FATIGUE LIFE ESTIMATION OF A BUTT WELDED JOINT BY S-N APPROACH

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Abstract - A failure analysis based on stress life approach may be useful for predicting the life time of weld in the structure. This study presents an upcoming methodology in new three dimensional Finite Element Model to calculate the fatigue life of weld. Ansys 12.1 simulation software uses stress-life method, based on a static non-linear Structural analysis. The weld material S-N curve were experimentally determined by the Fatigue testing of the dumbell specimen as per 7608 standard. This study assumes that a flaw exist in weld due to welding process, material in-homogeneity, air voids, slugs or impurities in weld, improper surface machining and many more. This material curve is used in simulation to get more accurate results. Thus the fatigue life prediction with the material curves from experimentation will give us more accurate and close to actual failure results.

Keywords : *Fatigue Life , S-N approach, Equivalent Stress.*

I. INTRODUCTION

Failures due to fatigue in welded structures lead to loss of life and substantial costs. Remedies to this situation include the introduction of various standards and fatigue design codes. The foundation of such codes rely, in some cases, on old concepts that do not easily translate to the output from modern computer programs and are also limited to rather simplified structures.

The development of new generations of products means, in general, increased capacity, increased speed and increased demands on life. Improved maintenance and higher utilization place additional demands on the supporting structures.

The requirements in society towards improved functionality and minimizing of Life Cycle Cost (LCC); force companies to design structures with reduced weights and “optimum” fatigue resistance. Actions to meet these demands are to introduce high strength steel, weld and/or surface improvement technologies and high productivity manufacturing technologies. The introduction of high strength steel in structures normally means higher stress levels and, hence, an increased sensitivity to defects, deviations in weld geometry (e.g. penetration, throat thickness, undercuts) and variations in material strength.

Expertise in developing and manufacturing fatigue loaded welded structure with low LCC is a key aspect in order to stay competitive. Shorter development time for new products means that it is important to make the correct design and fatigue assessment early on in the project.

A better understanding of the limits of the different fatigue design methods and the influence of fatigue strength due to the weld quality will improve the development of new fatigue loaded products. The understanding of the link between weld quality and the welding process would enable manufacturers to increase the utilization of high strength steel in fatigue loaded welded structures.

Being able to determine the rate of crack growth, an engineer can schedule inspection accordingly and repair or replace the part before failure happens. Being able to predict the path of a crack helps a designer to incorporate adequate geometric tolerance in structural design to increase the part life.

II. OBJECTIVES

Design validation of a fatigue analysis of weld joint which is most probable part to fail against fatigue. Hence it needs to find out the stresses in various region by nonlinear static analysis .

The following are the main objectives of the project.

- Non-linear Static Structural Analysis:-

To carry out non-linear static analysis of specimen using ANSYS Classic Version 12.1. This is done to find out safe value of resultant displacement (stiffness) and Von Misses stresses. A special attention is required to get convergence of non-linear system and then validation of converged results.

- Fatigue Life Calculation:-

To carry out the fatigue life prediction of welded joint using conventional methods. (S-N approach Method)

- Experimental Validation:-

To validate results obtained from FEA for fatigue analysis of weld by some external agency. Same validation is used for benchmarking of simulation results obtained with ANSYS Classic Version 12.1 software

III. DUMBBELL SPECIMEN EXPERIMENTATION TESTING

Weld material doesn’t fall in regular structural materials hence we need to either refer S-N curve through the previous research done in this field or through the fatigue testing of the same weld material.

Following is the details of the procedure to obtain S-N curve through the fatigue testing as per ASTM E647 standard and BS 7608 standard.

A. Specimen Preparation

In this work, a mild steel plate of thickness 4 mm is used. The mechanical properties & chemical composition of mild steel shown in Table.

Dumbbell specimens were prepared with ASTM E647 and BS 7608 specifications. Two plates of size 110x20 mm is taken for welding & single V-joint with bevel angle 35 degrees, root face 2 mm are prepared. The plate is butt-welded by shielded metal arc welding process with E-6013 electrode.Butt weld joint is prepared with good surface finishing conditions and with an electrode specification E6013. Then milling the plate as per specimen diagram given below. Figure 1 explains the geometry details of Dumbbell Specimen for Experimental Testing.

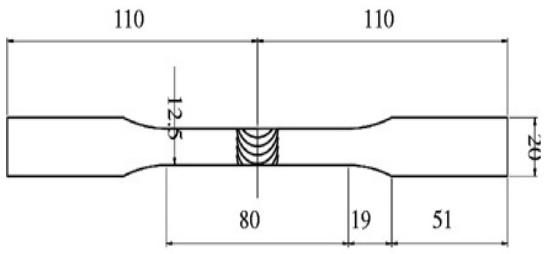

Fig. 1 : Dumbbell Specimen for Experimental Testing

Figure 2 : Specimen prepared for fatigue Testing

B. Experimental Testing

Experimental testing to get the weld material parameters were performed at Metallurgical Services Pvt LTD, Mumbai. This is the reputed material testing laboratory and accredited by NABL India. Tests were performed on MTS 31.810 fatigue machine.

Followings are load specifications.

Load unit specifications

Model	31810
Force capacity (maximum)	100 kN (22 kip)
Available actuator ratings	15, 25, 50, 100 kN (3.3, 5.5, 11, 22 kip)
Vertical test space* (A)	1308 mm (51.5 in)
Working height (B)	889 mm (35 in)
Column spacing (C)	533 mm (21 in)
Column diameter (D)	64 mm (2.5 in)
Base width (E)	864 mm (34 in)
Base depth (F)	610 mm (24 in)
Diagonal Clearance (G)	2718 mm (107 in)
Overall Height (H)	2540 mm (100 in)
Stiffness†	2.6 x 10^8 N/m (1.5 x 10^6 lb/in)
Weight	500 kg (1100 lb)

Figure 3 : Load Unit Specification and Fixture with CTOD Sensor

Figure 4 : Fatigue Testing of Specimen loaded on MTS machine

Figure 5 : Fatigue Testing of Specimen on MTS machine with Software Interface

C. Machine Capabilities

MTS provides the most complete Linear Elastic and Elastic-Plastic Fracture, Toughness solutions. In addition to CTOD fracture criteria software, MTS provides Fatigue Crack Propagation solutions. MTS Fracture Mechanics Application software improves the accuracy of your testing while still being easy and flexible to use. Predefined test templates provide the capability of testing to various ASTM, ISO and British test standards. Run-time graphical displays allow for monitoring the tests in progress and in order to react to events as they occur.

a) Test Examples

Fracture Toughness, Fatigue Crack Growth, Crack Propagation

b) Standards

ASTM E399, E647, B645, E1820, ISO 12737, 12108, 12135

Figure – 6 : Specimen before fatigue failure

Figure 7 : Specimen after fatigue failure.

D. Experimental Results of Fatigue Test

Table 1 :Fatigue test results

Sr. No.	**Thickness mm**	**Breadth mm**	**Load kN**	**Applied Stress MPa**	**Cycles**
1	4	12.5	4	80	107520
2	4	12.5	5.5	110	100080
3	4	12.5	7	140	52192
4	4	12.5	8	160	53808
5	4	12.5	Ulti.Load 1206 kgf	245	1

E. S-N data obtained by specimen testing

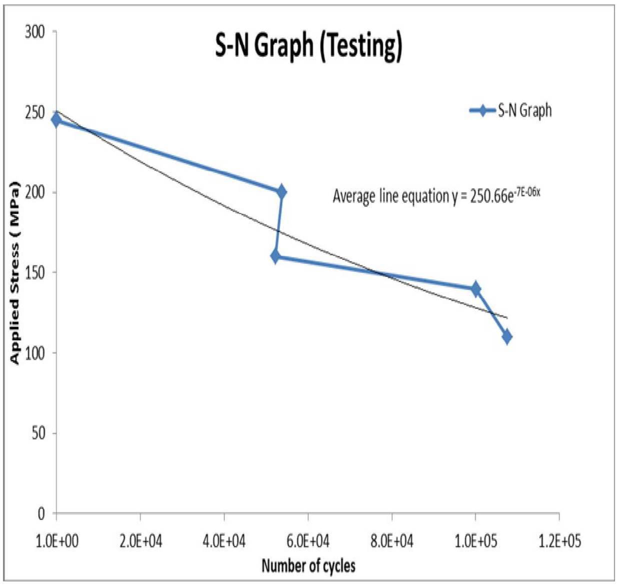

Figure 8. S-N curve of test specimens

F. Result Table

Sr.No.	Load kN	Experimental fatigue life
1	4	107520
2	5.5	100080
3	7	52192
4	8	53808
5	Ultimate Load 1206 kgf	1

IV. CONCLUSIONS

1. It is also observed that weld component survive for 1e7 cycles even though the fatigue load was scaled by 5 times.
2. At the 10 times fatigue load scaling weld part failed in first cycle or in static loading hence it is concluded that the design will fail to survive its designed fatigue life of $1e^6$ cycles if it is loaded between 5x times to 10x times fatigue load.
3. At the end it is concluded that the design is strong enough to sustain 1 millions cycle for operating loading conditions. The failure cause can be stated as the bad quality of weld material, improper welding, occurrences of multiple cracks, overloading, improper surface preparation, too much corrosive environment variables may have amplified the stress intensity by 5 times to 10 times. At this amplified stress intensity weld component has failed to survive 1 millions cycles.
4. The material specific S-N curve is obtained for the weld material. This is utilized to validate simulation data.
5. Testing were performed on dumbbell specimen to validate the concept of analysis. The fatigue life predictions of dumbbell specimen by using these methods were fairly in close agreement as shown in graph.
6. Analytical calculations were performed on CT specimen to validate the concept of analysis. The fatigue life predictions of CT specimen by using these methods were fairly in close agreement.
7. This simulation concept is not yet thoroughly implemented in industry as well as in academics because the simulation software's like ANSYS 12.1 which are designed and developed on fatigue failure concepts are in initial stage of development. But definitely this will be the future asset of fatigue prediction for all FEA engineers.

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