Fatigue Analysis Of Butt Welded Joint Using LEFM – Experimental Investigation

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Abstract

Experimental investigation has been carried out on butt welded joint of grade 2 steel materials. Fatigue test were carried out using 100 KN fatigue testing machine with a frequency of 25 Hz. The crack length was carefully monitored by using the compliance method. Results obtained during test were plotted on S-N curve and crack length vs number of cycles. The LEFM fatigue analysis shows good agreement with fatigue test in the crack growth analysis.

Keywords - Butt weld, Crack length, (CT) specimen, Fatigue analysis, LEFM, Number of cycles

"1. Introduction"

Failure of material under cyclic loading is termed as fatigue. Many engineering designs are based on the structural applications, for example, cranes, bridges, vehicles, in transportation industries etc. In such cases, fatigue analysis of welding is the major part of interest. In transportation applications such as welding joints faces the cyclic loading. Therefore such structural elements are designed on fatigue considerations.

Fatigue is a very complicated process in material. The fracture of the material starts in structure and initiation of micro crack takes place. These micro cracks propagate and becomes visible as main crack. Fatigue in welding is one of the more complicated processes. During welding process, material is affected by heating and cooling as well as fusion process with addition of filler material. Welding is also affected by, containing cavities, pores, undercuts, lack of penetration etc. During welding high stress concentrations occurred. In welding, fatigue failure occurs at the welds rather than in the base metal.

In fatigue analysis of welded joints different methods are used. Linear Elastic Fracture Mechanics (LEFM) method has become the most desirable method. From the viewpoint of fracture mechanics, fatigue crack initiates from the surface or near-surface defects of structure and then propagates until the structure fails. The fracture mechanics researchers have researches many advances, from the basic practical approach made by Paris and Erdogan, to many crack growth models. In fracture mechanics number of mathematical as well as experimental analysis of simple models and testing of complex structures, have been carried out. Number of models for crack growth and life predictions are introduced. LEFM can give both qualitatively and quantitatively estimating static strength as well as fatigue crack growth life and final structure.

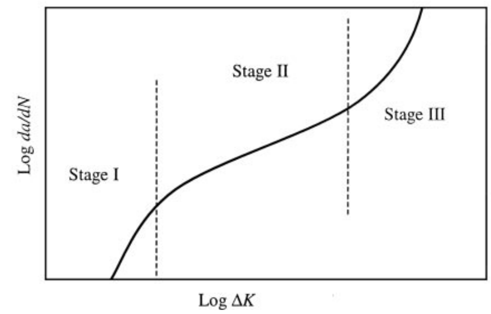
Steel materials are widely used in number of engineering applications. Now days, they are increasingly demand for structural applications. Steel materials give good mechanical and chemical properties. Many applications in the structural areas involve welded components, which have to be designed to avoid fatigue failure. In the present work, an attempt has been made to investigate on the fatigue performance of butt weld joint of Grade 2 Steel material.

"2. Literature Survey"

Fatigue analysis of butt weld joints has been investigated by many researchers. The residual and applied stresses are converted to stress intensity factors independently and combined using the superposition principle. The fatigue crack propagation rates are predicted by Y. Prawoto [1]. The literature on fatigue analysis of welded joints is reviewed by Wolfgang Fricke. 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 the crack propagation approach [2]. Chitoshi Miki, Fauzri Fahimuddin, and Kengo Anami identify fatigue performance of welded joint containing various defects. These defects are cracks, lack of fusion, incomplete penetration, slag-inclusions, porosity and blow hole [3]. A.M. Al-Mukhtar, H. Biermann, P. Hubner, and S. Henkel investigated Some Parameters for Fatigue Life in Welded Joints Using Fracture Mechanics Method. The parameters are stress intensity factor (SIF), initial and final crack lengths (a_i and a_f), crack growth parameters (C and m), and fatigue strength (FAT) [4]. The fatigue life of welded joint was calculated based on numerical integration of simple Paris law and a reliable solution of the stress intensity factor by A.M. Al-Mukhtar, H. Biermann, P. Hubner, and S. Henkel [5]. G. R. Jinu, P. Sathiya, G. Ravichandran and A. Rathinam used ultrasonic peening technique for improving the fatigue life of welded structures. The beneficial effect is mainly due to the introduction of favourable compressive stresses on weld toe regions, causing local plastic deformation and reducing stress concentration effect [6]. Farid Reza Biglari, Alireza Rezaeinasab, Kamran Nikbin and Iradj Sattarifar presented simulation of the crack growth for complex geometries. There are several criteria that have been developed to predict crack growth and its direction using linear elastic fracture mechanics (LEFM). These criteria are commonly adopted in the prediction of crack propagation in simple geometries and in straight crack paths [7].C.H. Wang focused on the essential concepts and analytical methods of fracture mechanics, local plastic deformation at crack tips, fracture criteria and fatigue life prediction [8]. Experimental work on gas tungsten arc welded AISI 304L cruciform joints with different LOP sizes was carried out by P. Johan Singh, D.R.G. Achar, B. Guha, Hans Nordberg. The predicted lives were compared with the experimental values [9].

"3.Fatigue crack propagation rate using LEFM"

Generally, fatigue crack propagation rates classified into three major regions- region I, II and III. Fig.1 shows fatigue crack propagation rate.



"Figure 1. Typical fatigue crack propagation rate of engineering materials"

All available models based on the LEFM can be classified into three groups. The first group represented by the Paris model. The second group considers the Walker model.

$$\frac{da}{dn} = C_2\left[\frac{\Delta k}{(1-R)^{1-\gamma}}\right]^n \qquad \text{(Eq.1)}$$

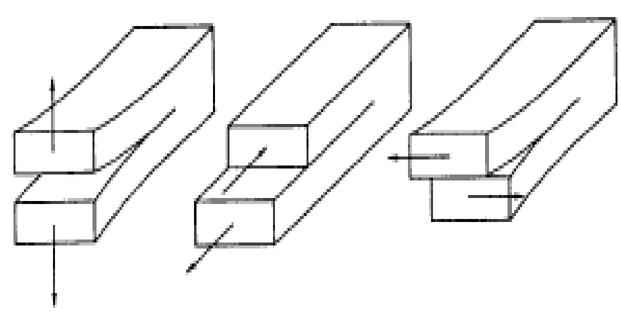
Where, Δk is stress intensity factor, R is the load ratio; γ is the material dependent constant.

The third group is represented by the three component model. The three component model is,

$$\frac{1}{\left(\frac{da}{dn}\right)} = \frac{A_f}{(\Delta K)^{n1}} + A_2\left[\frac{1}{(\Delta K)^{n2}} - C'\right] \qquad \text{(Eq.2)}$$

The constant Ć in above equation represents the load ratio term. [1]

Three basic modes in which a crack can extend are,



a) Opening Mode b) Sliding Mode c) Tearing Mode

a) Opening Mode - It is the most common mode, particularly in fatigue, because cracks tend to grow on the plane of maximum tensile stress.
b) Sliding Mode - It is the in-plane shearing or sliding mode.

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c) Tearing Mode - It is associated with a pure shear condition, typical of a round notched bar loaded in torsion. [8]

"4. Experimental Work"

4.1 Material and specimen preparation

The material used was an grade 2 steel in the form of 12 mm thickness. The chemical composition of the steel is given in table 1 and the mechanical properties in table 2

"Table1. Chemical composition of Grade 2 Steel Material"

Element	wt. %
C	0.21
Mn	0.55-0.80
P	0.035
S	0.040
Si	0.15-0.30
Cr	0.50-0.80
Mo	0.45-0.60

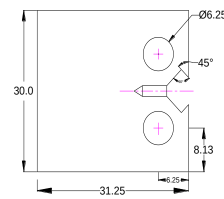
"Table2. Mechanical Properties of Grade 2 Steel"

Tensile Strength	550 (N/mm^2)
Yield Strength	450 (N/mm^2)

The steel plate was cut into two square pieces. The faces of pieces were prepared for perpendicularity. On same face getting the 35^0 chamfer by grinding. These two parts are joined by filling weld of rod specification E6013. A notch at one end of weld will be made by wire cut EDM.

The specimen was then machined into ASTM standard compact tension (CT) specimen. The (CT) specimen is shown in fig.2. The thickness B, and width W, may be varied independently within the limits, which are based on specimen buckling and through thickness crack curvature considerations.

In the (CT) specimen, a, is measured from the line connecting the bearing points of force application. It is required that the machined notch, a_n, in the (CT) specimen be at least 0.2W in length so that the K – calibration is not influenced by small variations in the location and dimensions of the loading holes. Fatigue experiment was carried out on a100 KN MTS 31.810 fatigue testing machine with a frequency of 25 Hz.



"Figure2. (CT) Specimen"

4.2 Fatigue crack propagation Measurement

Fatigue precracking was performed on the specimen. A precrack of approximately 4 mm was achieved before starting the fatigue tests. For both the precracking and cracking a test frequency of 25 Hz was used. The crack length was carefully monitored by using Crack Length Monitor Application Software. The loads used during ΔK tests were determined by the software so as to keep a constant applied ΔK.

"5. Results and Analysis"

5.1 Crack Propagation Analysis

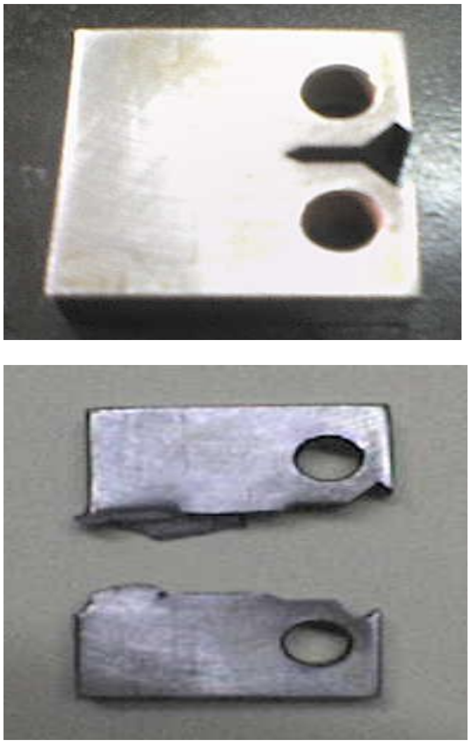
Due to stress concentration and cyclic loading, the crack initiates and grows in the weld region. The weld root has high stress concentrations due to which these regions have higher possibility to fatigue crack initiation.

The fracture mechanics analysis for most structural steel is based on the Paris law.

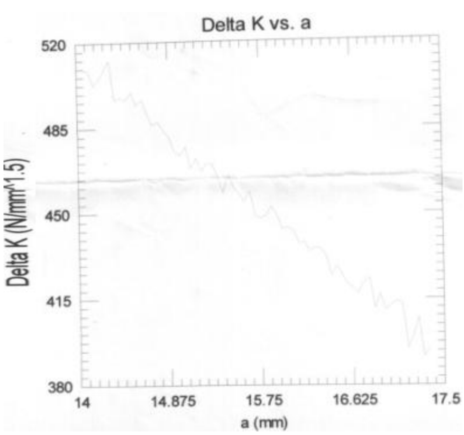
$$da/dn = C\,(\Delta K)^m \qquad \text{(Eq.3)}$$

Where, da/dn is the crack growth rate, ΔK is the stress intensity factor (SIF), and C and m are Paris material dependent constants. [9]

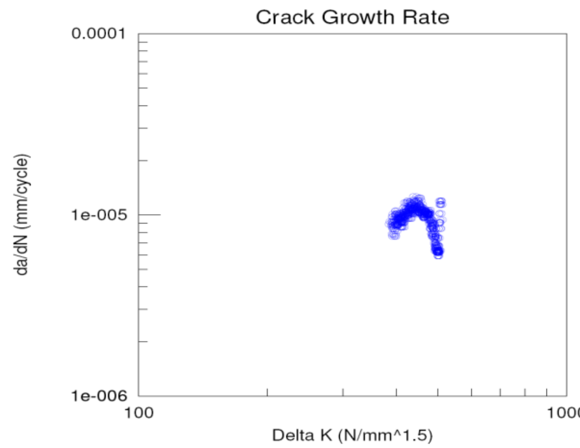
Following figures shows the results obtained during experimental work.



“Figure 3. Specimen before fatigue failure and after failure”



“Figure 4. Delta K vs. a”



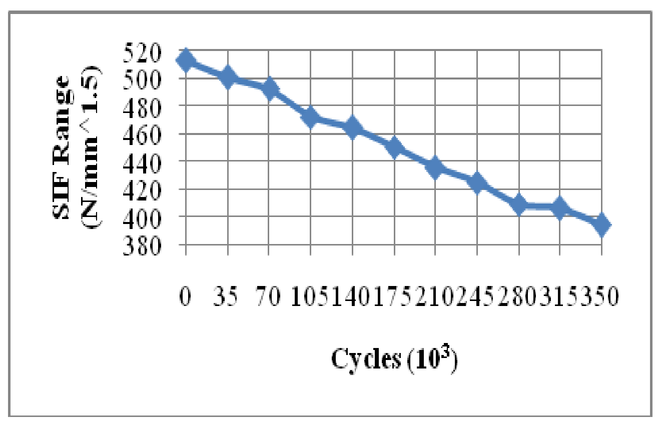
“Figure 5. da/dn vs. Delta K”

1) To grow the crack, from precrack length 14.0020 mm to final crack length 17.3892 mm total number of cycles completed are 351614.

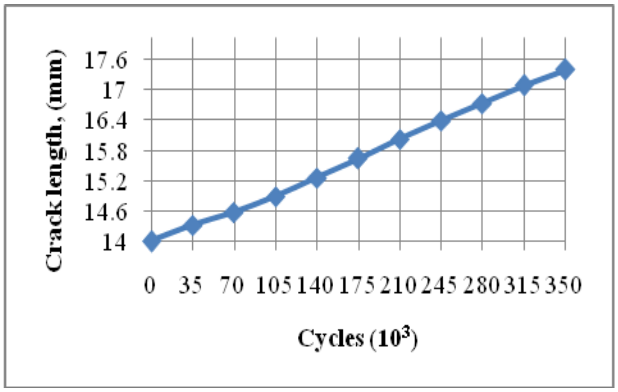
2) Maximum value of stress intensity (K_{max}) obtained during experiment are 572.656 N/mm^1.5.

3) Maximum value of load (P_{max}) is 2897.2 N.

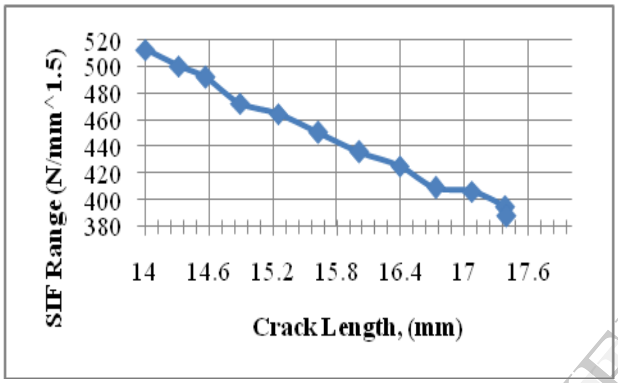
4) The crack growth behaviour of load carrying welded joint follows the Paris law.



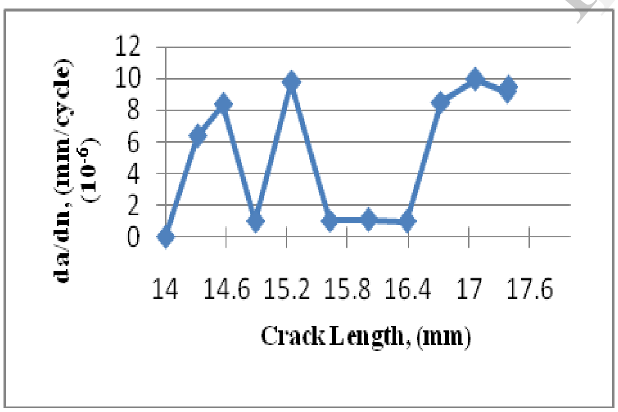
“Figure 6. SIF Range Vs No. of cycles”



"Figure 7. Crack Length Vs No. of cycles"



"Figure 8. SIF Range Vs Crack length"



"Figure 9. da/dn Vs crack length"

"6.Conclusion"

Fatigue in weld is one of the complicated processes. From the experimental investigations carried out to study the fatigue behaviour of Grade 2 steel material, the following conclusions have been drawn,

1) In this experiment, the relationship between the initial stress intensity factor (ΔK_i) and number of cycles to failure (N) can be presented in a similar way to that of conventional S-N curve.
2) Relationship between crack length and number of cycles are plotted. It shows that, crack length goes on increasing as the number of cycles increases.
3) Relationship between da/dn and crack length shows that, as the crack growth rate increases the crack length increases.

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