International Journal of Research and Development in Applied Science and Engineering (IJRDASE)
ISSN: 2454-6844

Fatigue Life determination of welded specimen by thermal and mechanical stress analysis Using FEM

Soni Singh
Dept of Mechanical Engg
SRIMT., Lucknow
svtsoni1010@gmail.com

Anurag Srivastava
Dept of Mechanical Engg
SRIMT., Lucknow

Abstract—This paper presents the study and analysis of fatigue life of dissimilar materials joined by welding. Because of the use of conventional welding process materials are subjected to thermal residual stresses additional to externally applied load. This study is aimed to show the finite element analysis for welded joint so that variation of induced stress because of applied load and thermal residual stresses with thickness of welded body.

Due to the influence of the welding residual stress, residual plastic deformation, heat affected zone and stress concentration effect the fatigue life of welded components is far lower than the parent metal. Fatigue life is most common word in engineering design.

Weld geometry leads to micro cracks that generally stimulate fatigue damage due to residual stress and stress concentration breakdown caused caused by fatigue can be major or minor repetition or variation in load cause failure in fatigue which never reaches a level sufficient to cause failure in single application of load. This is the time for engineers to design more sustainable, safe and desirable component for the society and finite element analysis tool is more convenient and very less time required solving the most complex structures.

Keywords— Fatigue life, Welding, Thermal residual stresses, finite element analysis, elastic deformation, heat affected zone.

1. Introduction:

Welding is a fabrication process which joins materials (metals) or thermoplastics. Heat or pressure is used in the joining process of welding application, with or without the supplementation of filler material. To make the process easier and possible various additional materials may be used namely shielding gases, flux or pastes. For welding process the energy is supplied from outside sources.

Fillet welding is the process of joining two pieces of metal together whether perpendicular or in angle between 80-100 degrees (AWS 2010). These welds are often named as Butt joints or lap joints which are kept beside each other or cover a part of one another and welded at the fringe.

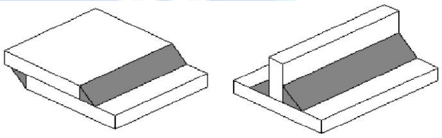


Fig. 1. Different Fillet welding Diagram

Fatigue life simply means life of structure under repeated or fluctuating loading. Fatigue failure of the welded structures remains the most common type of failure. In general, welded joints are more susceptible to fatigue cracking in comparison with bolted joints. His consequences of failure are often very costly and it is estimated that 80-90% of all structural failures are caused by fatigue. Statics shows 70-90% of the welded structures invalidation accidents in the past several years were caused by fatigue failure.

In welding process used electric current and produce arc to melt the consumable electrode and the work piece to be welded. Electric current flow through high resistance air gap generates an intense arc with temperature running from 3000 ºC – 6000 ºC. Residual stresses caused by welding can have various kinds of influence on the welded structure, e.g. increasing the susceptibility of a weld to fatigue damage, stress crossing cracking and fracture. Moreover, residual stresses developed in Butt-joint fillet welds made of steels are probably different from those of full penetrated welds in magnitude. Residual stresses are unavoidable, and the effects on welded structures are cannot be disregarded. Therefore, it is very important to clarify the characteristics of residual stresses in Butt-joint fillet welds in the structures. Welded steel joints always susceptible to fatigue damage when subjected to repetitive loading. Fatigue failure may occur even under modest in-service stresses. Furthermore, fatigue live exhibit considerable scatter even under constant amplitude loading conditions. This phenomenon makes statistical methods more indispensable and fatigue life has to be predicted at the given probability levels of failure for a given welded specimen under defined environment and loading conditions.

The driving factor for conducting this research project is need for a more confidently using of finite element analysis tool to predict life of the welded structures.

The comparison of physical test with finite element analysis is not much available which can refer to predict the life of structures. Finite element analysis (FEA) is a computer based method of simulating/analyzing the behavior of engineering structures and components under variety of conditions.

Fillet weld is most common welding in the engineering field and this weld used almost everywhere in building structures. Finite element analysis of simple fillet welding compare with physical testing will allow us to analyze more complex structures with more accurately with minimum error.

2. PROBLEM FORMULATION:

Two rectangular plates of dimension 30 mm X 50mm x3 mm made up of two dissimilar material SA106 and STS 304, separated by 3 mm gap is modeled in ANSYS 17.1 and then gap is modeled as weld connection of filler material M309. The tensile force of 20KN is applied on it keeping other end under fixed constraints. The specimen is again analyzed for the thermal load as temperature. Butt welded joint specimen using gas metal arc welding (GMAW) process was analyzed to cyclic loading. At first thermal analysis is done by giving a heat input which is equivalent to the heat generated by a GMAW welding process. In the next step, a structural analysis was carried out to obtain the mechanical response of the structural model, where the temperature history obtained from the first step was employed as a thermal load in the analysis. Then on the same specimen, fatigue analysis is conducted by applying cyclic loading.

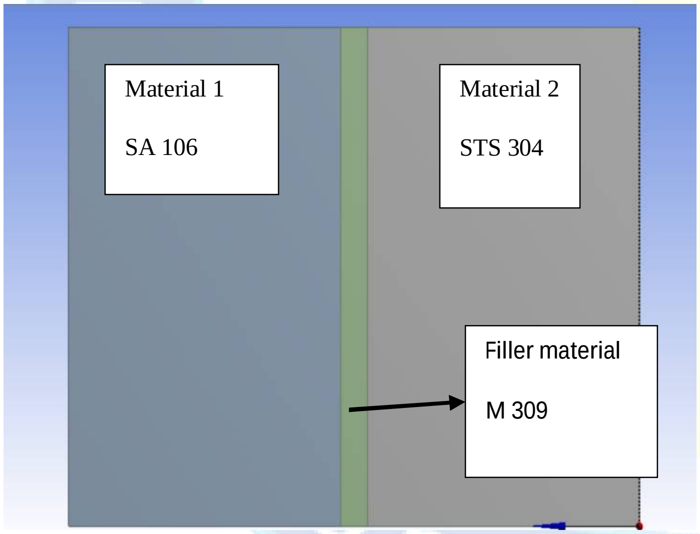


Fig. 2. Specimen of welded section

2.1 Analysis of Butt Welded Joint

The analysis of welded section is broadly divided into several parts which include modelling of Butt joint which is in ANSYS WORKBENCH 17.1 and all the modelling procedure This is followed by static structural analysis under tensile and thermal loading conditions. This is followed by thermal analysis of the weld section and results obtained from it will be used for determining stresses in the plate section and also for the computation of the fatigue Life of the specimen.

In traditional finite element analysis we know that, the number of element increases the accuracy of solution will be improved also it is not necessary to put element size very small. Smaller element size will takes longer time to analysis and some time it is almost impossible to run the model.
In order to find optimum element size I have chosen different element size and analyse the model, where the stress are not changing dramatically assume that is the optimum size.

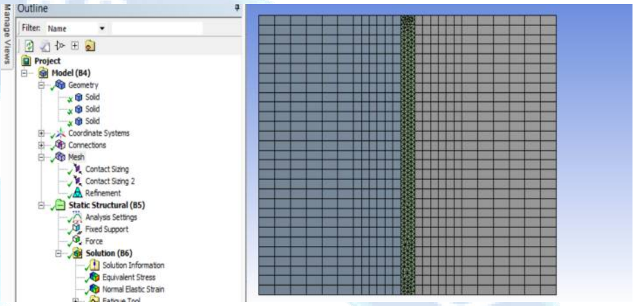
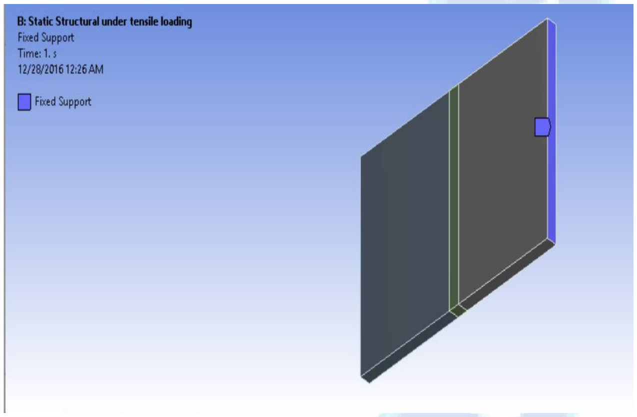


Fig. 3. Meshing of Butt weld joint

2.2 Boundary Conditions

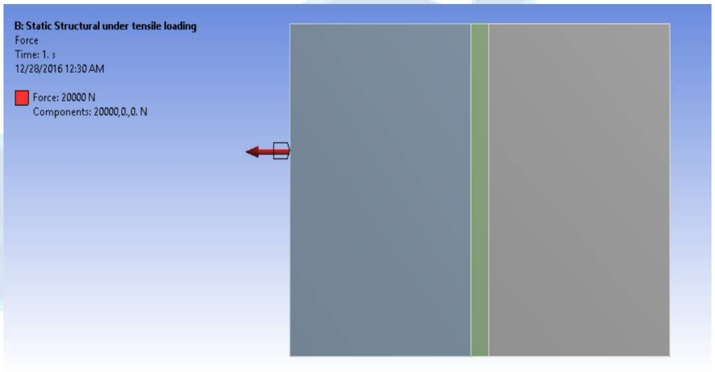
2.2.1 Fixed Support


B: Static Structural under tensile loading
Fixed Support
Time: 1. s
12/28/2016 12:26 AM

🟦 Fixed Support

Fig. 4. Figure showing one end fixed

2.2.2 Application of Tensile Load


B: Static Structural under tensile loading
Force
Time: 1. s
12/28/2016 12:30 AM

🟥 Force: 20000 N
Components: 20000,0.,0. N

Fig. 5. Application of tensile load of 20KN on Butt weld joint

2.2.3 Equivalent Stresses

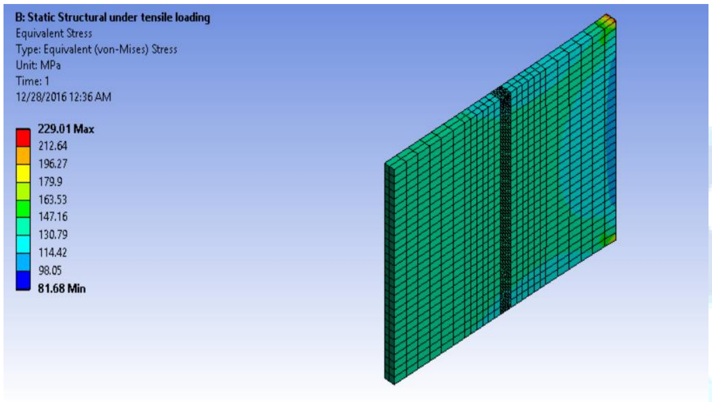


Fig. 6. Equivalent Stresses of tensile load of 20KN on Butt weld joint

2.2.4 Normal Elastic Strain

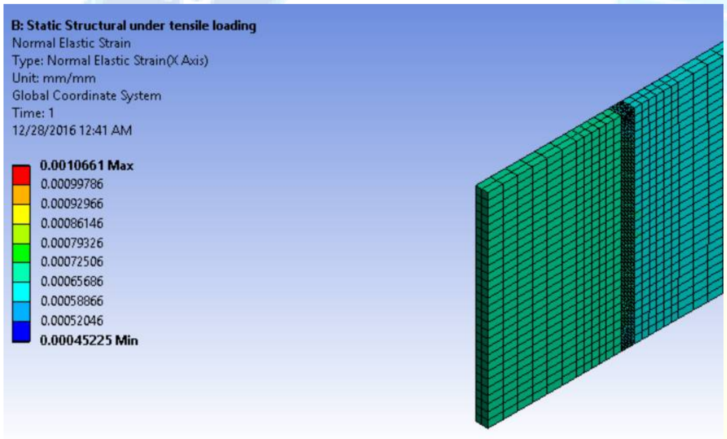


Fig. 7. Normal Elastic Strain in X direction under Tensile loading

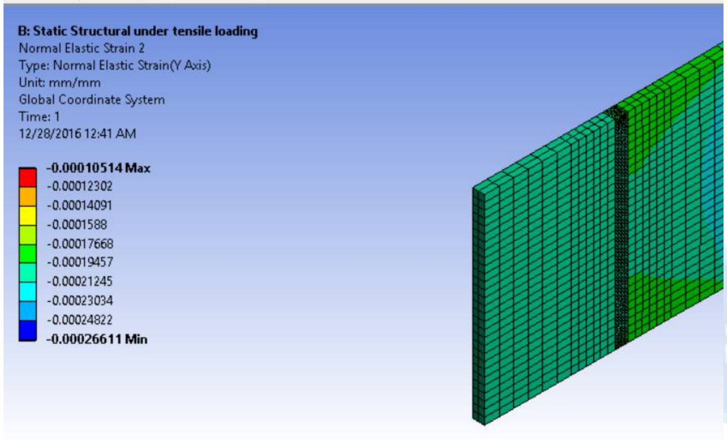


Fig. 8. Normal Elastic Strain in Y direction under Tensile loading

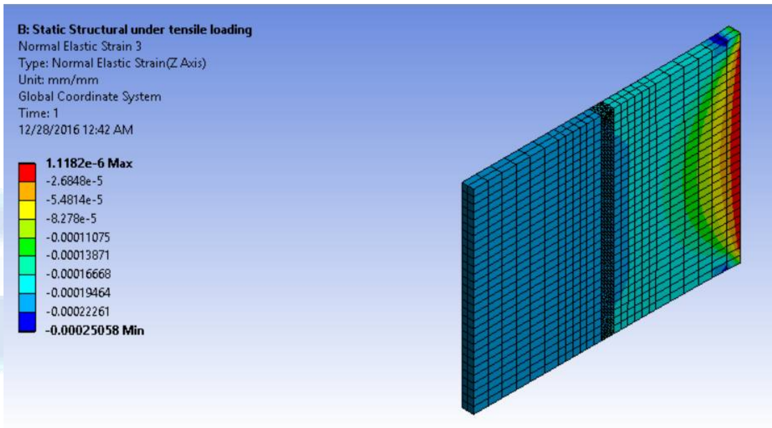


Fig. 9. Normal Elastic Strain in Z direction under tensile loading

2.3. STATIC STRUCTURAL ANALYSIS UNDER THERMAL LOADING

2.3.1 Thermal Load calculation

A thermal analysis of heat conduction was carried out in the first step to obtain temperature distribution histories over the structural model. In the thermal analysis, the welding heat input, Q was calculated by using equation given below

$$Q = \eta_A \left(\frac{V \times I}{W_s}\right)$$

where η_A is welding efficiency; V is welding arc voltage; I is welding current; V is welding arc voltage; Ws is the arc welding speed; and Q is the heat input.

The arc efficiency, ηA for GMAW was assumed to be 0.80. Also, the values of convective heat transfer coefficient, he was taken as stagnant air-simplified case and reference temperature was taken 22°C. The parameters used for giving heat input are selected from the recommended values of current and voltage for the particular thickness of weld where the voltage equals to 22.73 V, current is equal to 277 Amp and welding speed is 5 mm/sec.

Substituting the above values, we will calculate the Q=1007.39 watt

After finding Q, we will apply following relationship

$$Q = mc\Delta\theta = V \times \rho \times c \times \Delta\theta$$

Here mass ‘m’ will be of surface which receives heat due to electric current and potential difference.

$$\Delta\theta = 2380℃$$

$$\theta - 22 = 2380℃$$

$$\theta \approx 2400℃$$

So thermal boundary condition is application of thermal load as 2400°C.

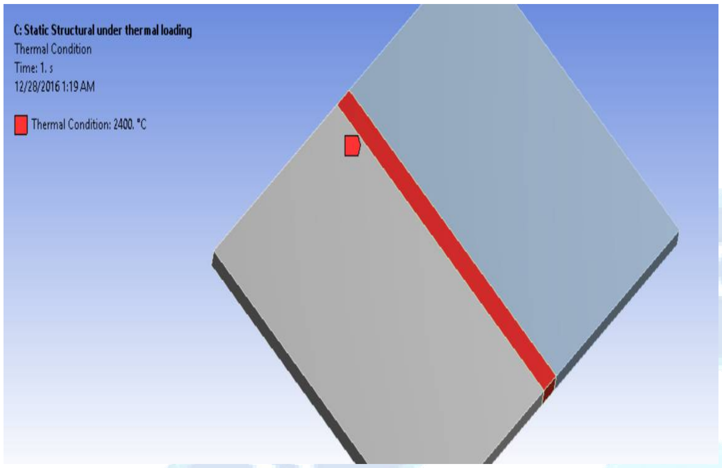


Fig. 10. Application of thermal boundary condition

2.3.2 Equivalent stresses under thermal condition

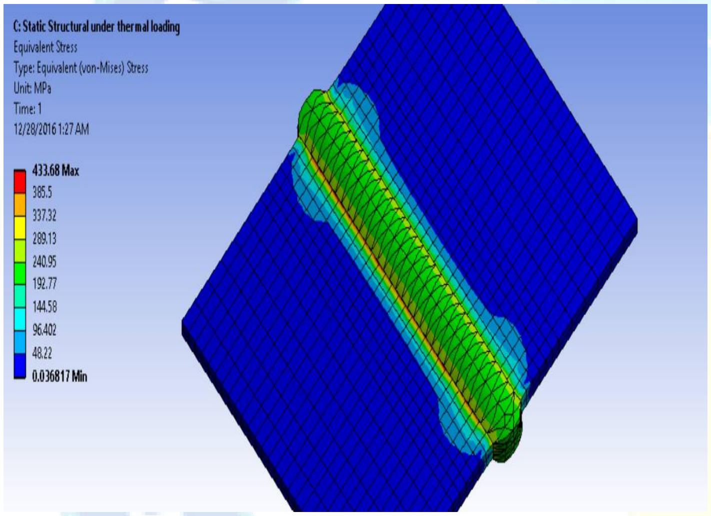


Fig. 11. Equivalent Stresses of thermal load on Butt weld joint

2.3.3 Variation of the temperature in the welded specimen

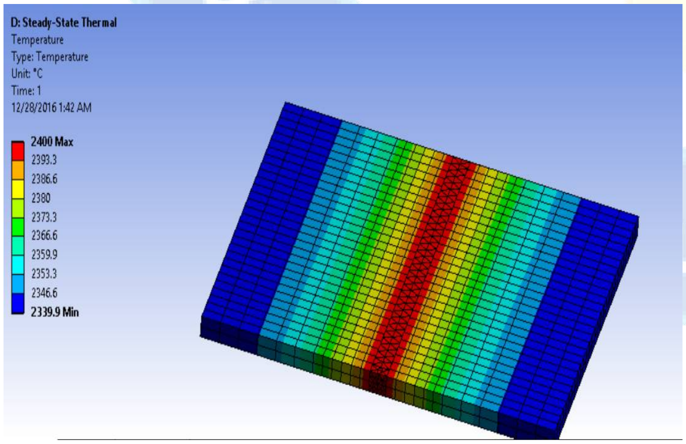


Fig. 12. Variation of temperature on butt weld joint

2.3.4 Structural Analysis Under Thermal Load Computed From Thermal Analysis

The material model of elastic- plastic based on the Von Mises yield criterion and isotropic strain hardening rule was chosen, in which its response over the history was determined by the temperature-dependent material properties inputted.

a. Equivalent Stresses on Butt weld joint due to variation in temperature

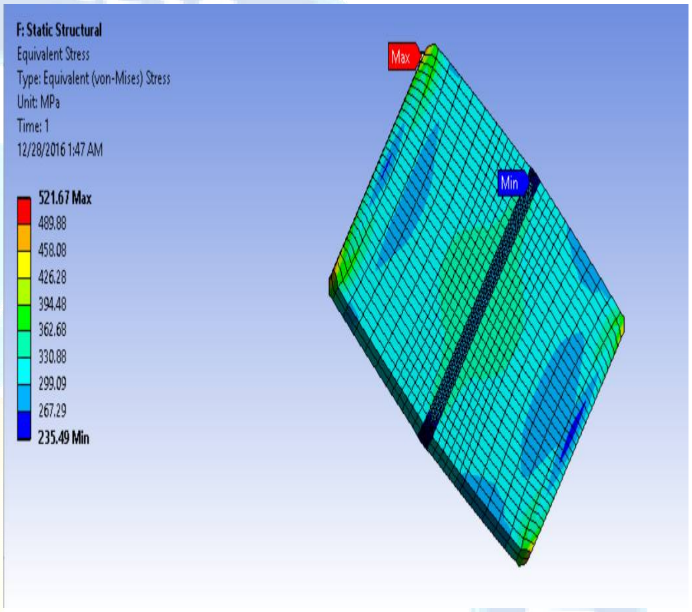


Fig. 13. Equivalent Stresses on Butt weld joint due to temperature difference

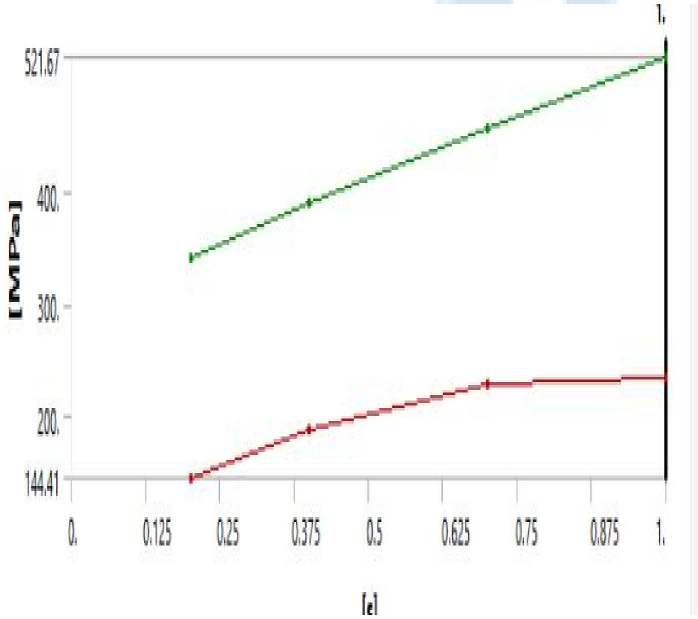


Fig. 14. Graphical representations of maximum and minimum Equivalent Stresses on Butt weld joint due to temperature difference with respect to time

3. FATIGUE LIFE

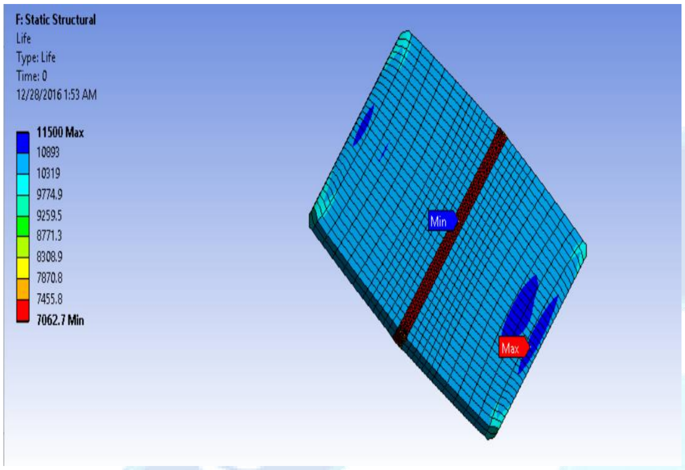


Fig. 15. Fatigue Life on Butt weld joint due to temperature difference

3.1 Design of Experiment

To understand the variation in the equivalent stresses under tensile loading and thermal loading, the change in maximum and minimum temperature and the fatigue life with respect to thickness of plate, the design of experiment is used. This enables us to determine the values of the unknown without actually doing any change in the dimensions of the geometrical design.

3.1.1 Maximum Equivalent stress vs. thickness under tensile loading

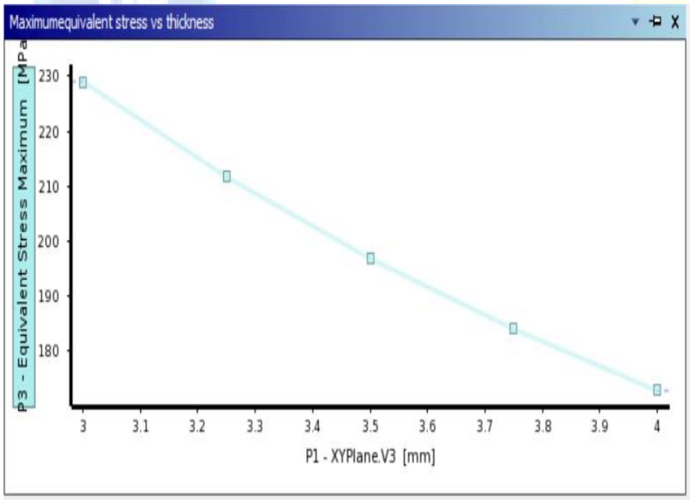


Fig. 16. Graphical representation of Equivalent stress with change in plate thickness under tensile loading

3.1.2 Maximum Equivalent stress vs thickness under thermal loading

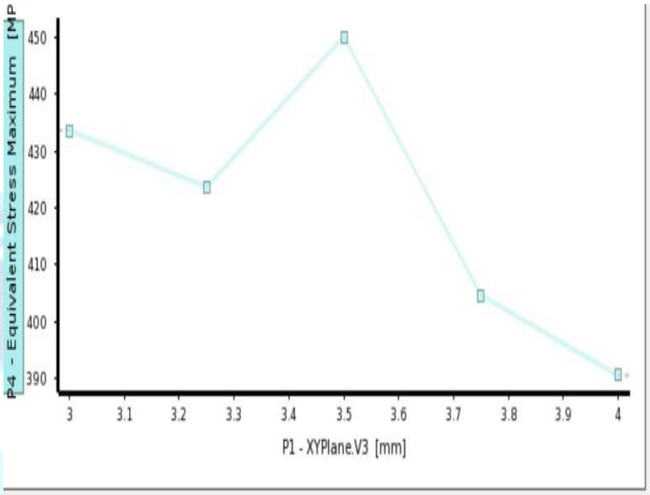


Fig. 17. Graphical representation of Equivalent stress with change in plate thickness under thermal loading

3.1.3 Maximum and minimum temperature vs thickness under thermal loading

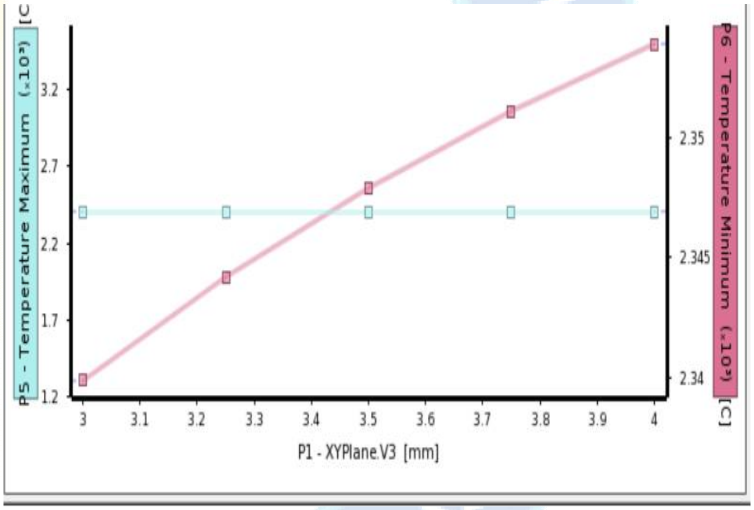


Fig. 18. Graphical representation of Maximum and minimum temperature with change in plate thickness under thermal loading

3.1.4 Maximum Equivalent stress vs thickness under temperature variations

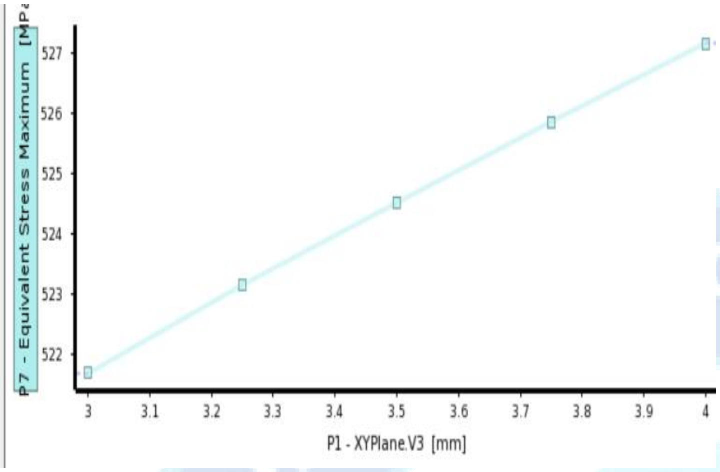


Fig. 19. Graphical representation of Equivalent stress with change in plate thickness under temperature variation

3.1.5 Minimum Fatigue life

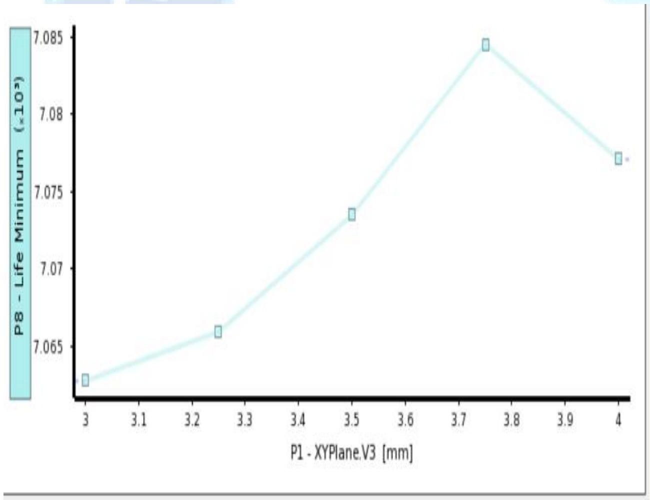


Fig. 20. Graphical representation of Fatigue life with change in plate thickness

4. CONCLUSION

The following points may be concluded from the Fatigue analysis of dissimilar material welded specimen using finite element analysis made up of SA 106, STS 304 and filler weld material (M 309).

1. The Maximum equivalent stresses of welded specimen of thickness 3mm were found to be 230MPa under tensile loading of 20kN (Figure 4.21). These stresses go on decreasing with the increases in the thickness of the plate (Figure 4.31).

2. The Maximum equivalent stresses of the welded specimen of thickness 3mm were found to be 433 MPas under thermal loading (Figure 4.26). These stresses normally decreases as thickness of the plates increases with the exception at thickness 3.5mm where maximum equivalent stresses was found to be 450MPa (Figure 4.32).

3. The temperature decreases from hot surface (filler material) to cold surface (extremities of plates end) which is normal (Figure 4.27). The minimum temperature goes on increasing with the increase in the thickness of the plates (Figure 4.33).this proves thicker material retains heat for the longer duration.

4. The maximum Equivalent stresses was found at the edges of the plates under thermal loading of temperature variation and random stress variation is shown in the figure 4.28.The maximum stress increases linearly with time (Figure 4.29). The maximum equivalent stresses increases with the increases in thickness of the plates (Figure 4.34).

5. The Fatigue life of the weld was found to be 7065 cycles. This means weld section becomes weaker with the application of thermal loading of temperature variation (Figure 4.30). the fatigue life increases with the increase in the thickness of plates.

REFERENCES

[1] Roy s. Hubbard, Energy Impacts of Chilled Water Piping Configuration, Johnson control Inc. Teng, T-L, Fung, C-P, Chang, P-H & Yang, W-C 2001, 'Analysis of residual stresses and distortions in T-joint fillet welds', *International Journal of Pressure Vessels and Piping*, vol. 78, no. 8, pp. 523-38.

[2] AWS 2010, *Structural Welding Code Steel*, American Welding Society, Miami, Florida.

[3] Seok, C-S, Suh, M-W & Park, J-H 1999, 'Investigation of welding residual stress of high tensile steel by finite element method and experiment', *KSME International Journal*, vol. 13, no. 12, pp. 879-85,

[4] Aygul, M 2012, 'Fatigue Analysis of Welded Structures Using the Finite Element Method ', Chalmers University of Technology, Sweden.

[5] Brickstad, B & Josefson, BL 1998, 'A parametric study of residual stresses in multi-pass butt-welded stainless steel pipes', *International Journal of Pressure Vessels and Piping*, vol. 75, no. 1, pp. 11-25,

[6] Chang, K-H & Lee, C-H 2009, 'Finite element analysis of the residual stresses in T-joint fillet welds made of similar and dissimilar steels', *The*

International Journal of Advanced Manufacturing Technology, vol. 41, no. 3-4, pp. 250-8,

[7] Deng, D, Liang, W & Murakawa, H 2007, 'Determination of welding deformation in fillet-welded joint by means of numerical simulation and comparison with experimental measurements', *Journal of Materials Processing Technology*, vol. 183, no. 2–3, pp. 219-25,

[8] Hicks, JG 1987, *Welded joint design*, 2nd ed. edn, BSP Professional Books, Oxford.