentration.

Other quantitative approaches, such as correlations based on notch radius, or of stress at a given depth below the surface, represent a type of empirical approach deduced from speculative thinking which lacks evidence in the light of recent fatigue tests or theories. Other developments based on statistical effects and the homogeneity of metals

Experimentally it is observed that the amount of reduction of load-carrying capacity due to a notch roughly tends to increase with (but always is smaller than) the factor Kt. The ratio of the endurance limit of an unnotched specimen to that for a notched specimen is called the "strength reduction factor" or "effective stress concentration factor," Ke. The endurance limits are determined by fatigue testing in which only elementary stress formulas are used for calculating the stresses in the specimens, whether notched or unnotched.

The discrepancy between theoretical and effective stress concentration factors Kt and Ke varies not only for different metals but also for different sizes of specimen and different types of notch; the lack of a rational explanation for these variations has led to much confusion and speculation. The fundamental cause for this discrepancy may be attributed to the fact that the response of a material subjected to a repeated loading is quite different from the behavior of the same material when subjected to an elastic static loading. The analyses upon which the theoretical factors are based depend on the assumptions of an isotropic material which is perfectly elastic and homogeneous and whose stress, conditions and strength properties are not influenced by time or temperature. However, when dealing with fatigue tests of metals, the small localized spots (crystals, slip bands or grain boundaries) in which fatigue failure initiates are anisotropic and far from homogeneous. Localized in-elastic readjustments which are sensitive to time and temperature and which alter the stress and strength occur in the material at stress levels a slow as its endurance limit, or even lower. Better understanding of the mechanism of deformation in polycrystalline metals under repeated loading will therefore help to clarify the reason for the discrepancy between Kt and Ke.[2]

The problem of notch-sensitivity of metals has been investigated in experiments employing three different types of loading -static tension, Charpy impact, and rotating-beam fatigue tests. From results of static tension tests it has been shown that for ductile steels the ulti-mate strength and yield strength increase with notch depth and sharpness of the notch angle; the breaking stress (load per unit of actual area at fracture) also increases, moderately or remains approximately constant. For brittle metals such as cast iron, cast brass, and magnesium alloys (which may have many internal defects or high residual stresses but little capacity for plastic flow) there often is little difference be twine the strength values of notched and unnotched bars.[7]

The proposed fracture mechanics approach allows accounting for the effects of notch acuity, notch size and intrinsic material fatigue properties on fatigue notch sensitivity. It opens the door to a new simple method for predicting fatigue notch sensitivity and fatigue strength of components with geometric concentrators by using parameters that can be easily measured or estimated, without the necessity of any fitting parameter.[3]

The application of the body force method to the limiting cases of deep and shallow notches, accurate formulas were obtained as Ktd and Kts for the whole range of notch shape. However, the Kts solution cannot be a good approximation for the stress concentration factor Kt under torsion compared to the cases of tension and bending. On the other hand, the K_{td} solution can be used as a good approximate formula compared to the cases of tension and bending.[4]

These concentration factors are of importance to the design engineer the presentation of this data is only the beginning of a study which should be pursued. Design problems often involve two stress-concentration factors, one due to shape and the other due to material. The present tendency toward reduced weights and costs of machine parts requires accurate knowledge of the factor of safety and demands consideration of these two factors separately.[5]

It is observed that the life prediction by FEA simulation is acceptable for different stress amplitudes and also at different no. of cycles. The accuracy of the predicted life by FEA simulation depends on the selection of appropriate material model and the accuracy of the value of the material parameters used . It is very important to know that the prediction in this method depends on the correctness of the material total S-N curve (simple regression) generated from experimental results of high cycle fatigue data of cylindrical specimens and the accuracy of simulated value of maximum stress of notched specimens.[6]

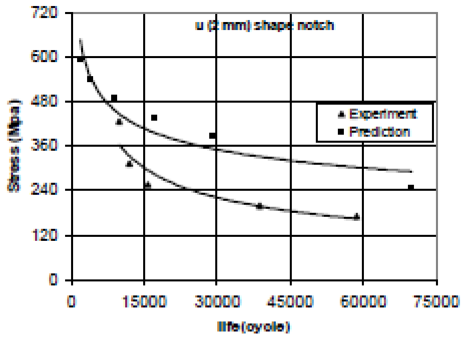
When several identical specimens were tested at two different stress levels, but close to each other, Weibull quantiles were used to obtain estimates of the shape parameter associated with the fatigue strength distribution. Each estimate was also checked from the observation traced on the Weibull probability paper.[7]

Visual investigation of the fracture surface it is concluded that the failure occurred due to torsional-bending fatigue. Fatigue crack has initiated at the relief groove. Forces and torques acting on the shaft are determined; stresses occurring at the fracture surface are calculated. Endurance limit and fatigue safety factor is calculated, fatigue life of shaft is estimated.[8]

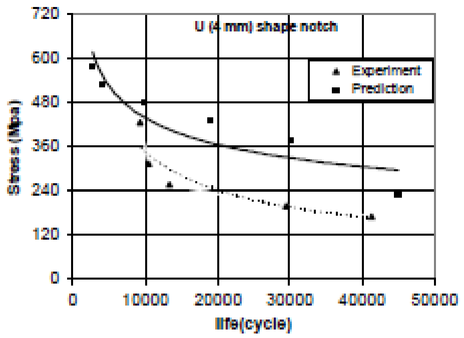
By considering the relative importance of the prevailing intrinsic damage and extrinsic shielding mechanisms, a commonality of behavior can be found for the cyclic fatigue of both ductile and brittle materials.[9]

The fatigue life is assumed to be controlled by the local stress amplitude at the critical location of a joint. The effect of the interference fit between the rivet and the hole and the effect of the sheet interface friction condition on the fatigue life of a joint are considered individually.[11]

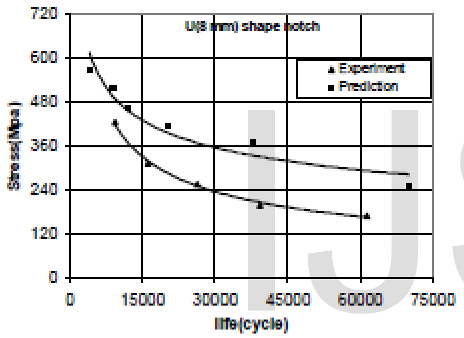
If the correct value of actual maximum strain is compared with the fatigue life, the same relationship will be obtained for the same material for any geometry. The Advancement in FE analysis for accurate prediction of strain at the notched cross section can be used for life prediction of life of components having complex geometry or discontinuity. The strain life curve for a material can also be generated using experimental results of notched specimens with correction in strain value to be computed from FE analysis. The method is straightforward and more generalized compared to other methods. The degree of applicability of this method is further to be tested for other type of specimens and notch conditions. From the results it is also observed that in most of the cases the predicted life is found to be less compared to experimental values for all the types of notched specimens.[12]



(a)



(b)



(c)

Fig. 2

The trans-crystalline fatigue growth rate during bending showed a strong size effect up to one order in the applied load. The formation of a dislocation pile-up at the neutral axis of micro-beams should increase the fatigue lifetime of a bending beam compared to a tensile load geometry. These results show that the dislocation pile-up effect must be taken into account when measuring the local fracture toughness or fatigue crack growth rates at this length scale by bending.[13]

Statistical analysis of the geometric variations in the TIG dressed fillet weld joints showed that compared to the as welded condition the great change was in the weld toe radius. After TIG-dressing, a major part of the weld toe radii were between 3.0 and 5.0 mm, whereas the radii were below 2.0 mm in the as-welded condition. The undercut produced by TIG-dressing was found to remain at a relatively low level, and no undercut was observed in most of the analyzed joints.[14]

The combination of cyclic fatigue loading and the residual stress due to the FOD for fatigue crack growth has been explored, with emphasis on the largest (critical) crack size that remains below the fatigue crack growth threshold. For cracks at moderately shallow indents, FOD can reduce the critical crack size by as much as 60%, depending on the cyclic loading history.[18]

Neuber took the effect of the size of elementary structural unit into consideration by selecting the following equation for predicting the effective stress concentration factor K, from the theoretical value of K,

$$K_e = 1 + \frac{K_t - 1}{1 + \sqrt{\frac{\rho'}{r}}}$$

It has been well known for many years that most failures in machine parts (and in some structural members) are progressive fractures resulting from repeated load; these "fatigue failures" nearly always start at an imposed or accidental discontinuity, such as a notch or hole.[19]

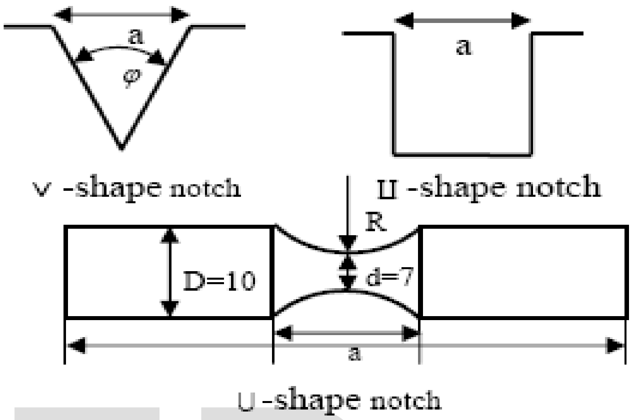


Fig. 1

Two major elements indicate that the fatigue mechanism requires a physical volume to take place; fatigue tests are generally affected by a large scatter and fatigue resistance is influenced by the size of specimen and the relative stress gradient which are dimensional parameters. This approach leads to a two parameter fatigue initiation criterion, the effective stress and the effective distance. The effective distance is associated with a particular point of the elastic plastic stress distribution presented in a bi-logarithmic graph. The effective stress corresponds to an average value over this distance of the stress distribution weighted by the distance and the relative stress gradient.[20]

The strain-based, or local strain approach to fatigue life prediction assumes that smooth and notched specimens with the same local strain amplitude experience the same number of cycles to failure. The local strain amplitude, ε a, at the notch root can be determined from the FEA notch analysis or from the analytical notch deformation models discussed in the previous section. Fatigue life can then be predicted according to the ε a-2Nf curve (Coffin-Manson equation) obtained from smooth specimens tested under completely reversed strain-controlled conditions.[22]

The fatigue behavior is controlled by the material resistance to crack propagation in all cases. The short crack propagation lives at V-notches under under axial and torsional loadings are well correlated by the mode I NSIF and the mode III NSIF respectively. The fact that the fatigue notch factor is close to unity is due to a very high resistance to mode III crack propagation. The NSIF approach opens the door to a new way to make fatigue life prediction of notched components. The theoretical foundations are similar to those of Linear Elastic Fracture Mechanics. It is not required to take into account the notch tip plasticity as long it is confined within the singular stress zone.[23]

Due to the rather high value of the notch depth, it has practically been impossible to analyse the propagation of fatigue cracks during the tests by using an optical microscope. However, the analysis of the fracture surfaces of biaxially loaded specimens, obtained by means of scanning electron microscopy is that Cracks nucleate at the notch tip and propagate in a radial direction around an axis which is not coincident with the specimens' axis.[24]

The circumferential notch is assumed to have a circular-arc shape, whereas the surface flaw at the notch root presents an elliptical-arc shape. to obtain the Stress-Intensity Factor (SIF) distribution for different values of the SCF and crack geometries, a three-dimensional finite element analysis has been performed. The notch effect on the SIF is significant for any crack size and shape. Insofar as fatigue behaviour is concerned, a remarkable influence of the stress field caused by the notch is observed. In particular, the crack aspect ratio vs relative crack depth curves for notched bars are very different from those for unnotched (smooth) bars, in the case of both tension and bending.[25]

Figures

Fig. 1 Specimen's geometry used in this work
Fig.2 Experimental and the predicted fatigue life for ∪-shape notch:(a) r=2 mm, (b) r=4 mm and (c) r=8 mm

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