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Equivalent Stress Analysis ofWelded Joint using Finite Element Method (FEM)

Daso Dokibo[1], Mbuide Saturday.B[2], Nwidebom Deesibari. E[3], Adonye Ebirien.I[4]
[1, 2, 3, 4]Department of Mechanical Engineering, ken saro-wiwa Polytechnic, Bori, Rivers state, Nigeria
Author's Email: [1]mori7real@yahoo.com, [2]mbuidesaturday8@gmail.com, [3]ernestdeesibari@gmail.com, [4]isrealadonye@gmail.com

Abstract*— The study is focused on analyses of stresses at welded joints using finite element method. ANYSYS structural 16.0 workbench is used to simulate stress under the influence of repeated load application at weld. Solid works is used to model the joint. Welded joints are regions that inter-connect mechanical engineering structure of several production outfits in the today's field of engineering. A double fillet joint of A36 structural steel material is considered in this report. it was discovered that higher tensile stresses on the weld is a major influence on the strength of the weld especially at the toe of the weld resulting to crack initiation at that region leading to plausible failure. Simulation result reveals that the weld risks shear fatigue failure at higher maximum stress of 300.89 MPa, 322.38 MPa, 335.28 MPa at loads of 14, 15.2 and 15.6N along the plane of the weld throat or toe since it has exceeded the yield strength limit of the material/weldment of 250MPa. A reduction in stress concentration due to lower cyclic tensile load application increases the fatigue life of the weld as illustrated from the S-N curve, hence making fillet joints vulnerable to higher stresses according to the research.*

Keywords*—Fatigue life, welded joint, weldment, simulation, stress concentration, yielding strength.*

I. INTRODUCTION

The permanent joining of similar or dissimilar metallic or thermoplastic materials to form metallic structure is commonly an application of welding process.[5]. According to American Society of welding [1] it is a localized coalescence of metal produced by either heating the material to a suitable temperature with or without the application of pressure or by application of pressure alone with or without the use of filler metal, other materials like shielding gases, flux or paste maybe use to make its process possible or easier. Steel structures are mainly connection of welded joints which are often subjected to static or dynamic impact loads either concentrated or distributed.

These Joints are the most critical and vulnerable connections between welded structural members are often times gateway to stress formation where failure begins is originated (Anca at al.,[9]; [8]). These load induced stresses which could be tensile, compressive, torsional, bending, bending etc., microscopically initiate crack(s) propagation leading to plausible fatigue failure. Regardless of moderate load application, the local stresses at the weld toe will be elevated. These stresses are amplified because of the stress concentration effect. For a welded joint stress concentration is inevitable due to the geometrical differences of the joints, weld inclusion, fusion line, HAZ (heat affected zone), lack of penetration etc. [5].

Structures under repetitive cyclic loading are known to possess critical locations prone to fatigue failure at the welded joints due to high stress concentration. Both the fatigue crack initiation and propagation stages are determined by the magnitude and the distribution of stresses in the potential crack plane [4].

Stephen *et al.* [7] conducted a study to investigate the fatigue stress analysis of a structural steel using finite element analysis in ANSYS workbench adopting Goodman theory. The study showed that as load was reduced there was no corresponding increase in the fatigue life of the structure.

Anilkumar and Murali [3] did stress and strain analysis of welded joints (fillet, butt and lap joints) analyzing their stress concentration and fatigue usage using finite element analysis in ANSYS under static load. It was revealed that the fillet joint(T-joint) produced more stress than other joints, so if the load on the weld is more, the fillet joint fail first than the other two, with stresses; 34 N/mm^2 fillet, 22 N/mm^2 butt and 33 N/mm^2 lap joint respectively. It was concluded that due to cyclic loading application fatigue life for butt joint is less than fillet and lap joints.

Ashutosh *et al.* [2] studied a theoretical and experimental analysis of fillet weld which gives the welded joints have the effect of residual stress on its strength. Therefore, the theoretical and measured stress values might differ. The stress analysis of welded joints can be performed using the strain gauge rosette method, which produces consistent results. In this work, the values of stress and deflection rise along with the load. However, the stress distribution pattern in the welded joints was consistent across all loading situations.

Sonawane *et al.* [10] studied experimental stress analysis & finite element analysis of T-Joint under tensile and bending loading. Tensile, bending, torsion and multi axial loads acts on various welded joints during operations' joints are used for various members coming together at same location joints behavior at tensile and bending loading needs to be investigated. T Joints are stronger in tensile loadings as compared to bending loadings.

In fillet weld joint stress concentration occurs at the weld toe, weld root and between the base metal and weld. The regions with higher stress concentration are more likely to initiate cracks when subjected to load.

This research is geared towards finding possible solutions in attempt to prevent failure due to fatigue stress by caring out stress analysis of fillet welded joint using finite element method.

II. MATERIALS/METHOD

2.1 Materials:

The materials used are; ASTM A36 structural steel material with the following dimensions; T-joint fillet welded; 130mm x 130mm and 5mm thickness. The weld radius is 4mm.

It has a mechanical property with an ultimate tensile strength of 400–550 MPa, a yield tensile strength of 250 MPa, a modulus of elasticity of 200 GPa, a bulk modulus (typically for steel) of 140 GPa, and a shear modulus of 79.3 GPa, respectively [6].

2.2 Method

The method use was modeling in solidworks and Simulation done in ANSYS to determine the equivalent stresses and fatigue life relationship.

Finite Element Method in ANSYS structural 16.0 workbench was used for simulating the model which was done in solid works. The models were adequately meshed and boundary conditions added and simulated using constant amplitude loading. The load was applied biaxially at the fixed ends of the base material in the tensile direction. The fatigue tool was added to determine the corresponding fatigue life in relation to the equivalent stresses as the system was subjected to loads of 2, 4, 6, 14, 15 and 15.6KN. The result and discussion are presented and explained below.

III. RESULTS AND DISCUSSIONS

3.1 Results

The Simulation results presented, includes equivalent stresses and fatigue life data of double fillet (cruciform) welded joints.

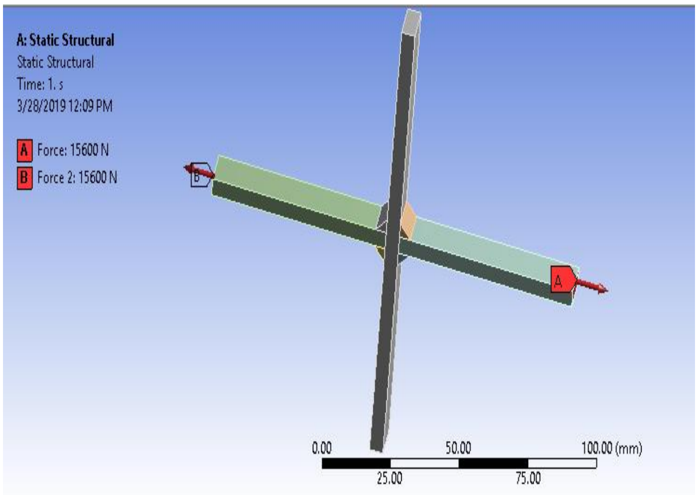

Figure 1.0: double fillet welded joint under tensile loading

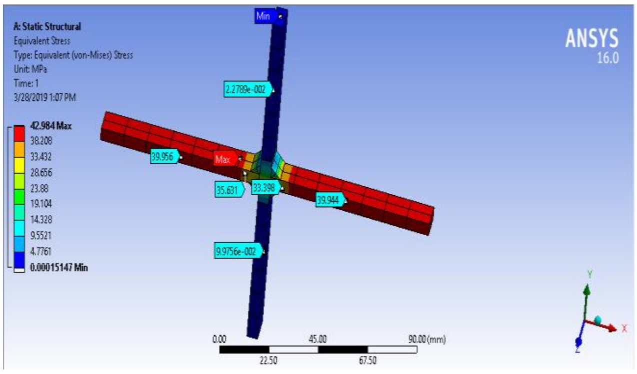

Figure.1.1: Equivalent stress distribution for 2kN

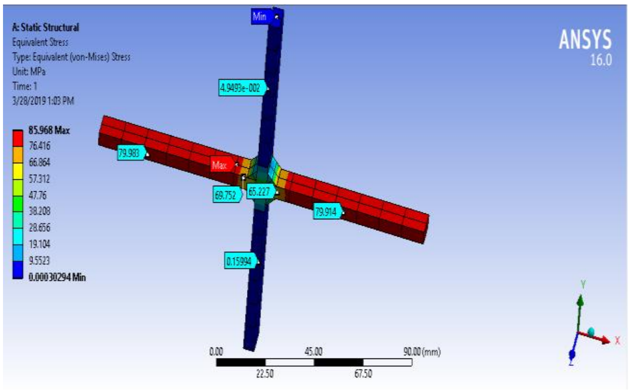

Figure 1.2: Equivalent stress distribution for 4kN

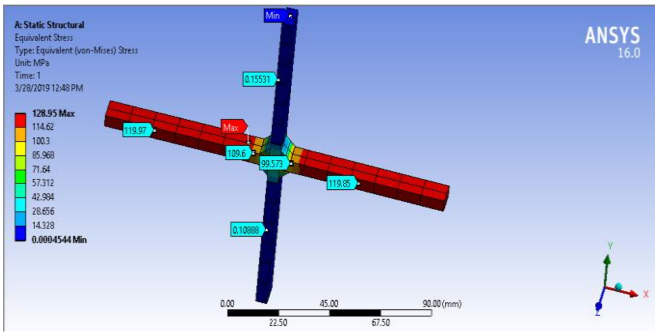

Figure 1.3: Equivalent stress distribution for 6kN

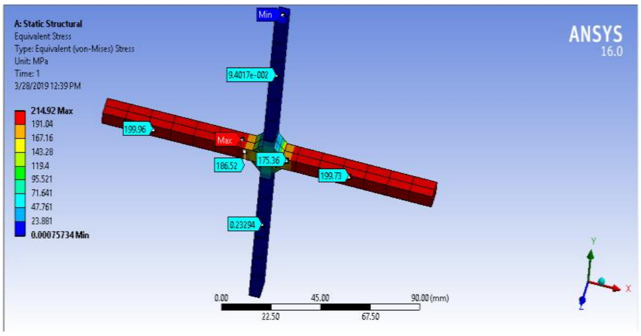

Figure 1.4: Equivalent stress distribution for 10kN

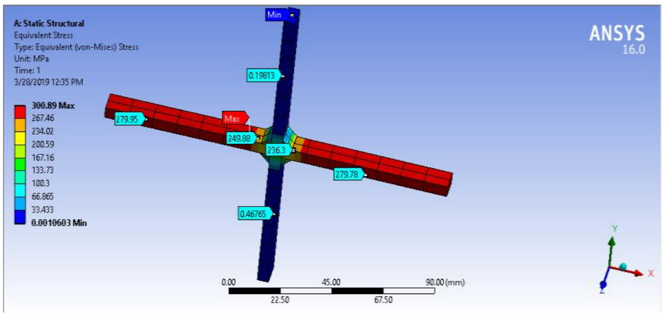

Figure 1.5: Equivalent stress distribution for 14kN

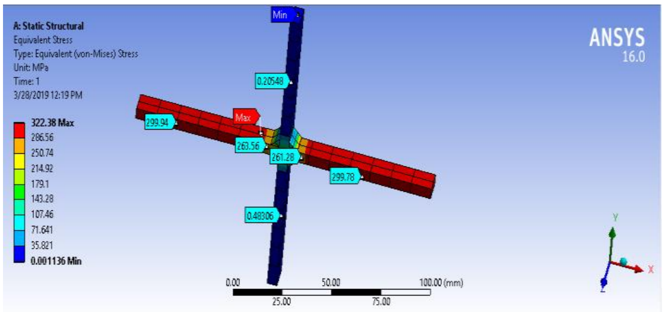

Figure 1.6: Equivalent stress distribution for 15kN

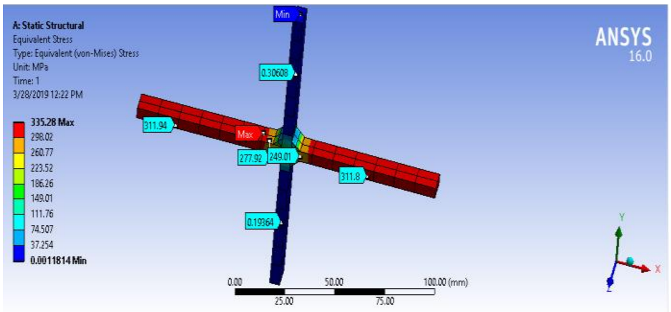

Figure 1.7: Equivalent stress distribution for 15.6 kN

3.1.1 Fatigue life assessment for Fillet-welded joint

Simulation result for cyclic loads of 2, 4, 6, 14, 15 and 15.6KN are presented as follows

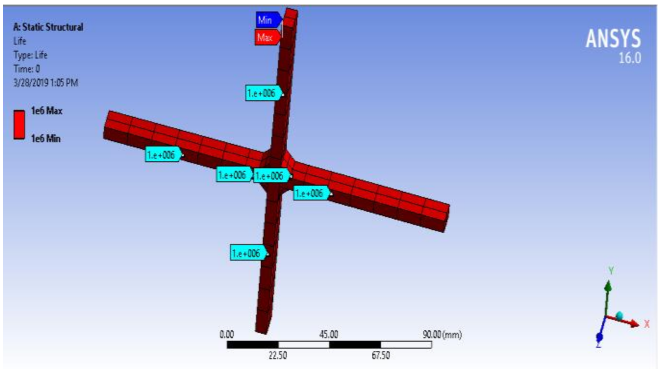

Figure 1.8: Fatigue life of a fillet-welded joint at load 2 kN

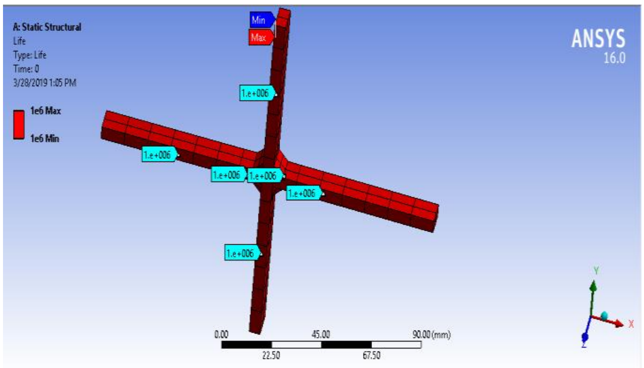

Figure 1.9: Fatigue life of a fillet-welded joint at load 4 kN

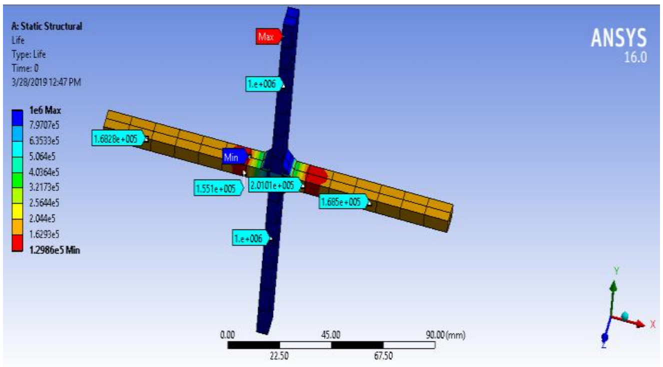

Figure 1.10: Fatigue life of a fillet-welded joint at load 6 kN

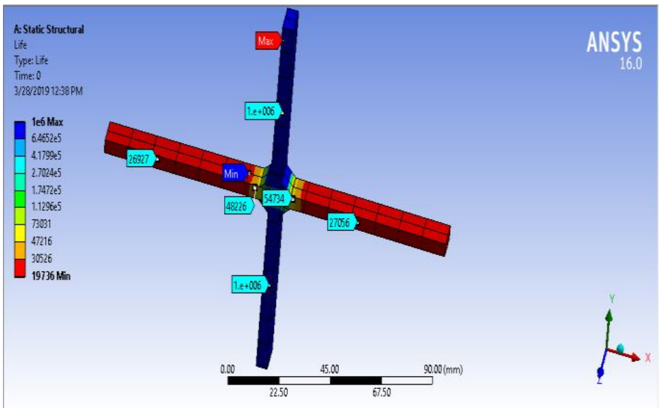

Figure 1.11: Fatigue life of a fillet-welded joint at load 10 kN

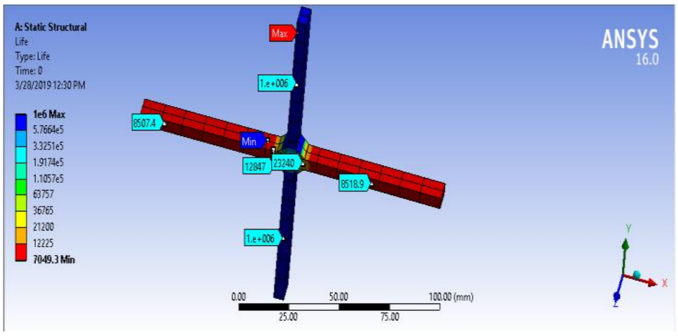

Figure 1.12: Fatigue life of a fillet-welded joint at load 14 kN

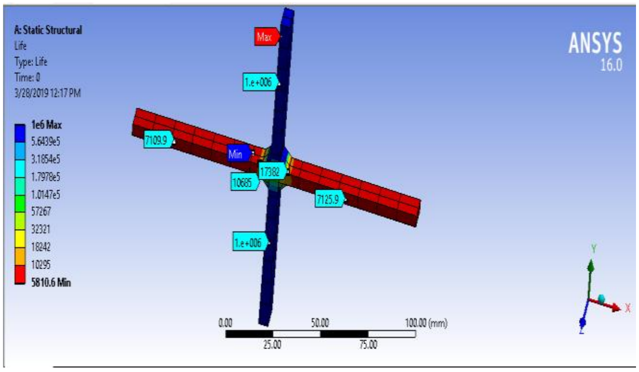

Figure 1.13: Fatigue life of a fillet-welded joint at load 15 kN

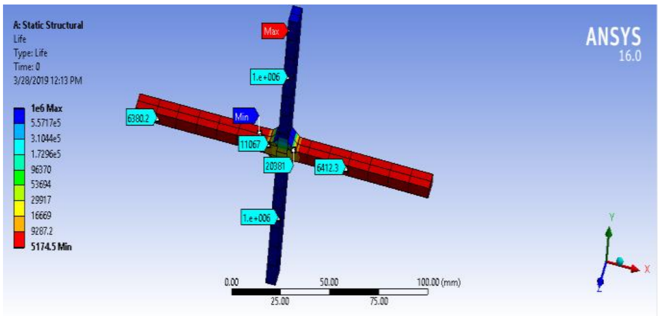

Figure 1.14: Fatigue life of a fillet-welded joint at load 15.6 kN

Table 1.0: Collated Fillet joint Simulation results

LOAD(KN)	FILLET JOINT			
	STRESS(Mpa)		Fatigue life	
	MAX(Red)	MIN(Blue)	Max(Blue)	Min(Red)
2	42.98	4.78	1.00E+06	
4	85.97	9.55		
6	128.95	14.33	1.00E+06	1.30E+05
10	214.92	23.88	1.00E+06	19736
14	300.89	33.43	1.00E+06	7049
15	322.38	38.82	1.00E+06	5811
15.6	335.28	37.25	1.00E+06	5175

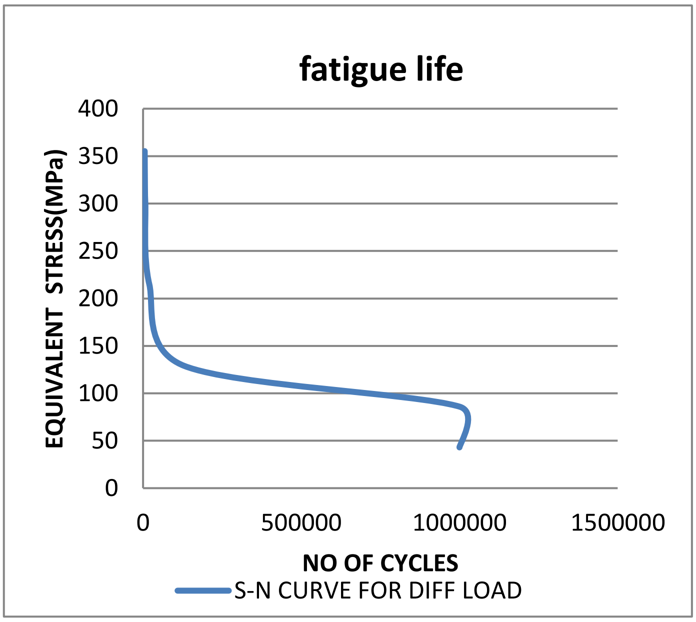

Figure. 1.14: fatigue life cycle of the welded joint (S-N curve).

3.2 Discussions

The fillet welded joint was subjected to tensile loading as shown in figure 1.0 .Figure 1.1 through 1.7 shows a progressive stress values ranging from the maximum (red, indicating unsafe zone with maximum stresses of 300.89, 322.38 and 335.28MPa at an applied loads of 14, 15, and 15.6 KN which implies possible crack near the weld toe or root, weakening the strength of the weld for failure to occur, to the minimum (blue, indicating safe zone with minimum stresses of 33.43, 38.82 and 37.25MPa with same applied loads aforementioned which implies no stress effect resulting to unaffected strength properties of the weld)..

Figures 1.8 through 1.18 show the fatigue life of a fillet-welded joint under cyclic loading at loads ranging from 2 kN to 15.6 kN. The fatigue life is expressed as the number of cycles the joint can withstand before failure, with a descending trend from maximum to minimum cycles for loads of 6 kN and above, indicating a variation in fatigue performance across the joint. The fatigue life of the fillet joint decreases(blue) significantly as stresses due to load application increases from 42.98 to 335.28MPand increases (red) as stress due load application decreases. However, it remains constant for both 2 kN and 4 kN loads at 1e6 cycles, indicating that at minimum cyclic load application fatigue life of the weld is maximized, increased or unaffected as shown in table 1.0. This suggests that at high stress, the fillet welded joint can experiences rapid fatigue failure in some cases, higher cyclic stresses will aggravate fatigue damage leading to sudden collapse, with the minimum fatigue life approaching very low values, suggesting that the joint is nearing its failure threshold under these conditions

IV. CONCLUSION

High stress concentrations were found at the weld toe and root in both joint types, with maximum equivalent stresses increasing linearly with the applied loads—reaching 335.28 MPa at 15.6 kN.

Fatigue life assessments showed an inverse relationship with load size: life stayed at 1,000,000 cycles for loads up to 4 kN but dropped sharply to 5,175 cycles at 15.6 kN. These trends highlight how welded joints are sensitive to cyclic loading beyond their endurance limit, primarily due to geometric discontinuities and residual stresses.

To this end, it is discovered according to the research, that fillet welded joint is susceptible to fatigue failure under increased cyclic stresses. This research affirms the effectiveness of FEM in predicting welded joint performance, thereby reducing dependence on costly physical testing and enhancing structural design for safety and durability across various engineering fields

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