Thi_Qar University Journal for Engineering Sciences
Vol. 9 No.1 (2018)
ISSN 2 075– 9764
Available at http://jeng.utq.edu.iq
engjrnal@jeng.utq.edu.iq

Variation of Weld Profiles and Their Influence on Fatigue Strength

H. E. Radhi.University of Thi-Qar College of Engineering Mechanical Eng. Dept.
Hayder Abdulhasan Lafta University of Thi-Qar College of Engineering Mechanical Eng. Dept.

Abstract

The determination of fatigue life of mechanical parts such as welded joints during service which subjected to high stresses and cyclic loading is extremely important. In order to investigate life span of mechanical parts a finite element analysis is used. In this paper, an experimental investigation and numerical analysis is used to study the effect of geometrical parameters on fatigue life span. The experimental parts include monotonic tensile test and hardness test of welded joints of steel S355JR laser butt welded joint. A parametric finite element analysis is performed by using ANSYS 11 software to investigate the effect of plate thickness (h) and weld toe radius (ρ) in butt welded joint on fatigue life. Different values of plate thickness and radius of weld toe have been investigated during this study; the results indicate that increasing the plate thickness and radius of weld toe will improve the stress distribution in the joint and increase the fatigue life span of welded joint.

Keywords: **fatigue; finite element analysis; welded joint; steel S355JR.**

1. Introduction

Fatigue testing and assessment of welded structure is mainly expressed on S-N curves, which is based on nominal stresses. The main disadvantages of this approach are:

1. No clear differences between local and nominal stresses.
2. The distinction between weld geometrical details in real operating condition and test specimen.
3. No additional information is obtained by S-N curve about the different stage of fatigue which gives only the total fatigue life.

In the last two decades, due to advance in finite element method the local approach of fatigue assessment plays very important role in design and optimization of welded joints. The fatigue failure of structure consist of three different stages; crack ignition, crack propagation and final fracture. Therefore, the geometrical parameters and loading have a significant effect on the fatigue life of the welded joints. They must be taken into account when conducting fatigue life assessment in design process. Many approach for global approach of fatigue assessment which based on nominal stress; it only take only local geometrical parameters roughly into account. The global approach is insufficient in this domain especially when structures subjected to cyclic load amplitude with specified number of cycles. The Local approach is more satisfactory in those domain which are based on local strain and local stress.

Welding is a process of material joining. It is complex process that includes the of thermal, mechanical, and metallurgical interaction. The resulting geometrical parameters in a welded structures may different from those of real life. All these influencing factor should be taken into account while modeling a real geometrical parameters of welded joint in finite element analysis FEA. Additionally, parameters such as loading, boundary conditions and material properties that are involved in FEA should be taken in consideration. The aim of this study is to establish a finite element model for fatigue life prediction of a welded joint. In this study, a general purpose finite element software ANSYS 11 is used for numerical analysis of the welded joint. The ANSYS software has features for fatigue assessment ranging from constant amplitude cyclic loading to proportional variable amplitude loading [1]. The aim of experimental study is to investigate the geometrical parameters that influence on fatigue life of welded joints.

2. Experiment Study

The main tasks of experimental study are to determine the geometrical dimension and mechanical properties of the welded joints [2]. The first mechanical test is Vickers hardness and secondly the monotonic stress- strain curve of the joints. The welded joint is make from S355JR steel with 6 mm thickness of plate. After welding process the test specimens are extracted from the main welded plate. To avoid interfering of base metal with the heat affected zone [HAZ], and heating a water-cut is used to extract a test specimen from the welded plate consequently clean surface is obtained, so it is easy to distinguish different material region. A tensile test according to British Standard: Metallic materials tensile test (EN ISO 6892-1:2009) [2] is conducted to specify the properties of welded joints material, with constitutive relationship. The machine used during this test is a table mounted materials testing system Instron 3369 with the following features:

1. Maximum loading capacity 50 kN.
2. Testing with range of speed from 0.05 to 500 mm/min.
3. digital closed-loop control and data acquisition are Integrated with the machine

Table 1 and Fig. 1 summarized the experimental mechanical properties for : three specimens, while Table 2 specify the standard mechanical properties from EN 10025 [3] , the range testing speed was 5 mm/min.

Table1:Mechanical properties of material used in this study (steel S355JR)

Structural Steel S355JR	
Modulus of elasticity, E	207 Gpa
Poisson's Ratio, ν	0.3
Tensile Yield Strength	370 Mpa
Ultimate Tensile Strength	520 Mpa

Table2:Mechanical properties of material used in this study steel S355JR (EN 10025)

Designations		Tensile Yield Strength Re (Mpa)	Ultimate Tensile Strength Rm (Mpa)	Fracture Energy (J)
According to EN 10027-1	According to EN 10027-2			
S355JR	1.0045	355	470-630	27

The definition of hardness is a measure the ability of material to resist external deformation [4], and it could be specify by using a macro or micro hardness machine. The micro-hardness machine is used to determine the hardness value of a joint. Measurements are conducted under the surface along the longitudinal directions of joint in cording to (EN 288-3). A loading time of 15 seconds with a load of 200 gf was applied. The results of hardness measurement with three different zone, filler material, base metal and [HAZ] are indicted in Table 3. The value of maximum hardness is (250) in the weld metal and (264) in the heat affected zone (HAZ) region. This means the heat affected zone and metal of the welded joint are overmatched significantly in comparing with base steel metal which had the mean value of 228.

Table 3: Micro Hardness Experimental Results of Welded Joint

<table>
<tr><th rowspan="2">Material used</th><th colspan="15">Hardness experimental measurement</th></tr>
<tr><th colspan="3">Base metal</th><th colspan="3">Heat affected zone</th><th colspan="3">Filler metal</th><th colspan="3">Heat affected zone</th><th colspan="3">Base metal</th></tr>
<tr><td>S355JR</td><td>221</td><td>224</td><td>238</td><td>249</td><td>262</td><td>280</td><td>249</td><td>256</td><td>247</td><td>274</td><td>271</td><td>249</td><td>238</td><td>221</td><td>226</td></tr>
<tr><td>Mean value of measurments</td><td colspan="3">227.6</td><td colspan="3">263.6</td><td colspan="3">250.6</td><td colspan="3">264.4</td><td colspan="3">228.3</td></tr>
</table>

The determination of joint geometrical parameters is conducted using non-destructive test NDT. Macro photograph are conducted of the welded joint. The geometrical dimensions were specified from the photograph with the aide of AutoCAD software. The radius of weld toe has a significant influence over the distribution of stress therefore it is important to measure it. It is difficult to fit a circle at the toe of the weld. The definition of a radius of weld toe is the smallest circle that fit the toe of the weld [5]. Weld toe angle is the angle between the base metal tangent line drawn with 1 mm distance above the base metal [6]. The geometrical dimensions of a welded joint can be categorized into four different groups: the height of the weld h, weld toe angle **α,** weld toe radius ρ and the width of weld **w**, as shown in Fig 1.

3. Numerical Study

In order to obtain better understanding of the effect of geometric parameters and their influence on local stress that affects the fatigue properties of joints a finite element model is conducted The measurement of specimen local parameters are extracted from 5 specimens. In the analysis the weld width **w,** weld toe radius ρ, and height of upper and lower side (h1, h2) are extracted from measured data. In a finite element numerical model, it is seen that the geometry of joint and loading are symmetrical about global Z and X axis, because there is no big difference between weld toe radii ρ1, ρ2, ρ3 and ρ4. Only one quarter of the welded joint is modeled. The main advantage of symmetric conditions is to save computation time. The dimension of welded joint are 20 mm width, 60 mm length and 6 mm thickness.

In this study, the meshing of welded joint is done using quadrilateral SOLID 45 [7] elements. This element has eight nodes with three degrees of freedom at each node. The element has different features such as swelling, stress stiffening, plasticity, creep, large deflection, and large strain. The welded joint is meshed with 34 elements along its length, 8 elements along its thickness direction 10 elements along its width,. during these simulation 2720 elements are used. Three different values for weld plate thickness 4 mm, 6 mm and 10 mm and weld toe radius i.e. 0.4 mm, 0.8 mm and 1.2 mm are used to study the influence of geometrical parameters on fatigue response of a welded joint. Von-Mises equivalent stress, fatigue life, fatigue safety factor and total deformation, are used after meshing the model and running the analysis with specify boundary conditions and load. Figures (3 to 6) indicate the result of one case, i.e. 0.4 mm toe radius and 6mm plate thickness. For other cases, numerical results from the analysis are extracted to compare all the cases and plot graph. in constant amplitude a fatigue life analysis contour plot indicates, this indicates the number of cycle until the weld will fail due Fatigue. Fatigue safety factor: is a contour which represent the safety factor with respect to a fatigue failure of welded joint at a given design life. The maximum value of factor of safety indicated is 15 a value less than one indicate failure will occurs before reaching the design life.

4. **Results and Discussions**

In order to obtain the correct failure locations, stress distribution was be investigated. a clear representation of stress distribution can be obtained from stress contour. It is clear to notice from Figure 2 ,that the maximum Von-Mises equivalent stress occurs at the weld toe with 231.2 MPa for joint with 0.4 toe radius and 4 mm plate thickness. This value rises to 234.1 MPa for 6 mm plate thickness and then reduce to 246.1 for 10 mm plate thickness. A similar trend is obtained for 0.8 toe radius with maximum value 232.4 MPa at 10 mm plate thickness. For 1.2 mm toe radius the value of maximum stress is 228.8 MPa with 10 mm plate thickness. The big difference between these two curves is at 6 mm plate thickness. When the weld toe radius is doubled the stress is declined by 5.5 %, when it is tripled stress is decreased by 8.2%. In Figure 3, the value of maximum total deformation is indicated.

The value is significantly small, and the value of maximum deformation is achieved at the free end of the welded joint. The minimum value is achieved at 0.4 toe radius and 6 mm plate thickness.

Figure 4, indicates the minimum fatigue life plot, it is clear to notice that the minimum life is 27.5×105 cycles for 0.4 toe radius and 10 mm plate thickness, in addition maximum life is 1×107 for (4,6) mm plate thickness and 1.2 toe radius. For 6 mm plate thickness life is increased 1.7 times due to toe radius is doubled, and life is increased 2.2 times. when weld toet is tripled. A safety factor below 1 indicates that failure occurs before design life is reached and 15 means that design life is achieved. For 1×107 cycles design life, a safety factor less than 1 means the failure will occurs. For 4 mm plate thickness when the safety factor increases from 0.93 to 0.98 due to toe radius is doubled from 0.4 mm to 0.8 mm, , and reaches 1.0 at 1.2 toe radius. For 6 mm plate thickness safety factor increase from 0.97 to 1.0 as a consequent of the toe radius is doubled.

it is clear to notice, From all the cases have been investigated ;

1. Plate thickness and Weld toe radius have significant effect on stress concentration. The higher value of weld toe radius will decrease the stresses.
2. The best case can be obtained is 4mm and 6 mm plate thickness with 1.2 weld toe radius in term of life. Whereas the worst case is 0.4 weld toe radius with 10 mm plate thickness .
3. A similar trend can be obtained in term of safety factor . the increase the factor of safety can be achieved by increases in the weld toe radius.

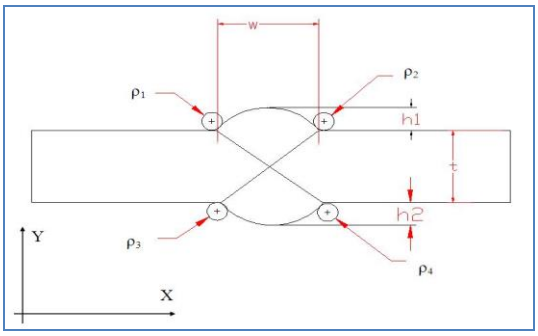

Figure 1: Geometrical parameters but welded joint

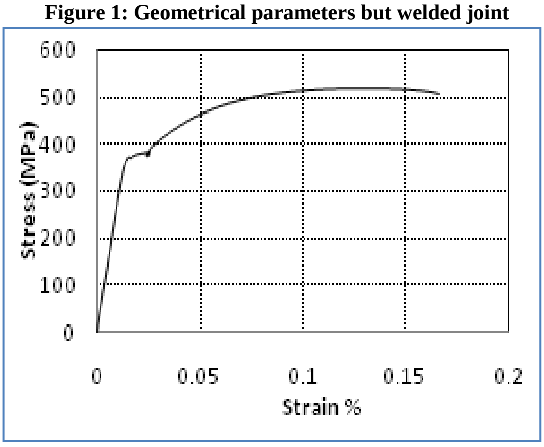

Figure 2: Stress strain diagram of steel S355JR

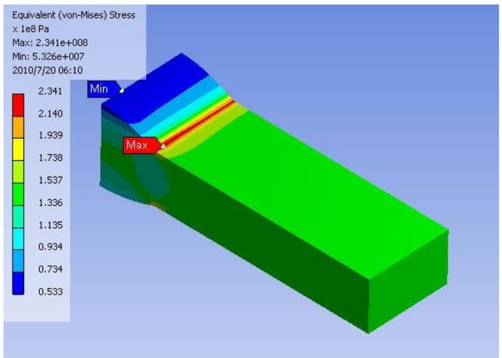

Figure 3: Equivqlent Von-Mises stress for 0.44 toe radius, 6 mm plate thickness.

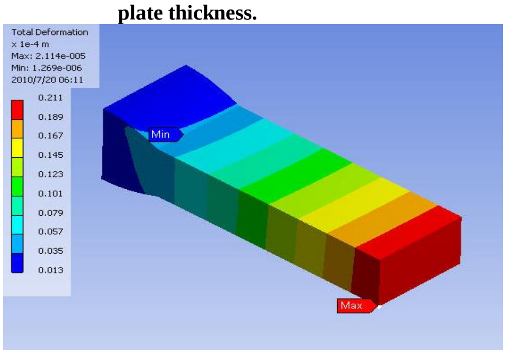

Figure 4: Total deformation contour for 0.44 toe radius, 6 mm plate thickness.

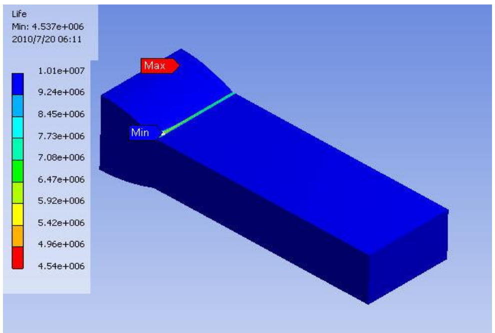

Figure 5: Life plot contour for 6 mm 0.44 toe radius, plate thickness.

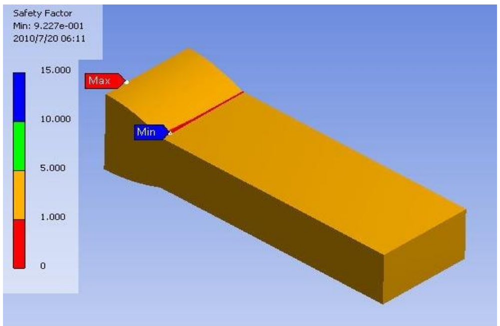

Figure 6: Safety factor contour for 0.44 toe radius, 6mm plate thickness

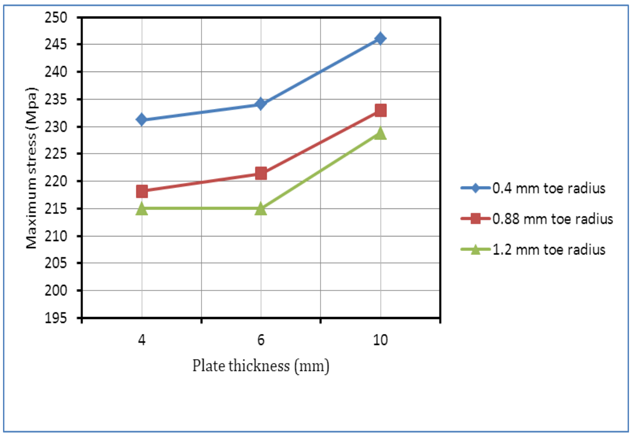

Figure 7: Equivalent maximum Von-Mises stress.

Figure 8: Maximum total deformation.

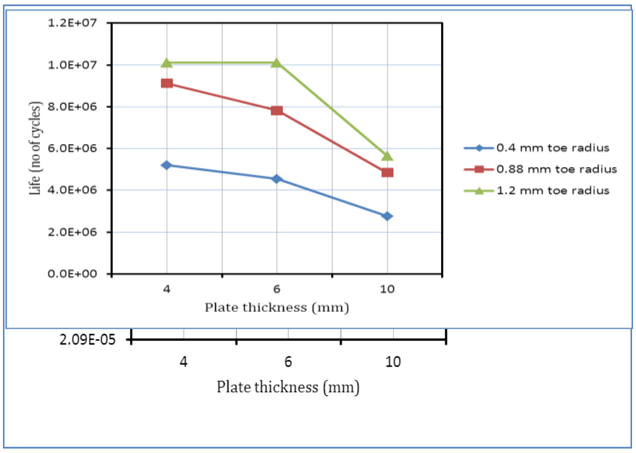

Figure 9: Minimum fatigue life

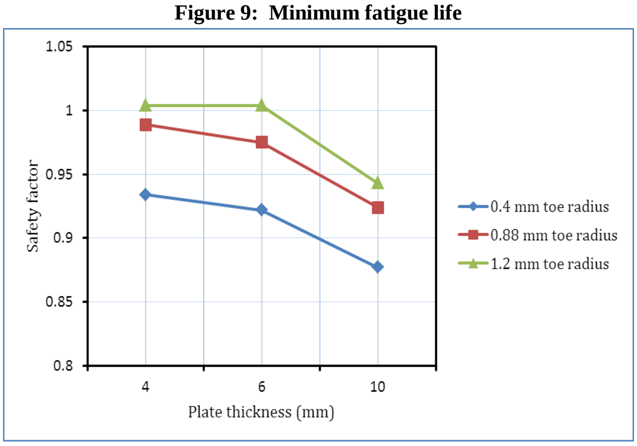

Figure 10: Minimum fatigue safety factor.

References

[1] K. L. Lawrence, Ansys Workbench Tutorial, Mechanical and aerospace engineering. University of Texas at Arlington, 2006.

[2] British Standard Institution “Metallic materials-Tensile testing. ” BS EN ISO 6892-1:2009 London, 2009.

[3] British Standard Institution “Hot rolled products of structural steel. ” BS EN 10025-2:2004 London, 2004.

[4] D. William, And J. Callister, Material Science and Engineering. 6th ed., John Wiley, 2003.

[5] H. Lieurade, I. Huther, and D. Lebaaillif, Weld Quality Assessment as Regard to Fatigue, IIW Commission XIII. Centre Technique des Industries Mecaniques, 2002.

[6] A. Sechadri, Statistical Variation of Weld Profiles and their Influence on Fatigue Strength. MSc. Thesis, Lappeenrante University of Technology, 2006.

[7] ANSYS Inc., Release 11. Documentation, 2008.