Determination of Failure Strength of Flat Plate Weld Joint Using Finite Element Analysis

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Abstract **- 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 is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. Welding enables direct transfer of stress between members, eliminating gusset and splice plates necessary for bolted structures. Two types of fillet weld are possible. A single transverse fillet weld and double transverse fillet weld. Strength of single transverse fillet weld is improved by the application of restraining force.**

Keywords-finite element analysis, double transverse weld,single transverse weld, restraining force.

I. Introduction

Welding is a process of permanent joining of two materials (usually metals) through localised 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 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 [7]. 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 [8]:

i) 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.

ii) 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.

II. Literature survey

Kyungwoo Lee investigated that the large deflection of a cantilever beam made of Ludwick type material under a combined loading [4]. 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 1fifth 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.

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

Where E and n are material constants, k= dΦ/ds is the curvature.

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

T. Ninh Nguyen and M. A. Wahab 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 [1].

According to Robb C Wilcox 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 [9].

Considerable research on the fillet weld joint has been carried out and reported in literature. However, there is no complete study available that considers tha effect of overlap length on weld strength. Therefore this study aims to determine effect of overlap length on strength of fillet weld joint.

III. 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.

a) 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.

b) 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.

c) 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).

IV. Stress Flow Pattern In Fillet Weld

In the design of welded joints, the calculated stresses to be compared with allowable stresses shall include those due to design eccentricity [5]. It is observe that as the weld penetration depth increases the strength of weld also increases [3]. 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 [2]. Fig. 1 shows the stress flow pattern in double transverse weld.

Figure 1 Stress flow pattern in double transverse weld

$$P=0.707.n\ h.l.\tau \qquad (2)$$

Where, n = 1 for single transverse weld
n = 2 for double transverse weld
P = tensile force on plate (N)
h = leg of the weld (mm)
l = length of the weld (mm)
τ = permissible shear stress for the weld (N/mm^2)

Double transverse weld: Fig. 2 (i) and Fig. 2 (ii) shows that after application of force stress flow pattern before and after loading respectively. It is observed that after loading the plates joined by double transverse weld get bent across overlap length.

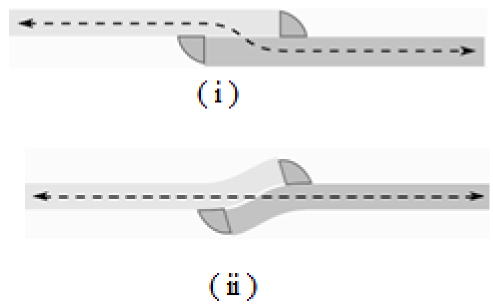

Figure 2 Double transverse weld before and after loading

Single transverse weld: Fig. 3 (i) and Fig. 3 (ii) shows that after application of force stress flow pattern before and after loading respectively. In case of single transverse weld after application of force the plate whose end is not welded get warp out. Due to warping of plate the joint get failed earlier as compare to double transverse weld.

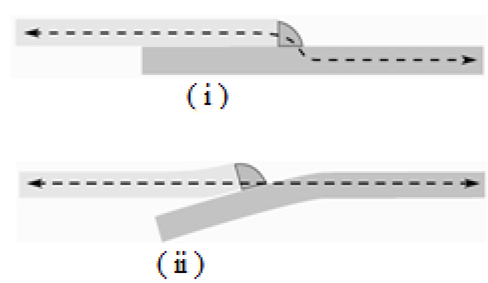

Figure 3 Single transverse weld before and after loading

To avoid warping of plate a restraining force is applied as shown in Fig. 4. After applicaion of restraining force it is observed that maximum force that joint can carry is increased considerably.

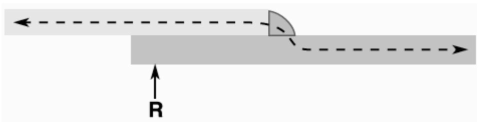

Figure 4 Single transverse weld with restraining force, R

a highly integrated engineering simulation platform, supports multi-physics engineering solutions and provides bi-directional parametric associability with most available CAD systems. Mesh can be generated directly from a solid model for the detailed part model designed in a three-dimensional (3D) CAD system. Since the detailed solid model (see Fig. 8) is so simple to analyses efficiently, some simplification with an appropriate idealization process including changing length of overlapping plate, no. 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 lengths. The graph of overlapping length v/s force required to induce stress of 210 MPa is plotted and is shown in figure.

Restraining force of 1-25 KN is applied on face of 10mm from free end as shown in Fig. 7. The graph of restraining force v/s maximum stress induced in the system is plotted as shown in Fig. 15.

Material

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

300 x 200 x 50 mm

Fig. 9 and Fig. 10 shows stress plot for the double transverse weld and single transverse weld respectively. In both the cases failure of weld joint occurs at the connection of plate and weld. When restraining force is applied on the free end of single transverse weld we get different stress pattern. Before application of restraining force critical part was weld as shown in Fig. 12 and then critical stresses are observed on weld as well as plate (Fig. 11) which increases failure strength of joint.

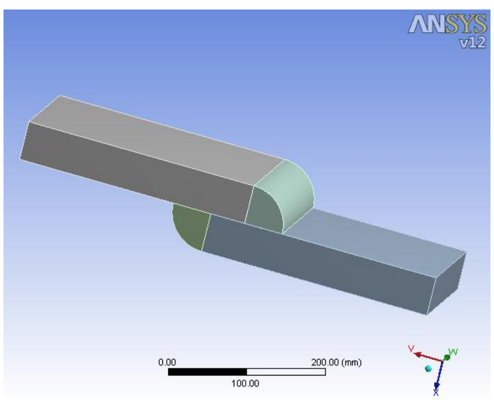

Figure 5 Double transverse weld

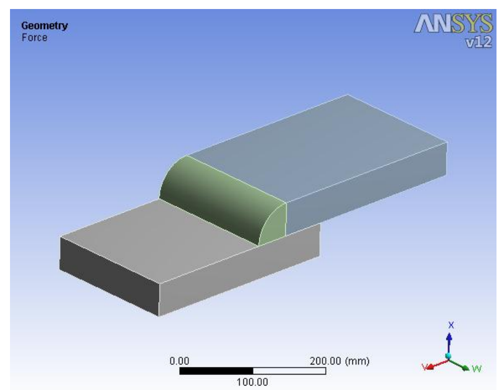

Figure 6 Single transverse weld

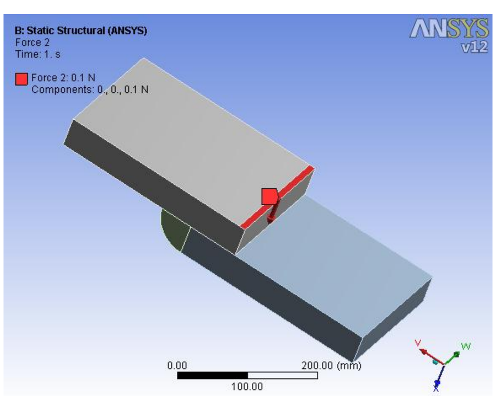

Figure 7 Single transverse weld with restraining force, R

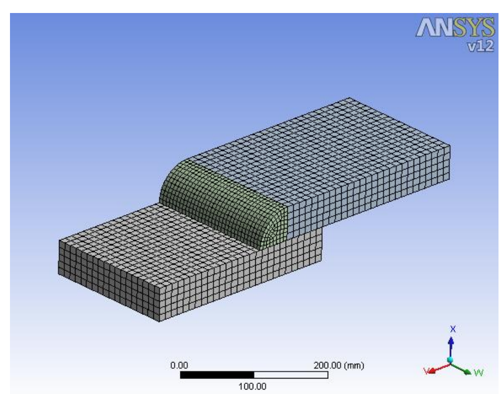

Figure 8 Type of Meshing used in 3D model

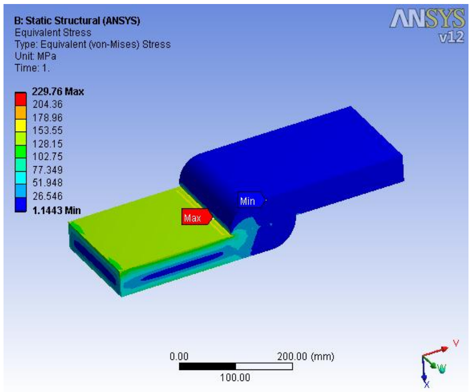

Figure 9 Stresses induced in double transverse weld with overlap length 35 mm

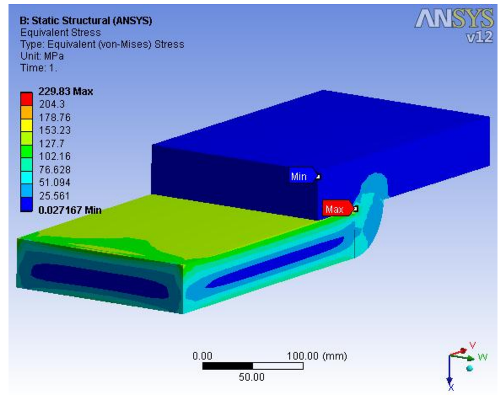

Figure 10 Stresses induced in single transverse weld with overlap length 65 mm

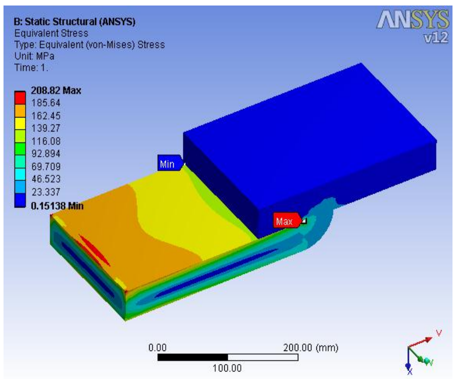

Figure 11 Stresses induced in single transverse weld with overlap length 77 mm

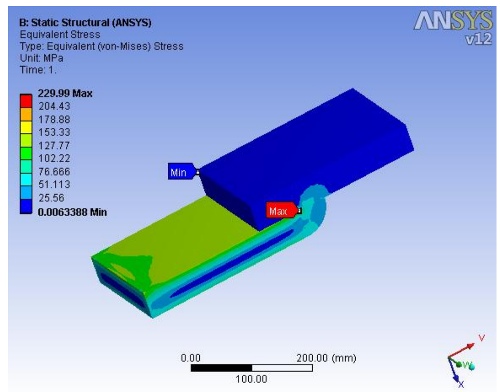

Figure 12 Stresses induced in single transverse weld with overlap length 77 mm

Table 1 Results of double transverse weld

OVERLAP LENGTH (mm)	FORCE (KN)
35	213.70
45	214.65
50	215.00
65	225.00
80	220.50

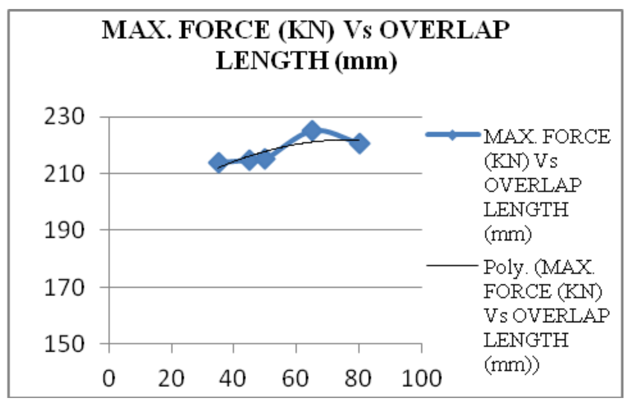

Figure 13 Max. Force vs Overlap Length

VI. Results and discussion:

Table 1 and table 2 shows that as the overlapping length of double transverse weld increases the maximum force carried by weld joint increases first and later on decreases (Fig. 13 and Fig. 14). At 65 mm overlap length it carries maximum force after that force decreases. In case of single transverse weld axial tensile force carried by weld is increased by application restraining force. For 77 mm overlap length a graph of restraining force v/s stress induced in system is plotted as shown in Fig. 15. When restraining force of 23 KN is applied on system minimum stresses are induced. It shows that at minimum stress we can increase the axial tensile force, which increases load carrying capacity of system.

Table 2 Results of single transverse weld

Overlap Length (mm)	FORCE (KN)
35	194.50
45	197.75
55	202.50
65	203.55
75	191.30
80	188.85

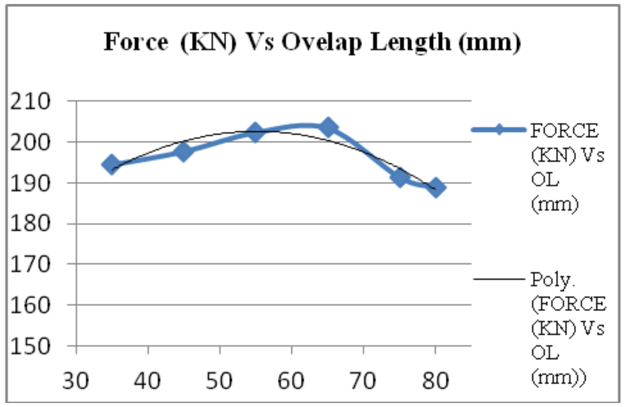

Figure 14 Force vs Overlap Length

Table 3 Results of single transverse weld with restraining force, R

Restraining Force (N)	Stress At Max Tensile Force (Mpa)
1000	229.1666118
5000	225.2893459
10000	220.5692947
15000	215.9982401
20000	211.585639
21000	210.7229904
22000	209.8671588
23000	**209.0182182**
24000	210.8792489
25000	213.5995823

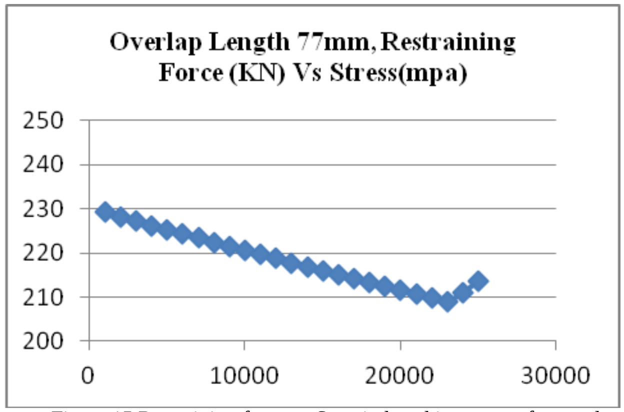

Figure 15 Restraining force vs Strss induced in system, for overlap length 77 mm

Conclusion

From above discussion it is concluded that as the Overlapping length increase strength of the joint increases. For equal overlap length single transverse weld fails earlier than double transverse weld. By applying restraining force the strength of single transverse weld can be increased.

This work is also useful in the analysis of welded curved plate which are used in the boiler manufacturing, ship building. Producing complicated parts or welding of curved surfaces depends on workers experience, skill and knowledge. So still large scope available in this field.

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