International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Review Article

Review of Fatigue Analysis of Welded Joints

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Accepted 20 June 2015, Available online 25 June 2015, **Vol.5, No.3 (June 2015)**

Abstract

Aim of this paper is to predict the fatigue strength of welded joints by means of fracture mechanics approach that takes into account the fatigue behavior of short cracks. The methodology helps to find out the fatigue crack propagation rate as a function of the difference between the applied driving force and the material threshold for crack propagation, a function of crack length. Analytical fatigue models were developed to estimate the fatigue behavior of notched plates. The analytical results obtained were compared to that with FEA to predict its life

Keywords: *fatigue, crack growth, stress concentration factor.*

1. Introduction

Fatigue of the materials is a very complex process, which is still today not understood in spite of vast research. Welded joints are vulnerable to fatigue damage when subjected to repeated loading. Welding strongly affects the material by heating and subsequently cooling as well as addition of filler material gives rise to inhomogeneous and different material than the base material. Also welds are not uniform as it is having pores, inclusions, cavities etc. Also residual stresses and distortions resulting because of welding process affect the fatigue behavior.

As a result, fatigue failures appear in welded structure mostly in the welded area than in the base metal.

Improper knowledge of fatigue actions is one of the major sources of fatigue damage. Hence fatigue analysis of welded joint becomes of high interest in areas where the part is subjected to repeated loading such as railcars, cranes, bridges, ships etc. Due to its wide area of application and keeping in mind its complexity, it is not surprising that different methods have been used for fatigue analysis of welded joints. Different methods have been used for the analysis of welded joints. Among all of them for comparison, Nominal stress method, Hot spot stretch method, Effective notch method are considered in this study Different researchers considered these methods for their study and did a comparison study on all these.

A lot of research is being done in this regards. But it's not possible to cover all the areas. Hence a part of it been studied in this review paper.

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2. Phases of fatigue failure

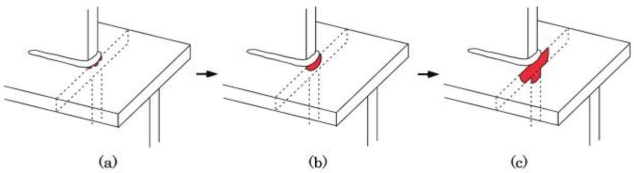

Fig.1 Behavior of fatigue cracks in welded joints. (a) Initiation of cracks, (b) Propagation and coalescence of surface cracks, (c) Propagation of a through-the-thickness crack

The fatigue failure occurring in any material is undergoing in the steps shown in fig. 1.

Crack Initiation- the welded structure which is undergoing repetitive loading, small crack generation starts in it at comparatively weak areas such as welded joints.

Crack Propagation/growth-the small crack generated goes on increasing as the specimen is going through the load cycle again and again.

Final breakage- the crack is now grown too much that the specimen can't withstand the anymore and immediate failure occurs.

3. Literature survey

In this section brief overview of fatigue analysis of welded joints is presented.

The statistical behavior of the fatigue life of fillet welded joints has been examined and modeled with reference to conventional S-N curves found in current rules and regulations.

An alternative statistical model based on a joint random fatigue life and a random fatigue limit has been applied. Constant amplitude fatigue life data near the "knee point" of the rule-based bilinear S-N curves are assembled to study and corroborate the model. The model has been fitted to experimental fatigue lives and the obtained S-N curve is compared with the traditional bilinear S-N curves given in rules and regulations. The rule-based S-N curves and the RFLM based curve coincide for stress ranges above 110 MPa. For stress ranges below 100 MPa, the RFLM curve will predict fatigue lives that are from 2 to 10times longer than the predictions made by the F-class S-N curve. It appears that the nonlinear curve obtained from the RFLM has a much better ability to model fatigue life behavior in this stress region. The abrupt knee point of rule-based bilinear curves does not fit the experimental facts for the assembled data. The fatigue life behavior in this stress regime is obviously more complex than the conventional bilinear S-N curve can describe (T. Lassen *et al*, 2005).

A fatigue life prediction system for welded structures has been developed, wherein small initial cracks are assumed to form along the toe of a weld bead, and their growth and coalescence behavior is simulated up to the time when a crack breaks through the plate thickness, which represents the fatigue life. The simulation of crack opening/closing behavior by applying a strip yield model makes it possible to adequately analyze the propagation of fatigue cracks considering the effects of the residual stress and loading sequence. The developed system proved capable of analyzing the effects of overloads on the fatigue life of welded joints and the fatigue strength improvement effects of UIT, and the prediction results agreed well with those obtained with actual fatigue tests. The system is expected to find wide application in the fields of fatigue design and maintenance for ships, bridges, plants, construction machinery, and other welded structures as a means for improving their reliability, extending their service life, and reducing environmental loads (Teppei Okawa *et al*,2013).

Wolfgang Fricke (2003) reviewed fatigue analysis of welded joints, for the past 10–15 years. After a short introduction, the different approaches for fatigue analyses are covered, i.e. the nominal stress approach, the structural or hot-spot stress approach, the notch stress and notch intensity approach, the notch strain approach and finally the crack propagation approach. Only seam-welded joints are considered, and not the behavior of spot-welds, which is a very special field. Due to the vast amount of relevant literature, some specific areas are left for other reviews or only touched, i.e. fatigue testing and evaluation, fatigue loading and variable amplitude effects, environmental effects and fatigue reliability.

L.F. Jaureguizahar and M.D. Chapetti studies crack like defect. Crack-like defect lengths of about 0.1 mm is obtained. However, much effort should be done in order to analyses the influence of short crack effect in the definition of fatigue strength. The influence of short crack effect depends on the applied stress ratio and only can be neglected when the transition from short to long crack regime become similar to the initial crack length. It is necessary to keep in mind when estimating fatigue strength that the smaller the initial crack length is, the greater the over-prediction of fatigue strength will be if the short crack effect is not taken into account. Besides, even though more detailed experimental results should be obtained and extensive parametric studies should be carried out in order to reach important conclusions about the influence of the geometrical, micro structural and mechanical parameters involved in the definition of the fatigue behavior of welded joint, the analysis showed that the present model could be able to describe most of their interactions and to provide a powerful tool to estimate the fatigue strength of different weld configurations.

A.Chattopadhyay *et al* studied an efficient shell finite element technique for obtaining stress data in welded structures relevant for fatigue analyses has been proposed. According to the proposed method the entire welded structure can be modeled using a relatively small number of large shell finite elements. The modeling technique captures both the magnitude and the gradient of the hot spot stress near the weld toe which are necessary for calculating the stress concentration and the peak stress at critical cross-sections, e.g. at the weld toe. A procedure for the determination of the magnitude of the peak stress at the weld toe using the classical stress concentration factors (one for axial load and one for bending) has been laid proposed. The approach is based on the decomposition of the hot spot stress into the membrane and bending contribution. The method can be successfully applied to any combination of loading and weldment geometry. The stress concentration factors are used together with the hot spot membrane and bending stress σ Mhs and σ bhs at the location of interest in order to determine the peak stress at the weld toe and the through-thickness on-linear stress distribution.

C. Acevedo, A. Nussbaumer has been shown that the drilling system developed for tubes has given suitable results with an accuracy of 10% in residual stresses assessment. In this measurement campaign, the effective hole-diameter was greater than the theoretical hole-diameter, this difference was taken into account. The first residual stress evaluations on bridge tubular joints, presented in this paper, have led to drastically different residual stress field than found in the literature on pipe and pressure vessels tubes. In future work, influence of tube curvatures on the accuracy of the hole-drilling method, will be studied. Moreover, in order to evaluate both intensity as well as variability of the residual stresses at surface and in the depth, measurements by means of the non-destructive neutron diffraction technique, will be performed. It will give us a complete map of the triaxial stresses.

J. Cotrell presented the design, analysis, and testing of a two-bladed hub. This section discusses report conclusions and recommendations on design, methodology, and testing techniques, as well as work on the hub that remains to be completed. In thesis, author focus on the analysis and testing of the hub body. Work performed solid-mechanics calculations, ran a finite-element analysis simulation, and experimentally investigated the structural integrity of the hub body. Both the predicted and experimental results indicate that the hub body is structurally adequate.

Mustafa Aygul performed conclusions based on the work performed in this study are divided into two parts. In the first part, the conclusions and recommendations for the fatigue assessment of orthotropic bridge deck details are given. In the second part, the conclusions for the studied welded details for the three fatigue assessment methods are presented.

The application of the investigated fatigue life assessment methods on an orthotropic bridge details showed that the application of local approaches for the estimation of fatigue life of these complex details, yields more accurate results. When using the nominal stress method, special attention should, however, be paid to the distribution of shear stress over the welded section. Based on this investigation, the following recommendations for the application of the fatigue assessment methods and finite element modeling techniques can be presented:

Table 1 Advantages and disadvantages of fatigue life assessment method

Advantages	Disadvantages
Nominal Stress Approach	
Simple calculation	Fatigue life category dependency
Well designed and well known	Limitation for misalignment and macro geometric changes
Most common and widely used	Less accuracy in complex structures
Available experimental data	Thickness effect not included
Available parametric formula	
Available fatigue classes in design codes	
Suitable for weld root and toe cracking	
Hot spot stress approach	
Fewer S-N curves needed	Dependent on element size
The use of existing stress analysis	Dependent on element arrangement
Acceptable accuracy	Different stress determination procedures
Less FE modeling effort	Thickness effect not included
Macro geometric effect included	Limited effect not included
Utilized for tubular structures many years, well known	
Effective notch stress approach	
Thickness effect included in calculation	Applicable only with FEA
Not affected by the stress direction	Dependent on mesh density
Suitable for weld roots and toes cracking	Dependent on radius size
A single S-N curve	Effort for modeling-time consuming
	Larger models

The aim of these recommendations is to provide a basis for the design and analysis of welded components loaded by fluctuating forces, to avoid failure by fatigue. In addition they may assist other bodies who are establishing fatigue design codes. It is assumed that the user has a working knowledge of the basics of fatigue and fracture mechanics. The purpose of designing a structure against the limit state due to fatigue damage is to ensure, with an adequate survival probability, that the performance is satisfactory during the design life. The required survival probability is obtained by the use of appropriate partial safety factors (A. Hobbacher 2008).

Conclusions

This research work has discussed the modes of fatigue failure in different types of structures and preventive measures against it. As fatigue plays a vital role in applications where there is repetitive load. It helps in finding out the areas of failure and thereby accurately predicting service life of the application where the welded structure is to be used. The different methods find a wide application in areas such as ship and offshore structures, steel bridges, construction machinery other such welded applications for improving their reliability and also for improving service life.

Below is summary for the three methods considered in study viz., Nominal stress approach, Hot spot stress approach, Effective notch stress approach.

1) The nominal stress method provides good agreement with the test results only when the shear stress distribution over the welded section and the normal stress distribution over the girder section are considered correctly. A more clear definition for critical cross-sections where the stress calculations would be performed needs therefore be outlined in Euro code 3.
2) When using the structural hot spot stress approach, it is essential to correctly represent the welds in complex details with cut-out holes. For the studied welded joint, fine meshed solid element models yield more representative stress ranges at the hot spot points. The use of solid element models including the welds to evaluate the structural hot spot stresses for welded details with cut-out holes is therefore recommended. For

models incorporating shell elements, it is important to represent the welds in complex welded joints, not only in term of stiffness (thickness) but also with regards to shape (geometry).The study shows that this can be achieved in the best way by using oblique shell elements.

3) Using smaller tetrahedral solid elements facilitates the modeling work and the differences between the results when using hexahedral and tetrahedral elements are very small. However, the modeling work when applying the effective notch stress approach requires much more effort than the work involved in using the structural hot spot stress approach.

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