FEA Analysis and Optimization of Weld Joint using ANSYS

Yuvraj Mahajan
** Research scholar, Department of Mechanical Engineering, Beant College Of Engineering And Technology , Gurdaspur.*
****Dr Nirmal S. Kalsi**,
Dr Dilbag Singh Department of Mechanical Engineering, Beant Of College Of Engineering And Technology, Gurdaspur.

Abstract:Analysis of welded structures is still remains a challenge for the designer to produce desired output results. The research analysis the effect of different design parameters of weld joint on strength and fatigue life of weld joint. The design is optimized using response surface optimization technique from CCD (Central Composite Design scheme). The optimization parameters are geometric which is h, α and t. The responses of equivalent stress, shear stress and fatigue life would be generated from this optimization technique along with sensitivities of each optimization variable i.e. h, α and t. The CAD model of weld joint is developed using ANSYS design modeler and FEA analysis is conducted using ANSYS software. Out of the three variables selected for analysis h has highest sensitivity for shear stress and normal stress and therefore should be given highest priority in design of weld joints.

Key Words: FEA, Weld joint, Response Surface Method

1. INTRODUCTION:

In welding process, the two metals are joined at appropriate thermophysical conditions. These thermophysical conditions include temperature, pressure or metallurgical conditions. Welding process depends range of operating temperatures and pressures. The welding eliminates need of any gusset/plates as it enables direct stress transfer between members and helps to reduce the weight also. Welding is widely used by all industries (small or big) and is primary means of fabrication or repair of metals and the application it's found in space also. The welding has been very economical as well as dependable means of metal joining. The widely used weld types are fillet weld due to economy, adaptability.

2. LITERATURE REVIEW

T. Ninh Nguyen and M. A. Wahab[1] has investigated misalignments in welded joints and concluded that eccentricity and angular distortion are its two types. The force due to misaligned weld joint causes fatigue failure leading to crack initiation and propagation. This force can be resolved into axial and bending.

Kyungwoo Lee[2] conducted investigation on cantilever beam using Butcher's 1fifth order Runge-Kutta method. The large-scale deflection study involved both geometric and material nonlinearity and the numerical method served as viable method in study of welded joint with respect to its fatigue failure.

According to Robb C Wilcox [3] analysed various approaches in design of weld joint. The limitation of conventional method of designing which treats loading in fillet weld as longitudinal provides partial results and doesn't account for transverse loading effects.

Mahapatra et al. [4] investigated the use of constraint in one-side fillet welding to see its effect on angular distortion. Strategically placed tack welds were used to counter the effect of the welding process. Results of the experiment showed that applying constraints at the proper position could indeed counter the distortion from welding.

Michaleris[5] investigated the use of the thermal tensioning technique to reduce residual stress and distortion in welding . Thermal tensioning is pre-heating of the weldment before the welding takes place. He proposes the use of heating bands which move along with the torch on either side of the weld. Thermal tensioning works to control residual stress and distortion by generating a tensile strain and the weld zone prior to and during welding by imposing a temperature differential. The width and length of the band are obtained by optimization of the parameters that would lead to minimal stress and distortion.

3. OBJECTIVE

In the current research we are investigating tube-flange welded joints subjected to torsional loading using hot spot stress method. The design would be optimized using response surface optimization technique from CCD (Central Composite Design scheme). The optimization parameters are geometric which would be h, α and tas shown in figure 1 below. The responses of equivalent stress, shear stress and fatigue life would be generated from this optimization technique along with sensitivities of each optimization variable i.e. h, α and t.

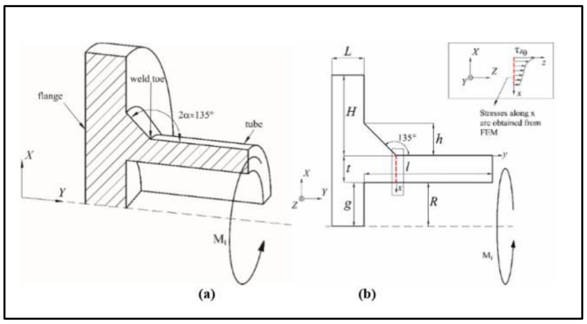

Figure 1: design and parameters of tube flange welded joint [6]

4. METHODOLOGY

The CAD model of geometry is developed as per schematic shown in figure 1 above. The model is developed in ANSYS design modeler using sketch and revolve tool. The dimensions are taken as shown in table 1 below.

Table 1: Dimensions of weld joint [6]

L	1 cm
H	2cm
h	.5cm
t	1cm
α	135^0

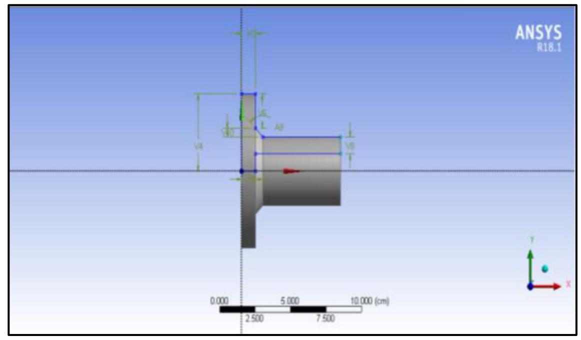

Figure 2: CAD model of weld geometry

The CAD model of geometry is developed as per literature [6] using ANSYS design modeler. Initially sketch is developed as shown by blue colored cross section in figure 2 above. The dimensions are defined as per table 1. The sketch is then revolved to 360^0 angle to developed full model.The CAD model has sharp angles and edges which makes it complex geometry and therefore it is meshed using tetrahedral elements. The tetrahedral element has 4 nodes with 3 degrees of freedom at each node as shown in figure 3 below .

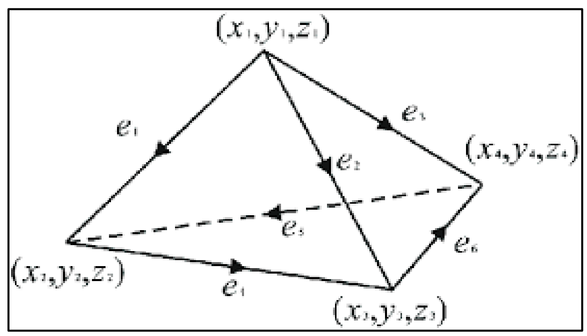

Figure 3: Tetrahedral element shape [7]

The relevance is set to fine, smoothing set to fine, transition ratio .272 and growth rate set to default. The mesh generated is shown in figure 4 below.

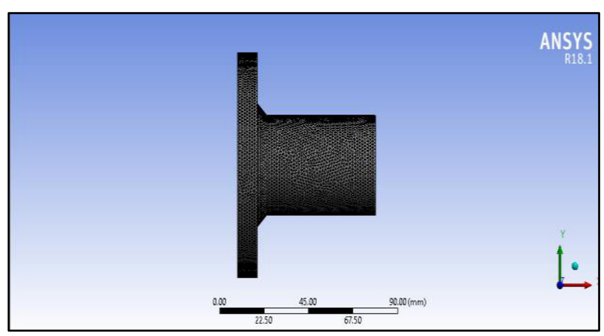

Figure 4: Meshed model

The CAD model is applied with fixed support at left face of geometry as shown in figure 5 below and rotational moment of 10 N-m on right face as shown in figure 6 below.

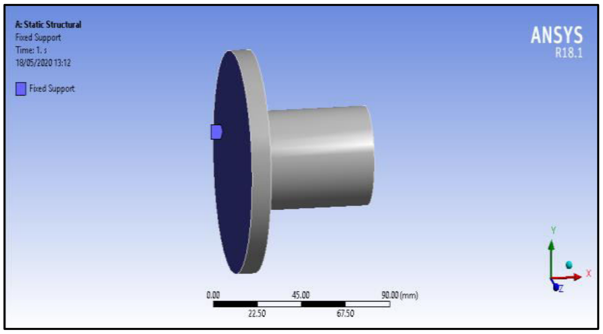

Figure 5: Fixed support

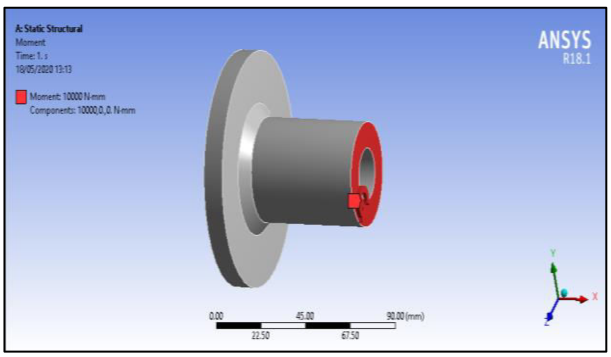

Figure 6: Moment on right face

In solution stage, the first step involves element stiffness matrix formulation which are assembled to global matrix. The next step involves matrix inversions, multiplications to get results at nodes which are interpolated for entire element edge length.The design is then optimized using response surface optimization method. RSM is used for the design and analysis of experiments; it seeks to relate an average response to the value of quantitative variables that effect response. The relationship between the dependent variable and independent variables can be represented as

$$y = f(X_1, X_2, X_3, X4\ldots\ldots X_n) + \varepsilon \qquad (1)$$

where, ε represents the noise or error observed in the response 'y'.

If we denote the expected response by

$$E(y) = f(X_1, X_2, X_3, X4\ldots\ldots X_n) = \eta$$

then, the surface represented by

$$f(X_1, X_2, X_3, X4\ldots\ldots X_n) = \eta \qquad (2)$$

is called the response surface.

The input parameters selected for optimization are shown in table 2 below.

Table 2: Input variables for optimization

X_1	h
X_2	α
X_3	t

5. RESULTS AND DISCUSSION

The FEA analysis is conducted on weld joint to get shear stress plot and curve as shown in figures below.

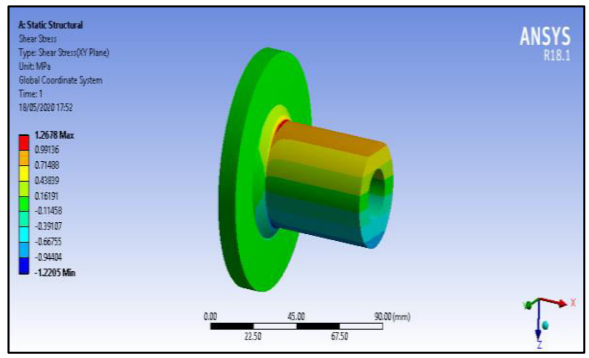

Figure 7: Shear stress distribution plot

The maximum shear stress is developed at corner point thereby making it highly susceptible to fatigue failure. The magnitude of stress generated at corner is 1.267MPa under given loading conditions as shown in figure 7 above.

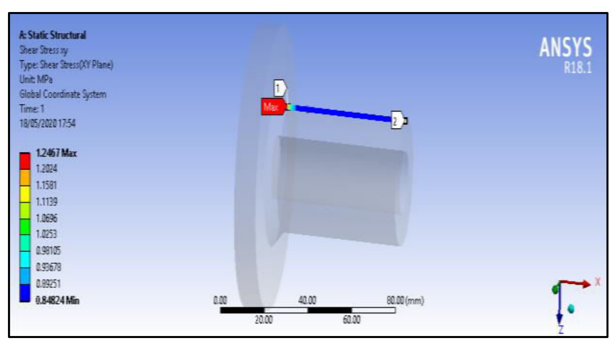

Figure 8: Shear stress along curve

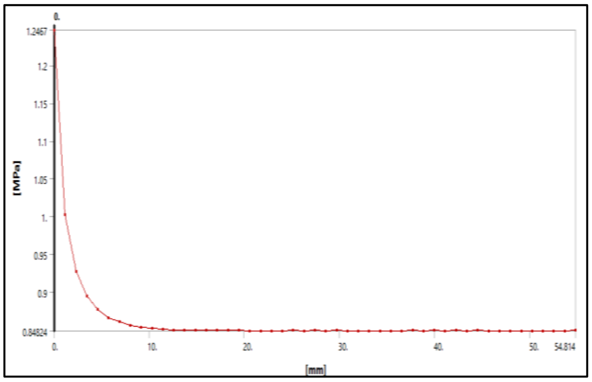

Figure 9: Shear stress vs distance from corner

The shear stress vs distance curve plot as shown in figure 9 above shows that shear stress decreases on moving away from corner and becomes minimal towards the end whereas the deformation is highest on open end. The deformation plot is shown in figure 10 below with maximum magnitude on open end of geometry.

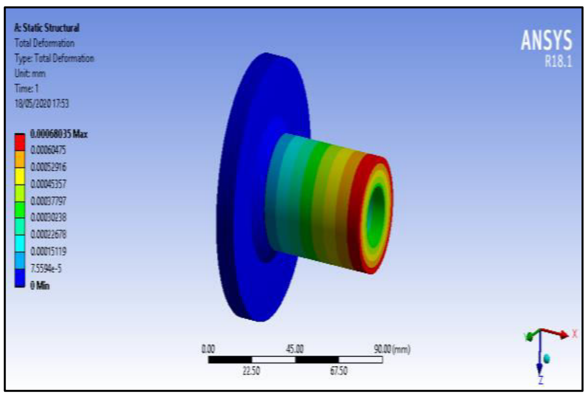

Figure 10: Deformation plot

Hot-spot stress for generic design (base design) is computed based on the following relationship [8].

$\sigma_{Hot\ Spot} = 1.67\sigma(0.4t) - 0.67\sigma(1.0t)$

$= 1.67 * 1.0055 - .67 * .92934$

$= 1.0565$ MPa

The design points are generated from Taguchi design of experiments are shown in table 3 below.

Table 3: Design points generated from Taguchi design of experiments

Table of Outline A8: Design Points of Design of Experiments

	A	B	C	D	E	F	G	H	I
1	Name	P5 - Alpha (degree)	P6 - h (cm)	P7 - t (cm)	P2 - Total Deformation Maximum (mm)	P3 - Normal Stress Maximum (MPa)	P8 - Shear Stress 2 Minimum (MPa)	P12 - hs1 stress Maximum XY Shear (MPa)	P13 - hs2 stress Maximum XY Shear (MPa)
2	1	135	0.475	1.09	0.00064719	0.011093	0.79283	1.0055	0.92934
3	2	130	0.475	1.09	0.00065118	0.0096293	0.79308	0.91075	0.88204
4	3	140	0.475	1.09	0.00064263	0.0076212	0.79309	1.0048	1.0535
5	4	135	0.45	1.09	0.00062774	0.0096059	0.75721	0.87258	0.86401
6	5	135	0.5	1.09	0.00066751	0.0089513	0.83075	1.1004	1.006
7	6	135	0.475	0.98	0.00066348	0.011715	0.81472	0.99413	0.93334
8	7	135	0.475	1.2	0.00063628	0.010047	0.77847	0.95945	0.89965
9	8	130.93	0.45467	1.0006	0.00064712	0.01167	0.78052	0.8946	0.8583
10	9	139.07	0.45467	1.0006	0.00064065	0.0087944	0.7805	1.0071	0.96345
11	10	130.93	0.49533	1.0006	0.00068006	0.012951	0.84089	1.0072	0.9622
12	11	139.07	0.49533	1.0006	0.00067228	0.0092809	0.83043	1.0279	1.1258
13	12	130.93	0.45467	1.1794	0.000625	0.0104	0.75158	0.84821	0.82768
14	13	139.07	0.45467	1.1794	0.00061881	0.009106	0.75162	0.98852	0.91072
15	14	130.93	0.49533	1.1794	0.00065804	0.0097148	0.81127	0.99739	0.93911
16	15	139.07	0.49533	1.1794	0.00065056	0.0082982	0.81109	1.0432	1.1061

The shear stress vs alpha plot shown in figure 11 below shows fluctuating behavior of stress w.r.t alpha. The shear stress decreases up to 132.5^0 alpha value and then increases up to 138.5^0 alpha value.

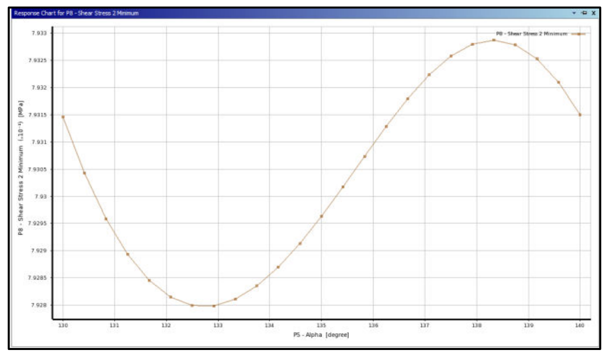

Figure 11: Shear stress vs alpha

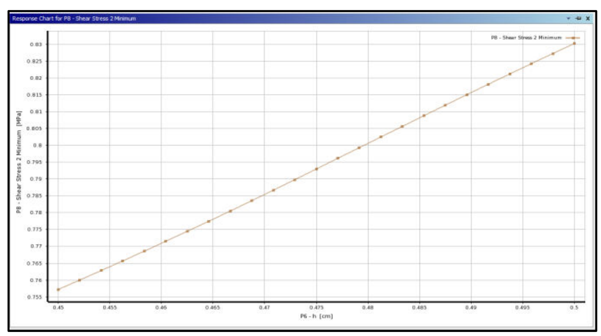

Figure 12: Shear stress vs h

The shear stress value increases linearly with increase in h as shown in figure 12 above. The minimum shear stress is observed for h value of .45cm and maximum shear stress is observed for h value of .5cm.

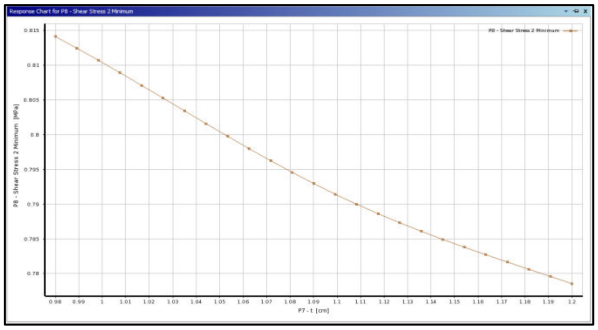

Figure 13: Shear stress vs t

The shear stress value decreases linearly with increase in t value as shown in figure 13 above. The minimum shear stress is observed for t value of 1.2cm and maximum shear stress is observed for t value of .98cm.

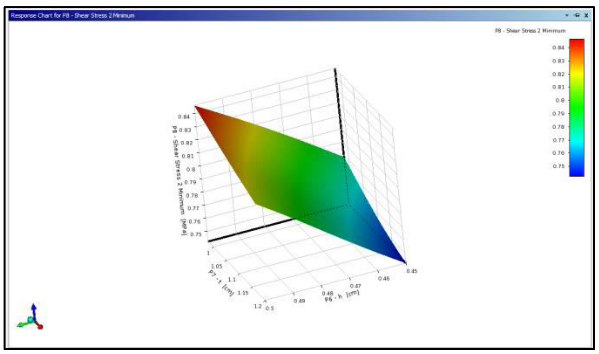

Figure 14: 3D response surface plot of shear stress vs h and t

As can be observed from figure 14 above, the maximum shear stress is observed for t values lower than 1cm and h values ranging from .45cm to .5cm as shown in dark red coloured region. The minimum values is observed for t values ranging from 1.15cm to 1.2cm and h values ranging from .47cm to .45cm as shown in dark blue coloured region.

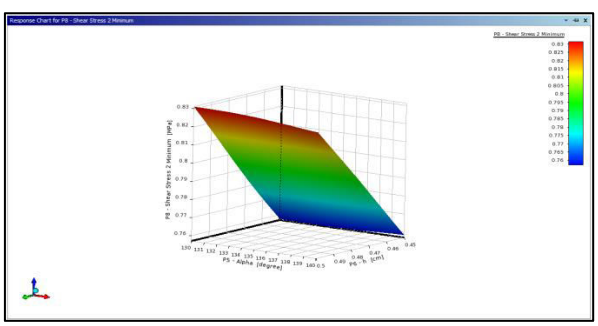

Figure 15: 3D response surface plot of shear stress vs alpha and h

As can be observed from figure 15 above, the maximum shear stress is observed for alpha values ranging from 130^0 to 140^0 and h values ranging from .49cm to 0.5cm as shown by red colored region. The minimum values is observed for h values ranging from .45cm to .47cm and alpha value ranging from 130^0 to 140^0 as shown by blue colored region.

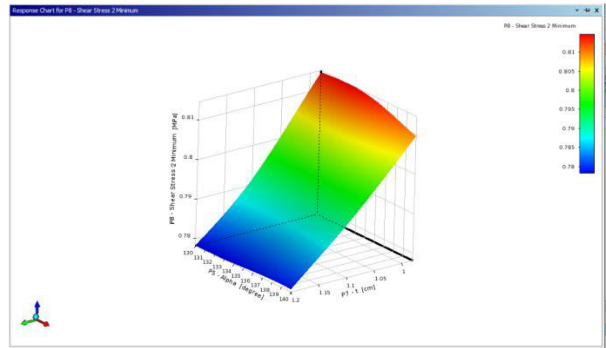

Figure 16: 3D response surface plot of shear stress vs alpha and t

As can be observed from figure 16 above, the maximum shear stress is observed for alpha values ranging from 130^0 to 138^0 and t values less than 1cm as shown by red colored region. The minimum values is observed for t values ranging from 1.15cm to 1.2cm and alpha value ranging from 130^0 to 140^0 as shown by dark blue colored region.

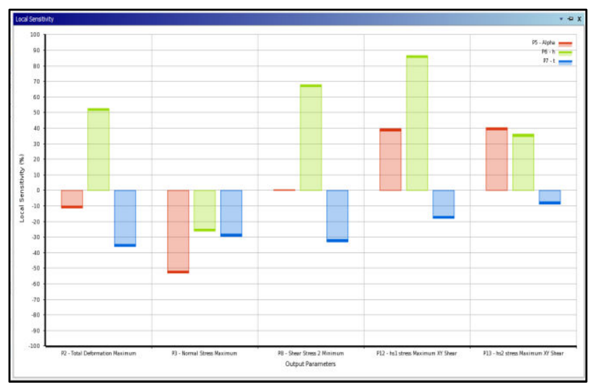

Figure 17: Sensitivity plot of different variables i.e. h, alpha and t

The sensitivity plot as shown in figure 17 above is obtained for different variables and its effects on deformation, normal stress, shear stress, hs1 shear stress and hs2 shear stress are evaluated. The alpha has 11.318(negative) sensitivity on total deformation. The negative sensitivity signifies that increasing alpha value would decrease total deformation and vice versa. The h variable has 52.65(positive) sensitivity on total deformation. The positive sensitivity signifies that increasing h value would increase total deformation and vice versa. The t has 35.99(negative) sensitivity on total deformation. The negative sensitivity signifies that increasing h value would decrease total deformation and vice versa. The alpha has 53.11(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing alpha value would decrease normal stress and vice versa. The h variable has 26.20(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing h value would decrease normal stress and vice versa. The t variable has 29.57(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa. The alpha has .43(positive) sensitivity on shear stress. The positive sensitivity signifies that increasing alpha value would increase shear stress and vice versa. The h variable has 67.92(positive) sensitivity on shear stress. The positive sensitivity signifies that increasing h value would increase shear stress and vice versa. The t variable has 33.08(negative) sensitivity on shear stress. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa. The alpha has 39.69(positive) sensitivity on shear stress at hs1. The positive sensitivity signifies that increasing alpha value would increase shear stress at hs1 and vice versa. The h variable has 86.63(positive) sensitivity on shear stress at hs1. The positive sensitivity signifies that increasing h value would increase shear stress at hs1 and vice versa. The t variable has 17.94(negative) sensitivity on shear stress at hs1. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa. The alpha has 40.30(positive) sensitivity on shear stress at hs2. The positive sensitivity signifies that increasing alpha value would increase shear stress at hs2 and vice versa. The h variable has 36.24(positive) sensitivity on shear stress at hs2. The positive sensitivity signifies that increasing h value would increase shear stress at hs1 and vice versa. The t variable has 8.83(negative) sensitivity on shear stress at hs2. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa.

The FEA analysis is conducted on design point obtained from different Taguchi Design of Experiments to determine shear stress curve. The design point has maximum magnitude of hot spot 1 stress and hot spot 2 stress. The shear stress curve (figure 18) for initial design point (generic design) is shown by orange curve (orange color) , for design point 10 (maximum hot spot stress point) and for design point 8(minimum hot spot stress point) is shown by grey color curve.

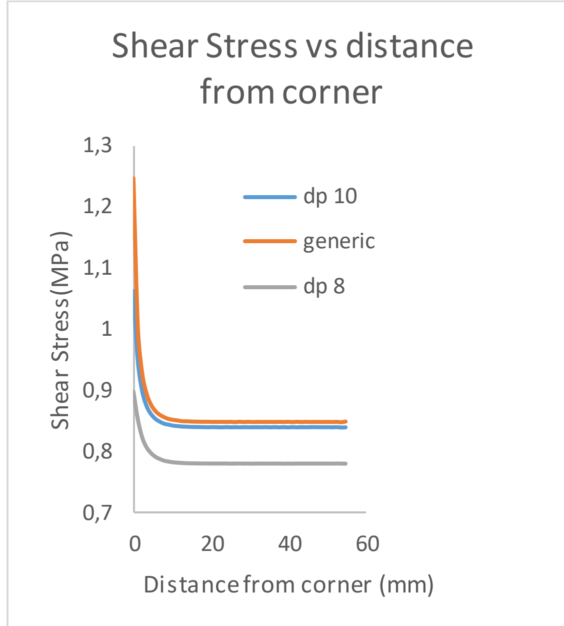

Figure 18: Shear stress vs distance for generic and DP10 point

$\sigma_{\text{Hot Spot generic}} = 1.67\sigma(0.4t) - 0.67\sigma(1.0t)$

$= 1.67 * 1.0055 - .67 * .92934$

$= 1.0565$ MPa

$\sigma_{\text{Hot Spot DP10}} = 1.67\sigma(0.4t) - 0.67\sigma(1.0t)$

$= 1.67 * 1.0072 - .67 * .9622$

$= 1.03735$ MPa

$\sigma_{\text{Hot Spot DP8}} = 1.67\sigma(0.4t) - 0.67\sigma(1.0t)$

$= 1.67 * 8946 - .67 * .8583$

$= .9189$ MPa

5. CONCLUSION

The FEA analysis of weld geometry is conducted using ANSYS software and results are analytically verified. The weld parameters of geometry are optimized using design of experiments and response surface methodology. The response surface plots are generated for deformation and shear stress. From response surface plots the range of magnitude of parameters (h, α and t) can be determined for maximum and minimum values of shear stress, deformation and safety factor. The details are as follows:

1. The maximum shear stress is developed at corner point thereby making it highly susceptible to fatigue failure. The magnitude of stress generated at corner is 1.267MPa under given loading conditions.

2. The shear stress vs distance curve plot shows that shear stress decreases on moving away from corner and becomes minimal towards the end whereas the deformation is highest on open end.

3. The sensitivity plot is obtained for different variables and its effects on deformation, normal stress, shear stress, hs1 shear stress and hs2 shear stress are evaluated The alpha has 11.318(negative) sensitivity on total deformation. The negative sensitivity signifies that increasing alpha value would decrease total deformation and vice versa.

4. The h variable has 52.65(positive) sensitivity on total deformation. The positive sensitivity signifies that increasing h value would increase total deformation and vice versa.

5. The t has 35.99(negative) sensitivity on total deformation. The negative sensitivity signifies that increasing h value would decrease total deformation and vice versa.

6. The alpha has 53.11(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing alpha value would decrease normal stress and vice versa.

7. The h variable has 26.20(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing h value would decrease normal stress and vice versa. The t variable has 29.57(negative) sensitivity on normal stress. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa.

8. The alpha has .43(positive) sensitivity on shear stress. The positive sensitivity signifies that increasing alpha value would increase shear stress and vice versa. The h variable has 67.92(positive) sensitivity on shear stress. The positive sensitivity signifies that increasing h value would increase shear stress and vice versa. The t variable has 33.08(negative) sensitivity on shear stress. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa.

9. The alpha has 39.69(positive) sensitivity on shear stress at hs1. The positive sensitivity signifies that increasing alpha value would increase shear stress at hs1 and vice versa. The h variable has 86.63(positive) sensitivity on shear stress at hs1. The positive sensitivity signifies that increasing h value would increase shear stress at hs1 and vice versa. The t variable has 17.94(negative) sensitivity on shear stress at hs1. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa.

10. The alpha has 40.30(positive) sensitivity on shear stress at hs2. The positive sensitivity signifies that increasing alpha value would increase shear stress at hs2 and vice versa. The h variable has 36.24(positive) sensitivity on shear stress at hs2. The positive sensitivity signifies that increasing h value would increase shear stress at hs1 and vice versa. The t variable has 8.83(negative) sensitivity on shear stress at hs2. The negative sensitivity signifies that increasing t value would decrease normal stress and vice versa.

11. The sensitivity percentage of alpha is 37.45 (positive) and t is 22.86(positive) for safety factor obtained from fatigue life analysis. The h variable shows negative sensitivity of 40.63(negative) which means increasing this variable value would decrease safety factor and decreasing this variable would increase safety factor. Out of all the 3 variables, the h variable has highest effect on safety factor.

REFERENCES

[1] T. Ninh Nguyen and M. A. Wahab, “The effect of weld geometry and residual stresses on the fatigue of welded joint under combine

[2] Kyungwoo Lee, “ Large deflections of cantilever beams of nonlinear elastic material under a combined loading,” International Journal of Non-Linear Mechanics 37 (2002) 439–443.

[3] Robb C. Wilcox, “The effect of weld penetration on tensile strength of fillet welded joints”,B.S., Naval Architecture and Marine engineering, U.S. coast guard acadamy, 1991

[4] Mahapatra, M., G. L. Datta, B. Pradhan, and N. R. Mandal. “Modelling the effects of constraints and single axis welding process parameters on angular distortions in one-side fillet welds.” Proc. IMechE 221 Part B: 397-407.

[5] Michaleris, P., J. Dantiz, and D. Tortorelli. "Minimization of welding residual stress and distortion in large structures." Welding Journal 11 (1999): 361-366s.

[6] Yaoyu Hua (2019), “Notch stress analysis and fatigue strength assessment of tube-flange welded joints under torsion loading” Elsevier, Ocean Engineering 186

[7]D. Bubanja (2014), “Static and dynamic measurement and computer simulation of diabetic mellitus foot biomechanics”Journal of the Serbian Society for Computational Mechanics / Vol. 8 / No. 1

[8] Hobbacher A. (Ed), 2009. Recommendations for fatigue design of welded joints and components. IIW doc. XIII-1823-07. Welding Research Council Bulletin 520, New York