# Structural Behavior Of Fillet Weld Joint For Bimetallic Curved Plate Using Finite Analysis (FEA)

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***Abstract***- *Fillet weld is the most common weld type used in the fabrication of structural member in shipbuilding ,pressure vessel ,water reactors ,boilers, automobiles and other industries. This work investigate effect of different geometrical as well as boundary condition parameters on mechanical properties of curved plate. The effect of geometric parameters like overlapping length ,angle of plate, thickness of plate as different mechanical properties like deformation, residual stress, equivalent von misses stress etc.*

*The standard data related to the number of welds ,thickness of plate ,size of overlapping length for flat plate is available. But such a type of standard data is not available in the market for curved plate.Finite element analysis(FEA) has become a practical method of predicting stresses and deflection for loaded structures .*

*So the objective of this paper is to analyze weld on curved plate and determine their strength and create similar catalogue for curved surface.*

***Keywords***- Finite element analysis,curved plate,Fillet weld joint,Welding deformation

## I. INTRODUCTION

Welding is the most commonly used process for permanent joining of machine parts and structures. Welding is a fabrication process which joins materials (metals) or thermoplastics, by causing union . In the joining process of welding application uses heat and/or pressure, with or without the addition of filler material. Various auxiliary materials, e.g. shielding gases, flux or pastes, may be used to make the process possible or to make it easier. The energy required for welding is supplied from outside sources.

Fillet welds are commonly referred to as Tee joints which is perpendicular to each other's or lap joints which are overlap one another and welded at the edges.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.

As boilers,ships buildings, pressure vessels, water reactors, concrete slab plates are fabricated from curved plates. To assemble such parts welding are commonly used. However it is impossible to avoid the deformation produced by welding. Therefore they are highly essential for structural integrity of the system. Since it is influenced by various factors like angle of weld, material of weld, thickness of weld, thickness of weld plate, radius of the weld material etc. A very few research papers of curved plates are available. But standard data of curved plate with respect to above parameters are not available. A better approach to the prediction of welding deformation is using the combined technologies of experiments with calculation. With modern computing facilities, the Finite Element (FE) technique has become an effective method for prediction and assessment of welding residual stress and distortions various factors, the quantitative prediction and the control of welding deformation especially for a large and complex welded structure is extremely difficult.

## II. LITERATURE SURVEY

Dean Deng et. Al.[1] had performed experiments to investigate the characteristics of welding deformation in the fillet welded joint .Dean Deng suggests the fillet welded joints usually suffer from various welding deformation patterns such as longitudinal shrinkage, transverse shrinkage, angular distortion and longitudinal bending.For prediction of welding deformation by numerical method ,a 3-D thermal elastic plastic finite element computational procedure is developed.

Dean Deng et.al.[2] has suggested that welding distortion during the assembly process is affected by not only local strinkage due to rapid heating and cooling but also root gap and misalignment between part to be welded.

The thermal elastic-plastic FEM developed in this study can be effectively used to estimate the inherent deformation for different welding joints.

Zuheir Barsoum et al[3] has discussed, the three different approaches of inherent strain method for prediction of welding induced distortion ,inherent strain, inherent deformation and shrinkage force approaches. Inherent strain and inherent deformation approaches are mainly used to predict transverse shrinkage and transverse bending whereas to predict the longitudinal shrinkage and longitudinal bending the shrinkage force approach is more suitable .Elastic plastic analysis is used to calculate longitudinal and transverse inherent strain.

Mato Peric et al [4] has suggested that for numerical investigations, a thermal-mechanical finite element analysis is performed by using a shell 3-D modelling technique. We known that the during the welding process, due to localized heating and subsequent rapid cooling ,residual stresses appear around welding zones and cause post-weld deformation of the structure. The use of three dimensional models is required for accurate prediction of post-weld deformation and residual stress distribution.

## III. PROBLEM DEFINITION

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. 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 paper is

1. To analyze variation of weld parameters of curved plate with respect to different geometrical parameters of welded joint for various materials.
2. To perform finite element analysis of above by varying geometric parameters like overlapping length, angle of plate and thickness of plate.
3. To experimentally validate results obtained by FEA analysis.

## IV. CURVED PLATE GEOMETRY

Model development is the crucial part of the analysis, if the model parameter is not match with the experiment then desire results will not match with the simulation results. The dimension of the first curved plate is taken 50mm width and 5mm thickness. Similarly the dimension of the second curved plate is taken 50mm width and 5mm thickness. The model separated in four main parts which is first (Left) curved plate, second (Right) curved plate and left weld and right weld. Reason to do that its can apply different type of material property. Figure drawn in CATIA V 5 and for analysis CATIA model will be exported to ANSYS for the simulation.

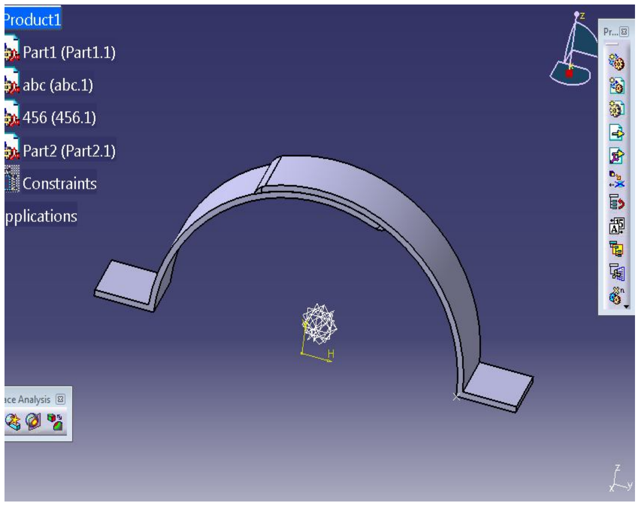


Figure 4.1 : Basic model of welded curved plate prototype

The following Figure is the exploded view of the model where can find the different parts of the model.

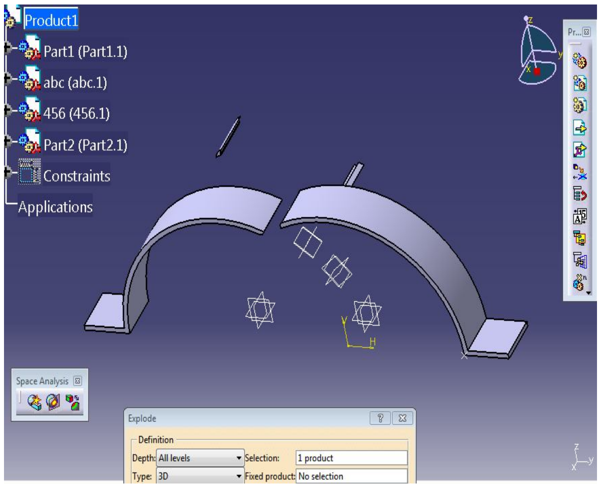


Figure 4.2: Exploded view of the welded curved plate prototype

## V. MESHING

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. The computational model of prototype after meshing is shown in fig.5.The mixed tetra type of mesh is used for this computational model.

Fig.5.1: Mesh Size 3mm

Fig.5.2 : Mesh Size 5 mm

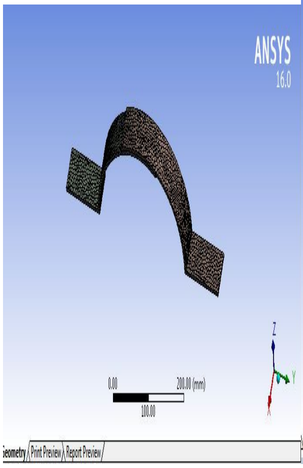

Fig.5.3:Mesh Size 8mm

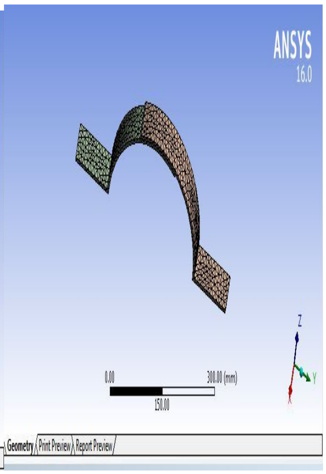

Fig.5.4:Mesh Size 10 mm

Figure 5: Mesh development

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## VI. GRID INDEPENDENCE STUDY

Grid independence study is carried out over the different numbers of mesh size. An effort is undertaken to obtain the grid independent results in a curved plate with both side fillet weld. The study was done for 5different mesh size having mesh size 3,4,5,8 and 10mm .The results obtained for 4mm and 5mm mesh size approximately equal. It is observed that the maximum discrepancy in the value of deformation for 4mm and 5mm is found to be within 0.45%. As we know that number of elements increases corresponding computational time also increases. So we choose the element size as 5mm.

## VII. CASES OF RESULTS AND EXPERIMENTATION

For the analysis and experimentation of curved plate weld we divided this analysis and experimentation in two cases which are as follows

1. Analysis for curved plate having uniform materials of both the curved plate with both side fillet weld
2. Analysis for curved plate having non uniform materials of both the curved plate with both side fillet weld

## VIII. EXPERIMENTAL SETUP AND PROCEDURE

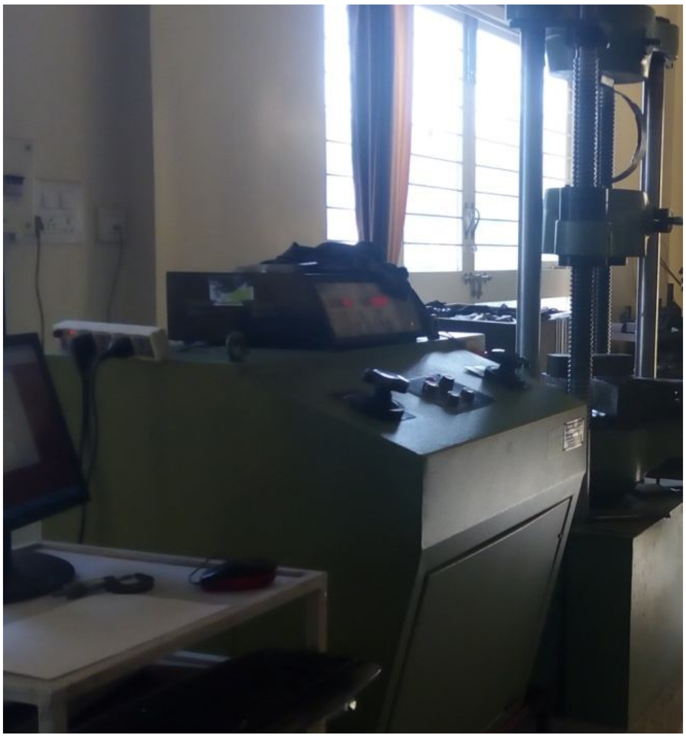

Fig.8.1: Actual Photograph of experimental setup

**Components:**

1) Loading unit
2) Control unit

With the help of Fluxed Core Arc Welding (FCAW) machine the welding of various prototypes is done and during the experimentation the results are getting for curved plate from Universal Testing Machine (UTM). Dimension of curved plate considered for the testing are of Non curved length of plate is 50mm, width of plate 50mm,Innermost radius is 62.5mm and Overlap angle is varying from 30 to 100 degree for 5mm thickness of curved plate.

**Experimentation for curved plate with both side welds:**

In this case the joint is both side welded and we are experimenting the force required to break the fillet joint by changing the overlapping angle. We are taking 30 degree as overlapping angle for first experimentation, then increasing the overlapping angle by 5 degree and taking results i.e. the force required to break the fillet joint and corresponding deformation. Total no of experiments will be 15 for 5mm thickness of curved plate. Similarly results are obtained for 6mm and 7mm thickness of curved plate.

The following are the results of the experimentation i.e. force required to break the fillet joint and corresponding deformation.

Table 8.1 Experimantal Results of curved plate with 5mm thickness and both side weld

| Test Specimen | Thickness(mm) | Overlapping Angle (Degree) | Force Required to Break the Joint(KN) | Corresponding Deformation (mm) |
|---|---|---|---|---|
| 1 | 5 | 30 | 8.9 | 94.12 |
| 2 | 5 | 35 | 10.6 | 101.32 |
| 3 | 5 | 40 | 11.12 | 107.42 |
| 4 | 5 | 45 | 13.96 | 124.1 |
| 5 | 5 | 50 | 17.2 | 127.45 |
| 6 | 5 | 55 | 19.44 | 130.65 |
| 7 | 5 | 60 | 22.92 | 134.37 |
| 8 | 5 | 65 | 26.8 | 137.18 |
| 9 | 5 | 70 | 30.32 | 139 |
| 10 | 5 | 75 | 34.6 | 141.1 |
| 11 | 5 | 80 | 37.7 | 146.34 |
| 12 | 5 | 85 | 41.3 | 151.5 |
| 13 | 5 | 90 | 45.6 | 155.88 |
| 14 | 5 | 95 | 48.1 | 162.9 |
| 15 | 5 | 100 | 52.8 | 168.11 |

Table 8.2 Experimantal Results of curved plate with 6 mm thickness and both side weld

| Test Specimen | Thickness (mm) | Overlapping Angle (Degree) | Force Required to Break the Joint(KN) | Corresponding Deformation (mm) |
|---|---|---|---|---|
| 1 | 6 | 30 | 9.35 | 60.12 |
| 2 | 6 | 35 | 11.057 | 66.1 |
| 3 | 6 | 40 | 11.578 | 70.13 |
| 4 | 6 | 45 | 14.419 | 73.1 |
| 5 | 6 | 50 | 17.661 | 79.88 |
| 6 | 6 | 55 | 19.902 | 84.12 |
| 7 | 6 | 60 | 23.385 | 96.8 |
| 8 | 6 | 65 | 27.265 | 110.64 |
| 9 | 6 | 70 | 30.788 | 120.12 |
| 10 | 6 | 75 | 35.068 | 126.4 |
| 11 | 6 | 80 | 38.17 | 130.32 |
| 12 | 6 | 85 | 41.775 | 142 |
| 13 | 6 | 90 | 46.072 | 156.19 |
| 14 | 6 | 95 | 48.576 | 162.18 |
| 15 | 6 | 100 | 53.26 | 169.5 |

Table 8.3 Experimantal Results of curved plate with 7mm thickness and both side weld

| Test Specimen | Thickness (mm) | Overlapping Angle (Degree) | Force Required to Break the Joint(KN) | Corresponding Deformation (mm) |
|---|---|---|---|---|
| 1 | 7 | 30 | 9.773 | 35.16 |
| 2 | 7 | 35 | 11.413 | 42.89 |
| 3 | 7 | 40 | 11.932 | 45.12 |
| 4 | 7 | 45 | 14.773 | 49.89 |
| 5 | 7 | 50 | 18.013 | 54.1 |
| 6 | 7 | 55 | 20.253 | 59.18 |
| 7 | 7 | 60 | 23.739 | 64.12 |
| 8 | 7 | 65 | 27.615 | 70.48 |
| 9 | 7 | 70 | 31.144 | 77.22 |
| 10 | 7 | 75 | 35.424 | 84.89 |
| 11 | 7 | 80 | 38.526 | 91.1 |
| 12 | 7 | 85 | 42.135 | 96.12 |
| 13 | 7 | 90 | 46.434 | 102.52 |
| 14 | 7 | 95 | 48.928 | 108.1 |
| 15 | 7 | 100 | 53.608 | 114.36 |

## IX. FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) is one of the most popular engineering analysis methods for Non linear problems. FEA requires a finite element mesh as a geometric input. This 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. 1) is so simple to analyses efficiently, some simplification with an appropriate idealization process including changing overlapping angle, thickness of curved plate and reducing mesh size in the FE model is needed to reduce the excessive computation time. The welded curved plates are made of up mild steels or structural steels; a different type of meshing approach is required.

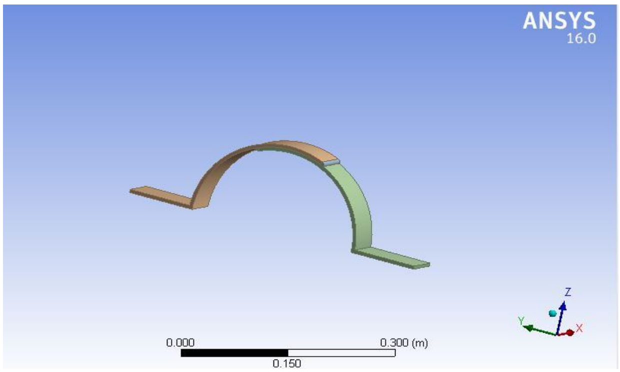


Fig.9.1: Geometry of both side weld of Curved Plate

Fig. 1 shows the FEM model of the existing design. The existing design has two curved plates. Both plates are given an axial loading for checking failure ultimate strength of a weld joint. The material used for Finite Element Analysis is Non Linear. The FEM Model having 6 freedoms: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes

Material properties applied to the body contains

Young‘s Modulus: 200 GPa
Poisson‘s Ratio: 0.3
Yield Strength: 250 MPa
Tangent Modulus: 10 GPa
Ultimate Strength: 360 MPa

**Boundary conditions**:

The boundary conditions applied for the plates are equally axial loading applied on the both end of plate as shown in the fig.9.3

Finite Element Analysis of 5mm thickness curved plate having uniform materials with 45 degree overlapping angle.

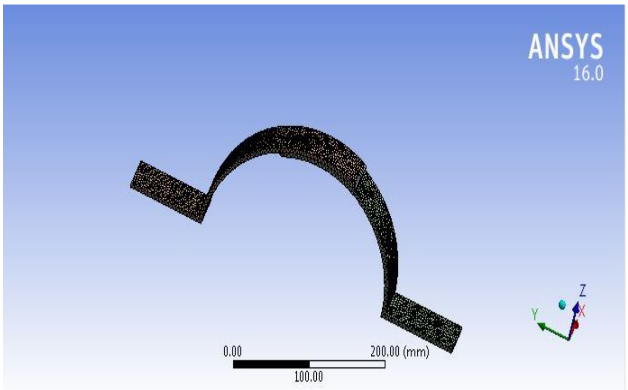


Fig.9.2: Meshing of welds and plates

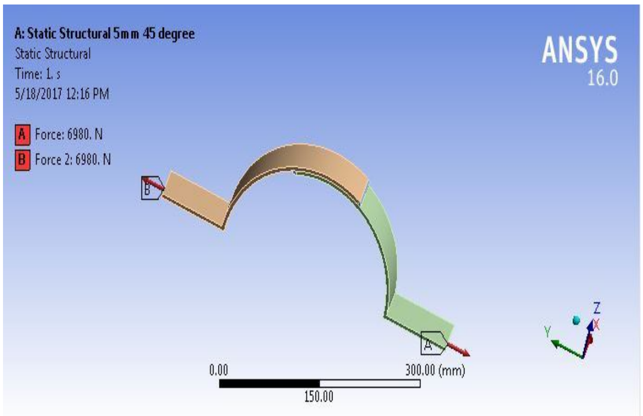


Fig.9.3: Applying Boundary conditions as applying equal force on both end surface

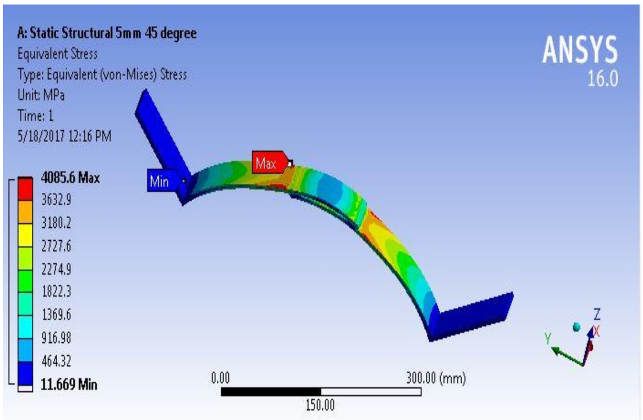


Fig.9.4: Results showing Equivalent (Von- Mises) Stress

- **Maximum Equivalent stress obtained is equal to 4085.6Mpa at the weld.**

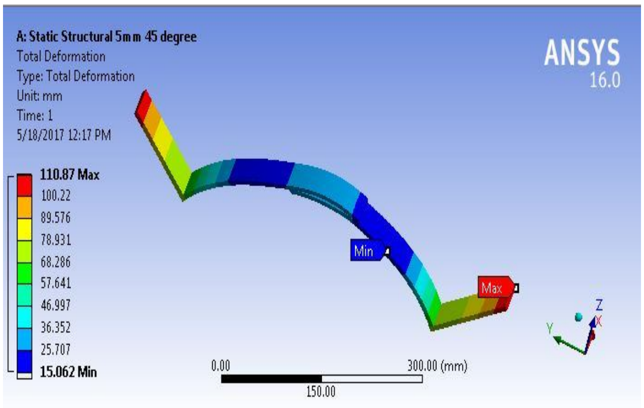


Fig.9.5: Results showing Total Deformation of Joint

- **Maximum deformation is equal to 110.87mm**

## 10. Result and discussion:

In this chapter, the results obtained by experimental and FEA are enlisted for curved plate. In welded curved plate we have considered the effect of Overlap angle, effect of thickness on failure load and deformation are observed.

### 10.1 Discussion on Welded Curved Plate

The Experimental testing is done on Universal Testing Machine (UTM) with standard shape and size of test specimen with fillet joint. The results are tabulated in the table no. 10.1, 10.2 and 10.3.The table contain FEA and Experimental results.

Table 10.1 Combine results between FEA and Experimental for welded curved plate having thickness of 5 mm

| Sr No | Angle of Overla p ing Deg. | FEA Results | | Experimental Results | | % Difference of deformation |
|---|---|---|---|---|---|---|
| | | Failure Load (KN) | Deformation (δ) in mm | Failure Load (KN) | Deformation (δ) in mm | |
| 1 | 30 | 8.9 | 82.24 | 8.9 | 94.12 | 13 |
| 2 | 35 | 10.600 | 88.84 | 10.600 | 101.3 | 12 |
| 3 | 40 | 11.120 | 96.80 | 11.120 | 107.4 | 10 |
| 4 | 45 | 13.960 | 110.8 | 13.960 | 124.4 | 11 |
| 5 | 50 | 17.200 | 112.2 | 17.200 | 127.4 | 12 |
| 6 | 55 | 19.440 | 124.0 | 19.440 | 130.6 | 6 |
| 7 | 60 | 22.920 | 142.8 | 22.920 | 134.3 | 9 |
| 8 | 65 | 26.800 | 150.3 | 26.800 | 137.1 | 9 |
| 9 | 70 | 30.320 | 152.0 | 30.320 | 139.0 | 8 |
| 10 | 75 | 34.600 | 152.9 | 34.600 | 141.1 | 9 |
| 11 | 80 | 37.700 | 157.0 | 37.700 | 146.3 | 7 |
| 12 | 85 | 41.300 | 167.3 | 41.300 | 151.5 | 10 |
| 13 | 90 | 45.600 | 184.9 | 45.600 | 155.8 | 15 |
| 14 | 95 | 48.100 | 186.9 | 48.100 | 162.9 | 13 |
| 15 | 100 | 52.800 | 187.2 | 52.800 | 168.1 | 10 |

Table 10.2 Combine results between FEA and Experimental for welded curved plate having thickness of 6mm

| Sr No | Angle of Overlapping Deg. | FEA Results | | Experimental Results | | % Difference of deformation |
|---|---|---|---|---|---|---|
| | | Failure Load (KN) | Deformation (δ) in mm | Failure Load (KN) | Deformation (δ) in mm | |
| 1 | 30 | 9.350 | 48.95 | 9.350 | 60.12 | 19 |
| 2 | 35 | 11.057 | 53.43 | 11.057 | 66.10 | 19 |
| 3 | 40 | 11.578 | 55.12 | 11.578 | 70.13 | 21 |
| 4 | 45 | 14.419 | 57.50 | 14.419 | 73.10 | 21 |
| 5 | 50 | 17.661 | 69.36 | 17.661 | 79.88 | 14 |
| 6 | 55 | 19.902 | 73.66 | 19.902 | 84.12 | 12 |
| 7 | 60 | 23.385 | 87.60 | 23.385 | 96.80 | 10 |
| 8 | 65 | 27.265 | 97.95 | 27.265 | 110.64 | 12 |
| 9 | 70 | 30.788 | 109.3 | 30.788 | 120.12 | 9 |
| 10 | 75 | 35.068 | 116.1 | 35.068 | 126.40 | 8 |
| 11 | 80 | 38.170 | 124.8 | 38.170 | 130.32 | 5 |
| 12 | 85 | 41.775 | 136.2 | 41.775 | 142..00 | 4 |
| 13 | 90 | 46.072 | 147.5 | 46.072 | 156.19 | 6 |
| 14 | 95 | 48.576 | 153.1 | 48.576 | 162.18 | 6 |
| 15 | 100 | 53.260 | 162.4 | 53.260 | 169.50 | 5 |

Table 10.3 Combine results between FEA and Experimental for welded curved plate having thickness of 7mm

| Sr No | Angle of Overlapping Deg. | FEA Results | | Experimental Results | | % Difference of deformation |
|---|---|---|---|---|---|---|
| | | Failure Load (KN) | Deformation (δ) in mm | Failure Load (KN) | Deformation (δ) in mm | |
| 1 | 30 | 9.773 | 26.81 | 9.773 | 35.16 | 23 |
| 2 | 35 | 11.413 | 30.13 | 11.413 | 42.89 | 29 |
| 3 | 40 | 11.932 | 33.78 | 11.932 | 45.12 | 25 |
| 4 | 45 | 14.773 | 36.62 | 14.773 | 49.9 | 26 |
| 5 | 50 | 18.013 | 43.03 | 18.013 | 54.10 | 20 |
| 6 | 55 | 20.253 | 46.96 | 20.253 | 59.18 | 20 |
| 7 | 60 | 23.739 | 53.43 | 23.739 | 64.12 | 17 |
| 8 | 65 | 27.615 | 62.59 | 27.615 | 70.48 | 11 |
| 9 | 70 | 31.144 | 67.43 | 31.144 | 77.22 | 13 |
| 10 | 75 | 35.424 | 75.64 | 35.424 | 84.89 | 11 |
| 11 | 80 | 38.526 | 79.83 | 38.526 | 91.10 | 12 |
| 12 | 85 | 42.135 | 85.39 | 42.135 | 96.12 | 12 |
| 13 | 90 | 46.434 | 93.31 | 46.434 | 102.5 | 9 |
| 14 | 95 | 48.928 | 96.90 | 48.928 | 108.1 | 10 |
| 15 | 100 | 53.608 | 103.5 | 53.608 | 114.3 | 9 |

**Case I: 5mm thickness welded curved plate:**

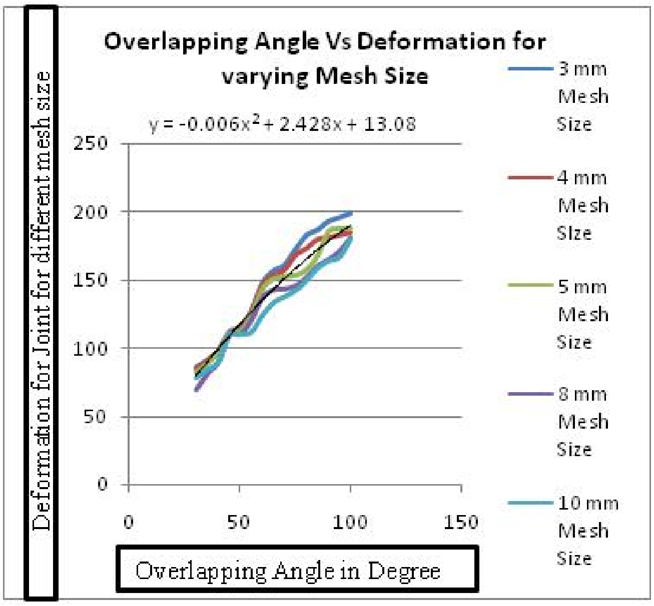


Figure 10.1: Graph of Overlapping Angle Vs Deformation for joints for different mesh size

**Case II: 6mm thickness welded curved plate:**

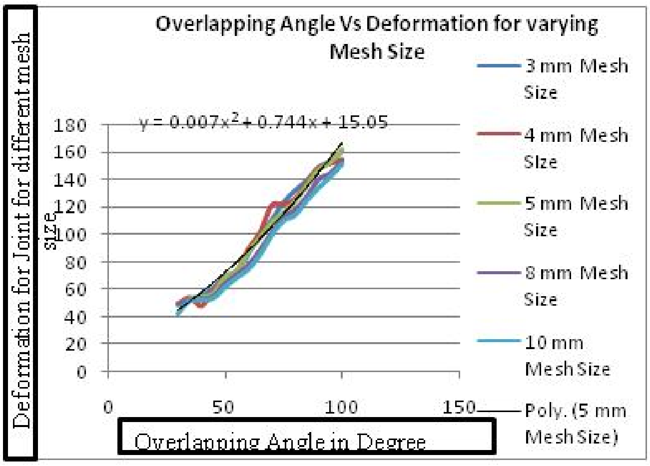


Figure 10.2: Graph of Overlapping Angle Vs Deformation for joints for different mesh size

**Case III: 7mm thickness welded curved plate:**

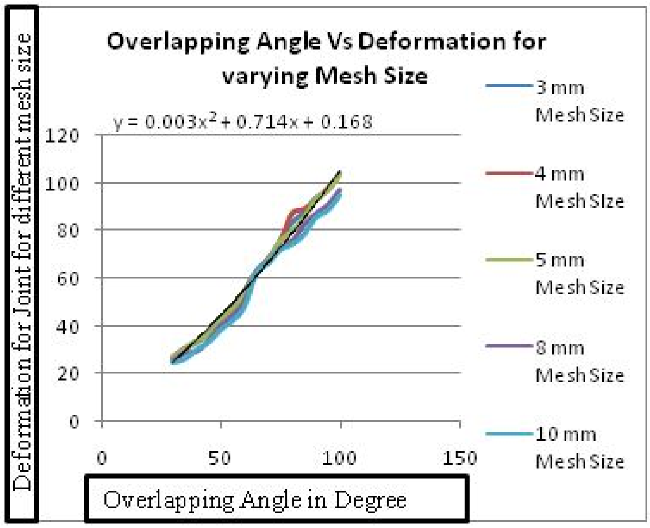


Figure 10.3: Graph of Overlapping Angle Vs Deformation for joints for different mesh size

**Case IV: 5, 6 and 7mm thickness welded curved plate:**

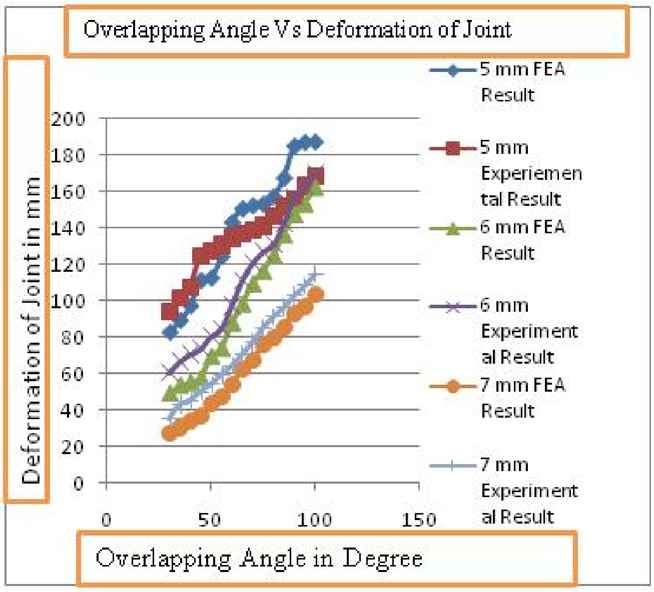


Figure 10.4: Graph of Overlapping Angle Vs Deformation for joints for different mesh size

- Curve Fitting for Effective Failure Force of welded curved plate

In this article the curve fitting technique is utilized to find the relation between angles of overlap with the failure strength of Welded curved plate. The angle of overlap is defined as the common angle prescribed by the two plates over each other. Total six data points (three for each of the perforated welded plate) are adopted from the failure force to determine the curve fitting functions.

It should be pointed out that when the overlap angle approaches to zero i.e. both plates are weld in front of each other like Butt weld no appropriate curve fitting function can found between the failure strength (force) and angle of overlap of Welded Curved Plate. In fact distribution of failure force is quite linear. In particular when overlap angle approaches 1 the slope of fitting curve become normal and found appropriately to process the curve fitting and obtained function. This function can be used to predict the trend of failure strength of a welded curved plate in a diagonal array. The function is expressed in mathematical form are as

$$y = -0.006x^2 + 2.428x + 13.08$$

Where,

x = Overlap angle of a welded Curved plate in Degree.
Y = Failure strength of Welded joint of Curved plate in KN

## XI. CONCLUSIONS

Discussion on results obtained by experimental analysis and analytical results is carried out here to reach the conclusion. Based on the results following conclusions are made:

1. Difference between deformation of welded curved plate in experimental result and analytical results are near about 13 to 15 %
2. The maximum stress developed is near weld section, so failure occurred at that point. It observed that overlap length of joint increases, force required to break the joint is also increases.
3. As thickness of base plate increases, the force required to break the joint is also increases
4. The average value of maximum displacement for welded curved plate is increases as the overlap angle increases simultaneously the failure load is increase.
5. As thickness of plate increases, its deformation decreases. It is clear that deformation is inversely proportional to the thickness of plate.

## XII. ACKNOWLEDGMENT

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