EFFECT OF FATIGUE ON LIFE OF WELDED JOINTS – A REVIEW

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Abstract

Welded joints find its importance in structures and machine manufacturing for its advantages over the nut & bolted joints in many ways. All the structures and machines experiences different loads according to the type they are subjected. Failures may occur in any form due to the loading on the structures. The paper is intended to discuss about the effect of fatigue loading and due fractures occurred in different type of welded joints under different loading conditions. The techniques suggested by the experts to define the occurring of failure and how to optimize the effects in the components are discussed.

I INTRODUCTION

A part failure mode is the way in which a component fails "functionally" on component level. There are almost 23 types of mechanical failures that occur in machines. One of them is a fatigue failure. The failure mechanism that caused this can be of many different kinds, and often multiple factors play a role at the same time. They include corrosion, welding of contacts due to an abnormal electric current, return spring fatigue failure, unintended command failure, dust accumulation and blockage of mechanism, etc. Some types of mechanical failure mechanisms are: excessive deflection, buckling, ductile fracture, brittle fracture, impact, creep, relaxation, thermal shock, wear, corrosion, stress corrosion cracking, and various types of fatigue. Each produces a different type of fracture surface, and other indicators near the fracture surface(s). The way the product is loaded, and the loading history are also important factors which determine the outcome. Of critical importance is design geometry because stress concentrations can magnify the applied load locally to very high levels, and from which cracks usually grow.

Designing of these structures will be taken place considering the strength and the type of loading. Many structures, off shore vehicles, automobiles and mechanical components uses welding in joining process. Advantages of using welded joints had replaced the use of other joints. These welded joints also experiences failure at some extent. The failure in welded joints generally occurs at the weld tips. It is necessary to test its functionality under the existing load situation and quantify damage if any. It is also important to evaluate the residual life and strength of these structures. When there is a crack in a structure and with a application of repeated loads or combinations of loads and environmental attack, this crack will grow with time. The longer the crack, the higher the stress concentration induced by it. The residual strength of the structure decreases progressively with increasing crack size. In order to ensure this safety, it has to be predicted how fast crack will grow and how fast residual strength or remaining life of the structure or structural component will decrease.

II LITERATURE REVIEW:

A literature review surveys scholarly articles, books, dissertations, conference proceedings and other resources which are relevant to a particular issue, area of research, or theory and provides context for a dissertation by identifying past research.

F. Pakandam, A. Varvani-Farahani proposed a combined approach which include both the stress and the strain components. They introduced Energy-based approach to analyze the damage accumulation of notched/welded components. They confirmed that in case of large numbers of cycles, the stress and energy models are the best for explaining fatigue, and for a small number of cycles the strain and energy models are superior. Three types of methods are described in the paper, (i) hysteresis-loop method, (ii) fracture mechanics approach (known as notch stress-intensity method), and (iii) critical plane/energy method.

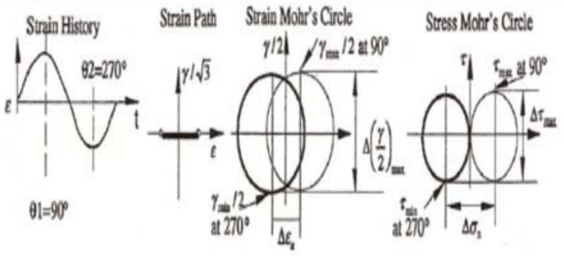
(i) In this hysteresis-loop energy method the plastic strain energy equation for Masing type metallic material is considered. The plastic energy range, Δ*Wp*, is calculated based on components of the stress range (Δσ) and the plastic strain range (Δε *p*) extracted from stabilized stress-strain hysteresis loops. The equations for the

$$\Delta W_P = 4\frac{1-n'}{1+n'}\sigma'_f\,\varepsilon'_f\left(2N_f\right)^{b+c}$$

(ii) In notch stress-intensity energy method, a strain energy density approach introduced by Lazzarin et al. has been used to estimate fatigue failure of welded joints. As per this approach, fatigue failure occurs when the average value of the total or plastic strain energy density reaches a critical value in a cylindrical volumetric region around the notch tip with a radius *Rc*, independent of the loading mode. The total deviatory strain energy density averaged over a circular sector with its center at the weld toe and radius *Rc* is given by

$$\overline{\Delta W}=\frac{e_{d1}}{E}\left(K_1\right)^2\left(R_C\right)^{2(\lambda_1-1)}+\frac{e_{d2}}{E}\left(K_2\right)^2\left(R_C\right)^{2(\lambda_2-1)}+\frac{e_{d3}}{E}\left(K_3\right)^2\left(R_C\right)^{2(\lambda_3-1)}$$

(iii) In the critical plane-energy fatigue damage model, both the normal and the shear energies are computed on the most damaging plane of materials, referred to as the critical plane. Fatigue coefficients are used to calibrate the damage model for local stress and strain components at the weld toe. The local stresses are calculated from nominal stresses and the fatigue notch stress concentration factor, K_f.



$$W=\frac{1}{\left(\sigma'_f\,\varepsilon'_f\right)}\left(\Delta\sigma_n\Delta\varepsilon_n\right)+\frac{1}{\left(\tau'_f\,\gamma'_f\right)}\left(\Delta\tau_{\max}\Delta\left(\frac{\gamma_{\max}}{2}\right)\right)$$

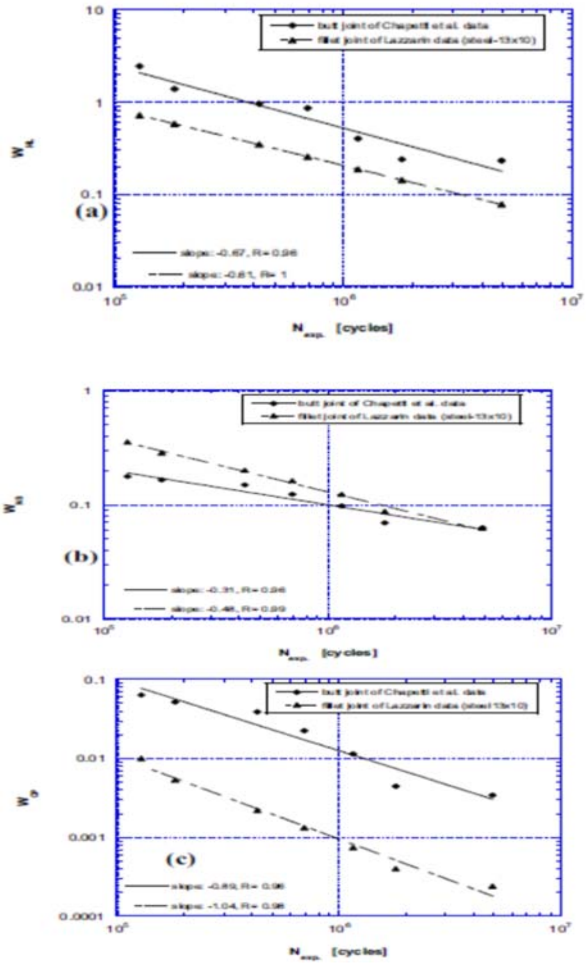


Fig. 1: Energy versus fatigue life diagrams for low carbon steel welded joint types of butt and cruciform, based on (a) hysteresis- loop energy, (b) notch stress-intensity energy , and (c) critical plane/energy.

Of these models, they observed that the critical plane/energy model possessed a steeper *W-N* curve slope. This suggests that the critical plane/energy approach has correlated the fatigue data for the joints with less scatter in fatigue life range. Both approaches of the notch stress-intensity and the critical plane/energy methods are dependent on *Kf* factor and they incorporate the effect of weld joint types in the fatigue analysis, while the hysteresis-loop energy approach fails to correspond to various joint types as the *Kf* factor is not used in the analysis.

Fuhai Cai et. al. had carried out their work on welds present on cranes lattice booms. For to obtain real crane stress spectra inexpensively and conveniently, a new stress spectra acquisition method based on the measured & simulated & compared & statistics' integrated strategy of crane K-type welded joints was proposed. They proposed a new theory named simplified Huffman non-linear cumulative damage theory to calculate the fatigue life of crane K-type welded joints based on the notch stress and strain approaches. A lattice boom is primarily welded by a large number of K-type and t-type pipe welded joints. Generally the Palmgren-Miner (PM) rule is a linear accumulation damage approach that is widely used for predicting the part's lifespan under variable amplitude loading. But due to its limitations in calculating the depression rate in damage a new method of obtaining the stress-time spectra is proposed in this paper, based on the simulation software with the advantages of being economical and convenient. The boom is mainly subjected to a plane axial load force and a bending load force in the luffing plane. The boom can withstand a compressive load, and the K-type weld joints are subjected to tension and compression composite fatigue loads. It was observed that the crack growth was mainly due to the stress perpendicular to the weld at which large cracks were found in the area of high structural stress and high stress concentration They found that the stresses in the chord at the welded joints on the bottom section near the variable cross-section were found to be relatively higher compared to those at the other sections

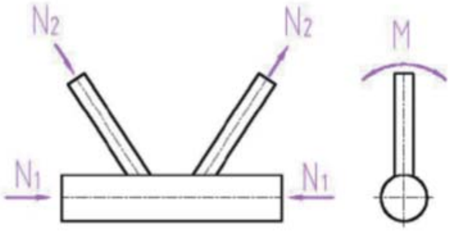


Fig. 2 : K-type welded joint

They used a non-linear fatigue cumulative damage calculations approach from Huffman which requires the cyclic stress-strain curve and the curve of the constant amplitude strain-life material properties. Using the intrinsically non-linear cumulative damage theory the structure fatigue life of the K-type welded joint is calculated and is given by

$$D_T = \sum_{i=1}^{2N_T} D_i$$

DT is the sum of the damage of all reversals and *Di* is the normalized damage caused by the i^{th} reversal ranging from $i = 1$ to $i = 2N_T$

$$D_i = \frac{\sum_{k=1}^{N_T+1} \sinh\left(\frac{2N_k}{2N_{fail}}\rho\right) - \sum_{k=1}^{N_T} \sinh\left(\frac{2N_k}{2N_{fail}}\rho\right)}{\sum_{j=1}^{N_f} \sinh\left(\frac{2N_j}{2N_{fail}}\rho\right)} \qquad \&$$

$$D_T = \frac{\sum_{k=1}^{N_T} \sinh\left(\frac{2N_k}{2N_{fail}}\rho\right)}{\sum_{j=1}^{N_f} \sinh\left(\frac{2N_j}{2N_{fail}}\rho\right)} \approx \frac{\int_1^{N_T} \sinh\left(\frac{2N_k}{2N_{fail}}\rho\right) dN_k}{\int_1^{N_f} \sinh\left(\frac{2N_j}{2N_{fail}}\rho\right) dN_j}$$

The calculations have been done by measured replacing stress spectra by the simulated stress spectra. The observations made them them gave an error percentage of only 10%.

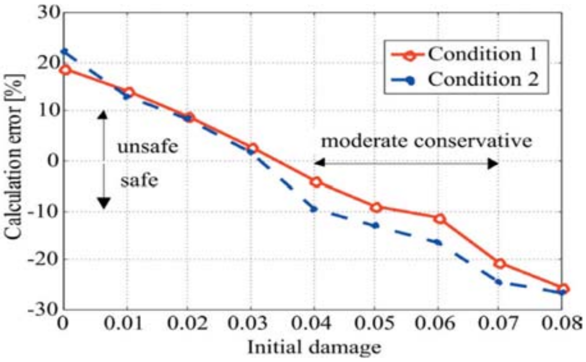


Fig.3 : Calculation error comparison

The stress spectra acquisition method based on the 'measured & simulated & compared & statistics' integrated strategy of crane K-type welded joints was found to be feasible. The non-linear cumulative damage theory was found to have a higher accuracy than that of the PM rule.

Asifa Khurram and Khurram Shehzad proposed FE technique using equivalent load to precisely predict welding deformations and residual stresses in butt joints. According to them equivalent load method is based on inherent strains which are a function of the highest temperature and degree of restrain. Transverse shrinkage, longitudinal shrinkage and out of plane deformations of the specimen are computed by FE simulation and validated with experimental measurements. They performed Nonlinear FE transient thermal analysis using surface heat source model with Gaussian distribution to compute highest temperature in mild steel plates. An APDL subroutine was used to define heat flux density q transferred to each point on the surface around the welding line at each time step using

$$q(x,y)=\frac{3Q}{\pi r^2}e-3\frac{x^2}{r^2}-3\frac{z^2}{r^2}$$

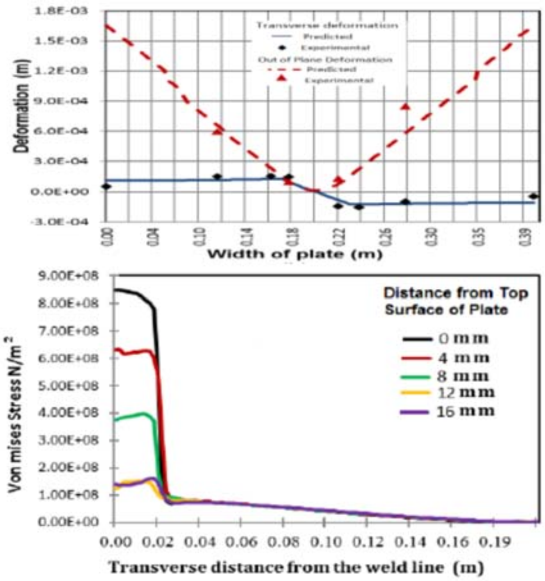


Fig.4: Transverse and out of plane deformation and Vonmises stress distribution across plate thickness at mid-section.

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They confirmed that the value of out of plane deformation is much higher as compared to transverse and longitudinal deformations, Von-mises residual stress decreases rapidly in transverse direction in areas near the weld region, an increase in plate thickness results in reduction of residual stresses in areas adjacent to fusion zone.

Philippe Darcis, Diego Santarosa, Naman Recho and Tom Lassen proposed a Fracture mechanics model to describe the entire fatigue process in which it is calibrated to fit the crack growth measurements carried out on fillet welded joints. The main importance of the work is put on how to choose growth parameters in conjunction with a fictitious initial crack size to obtain both reliable crack growth paths and predictions of the entire fatigue life. S-N approach and Fracture mechanics approach was taken as consideration. The equation for S-N approach is as

$$N=\begin{cases}A\Delta S^{-m} & \Delta S>\Delta S_0\\ \infty & \Delta S\le\Delta S_0\end{cases}$$

The equation for fracture mechanics approach is given by

$$\frac{da}{dN}=C(\Delta K)^m=C(\Delta S\sqrt{\pi a}\,F(a))^m,\qquad \Delta K>\Delta K_0$$

$$N=\frac{1}{C}\int_{a_0}^{a_c}\frac{da}{\left(\Delta S\sqrt{\pi a}\,F(a)\right)^m}$$

Paris law was used to both crack evolution and fatigue life at various constant amplitude stress levels.

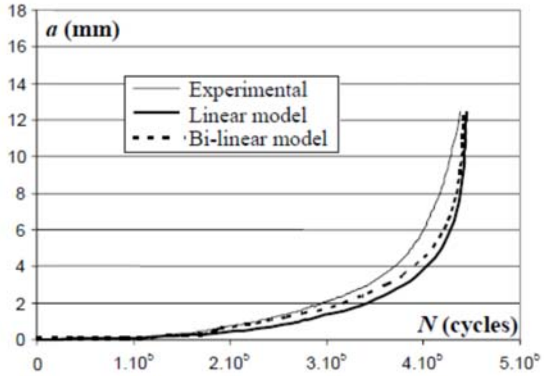


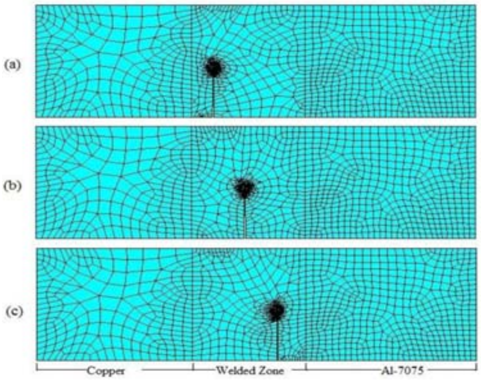
Fig.5: Comparison between BS 7910 relationships and experimental results.

They concluded that bi-linear relationship between *da*/*dN* and SIFR for a log-log scale also gives good agreement with experimental *a*-*N* curves. Observations made states that if the parameters proposed for the bi-linear relationship between the log *da/dN* and log Δ*K* are used the fatigue life estimates are far too optimistic at low stress levels and hence, the latter approach should not be applied for small surface breaking cracks at weld toes.

Soran Hassanifard, Amir Parghazeh, Mohammad Zehsaz carried out their work on fatigue crack growth in friction stir welding of Cu-Al7075-T6 joints. Four-point-bending tests were carried out and the results are compared with the numerical data. Applying maximum tangential stress criterion the kinked crack propagation in the welded zone was predicted. Butt friction stir welded joints of 2 mm aluminum 7075-T6 and pure cooper sheets were considered for this study. Different regions of the welded joints like nugget, heat affected zone and parent materials were employed. According to maximum tangential stress criterion the crack initiation is given by

$$\sqrt{2\pi r\left(\sigma_{\theta\theta}\right)}=\cos\frac{\theta_0}{2}\left[K_1\cos^2\frac{\theta_0}{2}-\frac{3}{2}K_{11}\sin\theta_0\right]$$

Fabrication of FSW specimen was carried by HEIDENHAIN TNC 155 milling machine. The cracks were created in three positions in welded zone near Cu, middle of the welded zone, and near Al.



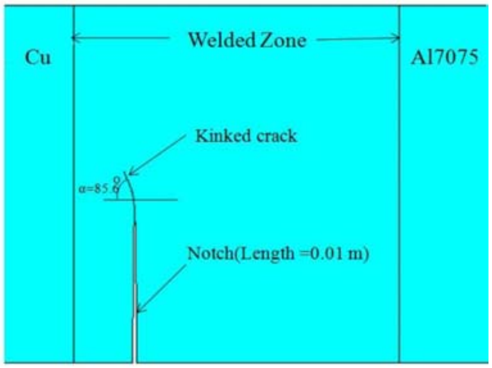


Fig. 6: Crack positions (a) near Cu, (b) middle, (c) near Al

Fig.: Typical kinked crack angle observed near Cu

Four point bending test were carried out on ROELL/AMSLER hydraulic machine. The observations concluded that when the original notch is close to the material with the higher fracture toughness the kinked crack angle becomes smaller but with higher fracture load.

Xiang Zhang, Haiying Zhang, Rui Bao performed Biaxial load fatigue crack growth tests on cruciform joint made of aluminium-lithium alloy 2198-T8 containing a butt weld joint fabricated by the friction stir welding process. they studied by considering two material rolling directions in relation to the welding and crack growth direction. They stated that the material rolling direction affects the crack growth path. The influence of applied stress biaxiality on stress intensity factors, *T* stress, crack trajectory are used to predict the crack growth rate and trajectory of the crack growth.

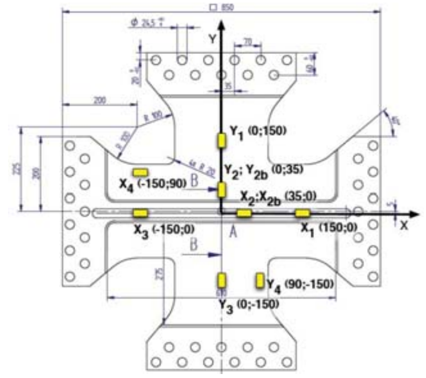


Fig.7: Test specimen and strain gauge locations

SIF was calculated using the interaction integral method available in the ABAQUS, which is similar to the *J*-integral method and it is given by

$$\beta = \frac{K_I}{\sigma_y \sqrt{\pi a}}$$

They observed that due to the secondary bending effect the panel exhibits out-of-plane deformation even the load is in-plane. obtained mode I stress intensity factors (*KI*) at the different *k* are presented and concluded that as *k* increases, *KI* will decrease

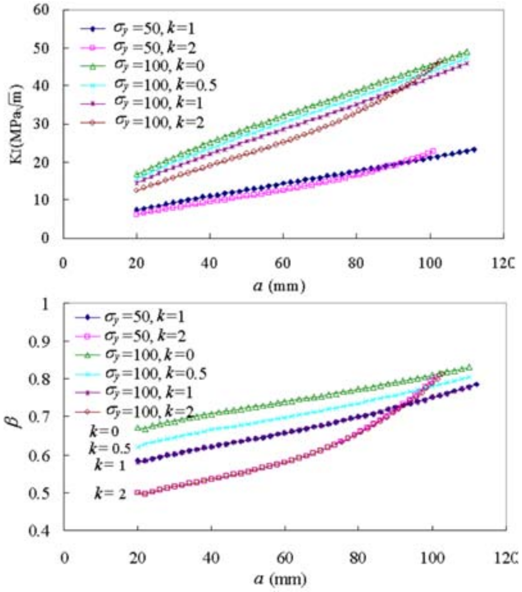


Fig.8: FE calculated stress intensity factors under various biaxial load ratios: a) KI; b) β factor.

Prediction of test measured crack growth lives includes three possible reasons for underestimating the crack growth life, 1) Residual stress effect 2) Influence of weld metal microstructure change 3) FE calculated *y*-axis strains.

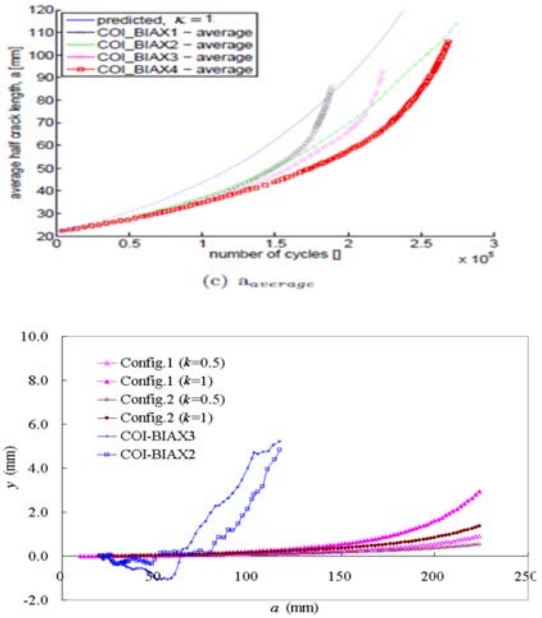


Fig.9: a) predicted crack growth life and b) trajectory, and comparison with test measurement

They concluded that as Mode-I stress intensity factor (SIF) decreases as the biaxial load ratio *k* increases and there is no crack path deviation for $k \leq 1$.

J. Maljaars, H.M.G.M. Steenbergen, A.C.W.M. Vrouwenvelder proposed a probabilistic assessment model for linear elastic fracture mechanics (LEFM) for determination of the failure probability of a structure subjected to fatigue loading. Assuming that for Δσ, a sufficiently mixing (ergodic) process, we may use the expectation of the stress range to find the expectation of da/dN.

$$E\left(\frac{da}{dN}\right)=A_1E\left[\Delta\sigma^{m1}\right]_{\Delta\sigma_{th}}^{\Delta\sigma_{tr}}\cdot\left(\left[\frac{B_{nom}}{B}\right]^{p}C_{load}C_{glob}C_{scf}C_{sif}Y_a\sqrt{\pi a}\right)^{m_1}\ldots$$

$$+A_2E\left[\Delta\sigma^{m2}\right]_{\Delta\sigma_{tr}}^{\infty}\cdot\left(\left[\frac{B_{nom}}{B}\right]^{p}C_{load}C_{glob}C_{scf}C_{sif}Y_a\sqrt{\pi a}\right)^{m_2}$$

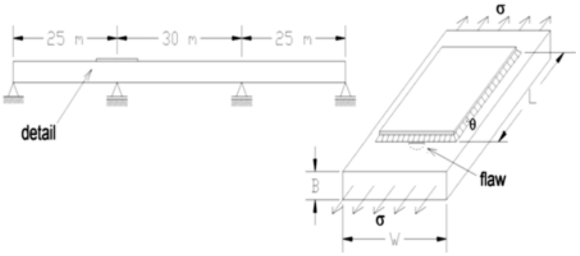


Fig10.: Geometry considered

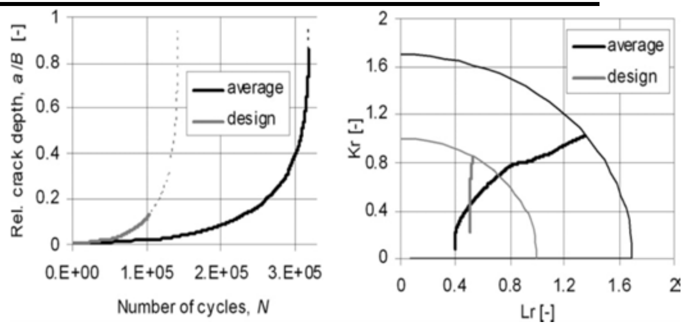


Fig11.: Result of the deterministic calculation (a) Crack growth, (b) Failure assessment

The crack growth and the failure assessment are determined with a deterministic approach considering two cases: one with mean values for all random variables and the other with a 'design set' of random variables. They confirmed that model uncertainty factors appear to be important in the assessment of the failure probability. Almost equal failure probabilities are observed for all the distribution functions of variables considered and it is sufficient only to consider the lower bound solution – which is considerably easier. The fracture criterion is not explicitly accounted for in standards based on S–N curves. to program that the failure probability is relatively insensitive to the failure criterion (acr = B or acr is associated with fracture) for the entire fatigue life of most engineering structures.

SUMMARY

The paper is intended to study about the different failure techniques applied for different types of joints and application the same. In each case it is found to that stress intensity factor plays an important role for the failure. Energy based techniques helps in assessing under uniaxial loading. Different joints like Butt, K-type, Cruciform joints and for different types of loading are studied. In all the cases it found that energy based techniques gives better results in finding the fatigue damage.

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