International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878, Impact Factor (2015): 3.791

Finite Element Simulation of Fillet Welded Cruciform Joint for Evaluation of Fatigue Behavior

Mahesh Dhone[1], Dr. R. D. Palhade[2]

[1]PG Scholar, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, India
[2]Professor, Shri Sant Gajanan Maharaj College of Engineering, Shegaon, India

Abstract: ***Finite element simulation, were carried out to study the effect of different weld geometry on the fatigue behavior in a cruciform fillet welded joint. In which, presence of welding residual stresses were considered for evaluating the fatigue behavior of joint. For that 3D coupled analysis was done, in which the temperature filed of transient thermal analysis is considered as thermal load to structural analysis. The fatigue behavior is evaluated under constant amplitude loading (R=0). The aim of this work is fatigue behavior evaluation of fillet welded cruciform joint for different weld geometry. The weld geometry are considered: isosceles triangle, scalene triangle, concave and convex geometries.***

Keywords: Transient thermal analysis, Heat input, Structural analysis, cruciform fillet welded joint, Weld geometry, Fatigue life

1. Introduction

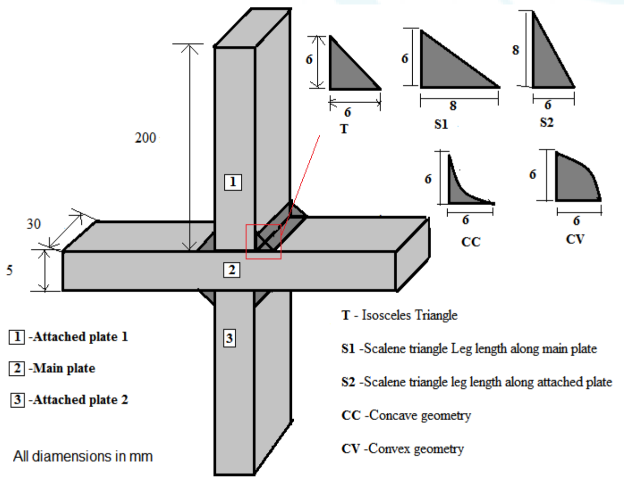
A weld joint is a permanent joint which is obtained by the fusion of the edges of the two or more parts to be joined together, with or without the application of pressure and filler material. Welding is a main technical method in the area of aerospace industries, automobile industries, shipbuilding, nuclear power, petrochemical industry. During welding Complex heating and cooling cycles encountered in weldments lead to transient thermal stresses and incompatible strains produced in region near the weld. After heat cycles of welding diminished, the incompatible strains remain and provoking locked stress deal with those remaining stress in a structure even though no external load applied (Masubuchi, 1980). It is unavoidable factor in the welded joints, while evaluating the performance of welded joint it is important to considerd the influence of residual stresse. For exemplar, Dongpo Wang et al. presented the effects of residual stresses on fatigue behavior of welded T-joint are investigated based on a coupled stress and energy criterion [1]. Kuang-Hung Tseng et al. presented a Gaussian distribution of heat flux with an effective arc radius that was selected for the finite element analysis to accurately describe the distributive nature of the heat source provided by the welding arc and predict the residual stress of TIG welded sheet [2]. Guangming Fu et al. discussed the influence of the welding sequence on residual stress and distortion of fillet welded structure [3]. Adinath V Damale et al. addressed the development of numerical simulation of side heating for controlling angular distortion in multipass MMAW butt welded plates [4]. Gurinder Singh Brar and Chandra Shekhar Singh studied the residual stress in cruciform welded joint of hollow section tubes by using FEA and results compared with X- ray diffraction experimental method [5]. Adinath V Damale et al. studied the Restrained Welding to Control angular Distortion with 3-D Coupled FE Analysis[6].

In general, most of the welded joints work under the condition of fluctuating loading, so fatigue failure is the main mode of failure in welded structure. Fatigue failure in part often result from applied stress levels significantly below those necessary to cause static failure. Fatigue, or metal fatigue, is the failure of a component as a result of cyclic stress. The failure occurs in three phases: crack initiation, crack propagation, and catastrophic overload failure. The duration of each of these three phases depends on many factors including fundamental raw material characteristics, and orientation of applied stresses, processing history, etc. It is well known that welding joints are often the weakest portion of welding structure and their quality directly affect the integrity of welding structure. With the large application in the engineering area it is important to study the nature of welded structure working under the cyclic loading. For exemplar, V. Caccese et al. studied the effect of weld geometric profile on fatigue life of cruciform welds made by laser/GMAW process [8]. Chin-Hyung Lee et al. carried out the effect of weld geometry on the fatigue life of non-load-carrying fillet welded cruciform joints [9]. A. Khodadad Motarjemi et al. studied the comparison of fatigue life for T and cruciform welded joints with different combination of weld geometrical parameters [10]. V. Balasubramanian and B. Guha established the criteria for root and toe cracking of load carrying cruciform joints of pressure vessel grade steel [11]. Shigenobu Kainuma et al. calculated a fatigue strength evaluation method for load-carrying fillet welded cruciform joints with different weld shape considered by using experiment approach and analytical method [12]. In-tae Kim and shigenobu Kainuma studied the fatigue life assessment of load carrying fillet welded cruciform joints inclined to uniaxial cyclic loading [13]. A Al-Mukhtar et al. compared the stress intensity factor of load-carrying cruciform welded joints with different geometries [14]. Fatigue life of a weldment is influenced by the material, environment, welding techniques, weld quality, connection details and the geometric profile of the weld. Welded joints are regions of stress concentration where fatigue cracks are likely to initiate. Geometry is one of the primary factors that control the fatigue life. Most of the authors worked on the geometric parameters like flank angle, toe radius and throat thickness of fillet weld joints. In the present work, fatigue behavior of load carrying fillet welded cruciform joint for different weld geometry were considered with the presence of residual stresses by using finite element method.

2. Joint Preparation

A cruciform joint is prepared among three members, with two members located approximately at right angle to the third member in the form of a sign +. In the present work mild steel plate (200 mm × 30 mm × 5 mm) is considered. The cruciform joint was prepared by using manual metal arc welding technique. All three members have same dimensions as shown in figure (1-a). Model prepared for different weld geometry as shown in figure (1-b). During welding operation, heat is produced to join the working plates which also increase the temperature in the joint. The temperature affect the properties of mild steel plates, in this study temperature dependent thermal and mechanical properties of mild steel were considered [6] shown in table (1). The properties of welding material were considered same as working material except the yield stress and ultimate stress shown in table (2). Fillet welded cruciform joint for Isoscales triangle, scalene triangle leg length along main plate, scalene triangle leg lemgth along attached plate, concave and convex geometry referred as T, S1, S2, CC and CV throught out the work.

(a)



(b)

Figure 1: Cruciform welded joint- a) Testing model, b) Different weld geometry with considered dimensions

Table 1: Thermal and Mechanical properties of Mild steel [6]

Temp (°C)	K (W/mK)	Specific Heat (J/KgK)	Poison's ratio	E (Gpa)	α (10^{-6}/°C)
0	51.9	450	0.2786	200	10
100	51.1	499.2	0.3095	200	11
300	46.05	5655	0.331	200	12
450	41.05	630.5	0.338	150	13
550	37.5	705.5	03575	110	14
600	35.6	773.3	0.3738	88	14
720	30.64	1080.4	0.3738	20	14
800	26	931	0.4238	20	15
1450	29.45	437.93	0.4738	2	15
1510	29.7	400	0.499	0.2	15.3
1580	29.7	735.25	0.499	0.00002	15.4
5000	42.2	400	0.499	0.00002	15.5

Table 2: Mechanical properties

	Yield Stress (MPa)	Ultimate Stress (MPa)
Mild Steel	374	508
Weld material	386	518

3. Fatigue Behavior of Cruciform Joint

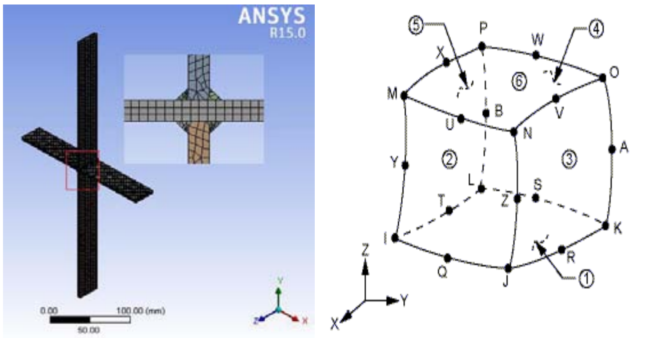
The fatigue behavior of load carrying cruciform welded joint for different weld geometry was investigated by considering the presence of residual stress. The cruciform joint was modeled in finite element program and simulation was done for different weld geometry.

3.1 Finite element Method

Finite element method is one of the accurate engineering technique is use in research work and in industry for analysis of actual problems. In this work welding simulation was done by using commercially available finite element program i.e. ANSYS15. For the Fatigue analysis, coupled analysis were done in which the first transient thermal analysis was done and then temperature field taken as imported thermal load with external cyclic load to performed fatigue analysis.

3.1.1 Transient thermal analysis

The cruciform weld joint of mild steel plates was modeled using an ANSYS 15 workbench design module. Figure 2 (a) shows the meshed isometric view of the cruciform joint. The element considerd is SOLID90. It is a higher order version of the 3-D eight node thermal element (SOLID70). The element has 20 nodes with a single degree of freedom, temperature, at each node. The 20-node elements have compatible temperature shapes and are well suited to model curved boundaries. The 20-node thermal element as shown in figure 2 (b), is applicable to a 3-D, steady-state or transient thermal analysis. Boundary conditions are applied for transient thermal analysis because the heat applied to the surface of model the amount of heat it get liberated by convection and radiation to surrounding area. In this work the initial temperature of working plate is 30°C and the combined convection and radiation film coefficient, h=15W/m2-k [6] is used on the total area of working plate except the surface of welding path as shown in figure 3(a) with ambient temperature of 30°C.



(a) (b)

Figure 2: (a) Quadratic Meshing used for joint, **(b)**Transient Thermal Element SOLID90 Thermal load is applied along the welding path

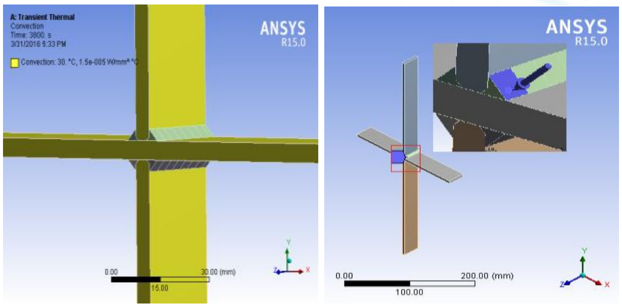
The most important welding parameter were considered for thermal load which are given in table (3). A thermal load in welding continuous travelling along the specific path on top of splited surfaces were fusion process take place as shown in figure 3 (b). In the analysis, the moving heat source is simplified by considering that the welding arc stayed at an element with constant specific surface heat flux and then moved to the next surface at the end of the load step. Time taken for each load step on the basis of welding speed. Time taken to cool the weld joint up to ambient temperature. After completion of each weld fillet 90 seconds interval was taken as manual handling, remove slag in joint and minimize temperature to avoid distortion. The amount of moving surface heat flux is calculate by using the Gaussian distributed heat source relation shown in eq. (1) [6].

$$q(r) = \frac{3Q}{\pi R^2} exp^{\left(-\frac{3r^2}{R^2}\right)} \quad (1)$$

Where q(r) is heat flux, Q is heat input, r is distance from the heat source center, R radius of heating spot.

Table 3: Welding parameters by experiment

Current (I)	Volt. (V)	Effi. (%)	Welding Speed (mm/s)	Heat input (W)
120	35	0.75	4	3150



(a) (b)

Figure 3 (a)- Thermal boundary condition on plate, **(b)** Thermal load applied on weld path

After calculating the temperature distribution on cruciform welded joint, this temperature field was applied to the structural model as a internal thermal load with cyclic loading. Figure (4) shows the temperature distribution during welding operation of fillet welded cruciform joint for T weld geometry by manual metal arc welding. The maximum temperature were generated in cruciform joint with concave geometry (CC) shown in figure (5).

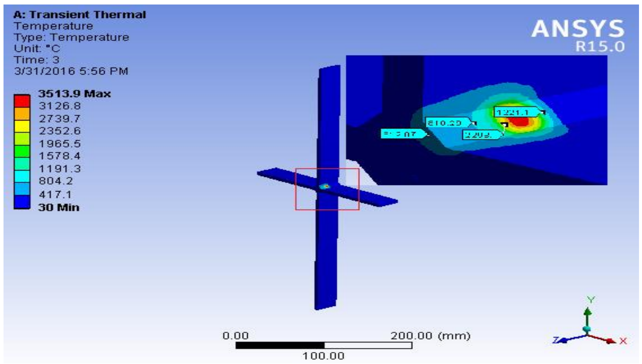


Figure 4: Temperature at 3sec during fillet 1 in T geometry

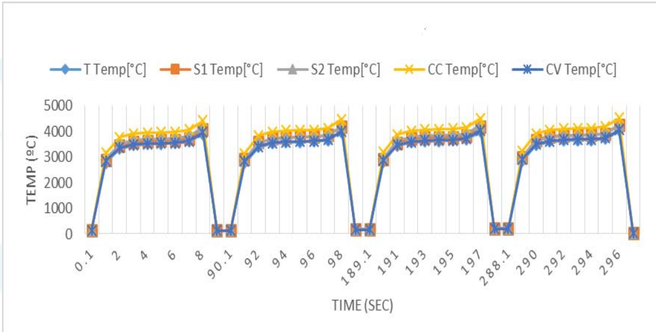


Figure 5: Tepmperature distribution in joint during fillet (1-4) up to room temperature.

3.2.2 Structural Analysis

In structural analysis the thermal element SOLID90 is replaced by the SOLID186 as shown in figure (6). It is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials.

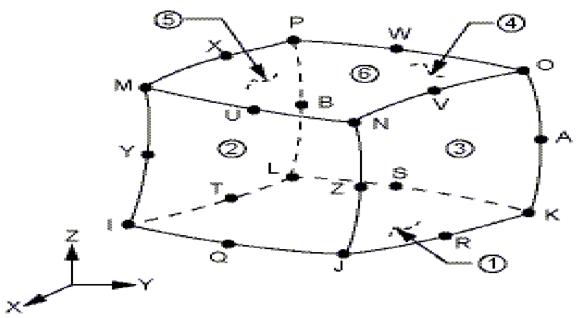


Figure 6: Strucural Element SOLID186

The boundary condition was applied at the attached plate 2 and Load applied at the end of attached plate1 shown in figure (7) to calculate the Equivalent stress for different loading conditions. This Equivalent stress further used in fatigue analysis to evaluate the fatigue life of load carrying fillet welded cruciform joint.

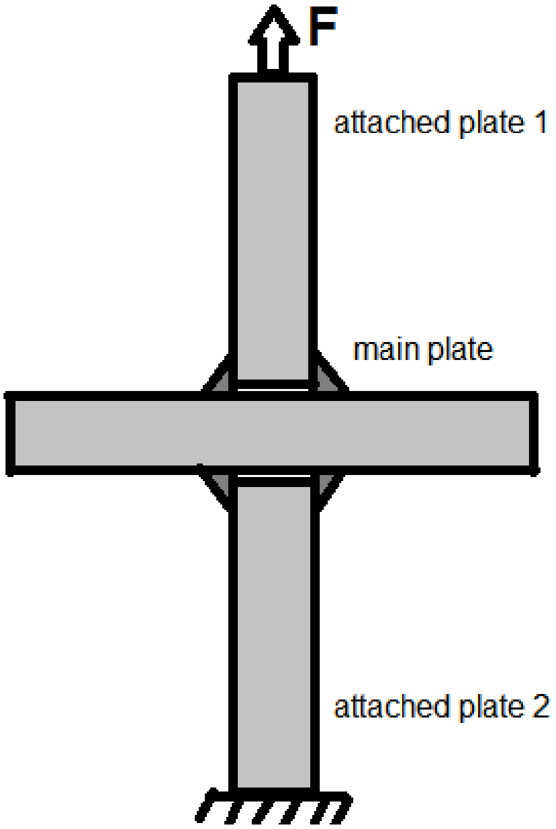


Figure 7: Structural boundary condition

3.2.3 Fatigue Analysis

Fatigue behavior of engineering component can calculate with the help of three basic approaches which are Stress-life Approach, Strain-Life approach, Linear elastic fracture mechanics approach. Fatigue failures are typically characterized as either low-cycle (<1000 cycle) or high cycle (>1000 cycles) as shown in figure (11). In the present work S-N approach is used. In S-N approach S' stands for the cyclic stress range while 'N' represents the number of cycles to failure. With the help of S-N approach total life of model including the crack initiation to crack propagation is calculate. The stress range applied was constant amplitude nature (R=0). Equivalent stress range component is consider on the basis of von-mises failure theory. There are four different mean stress theories can used to evaluate the fatigue behavior of components as shown in figure (8). In the present work Goodman mean stress correction theory is considerd to calculate the fatigue life. Fatigue data of material is considered on the basis of relation between the ultimate strength and endurance limit of the material[15-16].

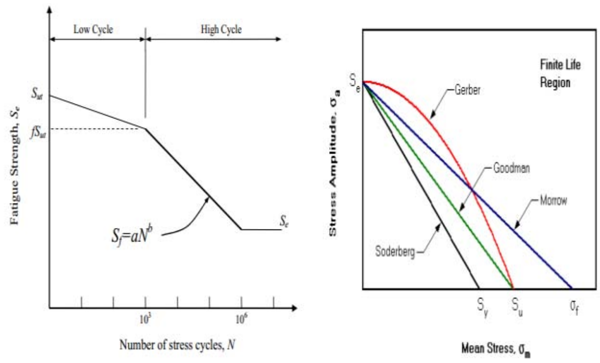


Figure 8: Fatigue characteristic curves

4. Results

4.1 S-N Curve for Different Weld Geometry

Fillet welded cruciform joint for S2 geometry work under the maximum loading condition and weld joint with CC geometry failed at minimum load . Figures (9-13) shows the stress versus fatigue life of cruciform welded joint with load for considered geometry.

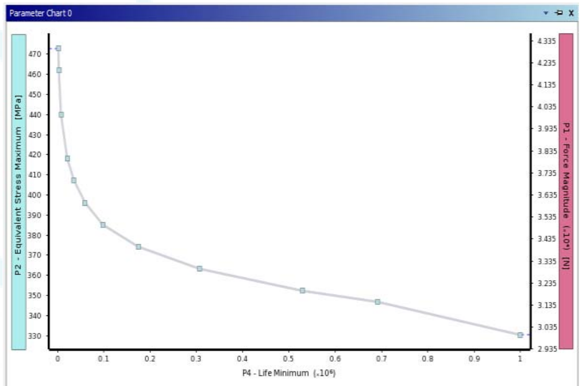


Figure 9: S-N curve for T geometry

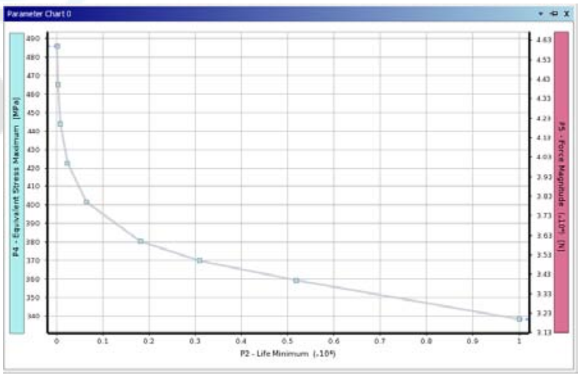


Figure 10: S-N curve for S1 geometry

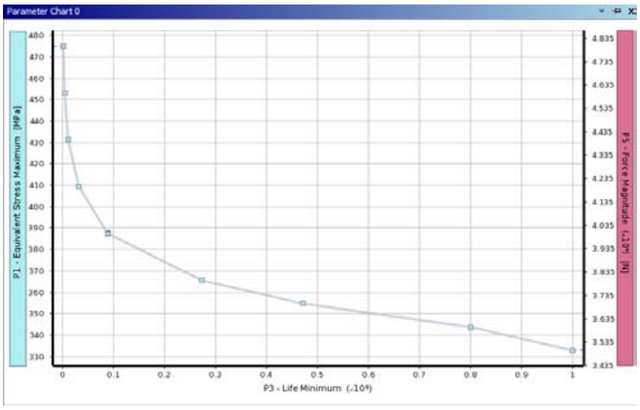


Figure 11: S-N curve for S2 geometry

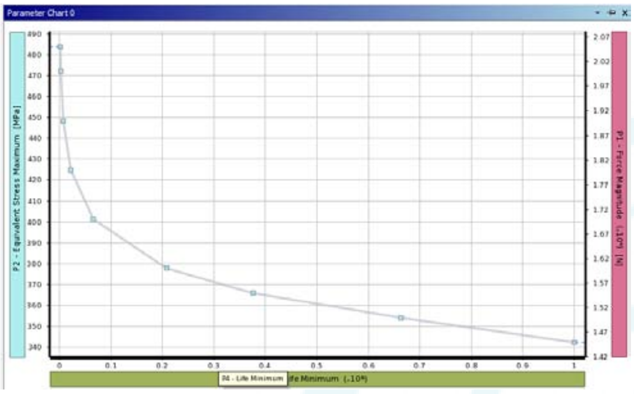


Figure 12: S-N curve for CC geometry

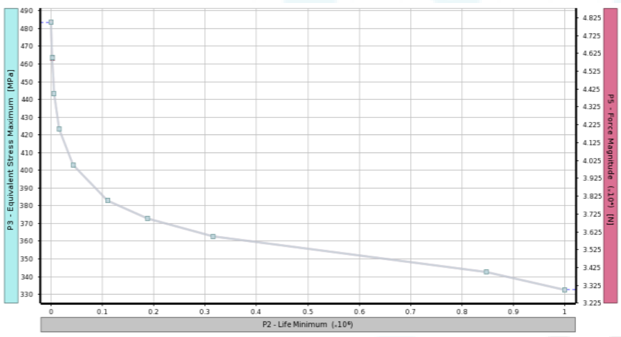


Figure 13: S-N curve for CV geometry

4.2 Result compared at common load condition

From the S-N curves it shows that the joint with concave geometry failed to early as compared to the other geometry because of the minimum weld material deposition. The range of load sustain for (1000-1000000 cycles) is 14 KN-20.5KN which is too less as compared to other geometry. Figure (14) shows the fatigue life against the cyclic loading.

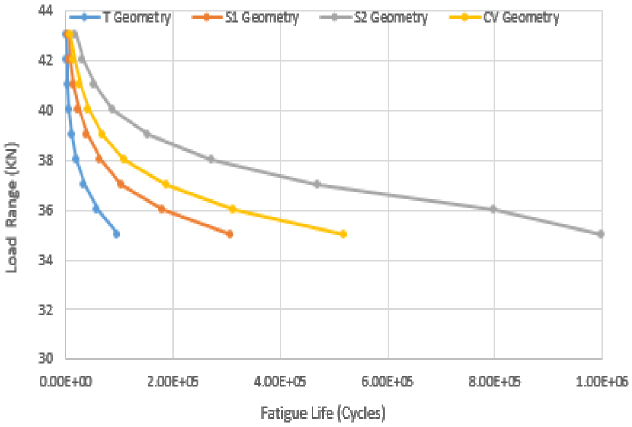


Figure 14: Fatigue life against applied load range

4.3 Fatigue Failure Region in Joints

Fillet welded cruciform joint for T, CC, CV geometry failed at weld root region ,joint with S1 and S2 geometry failed at weld toe region. Figure (15) shows the failure region in joints. Load applied for T, S1, S2, CC, CV is 43 KN, 46 KN, 48 KN, 20 KN, 47 KN. This are maximum load range taken from S-N curve of all geometry.

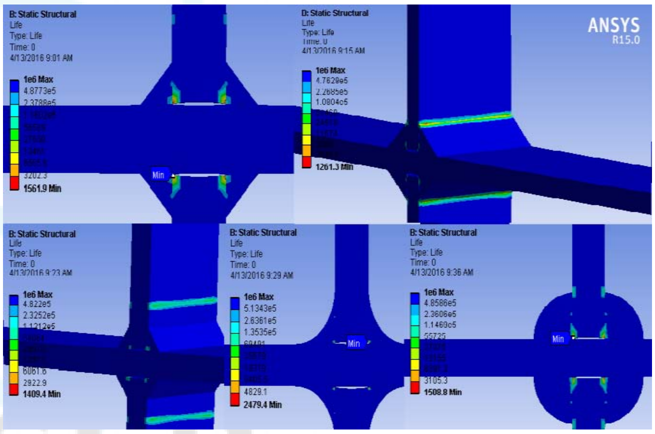


Figure 15: Failure regions for different geometry

5. Conclusion

In this study, the fatigue behavior of fillet welded cruciform joint for different weld geometry has been studied. On the basis of results and discussion, the following conclusions to be drawn are as follows:

1. The fatigue strength of joint with scalen triangle geometry and convex geometry was higher than the triangular geometry.
2. The geometry having scalen triangle along attached plate (S2) gives better fatigue strength compared with these joints.
3. The concave geometry for considered design value gives less performance in fatigue loading conditions.
4. Cruciform joint for I, CC and CV failed at weld root region.
5. Joint with S1 and S2 failed at weld toe region.

References

[1] Dongpo Wang, Hai Zhang, Baoming Gong and Caiyan Deng, Residual stress effects on fatigue behaviour of welded T-joint: A finite fracture mechanics approach, Materials and Design 91 (2016) 211–217.

[2] Kuang-Hung and Tseng Jie-Meng Huang, Arc Efficiency Assisted Finite Element Model for Predicting Residual Stress of TIG Welded Sheet, journal of computer,Vol.8 no.9, September 2013.

[3] Guangming Fu a, Marcelo Igor Lourenço a, Menglan Duan b and Segen F. Estefen, Influence of the welding sequence on residual stress and distortion of fillet welded structures, Marine Structures 46 (2016) 30e55.

[4] V. Damale and K. N. Nandurkar, Numerical simulation of side heating for controlling angular distortion in multipass MMAW butt welded plates, Sadhan © Indian Academy of Science.

[5] Gurinder Singh Brar and Chandra Shekhar Singh, FEA of residual stress in cruciform welded joint of hollow sectional tubes, Journal of construction steel research 102 (2014) 44-58.

[6] V. Damale and K. N. Nandurkar, 3-D Coupled FE Analysis and Experimental Validation of Restrained welding to control angular distribution, J. Inst. Eng. India Ser. C (October–December 2012) 93(4):365–371 DOI 10.1007/s40032-012-0044-y.

[7] V. Caccese, P.A. Blomquist, K.A. Berube,S.R. Webber, N.J. Orozco, Effect of weld geometric profile on fatigue life of cruciform welds made by laser/GMAW processes, marine structure 19 (2006) 1-22.

[8] Chin-Hyung Lee, Kyong-Ho Chang, Gab-Chul Jang and Chan-Young Lee, effect of weld geometry on the fatigue life of non-load-carrying fillet welded cruciform joints, engineering failure analysis 16 (2009) 849-855.

[9] A. Khodadad Motarjemi , A.H. Kokabi , F.M. Burdekin , Comparison of fatigue life for T and cruciform welded joints with different combinations of geometrical parameters, Engineering Fracture Mechanics 67 (2000) 313-328.

[10] V. Balasubramanian, B. Guha, Establishing criteria for root and toe cracking of load carrying cruciform joints of pressure vessel grade steel Engineering Failure Analysis 11 (2004) 967–974.

[11] Shigenobu Kainuma ,Takeshi Mori, A fatigue strength evaluation method for load-carrying fillet welded cruciform joints, International journal of fatigue 28 (2006) 864-872.

[12] In- Tae Kim and Shigenobu Kainuma, Fatigue life assessment of load-carrying fillet-welded cruciform joints inclined to uniaxial cyclic loading International Journal of Pressure Vessels and Piping 82 (2005) 807–813.

[13] Al-Mukhtar, H.Biermann, S.Henkel P.Hubner, Comparison of the Stress Intensity Factor of Load-Carrying Cruciform Welded Joints with Different Geometries JMEPEG (2010) 19:802–809.

[14] Hobbacher A. Recommendations for Fatigue Design of Welded Joints and Components. International Institute of Welding, doc. XIII-2151r4-07/XV-1254r4-07. Paris, France, October 2008.

[15] Julie A Bannantine, Jess J. Comes, James L. handrock, Fundamentals of metal fatigue and analysis.

[16] Bernard J. Hamrock, Bo Jacobson and Steven R. Schmid, fundamentals of machine Elements, ISBN 0-07-116374-3