International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 1, No. 3, October 2012

Research Paper

DETERMINATION OF FAILURE STRENGTH OF CURVED PLATE WELD JOINT USING FINITE ELEMENT ANALYSIS

Chetan S Baviskar[1]*, R M Tayade[1] and Vinay G Patil[2]

Corresponding Author: **Chetan S Baviskar, ✉ chetanbaviskar11@gmail.com*

Finite Element Analysis (FEA) has become a practical method of predicting stresses and deflection for loaded structures. FEA identifies the load path, which can be difficult using classical analysis with complex structures. Welding enables direct transfer of stress between members, eliminating gusset and splice plates necessary for bolted structures. In this paper single transverse fillet weld and double transverse fillet weld are used for analysis. Weld joints form an important part of pressure vessels, they are highly essential for structural integrity of the system. Typical welds are done on flat surfaces and their strengths are well catalogued for reference. The objective of this research project is to analyze welds on curved plated and determine their strength, and create a similar catalogue for curved surfaces of certain cases.

Keywords: Finite element analysis, Double transverse weld, Single transverse weld, Curved plate

INTRODUCTION

Welding is a process of permanent joining of two materials (usually metals) through localized coalescence resulting from a suitable combination of temperature, pressure and metallurgical conditions. Depending upon combination of temperature and pressure from high temperature with no pressure to high pressure with low temperature, a wide range of welding processes has been developed. Welding enables direct transfer of stress between members eliminating gusset and splice plates necessary for bolted structures. Hence, the weight of the joint is minimum. In the case of tension members, the absence of holes improves the efficiency of the section. Welding is used as a fabrication process in every industry, large or small. It is a principal means of fabrication and repairing metal products. The process is efficient, economical

1 Department of Mechanical Engineering, Veermata Jijabai Technological Institute, Mumbai, India.
2 Finite Element Analysis (FEA) Department, VAFTSY, CAE, Pune, India.

and dependable as means of joining metals. This is the only process which has been tried in the space. The process finds its applications in air, underwater and in space.

Fillet welds are widely used because of their economy, ease of fabrication and adaptability. The weld of concave shape has free surface which provides a smoother transition between the connected parts and hence causes less stress concentration than a convex surface. But it is more vulnerable to shrinkage and cracking than the convex surface and has a much reduced throat area to transfer stresses (Satish and Santh, 1999). Fillet welds are broadly classified into side fillets and end fillets. When a connection with end fillet is loaded in tension, the weld develops high strength and the stress developed in the weld is equal to the value of the weld metal, but the ductility is minimal. On the other hand, when a specimen with side weld is loaded, the load axis is parallel to the weld axis. The weld is subjected to shear and the weld shear strength is limited to just about half the weld metal tensile strength. But ductility is considerably improved.

Most common basic FEA packages are suitable for this analysis ANSYS was used for the present study. With its parametric command files, design variations are easily evaluated. With any FEA package, accurate load estimation depends on the quality of the model built by the analyst. The benefits of utilizing this method are as follows (David, 2001):

- Accurate determination of weld loads including distribution of weld loads along the joint. The weld joint loads are resolved at each FEA node of the joint in the model. This is useful for prediction of both static failure and fatigue failure.
- Shear loads induced by mismatch of lateral deflection due to restraint or Poisson effects are included in the calculated loads. These loads are often ignored with classical analysis.

LITERATURE SURVEY

Kyungwoo Lee investigated that the large deflection of a cantilever beam made of Ludwick type material under a combined loading (Kyungwoo, 2002). The problem involves both material and geometrical non-linearity and a closed-form solution to such problem cannot be obtained. He stated that, numerical solution was obtained by using Butcher's fifth order Runge-Kutta method. Equation (1) can be used for not only the combined load consisting of a uniformly distributed load and one vertical concentrated load at the free end but also the general loading condition.

$$\frac{dk}{ds} = \frac{\frac{dM}{ds}}{EI_n\left(\frac{1}{n}\right)(k)^{\frac{1-n}{n}}} \quad \text{...(1)}$$

where E and n are material constants, $k = d\Phi/ds$ is the curvature.

Equation (1) involves the shearing force dM/ds instead of the bending moment M.

Ninh and Wahab (1998) suggested that the misalignments in weld joints are of two types: eccentricity and angular distortion. Due to this misalignment in weld joint the force transmitted by the misalignment weld joint in axial loading can be split into an axial and bending component.

According to Robb (1991) there are several different theoretical approaches available for the design of fillet weld. Conventional design treats all fillet welds as if load was oriented in the weakest direction (longitudinally). The result obtained by his method was an over sizing of fillet welds loaded transversely since transverse loaded welds are stronger than welds loaded longitudinally.

Considerable research on the fillet weld joint has been carried out and reported in literature. However, there is no complete study available that considers that effect of overlap length on weld strength. Therefore this study aims to determine effect of overlap length on strength of fillet weld joint. In the design of welded joints, the calculated stresses to be compared with allowable stresses shall include those due to design eccentricity (*Structural Welding Code-Steel*). It is observe that as the weld penetration depth increases the strength of weld also increases (Shigenoobu and Takeshi, 2006). The weld gets failed due to stress concentration at weld toe and internal defect nearer to weld toe and weld root. These are the main factor responsible for decreased in strength of joint (Costa *et al.*, 2010).

MATERIALS AND METHODS

Types of Nonlinearities

Nonlinear structural behaviour arises from a number of causes. Because it isn't possible to point out a single cause of nonlinear behaviour in many problems, some analyses may have to account for more than one type of nonlinearity.

Contact Nonlinearities: Many common structural features exhibit nonlinear behaviour that is status dependent. Status changes might be directly related to load (as in the case of the cable), or they might be determined by some external cause. Situations in which contact occurs are common to many different nonlinear applications. Contact forms a distinctive and important subset to the category of changing-status nonlinearities.

Geometric Nonlinearities: If changes in stiffness come only from changes in shape, nonlinear behaviour is defined as geometric nonlinearity. In other words a structure experiences large deformations, its changing geometric configuration can cause the structure to respond nonlinearly.

Material Nonlinearities: Nonlinear stress-strain relationships are a common cause of nonlinear structural behaviour. Many factors can influence a material's stress-strain properties, including load history (as in elastoplastic response), environmental conditions (such as temperature), and the amount of time that a load is applied (as in creep response).

Problem Statement

For designing a lap joint there is a reference for overlap of flat plates, i.e., from literature reference. But as such no standard is there for curved plate (which is required for skirt to support pressure vessel). The major when it comes to welding curved plates together is that there are set standards for longitudinal welds on curved plates however for a overlap there are no set parameters. The objective of the project is to form certain set of guidelines or set of formulations which will serve as a guideline for welds of curve plates with an overlap.

Modelling and Analysis

3-D model of plate and weld is created in ANSYS Workbench (Figures 2 and 4), which

Figure 1: Curved Plate Dimensions

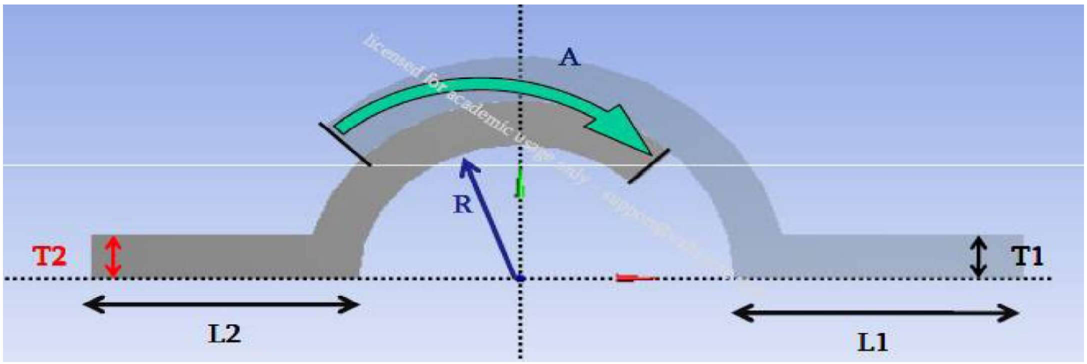


Figure 2: Both End Welded Geometry, Overlapping Angle 90°

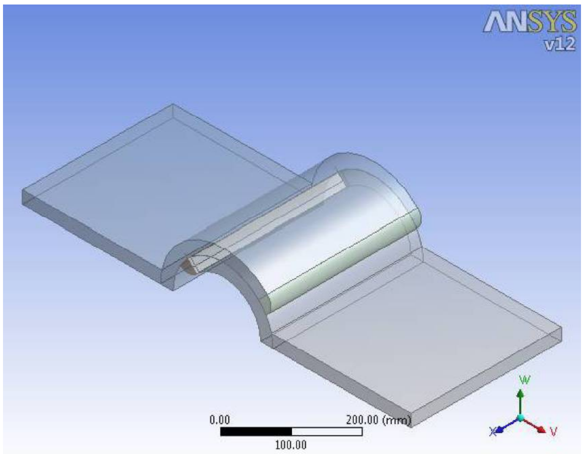


Figure 4: Single End Welded Geometry, Overlapping Angle 90°

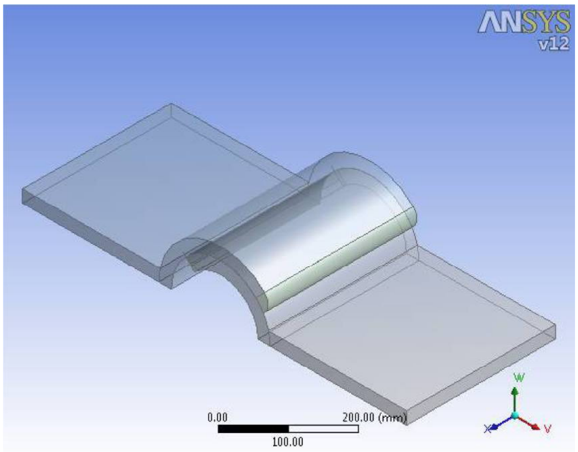


Figure 3: Both End Welded Meshing, Overlapping Angle 90°

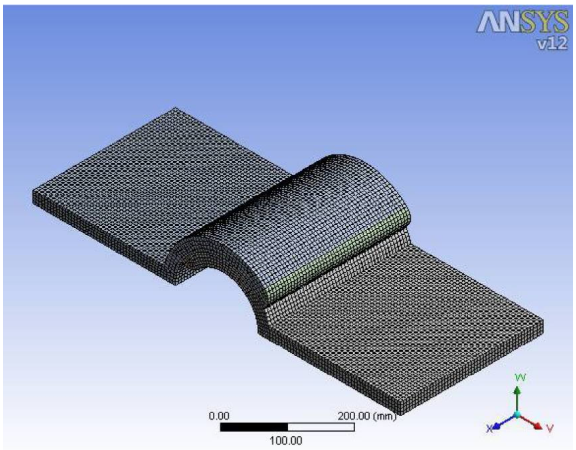
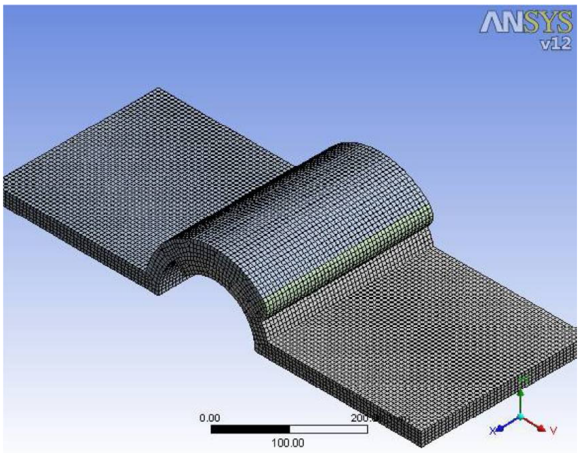


Figure 5: Single End Weld Meshing, Overlapping Angle 90°



is required for the purpose of further analysis. ANSYS Workbench provides a highly integrated engineering simulation platform, supports multi-physics engineering solutions and provides bi-directional parametric associability with most available CAD systems. Solid model is meshed with map meshing using element size as 6.25 mm.The curve plate is break into two entities for meshing, i.e., in curved part and flat plate as shown in (Figures 3 and 5). Since the detailed solid model (Figures 2 and Figure 6) is so simple to analyses efficiently, some simplification with an appropriate idealization process including changing angle of overlapping plate, number of sub steps during the analysis and reducing mesh size in the FE model is needed to reduce the excessive computation time. For this analysis one end is fixed and axial tensile force is applied on opposite end are the boundary conditions. This model is solved in ANSYS for various overlapping angle. The

Figure 6: Stress Plot for Both End Weld, Overlapping Angle 90°

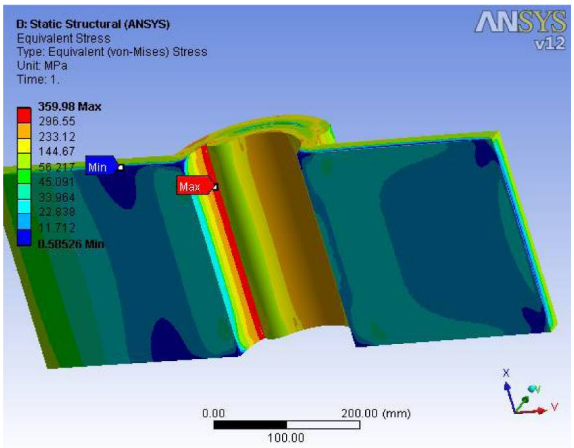


Figure 7: Deformation Plot for Both End Weld, Overlapping Angle 90°

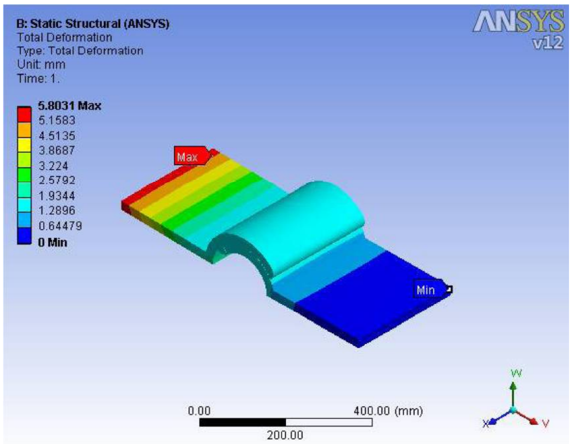


Figure 8: Stress Plot for Single End Weld, Overlapping Angle 90°

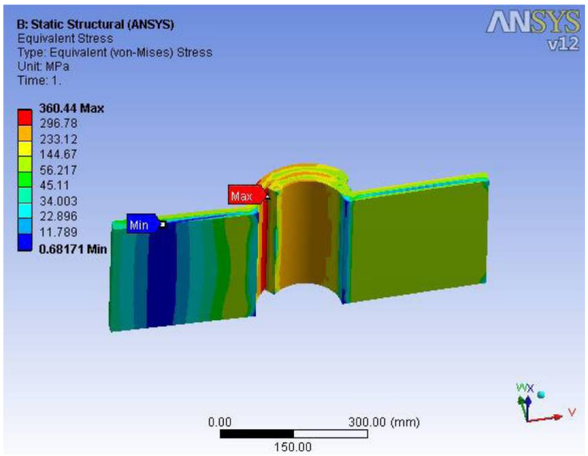
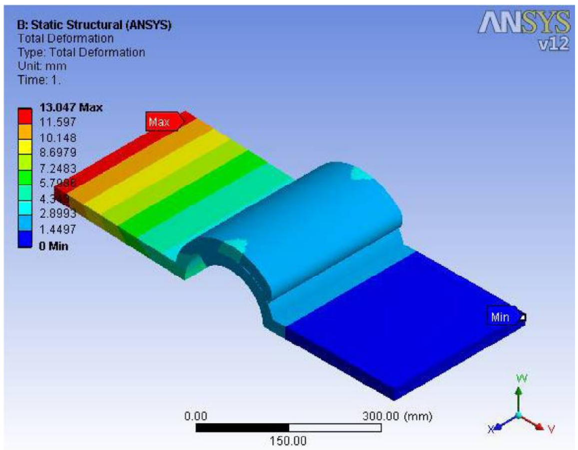


Figure 9: Deformation Plot for Single End Weld, Overlapping Angle 90°



graph of overlapping angle v/s force required to induce stress of 360 MPa is plotted (Figures 6 and 8) for both end weld and single weld end respectively. Also, the graph of deformation v/s force required to induce stress of 360 MPa is plotted (Figures 7 and 9) for both end weld and single weld end respectively.

Structural Steel

Young's Modulus: 210 GPa

Poisson's Ratio: 0.23

Yield Strength: 230 MPa

Tangent Modulus: 10 GPa

Ultimate Strength: 360 MPa

Dimensions of Pates

Dimensions of plate are as follow:

From (Figure 1)

L_1 = 300 mm

L_2 = 300 mm

T_1 = 25 mm

T_2 = 25 mm

R = 75 mm

A = 30° to 90°

RESULTS AND DISCUSSION

Figures 6 and 8 shows stress plot for the both end weld and single end weld respectively. In both the cases failure of weld joint occurs at welded portion. Table 1 shows that in case of single end weld as the overlapping angle increases there is increase in strength of weld joint. Strength of weld joint is increasing with increase in overlapping angle. As the overlapping angle increases the deformation is decreasing, i.e., increase in overlapping angle lead to decrease in deformation as shown in Figure 12. Table 2 shows that in case of both end welds also as the overlapping angle increases there is increase

Table 1: Result of Both Ends Welded Curved Plates

Both End Weld		
Overlapping Angle (θ^0)	**Deformation (mm)**	**Force (KN)**
30	10.1120	225.0
35	9.5111	228.6
40	9.1112	238.5
45	8.7161	250.0
50	8.1877	257.8
55	7.8232	270.8
60	7.5247	289.6
65	7.3209	315.4
70	6.6462	321.3
75	6.3878	350.0
80	6.3501	392.7
85	6.3228	392.7
90	5.8031	466.0

Table 2: Results of Single End Welded Curved Plate

Single End Weld		
Overlapping Angle (θ^0)	**Deformation (mm)**	**Force (KN)**
30	15.283	210.00
35	14.750	213.00
40	14.150	217.00
45	13.670	221.23
50	13.206	225.00
55	13.100	232.00
60	12.914	243.30
65	12.609	251.60
70	12.443	265.00
75	12.574	278.00
80	12.702	294.00
85	12.901	296.50
90	13.047	326.00

in strength of weld joint. Strength of weld joint is increasing with increase in overlapping angle. As the overlapping angle is increases the deformation is decreasing, i.e., increase in overlapping angle lead to decrease in deformation as shown in Figure 11.

$$y_1 = 0.0566\, x_1^2 - 3.105\, x_1 + 270.31 \quad ...(2)$$

$$y_2 = 0.0266\, x_2^2 - 1.3286\, x_2 + 226.54 \quad ...(3)$$

Equations (2) and (3) are the equation of curve of both end welded and single end welded as shown in Figure 10.

Figure 10: Maximum Tensile Force (KN) vs. Overlap Angle (θ^0)

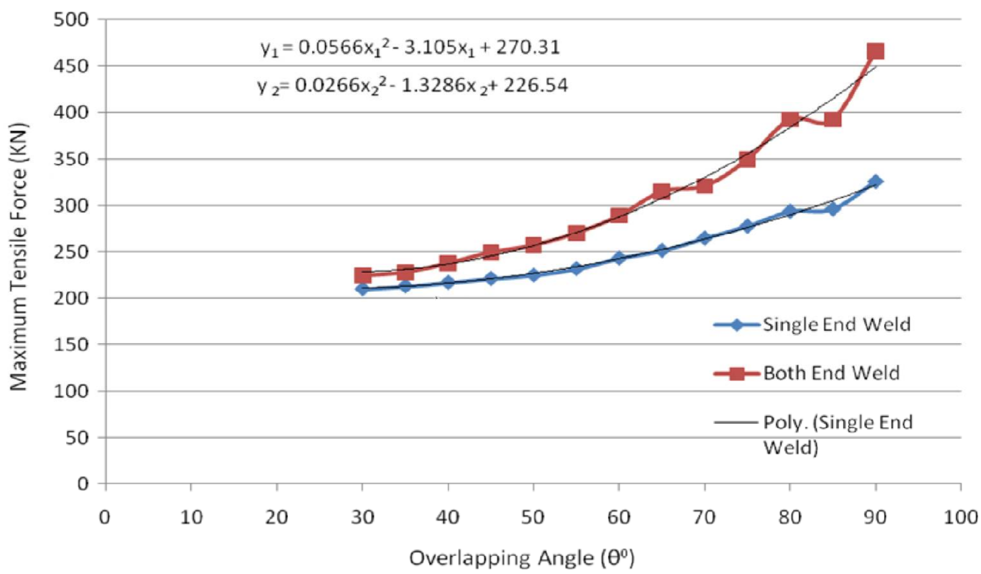


Figure 11: Both Ends Welded, Deformation (mm) vs. Maximum Tensile Force (KN)

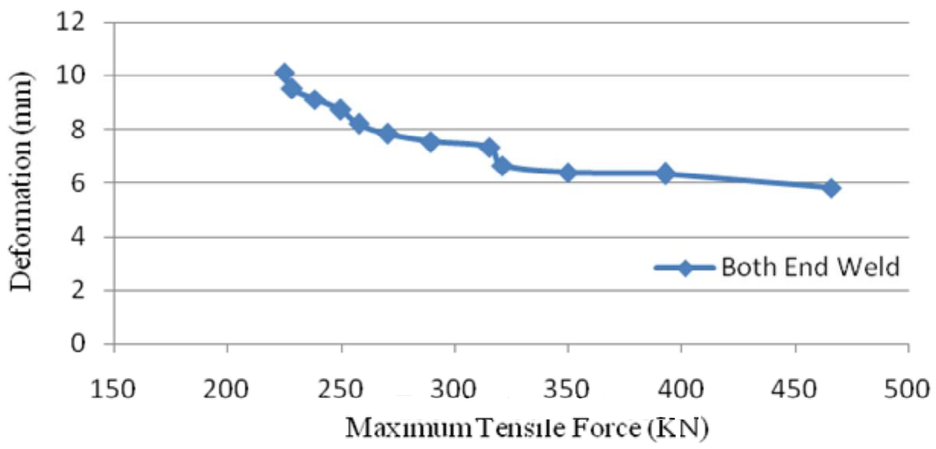
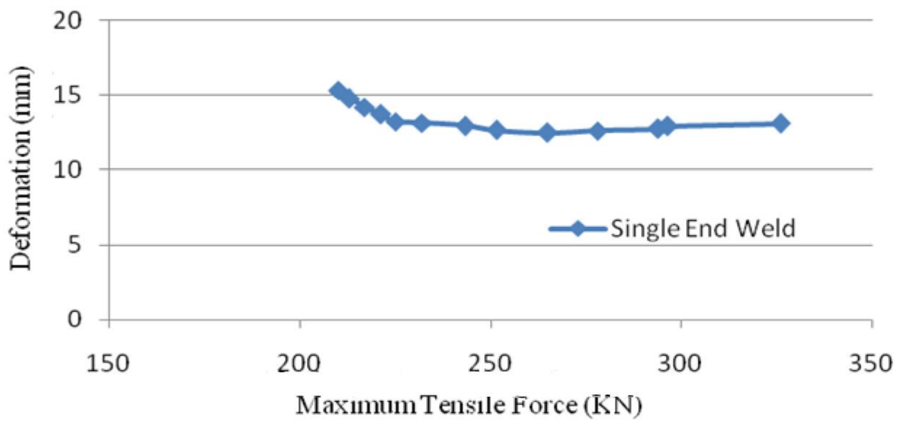


Figure 12: Single End Weld, Deformation (mm) vs. Maximum Tensile Force (KN)



Integrating Equations (2) and (3) we get area under the two curves.

$$\int_{\pi/6}^{\pi/2} y_1 = \int_{\pi/6}^{\pi/2} 0.0566\, x_1^2 - 3.105 x_1 + 270.31 \qquad ...(4)$$

$= 279.7333$

$$\int_{\pi/6}^{\pi/2} y_2 = \int_{\pi/6}^{\pi/2} 0.0266\, x_2^2 - 1.3286 x_2 + 226.54 \qquad ...(5)$$

$= 26.3685$

Subtract Equation (5) from Equation (4), we get

253.3647

It means that both end welded joint for this case is 90% more efficient than single side welded curved plates of overlapping angle 30° to 90°.

CONCLUSION

In case of curved plates joined by single end welded joint and both end welded joint as the overlapping angle increases there is increase in strength of weld joint and decrease in corresponding deformation. Also, in case of single welded joint and both end welded joint up to 50° overlap angle strength of welded joint is nearly same. Hence one side weld is more economical than both end welded joint. After 50° overlapping angle both end welded joint has relatively more strength. Hence after 50° overlapping angle both side weld joint is more economical than single end weld.

ACKNOWLEDGMENT

The authors would like to thank to the Vaftsy CAE Pune, India. for supplying the experimental results in this study.

REFERENCES

1. AWS D1.1/D1.1M (2006), *Structural Welding Code-Steel*, 20th Edition.
2. Costa J D M, Ferreira J A M and Abreu L P M (2010), "Fatigue Behaviour of Butt Welded Joints in a High Strength Steel", *Procedia Engineering*, Vol. 2, pp. 697-705.
3. David Roylance (2001),"Finite Element Analysis", Department of Materials Science and Engineering, Massachusetts Institute of Technology Cambridge.
4. Kyungwoo Lee (2002), "Large Deflections of Cantilever Beams of Non-Linear Elastic Material Under a Combined Loading", *International Journal of Non-Linear Mechanics*, Vol. 37, pp. 439-443.
5. Ninh Nguyen T and Wahab M A (1998), "The Effect of Weld Geometry and Residual Stresses on the Fatigue of Welded Joint Under Combine Loading", *Journal of Material Processing Technology*, Vol. 77, pp. 201-208.
6. Robb C Wilcox (1991), "The Effect of Weld Penetration on Tensile Strength of Fillet Welded Joints", B S Naval Architecture and Marine Engineering, US Coast Guard Acadamy.
7. Satish Kumar S R and Santh Kumar A R (1999), "Design of Steel Structure", Indian Institute of Technology Madras.
8. Shigenoobu Kainuma and Takeshi Mori (2006), "Fatigue Strength Evaluation Method for Load-Carrying Fillet Welded Cruciform Joins", *International Journal of Fatigue*, Vol. 28, pp. 864-872.