Mathematical Analysis & FEA Simulation for Effect of Throat Thickness on Mig Welded Joint Strength

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***Abstract*: Energy storage device is a very critical electrical component used at converter of the many locomotives. The energy storage devices are made up of AISI 1040 steel cases or boxes. Bulging effects in these boxes exerts tensile load on welded joint and breaks them. AISI 1040 is having good weld ability. The boxes of these materials are joined with MIG welding with the filler metal of ER 70S-6. In order to improve its tensile strength the throat thickness of the weld was insufficient. By increasing throat thickness strength of the joint will also improves. In this paper the effect of increasing throat thickness on the tensile strength of the joint is analyzed by using theoretical design equations. It is then simulated in the ANSYS software to confirm these effects. From result it is seen that increase in throat thickness will improve the tensile strength of the joint. It is also seen that the maximum stress acts at the area adjacent to the weld and stresses at weld are much lesser than the UTS of filler metal and just less than yield strength of the filler metal with higher throat thickness.**

***Keywords*: AISI 1040, ER 70S-6, ANSYS, Throat thickness, UTS, Yield.**

I. INTRODUCTION

MIG welding which is also called as GMAW. i.e. Gas metal arc welding is used to join the case of capacitor. In this type of welding a wire from reel is fed through a torch which is in contact with base metal & which supplies a current. The wire melts & converts into pool by arc. The welding arc is protected by shield gas. It is necessary to avoid oxidation of weld pool. Coating is given on electrode wire in order to produce a smoke which is also acts like a shield. Depending on the shielding gas process is divided into two types: i) MIG (Metal Inert gas) ii) MAG (Metal Active Gas). In Metal active gas welding a reactive gas like carbon dioxide (CO2) is used to protect the weld while MIG welding used an inert gas like argon. Generally MIG welding is applied for aluminum, copper, stainless steel and high alloyed steel, metal transfer in the MIG welding is done by two methods: spray arc & short circuiting arc. In spray arc process an arc is introduced in between welding wire & work piece. The transfer of metal pool is in the form of continuous spray. The arc avoids spatters and it provides deep penetration in base material. In order to obtain spray arc, it is necessary to keep welding current above certain minimum value. The current level is depends on shielding gas, alloy, size of welding wire. So generally for wire having diameter greater than or equals to 0.8mm uses the current limit above 150 amperes. In short arc process no metal is transferred through an arc. It creates short circuits between wire and work piece, wire is fed again into arc. The arc produced in this method is having low heat input. To obtain a better weld the arc voltage & arc length must be kept at constant value. This can be done by two ways: i) by adjusting the filler material feed speed to exactly the same as its melting. ii) by adjusting the ampere to exactly at the value required to melt the material. The basic elements of MIG welding equipment are

i) Power source
ii) Welding current switch
iii) Power supply to wire feeder
iv) Gas cylinder, Gas valve
v) Gas regulator with flow adjustment
vi) Wire feed motor with drive rolls.
vii) Cable package including welding current cable, gas hose, control circuit cables and wire feed tube Torch with contact tip for supplying current to the nozzle and control switch.

In this case of energy storage device base material of steel AISI 1040 & filler metal of ER 70S-6 is used. Following are the properties of both the materials.

Table 1 Properties of materials

Base Material- AISI 1040	
Ultimate Tensile Strength	620 MPa
Yield Strength (60 % of UTS)	372 MPa
Young's Modulus	210000 MPa
Poisson's Ratio	0.3
% Elongation	25 %
Filler Material- ER 70S-6	
Ultimate Tensile Strength	583 MPa
Yield Strength (60 % of UTS)	350 MPa
Young's Modulus	190000 MPa
Poisson's Ratio	0.29
% Elongation	26 %

Yield Strength: The yield strength of a metal is the stress level at which the metal exhibits a specified deviation from the proportionality of stress and strain.

Tensile Strength: The ratio of the maximum load sustained by a tension test specimen to the original cross-sectional area is referred to as the *ultimate tensile strength* (*UTS*).

Weld Joint Design: While selecting the types of joints following guidelines are necessary:

1. The joint design that requires the least amount of weld metal should generally be selected;
2. Otherwise, square-groove and partial joint penetration groove welds should be used whenever they satisfy strength and serviceability requirements
3. Double-V- or U-groove welds should be used instead of single-V- or U-groove welds on thick plates to minimize the amount of deposited weld metal and resulting distortion.

Size and Amount of Weld: Overdesign is a common error, as is over welding in production. The control of weld size begins with design, but it must be maintained during the assembly and welding operations. The following are basic guidelines regarding the control of weld size:

1. Adequate but minimum size and length should be specified for the forces to be transferred. Oversized welds may cause excessive distortion and higher residual stress without improving suitability for service; they also contribute to increased costs. The size of a fillet weld is especially important because as the fillet weld size increases, the weld metal cross-sectional area increases in proportion relative to the weld size squared.
2. Weld size should not be larger than that required for the strength of the thinner work piece based on the load.

II. THEORETICAL ANALYSIS

Strength of a welded joint: The main failure mechanism of welded butt joint is tensile failure. Therefore the strength of a butt joint is

$$F = \sigma h l_e$$

Where, σ = allowable tensile strength of the weld material in Mpa

h = Throat thickness of the weld in mm

l_e= Effective length of the weld in mm

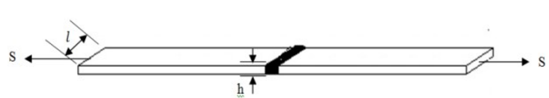

Fig 5 Welded joint sample

Effective length of the weld is given by

$l_e = l + 1.5 \times (Minimum\ metal\ thickness)$

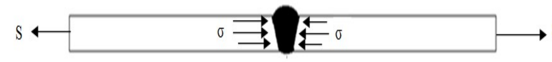

Fig 6 Stress on Welded joint

In this case the value of σ is taken as 350 Mpa (60% of the UTS of Material ER 70S-6)

Case 4 to calculate the strength of a weld Throat thickness is taken as h = 5mm.

$F = \sigma h l_e$

$= 350 \times 5 \times 16.5$

$= 28875N = 28.87\ KN$

By observing the result value of the weld strength is at safer side as it is more than applied load of 16 KN.

Similarly the values of equivalent stresses for throat thickness from 3 to 5 mm are as given in the table.

Table 2 calculated values of strength of weld

Yield strength σ (Mpa)	Maximum Force Sustain S (N)	Throat thickness 'h' mm	Length of weld l mm
175	8662.50	3	12
350	20212.50	3.5	12
350	23100.00	4	12
350	28875.00	5	12

Von Mises stress: As per distortion energy theory equivalent stresses on the welded joints are given by

$\sigma' = \sqrt{\sigma^2 + 3\tau^2}$

Where σ = Normal stress on weld (Mpa)

τ = Shear stress on weld (Mpa)

Normal stress on weld is given by the equation,

$\sigma = \frac{F}{hl}$ And $\tau = \frac{\sigma}{\sqrt{3}}$

Where F = Maximum normal Force applied (N)

h = Throat thickness of the weld in mm

l= Length of the weld in mm

For **case 1** having throat thickness h = 3mm

$\sigma = \frac{F}{hl} = \frac{16000}{36} = 444.44\ Mpa$

$\tau = \frac{\sigma}{\sqrt{3}} = \frac{500}{\sqrt{3}} = 220.00\ Mpa$

$\sigma' = \sqrt{\sigma^2 + 3\tau^2} = 585.43\ Mpa$

As the Maximum Stress is 585.43 MPa, which is higher than the Ultimate Tensile Strength of (583 MPa) Filler Material, hence the Weld is not safe and Fail against given tensile loading and throat thickness 3 mm.

For **case 2** having throat thickness h = 3.5 mm

$$\sigma = \frac{F}{hl} = \frac{16000}{12 \times 3.5} = 380.95\ Mpa$$

$$\tau = \frac{\sigma}{\sqrt{3}} = \frac{500}{\sqrt{3}} = 190.48\ Mpa$$

$$\sigma' = \sqrt{\sigma^2 + 3\tau^2} = 503.95\ Mpa$$

As the Maximum Stress is 503.95 MPa, which is less than the Ultimate Tensile Strength (583 MPa) of Filler Material, hence the Weld is safe against given tensile loading and throat thickness 3.5 mm.

For **case 4** having throat thickness h = 5 mm

$$\sigma = \frac{F}{hl} = \frac{16000}{12 \times 5} = 266.67\ Mpa$$

$$\tau = \frac{\sigma}{\sqrt{3}} = \frac{500}{\sqrt{3}} = 132.01\ Mpa$$

$$\sigma' = \sqrt{\sigma^2 + 3\tau^2} = 349.76\ Mpa$$

As the Maximum Stress is 349.76 MPa, which is less than the Ultimate Tensile Strength (583 MPa) of Filler Material and lower than Yield strength in tension (60% UTS = 350Mpa), hence the Weld is safe against given tensile loading and throat thickness 5 mm.

Table 3 calculated values of equivalent stress on welding

Throat thickness 'h' mm	Normal stress σ (Mpa)	Shear stress τ (Mpa)	Von Mises stress σ' (Mpa)	Maximum Force applied normal 'F' (N)
3	444.44	220.00	585.43	16000
3.5	380.95	190.48	503.95	16000
4	333.33	165.00	439.07	16000
5	266.67	130.67	349.76	16000

Result: Theoretical analysis of the welded joint shows that maximum stress at the weld for 3mm throat thickness 585.43 Mpa and minimum stress for 5mm throat thickness 349.76 Mpa. For 5mm throat thickness strength of the weld was 28.87 KN. This is much more than the applied load of 16 KN. Hence for 5mm throat thickness design was safe.

III. SIMULATION IN ANSYS

Simulation is done to find out exact solution for throat thickness and strength value for weld. Non Linear Structural Analysis has been performed by using Bilinear Isotropic Hardening Material Model.

Modelling of Sample: 3D modelling of a sample is done by using catia V5 software with a model dimension of 150mm x 12mm x 3mm thickness. Two strips of material AISI 1040 of dimensions 72.5mm x 12 x 3mm are joined by 5mm width of welding of material ER 70S-6. Material is applied to the model as mentioned. Throat thickness is taken as 3mm for first two cases and then it is varied as 3.5, 4 and 5mm respectively.

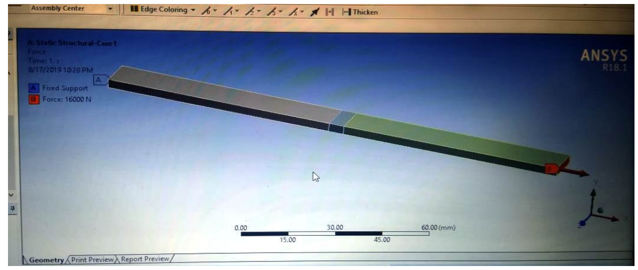

Fig. 1 3D Model of a test specimen

Loading & Boundary Conditions: Load of 16000 N is applied gradually from 0 to 16000 N from both end

Boundary Condition: Simulated as per Test conditions (40 mm Fixed at one end) See below image for Loading and Boundary Conditions:

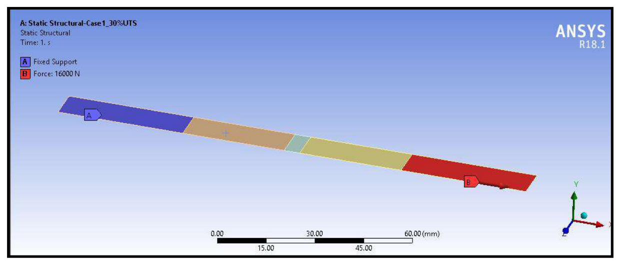

Fig. 2 applying boundary conditions while loading

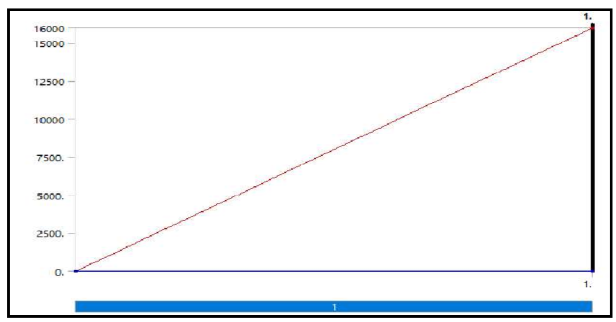

Figure 3: Load applied in Simulation

Case 1: Base Material Thickness – 3mm, Throat Thickness 3mm

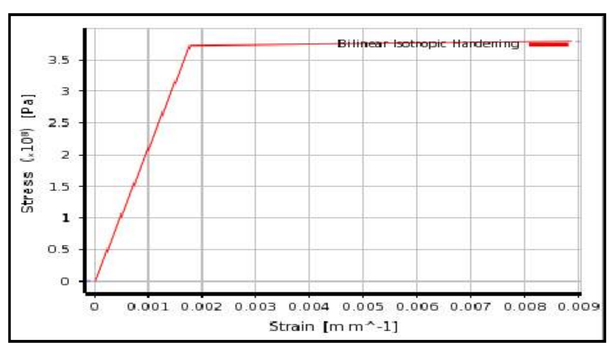

Figure 4: Input Material Properties of AISI 1040 for simulation-Case 1

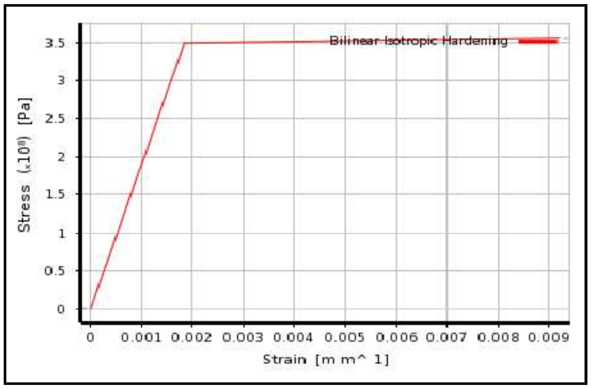

Figure 5: Properties of Filler Material for simulation-Case 1

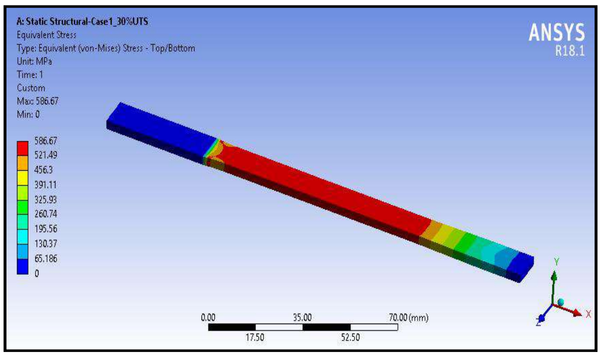

Fig.6 Stress Result-Case 1

Result Case1**:** As the Maximum Stress is 586.67 MPa, which is higher than the Ultimate Tensile Strength (583 MPa) of Filler Material, hence the **Weld is not safe** and **Fail** against given tensile loading and throat thickness 3 mm.

Case 2: Base Material Thickness – 3mm

Throat Thickness- 3.5 mm

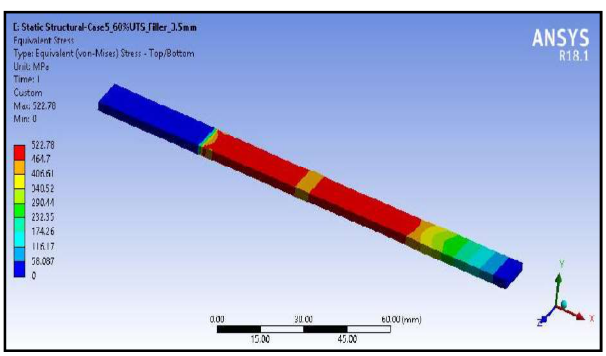

Fig.7 Stress Result-Case 2

Result case2: As the Maximum Stress is 522.78 MPa, which is less than the Ultimate Tensile Strength (583 MPa) of Filler Material, hence the **Weld is safe** against given tensile loading and throat thickness 3.5 mm.

Case 3: Base Material Thickness – 3mm

Throat Thickness- 4 mm

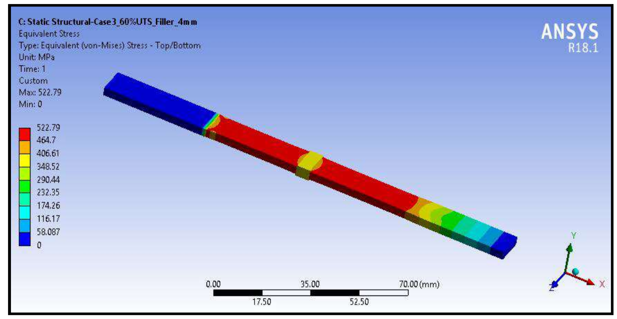

Fig.8 Stress Result-Case 2

Result case 3: As the Maximum Stress is 522.79 MPa, which is less than the Ultimate Tensile Strength (583 MPa) of Filler Material, hence the **Weld is safe** against given tensile loading and throat thickness 4 mm.

Case 4: Base Material Thickness – 3mm

Throat Thickness- 5 mm

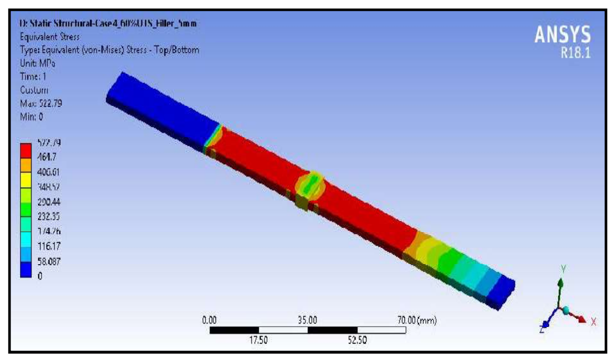

Fig.9 Stress Result-Case 4

Result case4: As the Maximum Stress is 522.79 MPa, which is less than the Ultimate Tensile Strength (583 MPa) of Filler Material, hence the Weld is safe against given tensile loading and throat thickness 5 mm.

IV. RESULTS AND DISCUSSIONS

1) Maximum stress on welded joints

Table No 4 Strength comparisons

Variable	For 3mm	For 5mm
Theoretical maximum stress on welded joint	585.43 Mpa	349.76 Mpa
Maximum stress on welded joint in ANSYS Simulation	586.67 Mpa	348.52 pa

2). Comparing Theoretical analysis with ANSYS:

Table No 5. Comparison of theoretical and ANSYS value

Throat thickness 'h' mm	Theoretical maximum stress value σ (Mpa)	Maximum Stress value through ANSYS σ (Mpa)	Result	Remark
3	585.43	586.67	Greater than UTS of 583 Mpa	Design is not safe
3.5	503.95	464.70	Less than UTS of 583 Mpa	Design is safe
4	439.07	406.61	Less than UTS of 583 Mpa	Design is safe
5	349.76	348.52	Less than UTS of 583 Mpa & Less than Yield strength of 350 Mpa	Design is very safe

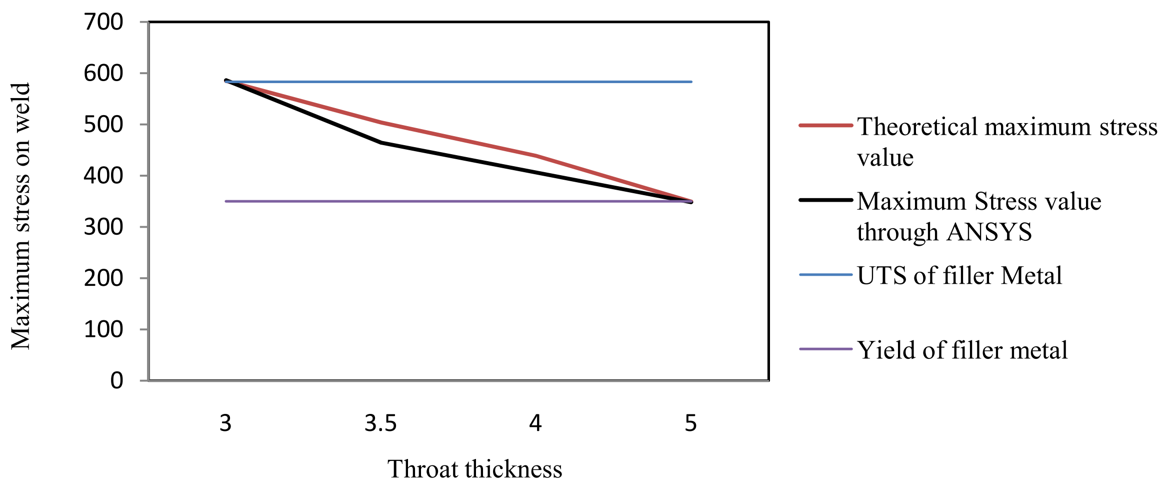

Fig 10 Comparing maximum stress with throat thickness

- From simulation it has been observed that for failure case maximum or Von Mises stress acting on welded joint was 586.67 Mpa which was greater than the Ultimate tensile strength of the filler material (583 Mpa) hence the joint has failed.
- In next consecutive trials, throat thickness of the weld increased by 0.5mm and yield strength of weld taken as 60% of UTS of filler metal 350 Mpa.
- In case 2 it is having 3mm throat thickness but yield strength can be taken as 60% of UTS of filler metal which exerts maximum tensile stress of 544.54 Mpa. In case 3 and 4 the throat thickness is increased by 0.5 mm that is 3.5 and 4mm respectively. Increase in throat thickness reduces the maximum stress on the weld which is 464.7 Mpa and 406.61 Mpa.
- For case 5 having throat thickness of 5mm maximum tensile stress acting on welded joint is observed to be 348.52 Mpa which is very less than UTS of filler metal 583 Mpa and even less than yield strength of filler metal 350 Mpa. Hence design of weld is very safe.
- From figure 10 it is seen that increase in throat thickness, there is decrease in maximum stress and increase in the UTS of the joint.

V. CONCLUSION

By comparing theoretical stress value with the stress value obtained in the simulation in ANSYS software, it can be seen that case 1 where design is not safe and in rest all other cases design is safe as it is clearly seen that Stress reduces with increase in throat thickness. It is also observed that throat thickness has linear relationship with the welding strength or UTS of the weld joint. As a design & functional limitations in order to freeze the welding parameters case 4 with throat thickness 5 mm is selected. Hence experimentation will be done with constant throat thickness of 5mm.

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