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Analyzing Weld Joint Efficiency in Metal Inert Gas Welding Using MATLAB Simulink

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ABSTRACT
This study is to improve the efficiency of weld joints in Metal Inert Gas (MIG) welding operations. Determine the strength of the base material of mild steel weld joint at throat thickness, shear stress and normal stress analyzed, residual stress evaluated. MATLAB computer program was employed to validate the results obtained in analyzing the welding parameters on AISI1020 mild steel. The experimental analyses were conducted using 9 mild steel specimens. The maximum residual Von Mises stress operating on a welded joint with a throat thickness of 2mm was 1697.06Mpa in the failure instance, was larger than the ultimate tensile strength of the filler material (583 MPa), and hence the joint collapsed. The throat thickness of the weld was increased by 0.5mm in subsequent trials, and the results revealed that as the throat thickness of the weld joint rose, the strength of the weld joint improved, while the normal stress, shear stress, and Von Mises stress on the weld joint reduced.The maximum stresses on the welded joints specimens with throat thicknesses ranging from 2.0mm to 5.5mm were greater than the filler metal's ultimate tensile strength, making them unsafe for the joint, except for specimen 9 with a throat thickness of 6mm, which had a maximum stress of 569 MPa, which was less than the filler metal's ultimate tensile strength of 583 MPa, making the weld joint safe against tensile loading of 36KN.

KEYWORDS: Analyzing Weld Joint Efficiency, Metal Inert Gas Welding, Von Mises Stress

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1. INTRODUCTION
Welding is one of the most crucial talents in modern civilization, literally holding things together. It makes significant contributions to today's global industrial revolution, since it is used in a variety of industries including shipbuilding, autos, and the oil and petroleum sectors. Welding is the process of permanently connecting two metal parts together by heating them together. (Klas, 2003). It is the process of permanently uniting two materials (typically metals) through localized coalescence caused by the right mix of temperature, pressure, and metallurgical conditions. Although most welding processes are used to join pieces composed of the same metal composition, some welding operations can be utilized to join parts made of dissimilar metals. (Kash *et al.,* 2016: Cary & Helzer, 2005). A wide range of welding methods has been created based on temperature and pressure combinations ranging from high temperature with no pressure to high pressure with low temperature.

Solid State Welding is a term used to describe joining methods in which coalescence is achieved through the application of pressure alone or in combination with heat. The temperature in the operation is below the melting point of the metals being welded if heat is applied. Diffusion welding (DFW), in which two surfaces are kept together under pressure at a high temperature and the pieces coalesce by solid state fusion, is an example of this set of welding methods; Friction welding (FRW) involves applying moderate pressure to two parts and using an oscillating motion at ultrasonic frequencies in a direction parallel to the contacting surfaces to achieve coalescence. Ultrasonic welding (USW) involves applying moderate pressure to two parts and using an oscillating motion at ultrasonic frequencies in a direction parallel to the contacting surfaces to achieve coalescence. The weld section's efficiency is improved by the lack of residual

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stresses. The most prevalent causes of welded structure failures are low quality weld joints or sections because of severe residual stresses. Failures could occur during the fabrication process or during service. Cracks, lack of penetration, lack of fusion, porosity, slag inclusions, deformation, and undercut are some of the failures that can occur in a weld joint during service, etc. (Smith & Warwick 1981).

In this study, welding simulation was carried out on AISI1020 mild steel butt joints using ANSYS finite element modeling (FEM) software and MATLAB Simulink software to evaluate the value of stress, strain, distortion, thermal history and hot spots for butt welding geometries and conditions. The weld loads and distribution of weld loads were determined along the joint. Weld joint loads were resolved at each FEA node of the joint in the model, which is useful for static and fatigue failure prediction. To increase the strength efficiency and quality of the AISI1020 mild steel weld joint, the physical, mechanical, and thermal properties of the base metal (AISI1020 mild steel), as well as the welding geometry and welding speed, were examined and adjusted.

2. MATERIALS AND METHODS

2.1 Materials

The material used in this research work were two strips of AISI1020 mild steel base metal, welded together by varying the throat thickness, and data of physical, thermo-mechanical properties of mild steel base metal and filler metal. The experiment was conducted in the welding workshop of Sky International Training Center, Kilometre II East West Road, Rumuokoro, Off Uniport Road, Port Harcourt. MATLAB computer program were tools used to analyse the data.

2.1.1 Work Piece Specification

The material used in this investigation is made of AISI 1020 mild steel. The physical, mechanical, and thermal properties are listed in Tables 1, 2, and 3, respectively. With a Brinell hardness of 119–235 and a tensile strength of 410-790 MPa, AISI 1020 is a low hardenability and low tensile carbon steel. (AZo Materials, 2020). It has excellent machinability, strength, ductility, and weldability. It is typically employed in a turned and polished or cold drawn state. It resists induction hardening and flame hardening due to its low carbon concentration. It will not respond to nitriding due to a lack of alloying elements. AISI 1020 steel has a good machinability when cold drawn or turned and polished. AISI 1020 steel can be welded together with different types of metals, according to machine maker specifications.
The physical properties of the AISI 1020 mild steel work-piece material are presented in Table 1.

Table 1: Physical Properties of the AISI 1020 Mild Steel Workpiece

Physical Properties	
Density	7.87g/m^3 (0.284lb/in^3)
Specific Gravity	7.9
Specific Heat	486J/kgK @ 373K/100°C 519J/kgK @ 473K /200°C 599J/kgK @ 573K /400°C
Electrical Resistivity	0.159µΩ.m @ 32°F/0°C 0.219µΩ.m @ 212°F/100°C 0.292µΩ.m @ 392°F/200° C
Melting Point	27600 ° F (1515 ° C)
Modulus of Elasticity	186GPa (27 x 10^{6}psi)

(Source: Azo Materials, 2020)

The mechanical properties of the AISI 1020 mild steel work-piece material are presented in Table 2.

Table 2: Mechanical Properties of the AISI 1020 Mild Steel Workpiece

Mechanical Properties Properties	Metric	Imperial

Hardness, Brinell	111	111
Hardness, Knoop	129	129
Hardness, Rockwell	64	64
Hardness, Vickers	115	115
Tensile Strength, Ultimate	394.72MPa	57249psi
Tensile Strength, Yield	294.74MPa	42748psi
Elongation at Break (in 50mm)	36.5%	36.5%
Reduction of Area	66.0%	66.0%
Bulk Modulus	140GPa	20300ksi
Poisson Ratio	0.29	0.29
Cyclic Fatigue Properties		
Cyclic strength coefficient	1205MPa	175ksi
Fatigue strength coefficient	850MPa	123ksi
Fatigue strength exponent	-0.12	-0.12
Fatigue ductility coefficient	0.44	0.44
Fatigue ductility exponent	-0.15	-0.15
Charpy Impact		
@ Temperature -30.0^{0}C/-22.0^{0}F	16.9J	12.5ft-lb
@ Temperature -18.0^{0}C/-0.40^{0}F	18.0J	13.3ft-lb
@ Temperature -3.0^{0}C/26.6^{0}F	20.0J	14.8ft-lb
@ Temperature 10.0^{0}C/50.0^{0}F	24.0J	17.7ft-lb
@ Temperature 38.0^{0}C/100.0^{0}F	41.0J	30.2ft-lb
@ Temperature 65.0^{0}C/149.0^{0}F	54.0J	39.8ft-lb
@ Temperature 95.0^{0}C/203.0^{0}F	61.0J	45.0ft-lb
@ Temperature 150.0^{0}C/302^{0}F	68.0J	50.2ft-lb
Izod Impact	125J	92.2ft-lb
Shear Modulus	80.0GPa	11600ksi

(Source: Azo Materials, 2020)

The thermal properties of the AISI 1020 mild steel work-piece material are presented in Table 3.

Table 3: Thermal Properties of the AISI 1020 Mild Steel Workpiece

Coefficients of Thermal Expansion	
Value (10^{-6}/K)	**Temperature ^{0}C (^{0}F)**
11.7	20 – 100 (68 – 212)
12.1	20 – 200 (68 – 392)
12.8	20 – 300 (68 – 572)
13.4	20 – 400 (68 – 752)
13.9	20 – 500 (68 – 932)
14.4	20 – 600 (68 – 1112)
14.8	20 – 700 (68 – 1292)
Thermal Conductivity	
Value (W/mK)	**Temperature ^{0}C (^{0}F)**
51.9	0 (32)
51.0	100 (212)
48.9	200 (392)

(Source: Azo Materials, 2020)

2.1.2 Filler Metal Specification

ER 70S-6 mild steel welding wire billets were used as filler metal. The ER 70S-6 welding wire is a solid bare wire that can be used in a variety of manual and semiautomatic applications across a wide range of industries.

Table 4: Mechanical Properties of Filler Metal ER 70S-6 Mild Steel Welding Wire

Mechanical Properties		
Properties	**Metric**	**Imperial**
Ultimate Tensile Strength	583 MPa	84, 535psi
Yield Strength (60% of UTS)	483 MPa	70, 035psi
Young's Modulus	190000 MPa	27, 550, 000psi
% Elongation	26%	26%
Poisson's Ratio	0.29	0.29

(Source: Azo Materials, 2020)

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Table 5: Recommended Welding Parameters for Filler Metal ER 70S-6 Mild Steel Welding Wire

Process	Dimensions of Wire (inches)	Amperage (A)	Voltage (V)	Gas/Flux
GTAW (TIG)	1/16''	50 – 120	7 – 13	Ar
	3/32''	120 – 200	10 – 16	Ar
	1/8''	150 – 220	12 – 18	Ar
GMAW (MIG) SHORT ARC	0.035''	90 – 160	14 – 20	CO_2
	0.045''	120 – 200	16 – 20	CO_2 or 75Ar/25 CO_2
	1/16''			CO_2 or 75 Ar/25 CO_2
GMAW (MIG) SPRAY TRANSFER	0.035''	180 – 230	25 – 28	98 Ar/ 2-5% CO_2 or O_2
	0.045''	250 – 350	25 – 30	75 Ar/25 CO_2
	1/16''	280 – 400	26 – 36	75 Ar/25 CO_2

(Source: Azo Materials, 2020)

2.2 Methods of Data Analysis

This study can improve weld joint efficiency of butt welding by analysing and simulation of MIG welding process.

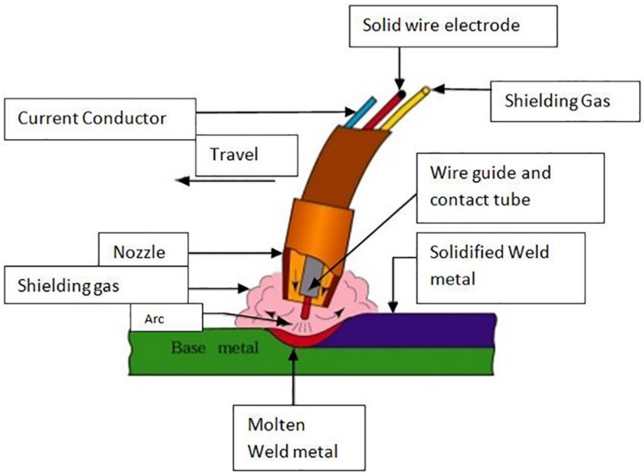

Figure 1: Metal Inert Gas Welding (Hitesh et al., 2018)

Figure 1 show MIG welding process, which is also known as GMAW (Gas metal arc welding), is used to join the case of capacitor. In this type of weld joint a wire from reel is fed through a torch which is in contact with base metal, and which supplies a current. The wire melts and converts into pool by arc. The welding arc is protected by shield gas.

To conduct the simulation, AISI1020 mild steel plate specimen was selected and analysed for tensile test, there are numbers of tensile test specimen geometries, the most common once are: parallel-sided, dumb-bell or dog-bone and waisted types. A typical dumb-bell specimen geometry used for the analysis is shown in Figure 2.

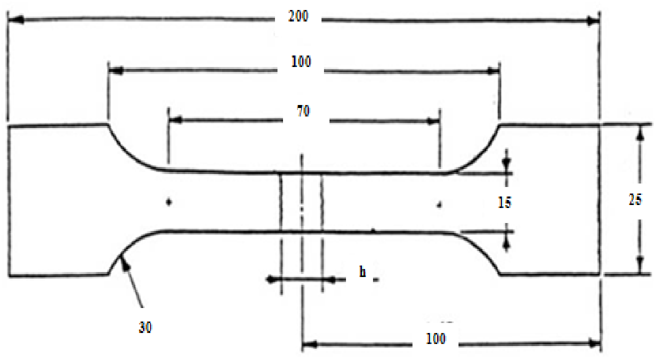

Figure 2: Butt Joint Welded Specimen for Tensile Test

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The major failure associated with the mechanism of welded butt joint is tensile failure. Therefore, the strength of a butt joint is expressed as:

$$F = \sigma h l_e \quad (1)$$

where

σ = allowable tensile strength of the weld material

h = throat thickness of the weld

l_e = effective length of the weld

The effective length of the weld is given by:

$$l_e = l + (1.5 \times \textit{minimum metal thickness}) \quad (2)$$

The Von Mises Stress on the welded joints are given by:

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

The normal stress on the weld joint material is given by:

$$\sigma = \frac{F}{hl} \quad (4)$$

The shear stress on the weld joint material is given by:

$$\tau = \frac{\sigma}{\sqrt{3}} \quad (5)$$

MATLAB Simulink was used to simulate the results obtained from the analysis of the strength and equivalent stresses on butt welded joint subjected to tensile test. The geometry, physical and mechanical properties of the specimen was obtained from Sky International Training Center, Kilometer II East West Road Rumuokoro, off Uniport Road, Port Harcourt, on the properties of AISI1020 mild steel from secondary sources and encoded into the MATLAB Simulink selected to perform the welding simulation, to estimate the stress, strain, distortion, thermal history and hot spots on the AISI1020 mild steel specimen for butt welding conditions and optimize the welding parameters that improves the efficiency of the weld joint in metal inert gas (MIG) welding.

2.3 Weld Joint Design

The following guidelines must be followed while choosing joint types:

i. In general, the joint design that requires the least amount of weld metal should be used.

ii. Otherwise, whenever strength and serviceability are required, square-groove and partial joint penetration groove welds should be employed.

2.4 Size and Amount of Weld

Overdesign, like over welding in production, is a common blunder. Weld size control begins with design, but it must be maintained throughout the assembly and welding processes.

3. RESULTS AND DISCUSSION

3.1The Analysis for the Strength of Weld Joint

The data of two strips of material AISI1020 mild steel base metal dimensioned 96.5mm x 15mm x 4mm were joined by 6mm width of welding material ER 70S-6 having yield strength and allowable tensile strength of 483MPa (see Table 4) making a dimension 200mm x 15mm x 4mm were subjected to a tensile tester, also known as a pull tester or universal testing machine which is an electrochemical test system that applies a tensile (pull) force of 36KN to the two strips of material welded with various throat thickness to determine the tensile strength and deformation behaviour until break, at each throat thickness of the welded material as shown in Figure 3.

Figure 3: The Universal Testing Machine

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The analysis for the determination of the strength of the square butt joint was performed for nine specimen steel base metals with similar length and breadth dimension but with varied throat thickness (h): 2mm, 2.5mm, 3mm, 3.5mm, 4mm, 4.5mm, 5mm, 5.5mm and 6mm. as shown in Figure 4.

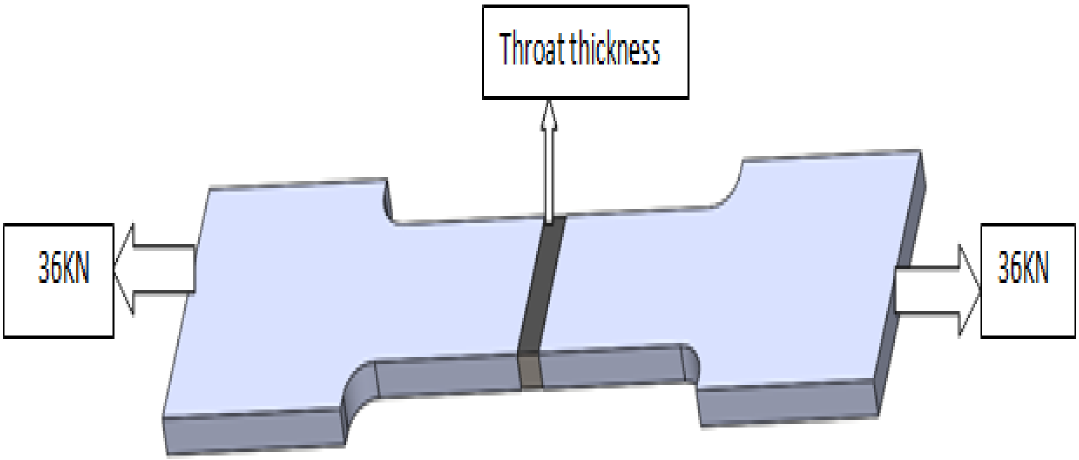

Figure 4: The Framework of Mild Steel Base Metal for Tensile Test

Table 6: Calculated Values for Weld Joint Strength

Specimen	Yield Strength (MPa)	Length of Weld (mm)	Throat Thickness (mm)	Weld Joint Strength/Maximum Force Sustained (KN)
	483	15	2.0	17.39
2	483	15	2.5	21.74
3	483	15	3.0	26.08
4	483	15	3.5	30.43
5	483	15	4.0	34.78
6	483	15	4.5	39.12
7	483	15	5.0	43.35
8	483	15	5.5	47.82
9	483	15	6.0	52.17

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Table 7: Calculated Values of Equivalent Stress on Weld Joint

Specimen	Ultimate Tensile Strength (MPa)	Length of Weld (mm)	Throat Thickness (mm)	Normal Stress (MPa)	Shear Stress (MPa)	Von Mises (MPa	Maximum Load applied (N)
1	583	15	2.0	1200.00	692.82	1697.06	36000
2	583	15	2.5	960.00	554.24	1357.62	36000
3	583	15	3.0	800.00	461.86	1131.35	36000
4	583	15	3.5	685.71	395.89	969.73	36000
5	583	15	4.0	600.00	346.40	848.58	36000
6	583	15	4.5	533.33	307.91	754.23	36000
7	583	15	5.0	480.00	277.12	678.81	36000
8	583	15	5.5	436.36	251.93	617.10	36000

Table 8: Theoretical and Simulated Values of Strength and Equivalent Stress on Weld Joint

Specimen	Ultimate Tensile Strength (MPa)	Throat Thickness (mm)	Strength of Weld Joint (kN)	Normal Stress (MPa)	Shear Stress (MPa)	Von Mises Stress (MPa)	Maximum Load applied (kN)
1	583	2.0	17.39	1200.00	692.82	1697.06	36
2	583	2.5	21.74	960.00	554.24	1357.62	36
3	583	3.0	26.08	800.00	461.86	1131.35	36
4	583	3.5	30.43	685.71	395.89	969.73	36
5	583	4.0	34.78	600.00	346.40	848.58	36
6	583	4.5	39.12	533.33	307.91	754.23	36
7	583	5.0	43.35	480.00	277.12	678.81	36
8	583	5.5	47.82	436.36	251.93	617.10	36
9	583	6.0	52.17	400.00	230.93	565.68	36

Figure 5 indicate the result of the weld joint's strength The strength of the weld joint improves as the throat thickness of the weld junction grows, as seen in the graph.

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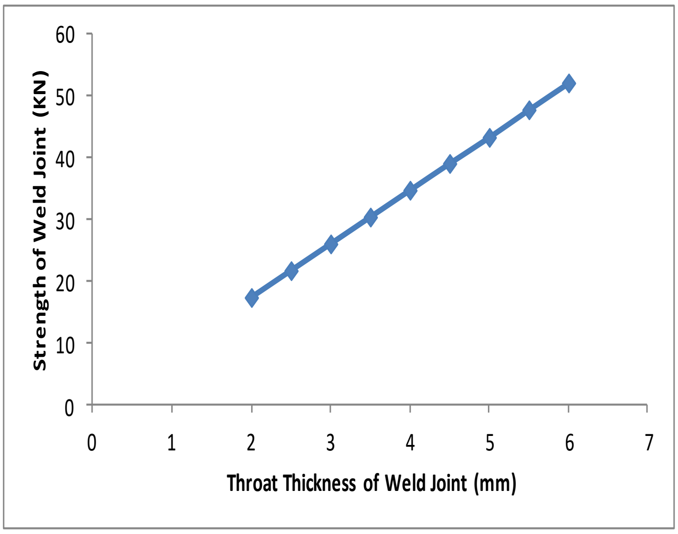

Figure 5: Strength of Weld Joint.

Figure 6.exhibitthe weld joint's response to typical stress. The graphical representation indicates that when the throat thickness of the weld joint grows, the typical stress on the junction reduces.

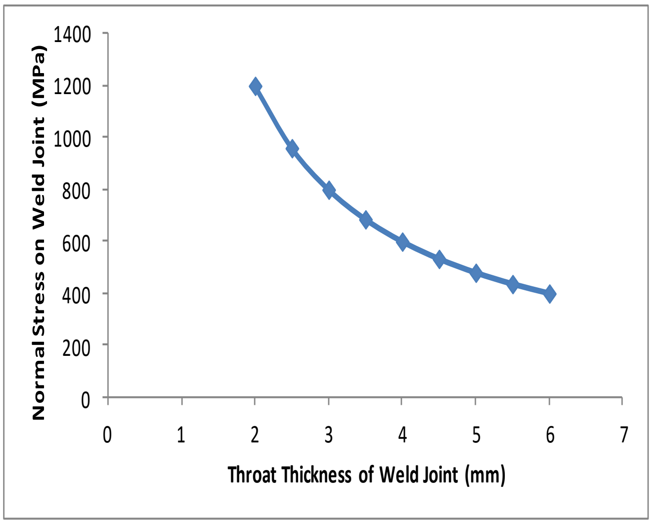

Figure 6: Normal Stress on Weld Joint.

Figure 7.exhibits the weld joint's reaction to shear stress. The shear forces on the weld joint decrease as the throat thickness of the weld joint grows, as seen in the graph.

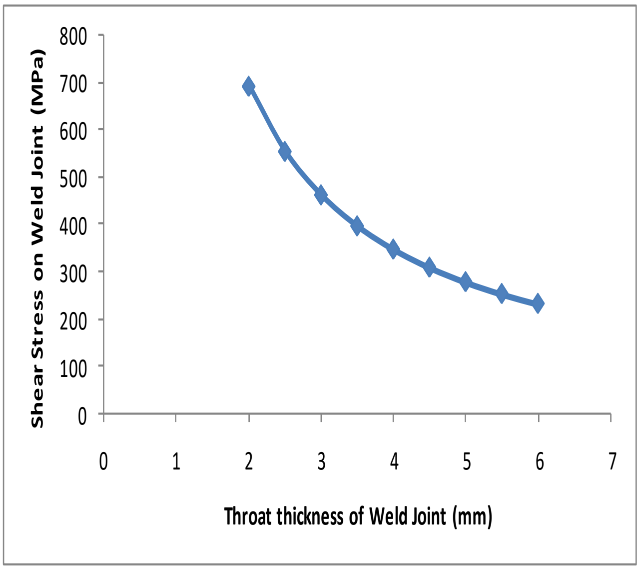

Figure 7: Shear Stress on Weld Joint.

Figure 8.depict the weld joint because of the von Mises stress. As the throat thickness of the weld junction increases, the von mises stress on the weld joint reduces, as shown in the graph. This is because of better preparation for the weldment, leaving the root gap at an accurate size, not too small or too large for a deep penetration of the weld pool.

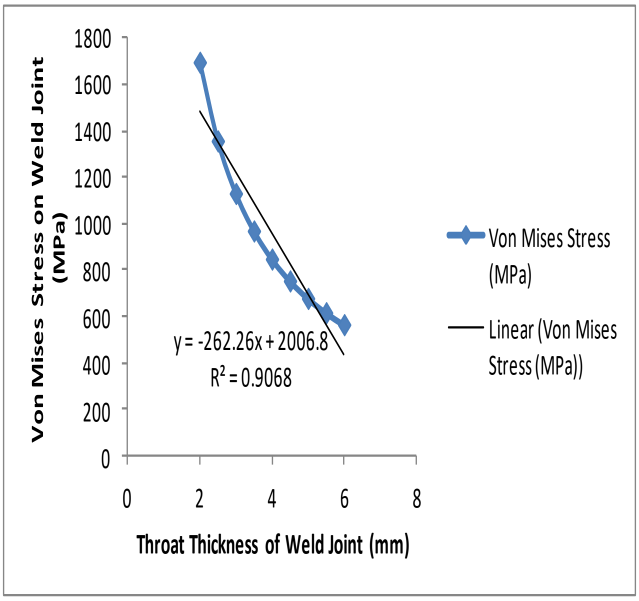

Figure 8: Von Mises Stress on Weld Joint.

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3.2 MATLAB Code for Modelling and Validation of the Strength of Weld Joint

```
clear all
clearclc
%% weld joint strength Analysis
% For each specimens,
% %% Definition of terms
%   σ   ====>allowable   tensile
strength of the weld material
% h ====> throat thickness,
% le ===>effective length of the
weld
% l ====>length of the weld,
% F_S ====>strength of the weld
joint, given as
  F_S = (σ x H x le)
% le ===>  effective  length  of
the weld, given as
% le - (l + 1.5hminimum)
disp('=========================
================================
======')
%% For weld joints, we have
σ  =  [483];  %  the  allowable
tensile  strength  of  the  weld
joint (MPa)
h = [2.0 2.5 3.0 3.5 4.0 4.5 5.0
5.5 6.0]; % throat thickness (mm)
l = [15]; % length of the weld
(mm)
%%  Calculation  for  effective
length of the weld
le - [18]  (mm)

%%  Calculation  for  weld  joint
strength
S_W = (σ x H x le) (N)

formatshortE
SPE_01 = [S_W(1)]
SPE_02 = [S_W(2)]
SPE_03 = [S_W(3)]
SPE_04 = [S_W(4)]
SPE_05 = [S_W(5)]
SPE_06 = [S_W(6)]
SPE_07 = [S_W(7)]
SPE_08 = [S_W(8)]
SPE_09 = [S_W(9)]
SPE  =  [SPE_01  SPE_02  SPE_03
SPE_04  SPE_05  SPE_06  SPE_07
SPE_08 SPE_09];
```

Results

```
>>
===============================
===============================
The strength of the weld for each
specimen SPE

SPE_01 = 1.79e+01
SPE_02 = 2.17e+01
SPE_03 = 2.61e+01
SPE_04 = 3.04e+01
SPE_05 = 3.48e+01
SPE_06 = 3.91e+01
SPE_07 = 4.34e+01
SPE_08 = 4.78e+01
SPE_09 = 5.22e+01
>>
```

4. CONCLUSION

The strength and efficiency of AISI1020 mild steel weld joints in metal inert gas (MIG) welding were simulated, examined, and enhanced in this research work.

i. The analysis revealed that increasing the throat thickness of the workpiece will reduce the maximum residual von misses stress imposed on the weld joint.
ii. It was discovered that increasing the weld joint's throat thickness increases the joint's strength.
iii. The goal of this study which was to estimate the strength of the AISI1020 mild steel weld joint in metal inert gas with various throat thicknesses was achieved as it was found that increasing the throat thickness of the workpiece will reduce the equivalent normal and shear stress imposed on the weld joint.

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