Numerical Solution to the Selection of Electrodes for Parallel Fillet Lap Joint Weld

Kale Tulin Sanjay
Research scholar

Barjibhe R.B.
PG- Coordinator

Patil A.V.
Head of Dept.

Department of Mechanical Engineering, S. S. G. B. College of Engineering, Bhusawal (MS), India

***Abstract* - Lap joints are used extensively in the manufacture of cars. In order to determine the effect of using a structural adhesive instead of spot-welding, a detailed series of tests were conducted using a range of loadings. The adhesive was a toughened epoxy and the adherent was mild steel typical of that used in the manufacture of car body shells. The lap joints were tested in tension. Various parameters are investigated such as the overlap length, the bond line thickness and the spew fillet. A failure criterion has been proposed based on the tensile load and bending moment applied to the joint.The single lap joint is the most studied type of adhesive joint in the literature. However, the joint strength prediction of such joints is still a controversial issue as it involves a lot of factors that are difficult to quantify such as the overlap length, the yielding of the adherent, the plasticity of the adhesive and the bond line thickness. In any case, there is still a problem that is even more difficult to take into account which is the durability. There is a lack of experimental data and design criteria when the joint is subjected to high, low or variable temperature and/or humidity.**

The objective of this work is to carry out and quantify the various variables affecting the strength of single lap joints in long term, especially the effect of the surface preparation in order to quantify the influence of the adhesive (toughness and thickness), the adherent (yield strength and thickness), the overlap, the test speed, the surface preparation and durability on the lap shear strength.

Keywords: Lap joint, overlap length, strength, and welding process.

1 INTRODUCTION

A Definition of Welding

According to American Society of Welding, welding is a localized coalescence of metal where coalescence is produced by heating to suitable temperature, with or without the use of filler metal. The filler metal either has a melting point approximately the same as the base metal or below that of the metal. Heating to suitable temperature is compulsory; in addition either pressure or filler metal is required for welding to take place. Figure 1 shows typical lap joint connected to two parallel plates.

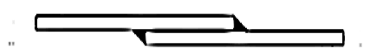

Figure 1 Typical Lap Joint

B Weld-Bead Geometry & Mechanical Properties

Theoretically, an extremely thin fused layer might be sufficient for connecting the parts to be joined. The fusion layer should also not be thicker than necessary in order to avoid wasting of energy, edge burn-off, sagging of the weld pool and deep weld end craters. Control of weld-bead shape is essential as the mechanical properties of welds are affected by the weld-bead shape. Therefore, it is clear that precise selection of the process parameters is necessary. In any welding process, the input parameters have an influence on the joint mechanical properties. By varying the input process parameters combination the output would be different welded joints with significant variation in their mechanical properties. Accordingly, welding is usually done with the aim of getting a welded joint with excellent mechanical properties. To determine these welding combinations that would lead to excellent mechanical properties. Electrodes of different grade have been used to achieve this aim. Figure 2 shows typical tension test behaviour of mild steel material.

The automotive industry has recently been implementing what the aerospace industry has been using for decades, namely that adhesives can be used for joining load-bearing components. As the designers of road vehicles try to produce cheaper and lighter products, more ways are needed for joining new and dissimilar materials together. The main method of joining in the automotive industry is bymeans of spotwelds.

This has required large investment in the appropriate technology, such as

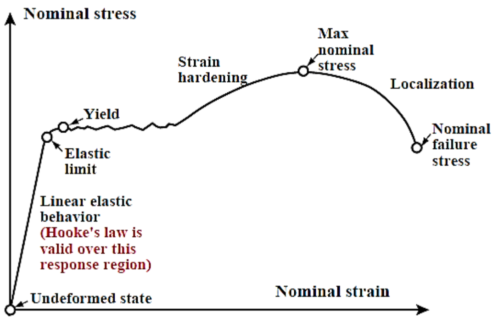

Figure 2 Typical Tension Test Behaviour of Mild Steel Material

highly auto- mated production lines and many years' experience of designing. However, there are disadvantages with spot welds as they require access to both sides of the joint, they cannot join aluminium effectively, or composites at all, and they generally destroy any coatings used to improve the corrosion resistance of steels. A good, cheap method that can solve all the above problems is to use adhesive bonding. In order to use adhesives, they must fulfil the performance requirements. The fundamental problems with using adhesives have been overcome, such as bonding directly to oily steel, high-speed application of adhesives using robotic technology in high-rate production lines, and the development of toughened adhesives that can withstand impact better than the older brittle forms. Adhesives are used today in a variety of places in the vehicle, and can be split into four categories; (i) sealants (ii) low-strength adhesives, (iii) medium-strength adhesives and (iv) high-strength adhesives. The high-strength category of adhesives is used where the adhesive plays the primary role in the joining and strength of a structure. At present, there is very little structural adhesive used in the car body shell. The first step towards greater use of structural adhesives is the characterization of those joints found typically in the automotive industry by a combination of testing and analysis, in order to improve the knowledge of the behaviour of these joints. The objective of this research is to increase the amount of data available to the automotive design engineer. Since a single-lap joint is widely known and used to characterize bond strength, the testing program was started with that joint and the results obtained are presented here.

2 LITERATURE WORK

M.S. Kafkalidis, M.D. Thouless in "The effects of geometry and material properties on the fracture of single lap-shear joints" discussedlap-shear joints is followed by a detailed analysis of the problem using a cohesive-zoneapproach. The cohesive-zone model allows not only the influence of geometry to be considered, but also allows thecohesive properties of the interface and plastic deformation of the adherends to be included in the analysis. The firstpart of the paper examines the strength of elastic joints, with an emphasis on the effects of geometry, the cohesive strength of the adhesive and mode-mixedness. The cohesive-zone models show a transition to the predictions of linearelasticfracture mechanics under conditions where these are expected to apply. The second part of the paper examines the effect of plasticity in the adherends, and looks at the transition between the elastic and plastic regimes.

G. Fessel, J.G. Broughton, N.A. Fellows, J.F. Durodola, A.R. Hutchinson in "Evaluation of different lap-shear joint geometries for automotive applications" discussed the joint strength is strongly dependent on theyield point of the metallic substrates. The lap-shear joints failed mostly due to the bending and subsequently yielding of the substrates, whereas the reverse-bent joints failed predominantly in shear or due to lateral straining of the substrates away from the overlap.

L.D.R. Granta, R.D.Adams, LucasF.M.daSilva in "Experimental and numerical analysis of single-lap joints for the automotive industry" discussedlap joints typical of those used in the automotive industry were studied under tension, three-point bending and four-point bending. Various geometric parameters were studied such as the overlap length, the adhesive thickness and the distance between loading points in the case of the bending tests.

Lucas, F.M.daSilva, R.J.C.Carbas, G.W.Critchlow, M.A.V.Figueiredo, K. Brown in "Effect of material, geometry, surface treatment and environment on the shear strength of single lap joints" International Journal of Adhesion & Adhesives discussed the effects of adherends yield strength, adherends thickness, adhesive thickness, overlap, adhesive toughness, surface treatment, durability and test speed on the lap shear strength were investigated using the Taguchi method. The experimental results were statistically treated to give a failure load predictive equation.

L.E. Lindgren. in "Numerical modelling of welding" discussed the author has in his industrial cooperation seen the use of simulation for avoiding cracking, controlling deformations and stresses by means of optimal weldingprocedures and even seen how simulations have been used in business to promote high tech products.

3 THEORETICAL FORMULATIONS

A Failure theory for fillet weld

The failure load predicted using the simple design methodology proposed by Adams et al. Theloadcorrespondingtothetotal plastic deformationoftheadhesiveisgivenas

$$F_a = \tau_y wl \ldots\ldots \text{Eq (1)}$$

Where, F_a is the failure load of the adhesive, τ_y the shear yield strength of the adhesive, w the joint width and l the overlap length.

The direct tensile stress (σ_t) acting in the adherend due to the applied load F is

$$\sigma_t = \frac{F}{w \times t_s} \ldots\ldots \text{Eq (2)}$$

wheret_s is the adherend thickness. The stresss at the inner adherend surface (σ_s) due to the bending moment M is

$$\sigma_s = \frac{6M}{w \times t^2{}_s} \ldots\ldots \text{Eq (3)}$$

where $M = \frac{kFt_s}{2}$, according to Goland and Reissner. The variable k is the bending moment factor which decreases (from unity) as the lap rotates under load. The stress acting in the adherend is the sum of the direct stress and the bending stress. Thus, the maximum load which can be carried which just creates adherend yield (F_s) is

$$F_s = \frac{\sigma_{ys}}{1+3k} w \times t_s \text{.....................................Eq (4)}$$

where σ_{ys} is the yield strength of the adherend. For low loads and short overlaps, k is approximately1. Therefore, for such a case $F_s = \frac{\sigma_{ys} \times w t_s}{4}$ ....Eq (5)

However, for joints which are long compared to the adherend thickness, such that $\frac{l}{t_s} \geq 20$, the value of k decreases and it is assumed here that it tends to zero. In this case, the whole cross section yields and $F_s = \sigma_{sy} w t_s$ ....Eq (6)

The methodology proposed by Adamsetal works reasonably well when there is yielding of the adherend. Eq. 6 shows that the experimental points corresponding to mild steel compare reasonably well with the three curves corresponding to the predictions for t_s=1,2 and 3mm using Eq (5) and (6). The predictions are slightly lower than the experiments because the initial yielding of the steel was used, ignoring the strain hardening of the steel.The table1 and 2 shows the chemical content and mechanical properties of various electrodes respectively.

Table 1 Chemical Content of Electrodes

Sr. No.	AWS. Spec.	C%	Mn%	Si%	S %	P %
1	E-6012	0.45	0.35	0.03	0.03	
2	E-7014	0.09	0.50	0.40		
3	E-7018	0.08	1.10	0.55		

Table 2 Mechanical Properties of Electrodes

Y.S. N./mm^2	UTS N./mm^2	Elongation % L=4D	Impact/ Joules	Testing Temp
340-480	460-560	22-30	50-75	27±2ºC
380-500	510-650	22-28	50-80	0ºC
400-520	510-660	26-35	60-100	-29ºC

B Theoretical calculations
Dimensions of plate
l×w×h = 100mm×60mm×6mm

Thickness of weld = 3mm
For electrode 1
Product name- Orange E-6012
Yield stress = 340-480N/mm^2
According to maximum principle or normal stress theory for ductile material,

$$\sigma_t = \frac{\sigma_{yt}}{F.S}$$
$$= \frac{360}{1.5}$$
$$\sigma_t = 240 \text{N/mm}^2$$

The tensile force acting is given by

$P = 0.707 \times t \times l \times \sigma_t$ for single weld
$P = 2(0.707 \times t \times l \times \sigma_t)$ for double weld
$P = 1.414 \times t \times l \times \sigma_t$

Where,
P = load acting
t = thickness of weld
l = length of weld

$$P = 1.414 \times 3 \times 100 \times 240$$
$$P = 101808 \text{ N}$$
$$P = 101.808 \text{KN}$$

Deformation in the plate is given by,

$$\delta = \frac{P \times l}{A \times E}$$
$$= \frac{101808 \times 100}{300 \times 2.1 \times 10^5}$$
$$\delta_1 = 0.16 \text{ mm}$$

For electrode 2
Product name- Orange Green E-7014
Yield stress = 380-500 N/mm^2
According to maximum principle or normal stress theory for ductile material,

$$\sigma_t = \frac{\sigma_{yt}}{F.S}$$
$$= \frac{400}{1.5}$$
$$\sigma_t = 266.67 \text{ N/mm}^2$$

The tensile force acting is given by

$P = 0.707 \times t \times l \times \sigma_t$ for single weld
$P = 2(0.707 \times t \times l \times \sigma_t)$ for double weld
$P = 1.414 \times t \times l \times \sigma_t$

Where,
P = load acting
t = thickness of weld
l = length of weld

$$P = 1.414 \times 3 \times 100 \times 266.67$$
$$P = 113120 \text{ N}$$
$$P = 113.120 \text{KN}$$

Deformation in the plate is given by,

$$\delta = \frac{P \times l}{A \times E}$$
$$= \frac{113120 \times 100}{300 \times 2.1 \times 10^5}$$
$$\delta_2 = 0.179 \text{ mm}$$

For electrode 3
Product name- Orange E-7018
Yield stress = 400-520 N/mm^2
According to maximum principle or normal stress theory for ductile material,

$$\sigma_t = \frac{\sigma_{yt}}{F.S}$$
$$= \frac{420}{1.5}$$
$$\sigma_t = 280\ N/mm^2$$

The tensile force acting is given by

$$P = 0.707 \times t \times l \times \sigma_t \quad \text{for single weld}$$
$$P = 2(0.707 \times t \times l \times \sigma_t) \quad \text{for double weld}$$
$$P = 1.414 \times t \times l \times \sigma_t$$

Where,

P = load acting
t = thickness of weld
l = length of weld

$$P = 1.414 \times 3 \times 100 \times 280$$
$$P = 118776\ N$$
$$P = 118.776 KN$$

Deformation in the plate is given by,

$$\delta = \frac{P \times l}{A \times E}$$
$$= \frac{118776 \times 100}{300 \times 2.1 \times 10^5}$$
$$\delta_3 = 0.188\ mm$$

The theoretical analysis shows that the maximum load carrying capacity is for 3rd electrode named Orange E-7018. Remaining two electrodes are generally used for light duty applications.

4 FINITE ELEMENT FORMULATIONS

Finite element analysis has been carried out by ANSYS12 software. ANSYS is a general-purpose finite-element modelling package for numericallysolving a wide variety of mechanical problems. These problems include static/dynamic, structural analysis (both linear and nonlinear), heat transfer, and fluidproblems, as well as acoustic and electromagnetic problems.

In general, a finite-element solution may be broken into the following three stages.

(1) Pre-processing: defining the problem

The major steps in pre-processing are

(i) Definekey points/lines/areas/volumes,
(ii)Define element type and material/geometric properties, and
(iii) Meshlines/areas/ volumes as required.

The amount of detail required will depend on the dimensionality of the analysis,i.e., 1D, 2D, axisymmetric, and 3D.

(2)Solution: assigning loads, constraints, and solving. Here, it is necessary to specify the loads (point or pressure), constraints(translational and rotational), and finally solve the resulting set of equations.

(3) Post processing: Further processing and viewing of the results

In this stage one may wish to see (i) lists of nodal displacements, (ii) elementforces and moments, (iii) deflection plots, and (iv) Frequencies and temperature maps.

Following steps show the guidelines for carrying out Modal analysis.

Define Materials

1. Set preferences. (Structural)
2. Define constant material properties.

Model the Geometry

3. Follow bottom up modelling and create/import the geometry

Generate Mesh

4. Define element type.
5. Mesh the area.

Apply Boundary Conditions

6. Apply constraints to the model.

Obtain Solution

7. Specify analysis types and options.
8. Solve.

The ANSYS 12 finite element program was used for static structural analysis of double parallel fillet weld. For this purpose, the total 3assembly models with plates and weld are created in CAD software (CATIA) and imported in ANSYS (.stp file). The model wasdiscretised into no. of elements with N nodes. Boundaryconditions can also be modelled by constraining all degrees offreedoms of the nodes located on the model. The subspace mode extractionmethod was used to calculate the total deformation of the model.

For the model creation different dimensions taken as follows:

Plate length - 100 mm
Plate width - 60mm
Plate thickness - 6 mm
Thickness of weld – 3 mm

The figure 3 shows the meshing of the model. The results of finite element analysis for the model have total deformation is shown below in the figure 4.

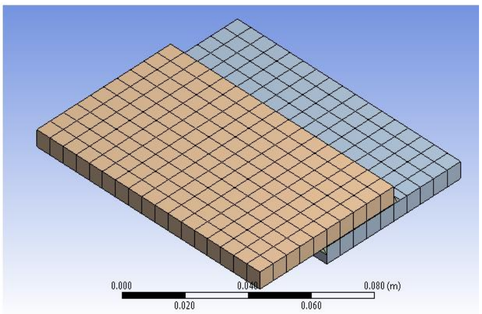

Figure 3 Typical Meshing of the Lap Weld Model

Similarly all the load and deformation have tested by finite element modelling. The results are tabulated in the table 3.

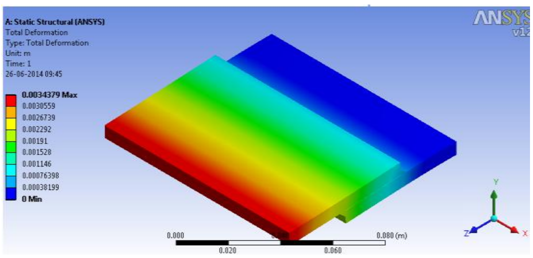

Figure 4 Typical Finite Element Analysis of the Lap Weld Model

Table 3Finite Element Results of the Different Models

Sr. No.	Electrode Name	Load (KN)	Deformation (mm)
1	E-6012	102.62	0.1642
2	E-7014	115.15	0.1765
3	E-7018	120.72	0.1892

5 DISCUSSION AND CONCLUSION

Discussion based on the output generated by Theoretical analysis and the information supplemented by FEA analysis in ANSYS is as follows:

It is already known that the welding material greatly effect on the structural part. Firstly determination of load and deformation on different models of different plates weld with different electrodes numerically and then FEA analysis in ANSYS. Here total 3 models have been used taking different combinations of electrodes. Several steps have been shown to develop a FE solution which is explained through an example and all the result values have been tabulated in table 3.

The figure 5 shows the effect of load on deformation for various electrodes.

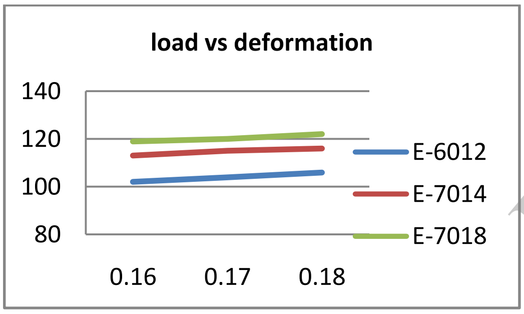

Figure 5 Loads vs. Deformation for Weld Electrodes

The deformations for first, second, third electrodes are 0.16, 0.179, 0.188 mm respectively.

From the above values the deformation for first and second electrodes is less than 3% of deformation value that is 0.18. However the value of third electrode is greater than the value of deformation. In such a case there is a chance of plastic deformation of the plate which is not required. The value 3% is used because the value for deformation in welding process is maximum 3%. If the value exceeds this value it may cause plastic deformation.

Hence the first and second electrode is better to use and third electrode is used for higher applications.

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