T-Joint weld optimization using Taguchi method

Midhun Ranjan[1], Seenivasagan Gunasekaran[2] and **Resmi Reghu[3]**
[1]Department of Mechanical Engineering, SVS College of Engineering,
Coimbatore, India.
[2]Department of Mechanical Engineering, Kalaignarkarunanidhi institute of technology
Coimbatore, India.
[3]Department of Electrical and Electronics Engineering, Amrita Vishwa Vidhya Peetham
Coimbatore, India
***Corresponding author: E.Mail: r44midhun@gmail.com**

ABSTRACT

Arc welded structures got its important due to the usage of them in the field of transportation systems, constructions and power plants. Design defect and overloading plays the main cause for weldment failure. Hence it is necessary to analyze the maximum stresses that can be applied in the weldment. In this work, investigation of welded T-joint by TIG welding process with varying gap and angle between the parent materials to determine the breaking stress under tensile load in the weldment has been done. Finite element (FE) analysis is used to carry out the maximum breaking stress using Ansys software. Experimental analysis has been done to find out the maximum breaking stress under tensile load. Taguchi optimization method is used to optimize the fillet weld section in the experimental analysis. Angle, arc force and gap between parent materials are the three process parameters used for the Taguchi optimization technique. The FE analysis & analytical results of breaking stress is also carried out and verified with the experimental results. The optimized best fillet weld section (low carbon steel AISI1020 and copper) is used to restrict the weldment failure.

Keywords: Taguchi Technique, TIG welding, MIG welding, FEA.

1. INTRODUCTION

The fillet welded joints usually suffer from various welding deformation patterns such as angular distortion, longitudinal and transverse shrinkage in fabrication of structural members in ship building, automobile and other industries. The angular distortion is clarified through numerical calculation in all these applications. The stresses in the weldment are evaluated by varying the gap between the parent plates which may occur during. Manufacturing. It is a type of mechanical joints like rivets and bolt used in ancient times. The residual stress in a welded T-joint, is compared by carrying out computations by making 3D models and 2D models.

A mathematical model for predicting weld penetration as a function of welding process parameters. The constrained optimization method is then applied to this model to optimize process parameters for maximizing weld penetration.

Welding has many merits over bolting and riveting. Welding permits direct stress between members eliminating gusset and splice plates necessary for bolted structures. So that joint weight is decrease. The elimination of holes increases efficiency when we consider tension member as factor. For this fabrication cost is less because of lesser parts, and operations, it reduces labour and economy. Usually welded joints are stronger than the base metal. While considering welded connection stress concentration effect is less. Skilled manpower and inspection is required for welding. Due to environmental conditions or location welding may be difficult. Under fatigue load welded joint obtain cracks due to improper welding.

Numerical calculation:

Weldment under tensile load: The below Fig.2.1 represents the T-joint fillet weld sections with dimensions (100mmx50mmx5mm) with fillet angle 45º. Here 25kN tensile acting upward on the top of the section. The base weld material is plain carbon steel and filler material is copper (Cu).

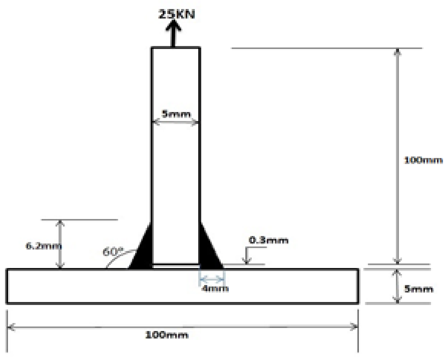

Figure.1.Arc weld of T-joint under tensile load for 0.3mm gap and 60º angle

F -Tensile load on vertical plate (N) = 25 kN
w -Leg length of weld = 4.0 mm
h -Throat of fillet weld (mm) = w * (cos45º)
l -Length of weld or size of weld = 50mm
l_T- Length of top load section = 5mm
b_T-breath of top load section = 50mm
l_t -throat length = 4mm
t - Throat thickness = 1mm
A -Area of weld section
The material properties are specified as follows.
Modulus of elasticity of parent plate material (E) = 2.1 x 10^5 MPa
Poisson's ratio of parent plate materia (μ) = 0.3
Modulus of elasticity of weld material (E) = 1.1 x 10^5 MPa
Poisson's ratio of weld material (μ) = 0.37
Formula used are,
Area of weld section (A) = 2 mm^2.
That is given by A_f+A_l-A_t (1)
Where,
A_f – Area of fillet section = 2*(cosθ*w) * l (2)
A_l – Area of load section = l_Tx b_T (3)
A_t – Throat area = t xl_t (4)
Breaking stress =$\frac{P}{A_t}$ k (5)
Where P is Breaking Load, A_t is Throat Area
k is Stress Concentration Factor
Stress concentration factor (k) of parent material is in the range of 3.5 to 4 given by Frank Karl Heinz [16].

Breaking Stress: Breaking stress is a maximum stress that a material can withstand while being stretched or pulled before failing or breaking. In other words, breaking stress is a greatest stress especially in tension that a material is capable of withstanding without rupture. The model calculation of breaking stress for tensile load with different angle and varying gap between parent materials are given below.

- For 25kN load, θ = 45º and 0.3 mm gap

Breaking stress (σ_b) = $\frac{F}{A}$× k (6)
A = 2 A_f+A_l-A_t (7)
A=2(cos45×6.2×50) + (5×50) + (.3×4) =531.8mm^2
σ_b= $\frac{25000}{531.8}$×4 = 188.04 Mpa.

- 25 kN load, θ = 60º and 0.3mm gap

A = 2(cos60×4×50) + (5×50) - (0.3×4)= 448.8 mm^2
σ_b= $\frac{25000}{448.8}$×4 = 222.2 Mpa

- 25kN load, θ = 30º and 0.3mm gap

A = 2(cos30×4×50) + (5×50) - (.3×4) = 768.4 mm^2
σ_b= $\frac{25000}{768.4}$×4= 130.1 Mpa.

Numerical Results: Tabulated breaking stress values from numerical calculation. The Maximum breaking stresses present in T-joint weldment at the throat thickness with gap variation are given in table.2.1 and the variation of Maximum breaking stress with respect to gap is also shown in Table.2.1. Where 30º, 45º & 60º chamfer is provided on the vertical plate by varying the gap of 0.3, 0.6 and 0.9mm.

Table.1.Numerical results for breaking stress with different angle and gap between parent materials

Gap between parent plats(mm)	Breaking stress for 25kN(Mpa)		
	30º	45º	60º
0.3	130.10	188.04	222.20
0.6	130.34	188.50	223.41
0.9	130.60	189.90	224.60

Experimental analysis:

Optimization: Optimization is used to reduce the time, cost of weld simulation parameters [10,11].Choosing welding process is necessary to obtain the weld bed shape because of weld current, weld speed, arc voltage and its time consumption. All these weld parameters are used for optimization [12].Optimization is a process of finding the maximum or minimum value of a function, where the function of effort required or the desired benefit represents the act of obtaining best result under the circumstances given. Design, maintenance and construction of systems in engineering involve both the technological level and managerial level decision making.

Taguchi Technique: Taguchi is one of the optimization technique used to obtain the optimum point of operation. Dr.Taguchi of Nippon telephones and telegraph company, japan has developed a method based on "orthogonal array" experiments which gives much reduced "variance'' for the experiment with "optimum settings" control parameters.

Thus the design of experiments with optimization parameters to obtain best results is achieved in the Taguchi method. "Orthogonal Array" provides a set of well balanced (minimum) experiments. Dr.Taguchi's optimization method obtains the objective function for optimization through the log functions of the optimum output needed by considering signal-to-Noise ratios(S/N).

2. EXPERIMENTAL WORK

In this experimental work, the machining process is done by Geekey engineering works near chinavedampatty, Coimbatore. Welding work done in S.S TIG welders. In this process TIG welding process is used with low carbon steel AISI1020 (base material) and copper (filler material) with dimensions (100x50x5) mm.

A welded T-joint is considered for determination of breaking strength is shown in figure.4.1. For experimental testing process, two plates are placed vertically and top and bottom portions welded with fillet. Bottom plate having the cross section of 100mm x 50mm x 5 mm and top with specification 60mm x 50mm x 5 mm thick. Fillet side size having 4 mm greater width than top side 8mm is used to study the breaking strength of top side T-joint weld.

Design of Experiment: Taguchi's designs aimed to allow greater understanding of variation than that of many available traditional designs. Optimizing process parameters of MIG welding process is done and compared the experimental result with FEA for optimizing parameter by using (DOE) technique in. Taguchi explains that conventional sampling is inadequate as there is no way of obtaining a random sample of future conditions. The nine types of welded T- joints by TIG welding process is shown in Fig.4.2.

Figure.2.Welded T-joint material by TIG welding process

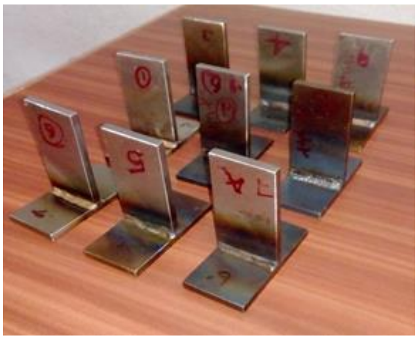

Figure.3.Nine types of welded T- joints by TIG welding process

Taguchi proposed extending each experiment with an "outer array" or orthogonal array to simulate the random environment in which the experiment would function as shown in below table 2.

Table.2.Experimental layout using L_9 Orthogonal Array

Ex. No	Gap (mm)	Arc force (mm/s)	Angle (degree)
1	0.3	5	45
2	0.3	10	53
3	0.3	15	60
4	0.6	5	53
5	0.6	10	60
6	0.6	15	45
7	0.9	5	60
8	0.9	10	45
9	0.9	15	53

Table.3.Welding process parameters

Parameters	Level-1	Level-2	Level-3
Gap (mm)	0.3	0.6	0.9
Arc force (mm/s)	5	10	15
Angle Degree	45	53	60

Universal testing machine used to test the tensile strength and compressive strength of the material. For this process two vertical plates are welded with fillet weld at top and bottom side of base plate having the cross section of 100mm x 50mm x 5 mm and 60mm x 50mm x 5 mm thick. The small cross section of the plate is fixed at the top of the testing machine and the bottom cross section move forward due to load applied. Finally the weld has broken to two pieces at the maximum load condition shown in the below fig.4, 5 and 6.

Figure.4.Universal testing machine (UTM)

Figure.5.Nine types of t-joint weld section for testing purpose

Figure.6.Testing before and after breaking

Finite element analysis: In this work to analyze distortions and residual stresses that can occur during the welding process, ANSYS Workbench software is used.

It is Finite Element Analysis based software. So by using this it is possible to predict the useful life of the welded structures along with the possible improvement modifications that can be carried out to increase the overall efficiency of the system. It is a computer-based numerical technique which makes the structure under analysis in to finite elements and calculate its strength individually. So the results will be more accurate. It can be used to calculate the effects of structures by the application of stresses which cause for the phenomena's like deflection, stress, vibration, buckling behavior etc. In finite element method, the joining points of finite elements are known as nodes. The variable like temperature, displacement, and velocity or pressure inside the nodal region is unknown, so approximation function is necessary, such functions are also called as interpolation models and are known in terms of field variable at the nodes.

The primary unknowns considered for the structural analysis here are displacements, strains, stresses, and reaction forces. Derivation of the same has been done using nodal displacements.

Static Analysis: Static analysis can be done in the body under equilibrium condition. It can be done for both linear and nonlinear type structures. Mainly non linearity referrers to large deformations, plasticity, creep, stress stiffening, contact elements etc. Calculating the static analysis the steady loading conditions effects on a structure, while avoiding damping effects and inertia, since they are the varying loads of time. The response conditions are assumed to vary slowly with respect to time in static analysis loading. The kind of loading that can be applied in static analysis includes,

1. Externally applied forces, moments and pressures.
2. Steady state inertial forces such as gravity and spinning.
3. Imposed non-zero displacements.

A static analysis in the structure is necessary to find out whether the structure can able to withstand the maximum applied forces by the loads. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself.

Equivalent (Von-Misses) Stress: Von misses stress is widely used by designers to check whether their design will withstand a given load condition. Von misses stress is considered to be a safe haven for design engineers, if the maximum value of von misses stress induced in the material is more than strength of the material. Its work well for most cases, especially when the material is ductile in nature.

For 25KN load, θ = 45º and 0.3 mm gap:

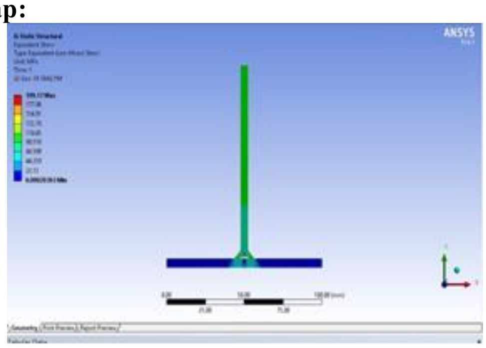

Figure.7.Equivalent von-misses stress for 45º degree and 0.3mm gap

The above Fig.7 represents the equivalent von misses stress value is 199.17 Mpa for 45º and 1mm gap between the parent materials.

For 25KN load, θ = 60º and 0.3mm gap:

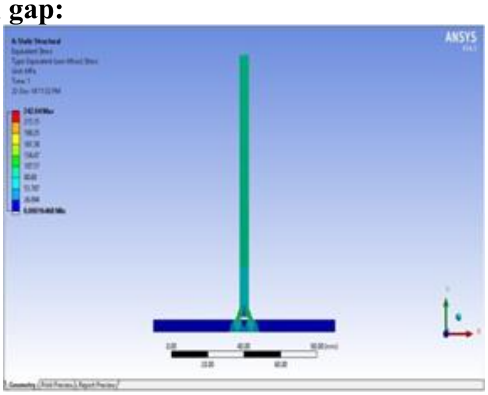

Figure.8.Equivalent von-misses stress for 60º degree and 0.3mm gap

For 25kN load, θ = 30º and 0.3mm gap:

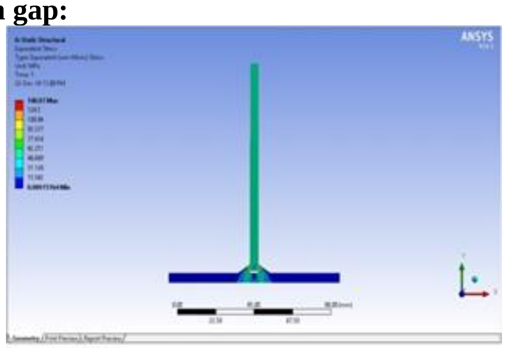

Figure.9.Equivalent von-misses stress for 30º and 0.3mm gap

Analysis Result: FE analysis is also carried out by considering the chamfer on vertical plate. The Maximum von-misses stresses present in T-joint weldment at the throat thickness with gap variation are carried out and the variation of Maximum breaking stress with respect to gap and angle is also shown in Table.4. Where 30º, 45º & 60º chamfer is provided on the vertical plate by varying the gap of 0.3, 0.6 and 0.9mm.

Table.4.Analysis results for Von misses stress with different angle and gap

Gap between parent plats(mm)	Breaking stress for 25KN(Mpa)		
	30º	45º	60º
0.3	140.07	197.17	242.04
0.6	142.89	197.91	247.02
0.9	149.12	205.09	252.73

The above table.4 shows the breaking stress for gap between parent plates. The maximum breaking stress 252.73Mpa for 60º angle with 0.9mm gap welded section. From the analytical and numerical results the equivalent von misses stress 80% approximately equal. The FE analysis of T-welded joint for the same geometry revealed the maximum Von-misses stress of 252.73Mpa it's approximately equal to numerical maximum breaking stress of 224.6Mpa.

3. RESULTS AND DISCUSSION

The finite element and numerical analysis results of equivalent von misses stress are carried out and it's approximately equal to the numerical breaking stress. The FE analysis of T-welded joint for the same geometry revealed the maximum Von-misses stress of 252.73Mpa it's approximately equal to numerical maximum breaking strength of 224.6Mpa.

Table.5.Stress Analysis

0.9 mm and 60º	Numerical Analysis	FEA Analysis
Breaking stress	224.6Mpa	252.73Mpa

From the finite element analysis maximum breaking stress is 252.73Mpa (0.9mm gap and60º) and minimum breaking stress is 140Mpa (0.3mm gap and 30º).

Table.6.Stress Analysis

0.3 mm and 60º	**Experimental result**	**FEA Result**
Breaking stress	236.2Mpa	242.04Mpa

The experimental and finite element results of breaking stress are carried out. The maximum breaking stress for experimental result is 236Mpa it's approximately equal to the same geometry revealed the maximum Von-misses stress of 242Mpa. From the experimental analysis maximum breaking stress is 232Mpa (0.3mm gap and60º) and minimum breaking stress is 151Mpa (0.3mm gap and 53º). The optimization of T-joint weld is successfully carried out both analytical and experimentally.

Testing results:

Table.7.Breaking load for fillet weld materials by UTM

Ex.No	Gap (mm)	Arc force (mm/s)	Breaking stress	Breaking load (KN)
1	0.3	5	45	22.4
2	0.3	10	53	23.5
3	0.3	15	60	26.5
4	0.6	5	53	21.7
5	0.6	10	60	22.3
6	0.6	15	45	19.2
7	0.9	5	60	20.2
8	0.9	10	45	18.3
9	0.9	15	53	17

The table.7.represents the breaking loads for T-joint welds with varies gap and angle. From this testing result carried out a maximum breaking load 26.5KN for 0.3 mm gap and 60º angle of fillet weld by taguchi method. Using this breaking load maximum breaking stress can be calculated as follows.

Maximum breaking load = 26.5 KN

Maximum breaking stress = 236.2 Mpa for 0.3mm and 60º angle.

The below report Fig.10 represents the sample for maximum breaking load.

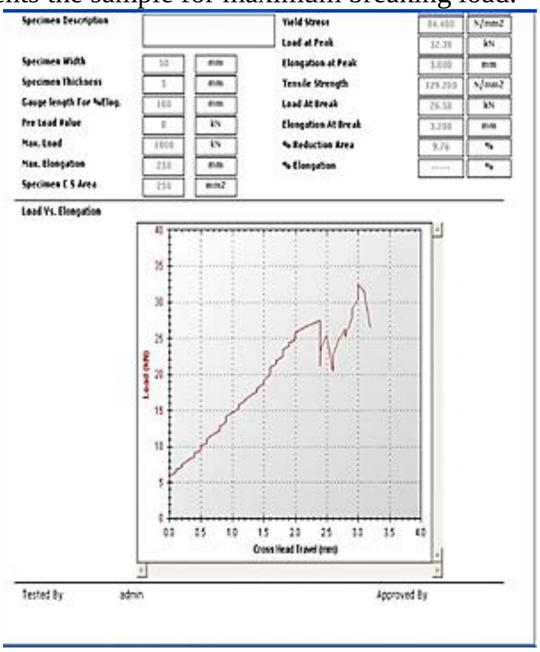

Figure.10.Sample report for maximum breaking load

4. CONCLUSION

The finite element analysis is used in this work to evaluate the deformation breaking stress of weld T-joint to restrict the weldment failure (using low carbon steel as a base metal and copper filler material). Static stress analysis performed on the weldment under tensile load revealed the maximum Von-misses stress with respect to the gap between parent plates using ANSYS work bench 14.5.The design and analysis of welded T-joint has been done successfully.

The experimental analysis is carried out by using Taguchi technique to evaluate the maximum breaking stress and results are compared with FE analysis and both are approximately acceptable. The conclusion obtained by this project work are summarized below,

- The 60º angle parameter gives better breaking stress results in experimental and analytical compared then 30º and 45º.
- The experimental investigation shows that 0.3 gap between parent materials with 60º angle gives a maximum breaking stress.
- If the gap is increased means breaking stress will gradually decreased by experimental analysis.
- Low carbon steel AISI1020 gives fine welding with copper and it's did not create any crack or flows during welding process.
- Arc force 15mm/s is giving a fine welding and increase the weld ability of the T-joint.
- Using optimized angle and gap between parent materials restricts the weldment failure.

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