International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 10 | Oct -2020 ISSN: 2582-3930

Analysis of Strength & Hardness of Weld Specimen of Mild-Steel Square Bars by Varying Arc Length and Voltage using Semi-Automatic Shielded Metal Arc Welding Machine

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ABSTRACT

Welding processes are widely used throughout industry to perform a range of fabrication tasks. Of the various welding techniques available, stick-electrode welding, more formally known as Shielded Metal Arc Welding (SMAW) is one of the most common. SMAW is a consumed electrode welding technique, i.e. the electrode not only supplies the filler-metal, but also acts as the consumable material. At present the feed rate of electrode is carefully controlled during the welding process to ensure that the arc length remains constant and Arc Voltage is also carefully controlled during the welding process by Voltage Regulator. The obtained results gives the Tensile Strength & Compressive Strength of the weld, and Weight of Specimen used when welding process is performed by varying Arc Length keeping the welding speed and arc voltage at constants. Also the results gives the Tensile Strength, Compressive Strength and Impact Strength of the weld, and Weight of Specimen used when welding process is performed by varying Arc voltage keeping the welding speed and arc length at constants. These parameters viz. Tensile Strength, Compressive Strength and Impact Strength helps to compare, analyse and conclude the result obtained. The strength of the welded work-piece is tested and recorded with the help of Tests performed in Universal Testing Machine viz. tensile test & compression test; .and the Impact Strength of the weld is determined by Impact Testing Machine (ITM). This will be helpful in confirming the values of process parameters in SMAW. Later on, Hardness Test can be performed to determine the hardness of the weld by Rockwell Hardness Testing (RHT) Machine. The Results obtained is validated with the help of ANNOVA Test.

Keywords: **SMAW** – Shielded Metal Arc Welding, **RHT Machine** - Rockwell Hardness Test Machine, **UTM** - Universal Testing Machine, **Process Parameters** – Arc Gap, Arc Voltage, **ITM** – Impact Testing Machine

1. INTRODUCTION :

Welding processes are widely used throughout industry to perform a range of fabrication tasks. Of the various welding techniques available, stick-electrode welding, more formally known as Shielded Metal Arc Welding (SMAW) is one of the most common. SMAW is a consumed electrode welding technique, i.e. the electrode not only supplies the filler-metal, but also acts as the consumable material. Currently the electrode feed rate is carefully controlled during the welding process to ensure that the arc length remains constant. At present SMAW (Shielded Metal Arc Welding) process is done at fixed Voltage, fixed welding speed & fixed arc gap. This research work focuses light on measuring, recording and analyzing the variations in the weld strength and hardness of the weld if the fixed parameters would be changed within a given range. In this research, three process variable parameters are taken into account viz. arc voltage, welding speed & arc gap. This can be done by varying one of the process variable parameters and making the other two constants. Figure 1 illustrates the above statement diagrammatically. Result will be obtained for each and every varying process variable parameters and will be recorded. The obtained results will give the Tensile Strength & Compressive Strength of the weld, and Impact Strength and Hardness of the weld at varying arc gap and varying arc voltage. These parameters viz. Tensile Strength, Compressive Strength, Impact Strength & Hardness of the weld will help to conclude the result obtained individually at varying arc gap and at varying arc voltage conditions. The strength of the welds are tested and recorded in Universal Testing Machine viz. tensile test & compression test. The Toughness Test is tested and recorded in Impact Testing Machine using Charpy Test. Later on, Hardness Test is performed for determining the hardness of the weld by Rockwell Hardness Testing Machine. The results obtained in each case are validated by using ANNOVA Test in MS Excel Data Analysis Tool. This will be helpful in determining and confirming the exact and accurate values of process parameters in SMAW. Then the results obtained at varying arc gap and at varying arc voltage are compared and a conclusion is made.

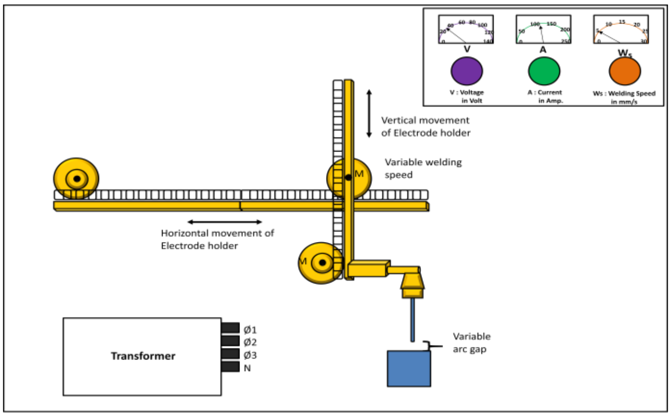

Figure 1.1: Front View of Set up

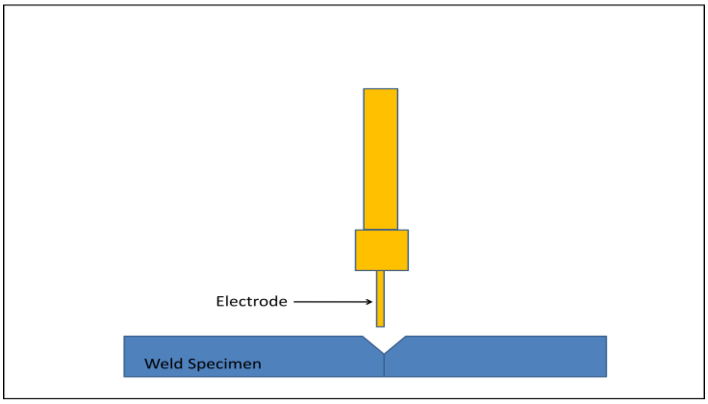

Figure 1.1: Right Side View of Set up

Tensile and Compressive Strength of the weld is determined by UTM. The Toughness of the weld is determined by Impact Testing Machine.

Figure 1.1: UTM

Figure 1.2: ITM

2. LITERATURE REVIEW :

Patnaik et. al. (2007) [15] established a relationship between the controlling factors and performance outputs by means of Non-linear Regression Analysis and developed a valid mathematical model and Genetic Algorithm (GA) to optimize the welding parameter and performance output.

S Kumanan et. al. (2007) [16] worked on the application of Taguchi Technique and Regression Analysis to determine the optimal process parameters for SAW. They have carried out an experiment on a semi automatic submerged arc welding machine and the signals to noise ratios have been computed to determine the optimum parameters. The percentage contribution of each factor has been validated by ANOVA technique. Multiple regression analysis has also been carried out using SPSS software to develop mathematical models to predict the bead geometry for the given welding conditions. They also predicted the bead geometry from the developed model from the corresponding input data.

Chandel and Seow [17] presented the mathematical prediction of the effect of current, polarity used, electrode diameter and its extension on the melting rate, bead height, bead width and weld penetration in SAW**.** They concluded that for a given current (heat input) the melting rate can be increased by using electrode negative polarity, longer electrode extension, and smaller diameter electrodes. There are two other ways to increase the deposition rate without increasing the heat input; these are: (i) using a twin-arc mode and (ii) adding metal powders.

Chandel, Yang and Bibby [18] while investigating the effects of process variables on the bead width of submerged-arc weld deposits concluded that bead width is affected by the electrode polarity, electrode diameter, electrode extension, welding current, welding voltage and welding speed. A positive electrode polarity, a large electrode diameter, a small electrode extension and a high welding voltage encourages a large bead width in most cases. The bead width is not affected significantly by the power source used (i.e. constant voltage or constant current) when an acidic fused flux is used. However, when a basic fused flux is used, constant-current operation gives somewhat larger bead widths.

Mostafa and Khajavi [19] described the prediction of weld penetration as influenced by Flux Cored Arc Welding process parameters like welding current, arc voltage, nozzle-to-plate distance, electrode-to-work angle and welding speed. The optimization result shows penetration will be maximum when welding current, arc voltage, nozzle-to-plate distance and electrode-to- work angle are at their maximum possible value and welding speed is at its minimum value. Increase in welding current (I) increases the depth of penetration (P). Increase in welding speed (S) causes a decrease in depth of penetration (P). Increase in arc welding voltage (V) resulted in an increase in depth of penetration (P), Increase in electrode-to-work angle from 90° to 120° (i.e. for normal to backhand) had resulted in increase of depth of penetration. Increase in nozzle-to-plate distance (N) also causes an increase in depth of penetration (P). Based on this investigation it can be concluded that the developed model can be used to predict adequately the weld bead penetration within the specified range of the process parameters. The optimization method can also be used to find optimum welding conditions for maximum weld bead penetration. Their results are in agreement with the results of Chandel at. el.

Cheng-Yu Wu et al. (2008) [3] develops an automatic welding control scheme for alternating current shielded metal arc welding (SMAW) system. A mathematical model of the welding control system is derived and the system parameters identified. An adaptive sliding mode controller is designed to estimate the bound of the system uncertainties and to modulate the electrode feed rate in such a way that the desired arc length and arc current are maintained as the electrode melts during the welding process. The proposed control method is suitable for any consumed electrode welding technique. The simulation and experimental results show that the automatic welding control system successfully maintains the magnitude of the arc current at the desired value and preserves the arc stability, thereby obtaining an enhanced SMAW control system performance.

3. PROBLEM IDENTIFICATION :

The present situation in the field of SMAW (Shielded Metal Arc Welding) is that the whole welding process is done at fixed arc gap and fixed arc voltage. This research work focuses light on the effect on Strength and Hardness of the weld if the fixed arc gap and voltage is changed within a given range. In this research, the process variable parameter is taken into account is Arc Gap, Arc Voltage and Welding Speed. This can be done by in two ways. One way is by varying process variable parameter i.e. the Arc Gap and keeping Welding Speed and Arc Voltage at constant i.e. Welding Speed is kept constant at 5 mm.s-1 and Arc Voltage is kept constant at 30 Volt. And the other way is One way is by varying process variable parameter i.e. the Arc Voltage and keeping Welding Speed and Arc Gap at constant i.e. Welding Speed is kept constant at 5 mm.s-1 and Arc Voltage is kept constant at 30 Volt. Result will be obtained for each and every values of the process variable parameter ranging from 1.5 mm to 3.0 mm and will be recorded. The results will give the best possible values of Arc Gap and voltage at which welding can be performed with best possible Tensile Strength, Compressive Strength, Toughness and Hardness of the weld.

4. METHODOLOGY :

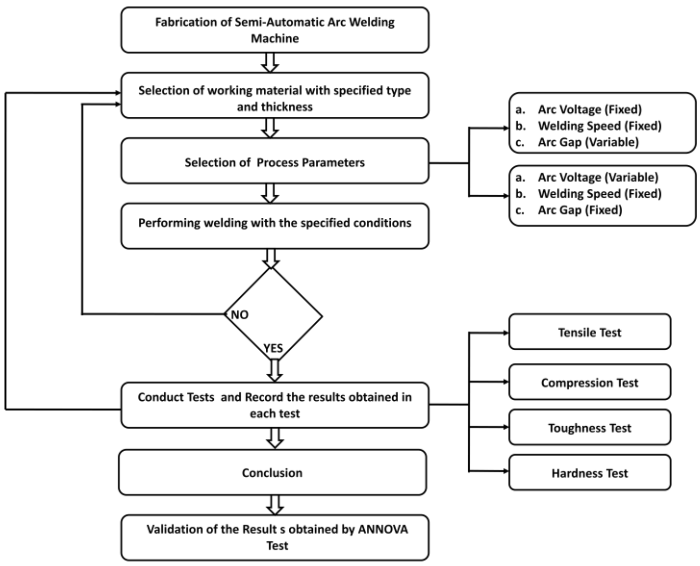

Figure 4.1: Methodology of the Research

The Tensile Test & Compression Test is performed on Universal Testing Machine. And the Impact Test is performed on Impact Testing Machine. Hardness Test is performed on Rockwell Hardness Test Machine.

The Specimens used for the experimental analysis of Tensile & Compressive Strength of the weld are as follows:

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 10 | Oct -2020 ISSN: 2582-3930

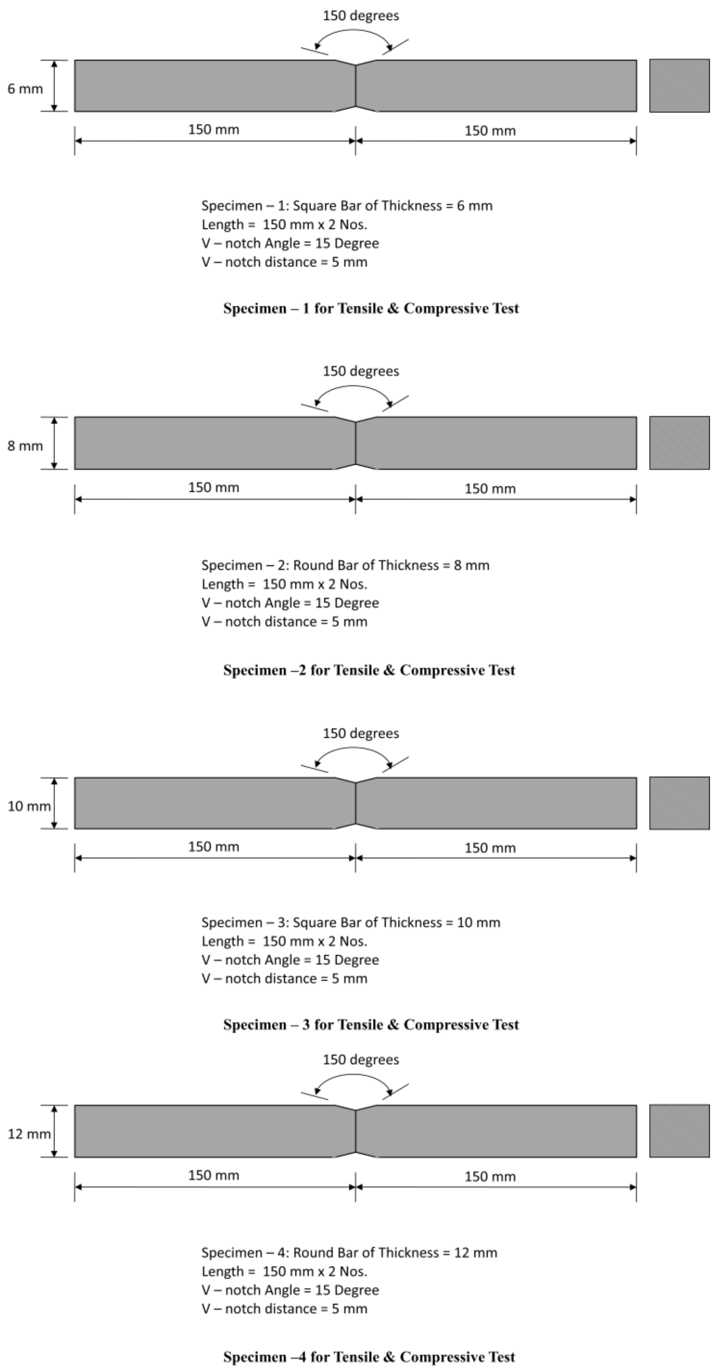

Figure 4.2: Specimens for Tensile and Compression test

The Specimens used for the experimental analysis of Toughness of the weld are as follows:

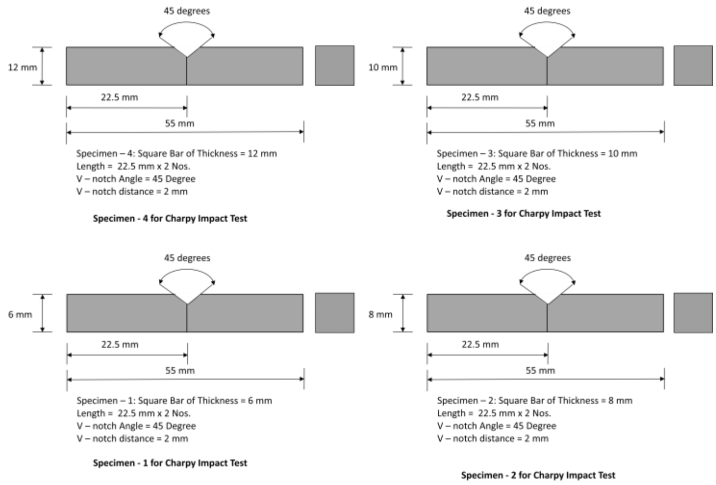

Figure 4.3: Specimens for Toughness test

5. RESULT :

The welded work piece will be tested for tensile test, compression test & shear test with the help of Universal Testing Machine (UTM) to obtain the best Arc Gap at which Welding can be performed thus keeping the Welding Speed and Arc Voltage at constants i.e. Welding Speed is 5 mm.s-1 and Arc Voltage is 30 Volt, so that the Tensile Strength and Compressive Strength is at its best. Thus, when the results will be obtained, one will be able to find out the best possible Arc Gap for performing welding at which the Strength of the work-piece will be at its best. Individual Strength Charts are generated using the results obtained by experimental analysis. This will be helpful for comparing the Strengths among them at a given Arc Gap. Thus at each Arc Gap values considered for experimental analysis, Strength analysis is done and a Strength Chart is generated for the same so that the comparison among the strengths for a particular arc gap may be easily made.

Calculation of Mass of Specimen used in Kilogram:

Source: https://sites.google.com/site/standardbasicengineering/home/weights-of-round-square-hexagon-steel-brass-bars

Table 5.1: Mass of Specimen used in Kilogram

Specimen No.	Weight of Steel (in Kg/m)	Thickness of Specimen (in mm)	Length of Specimen (in mm)	No. of Parts	Weight of Weld Specimen (in Kg.)
Specimen-1	0.283	6	150	2	0.5094
Specimen-2	0.502	8	150	2	0.9036
Specimen-3	0.785	10	150	2	1.143
Specimen-4	1.130	12	150	2	2.034

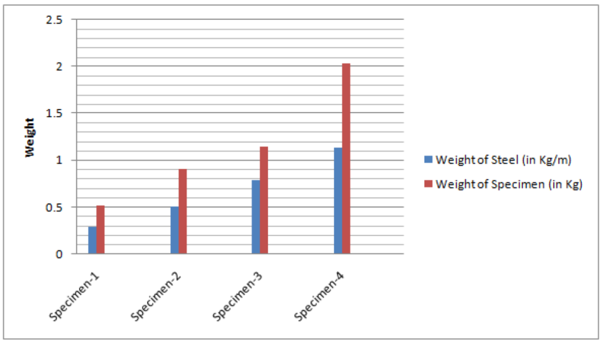

Figure 5.1: Weight of Specimens (in Kg)

Calculations for Thickness and Cross-sectional Area of the Specimens:

The number of specimens used for the research is four viz., Specimen-1, Specimen-2, Specimen-3 and Specimen-4. The thickness and cross-sectional area of the four specimens is as follows:

Table 5.2: Thickness and Cross-sectional Area of the Specimens

	Specimen-1	Specimen-2	Specimen-3	Specimen-4
Thickness of Specimen (in mm)	6	8	10	12
Cross-sectional Area (in mm^2)	36	64	100	144

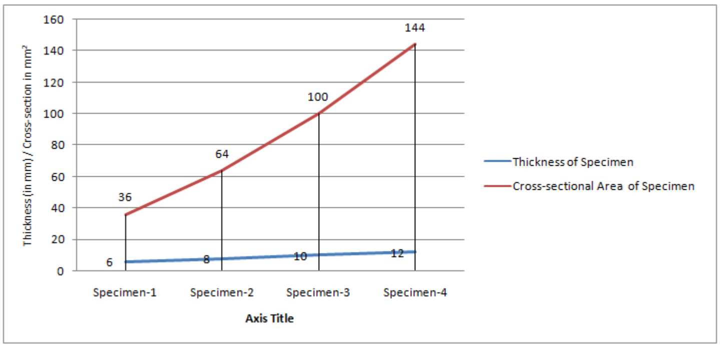

Figure 5.2: Graph for thickness and Cross-sectional area of the specimen

Result obtained by experimental analysis is as shown below:

Table 5.3: Tensile Strengths of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm :

		Tensile Strengths (in MPa)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Gap (in mm)	1.5 mm	91.5	95.3	103.5	110.5
	2.0 mm	85.4	91.1	98.6	106.2
	2.5 mm	63.2	72	77.4	83.6
	3.0 mm	45.5	50.2	58.2	68.7

Arc Voltage = 30 V, Welding Current = 110 A, Welding Speed = 5 mm.s^{-1}

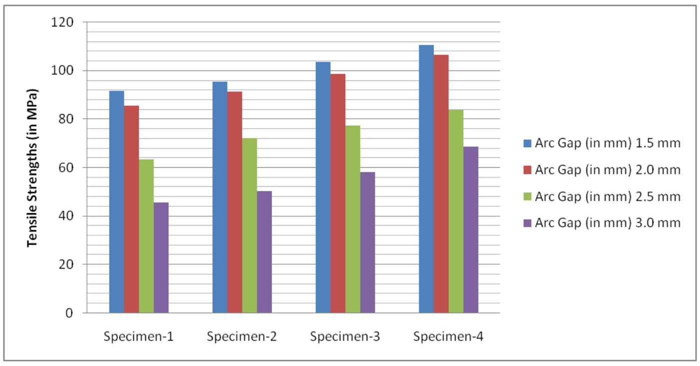

Figure 5.3: Graph for Tensile Strengths of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

Table 5.4: Compressive Strengths of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm :

		Compressive Strengths (in MPa)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Gap (in mm)	1.5 mm	105.4	113.4	120.2	132.4
	2.0 mm	99.2	107.5	102.2	109.5
	2.5 mm	81	89.6	95.8	102.8
	3.0 mm	69.3	76.4	82.3	91.3

Arc Voltage = 30 V, Welding Current = 110 A, Welding Speed = 5 mm.s^{-1}

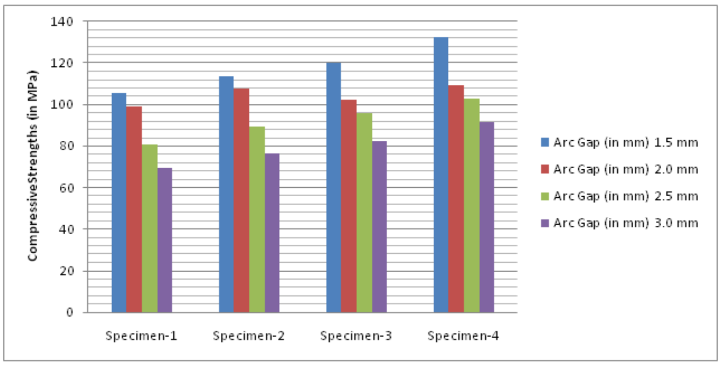

Figure 5.4: Graph for Compressive Strengths of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

Table 5.5: Impact Energy of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

		Impact Energy (in Joule)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Gap (in mm)	1.5 mm	10.2	12.8	14.0	16.5
	2.0 mm	9.0	10.4	11.2	12.9
	2.5 mm	6.6	8.7	9.3	10.7
	3.0 mm	5.3	7.5	7.2	8.1

Arc Voltage = 30 V, Welding Current = 110 A, Welding Speed = 5 mm.s^{-1}

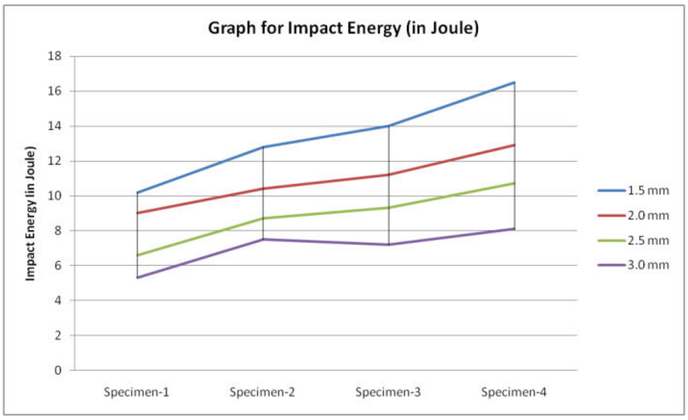

Figure 5.5: Graph for Impact Energy of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

Table 5.6: Impact Strength of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

		Impact Strength (in KJ/m^2)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Gap (in mm)	1.5 mm	283.33	200.00	140.00	114.58
	2.0 mm	250.00	162.50	112.00	89.58
	2.5 mm	183.33	135.93	93.00	74.30
	3.0 mm	147.22	117.18	72.00	56.25

Arc Voltage = 30 V, Welding Current = 110 A, Welding Speed = 5 mm.s^{-1}

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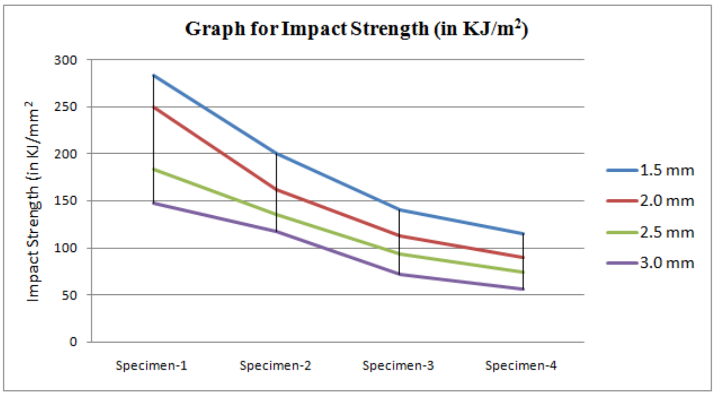

Figure 5.6: Graph for Impact Strength of four specimens for Arc Gap Ranging from 1.5 mm to 3.0 mm

Table 5.7: Hardness of four specimens for Arc Gap ranging from 1.5 mm to 3.0 mm obtained by Testing in Rockwell Hardness Testing Machine

Arc Voltage = 30 V Welding Current = 110 A Welding Speed = 5 $mm.s^{-1}$
Applied Load= 250 Kgf Penetrator Type = Diamond Cut (Code used is C)
Hardness Test Method: Rockwell Hardness Test Method (Code used is HR)

		Hardness of Weld Specimen			
		Specimen-1	**Specimen-2**	**Specimen-3**	**Specimen-4**
Arc Gap (in mm)	1.5 mm	HRC 28	HRC 37	HRC 36	HRC 36
	2.0 mm	HRC 27	HRC 35	HRC 34	HRC 34
	2.5 mm	HRC 24	HRC 32	HRC 31	HRC 31
	3.0 mm	HRC 20	HRC 30	HRC 28	HRC 30

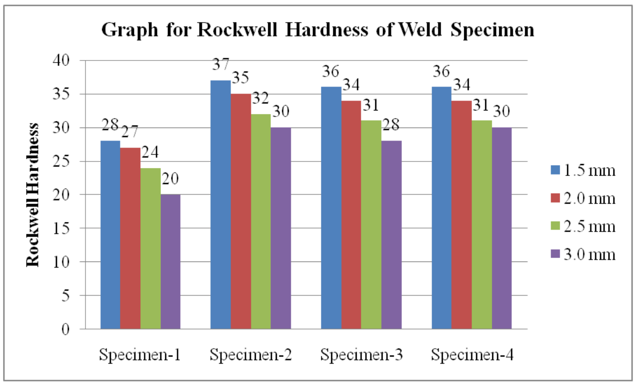

Figure 5.7: Graph for Rockwell Hardness of four specimens for Arc Gap ranging from 1.5 mm to 3.0 mm

Table 5.8: Tensile Strengths of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt :

		Tensile Strengths (in MPa)			
		Specimen -1	Specimen-2	Specimen-3	Specimen-4
Arc Voltage (in Volt)	25 Volt	109.7	112.6	118.0	125.5
	35 Volt	91.5	95.3	103.5	110.5
	35 Volt	89.5	91.4	100.8	106.8
	40 Volt	85.6	89.0	94.2	97.3

Arc Gap = 1.5 mm, Welding Current = 110 A, Welding Speed = 5 $mm.s^{-1}$

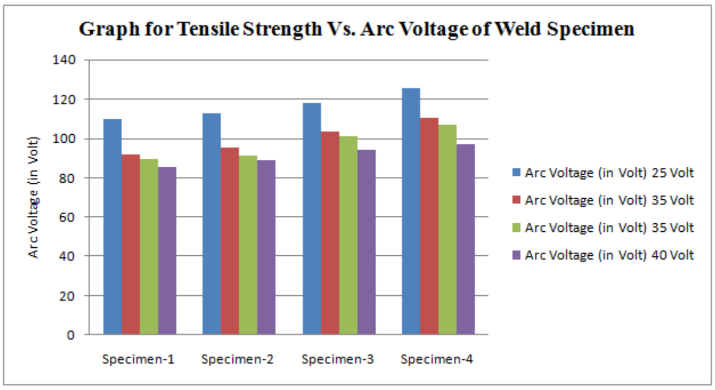

Figure 5.8: Graph for Tensile Strengths of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt

Table 5.9: Compressive Strengths of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt :

		Compressive Strengths (in MPa)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Voltage (in Volt)	25 Volt	109.2	116.1	127.3	138.6
	30 Volt	105.4	113.4	120.2	132.4
	35 Volt	99.1	102.3	105.2	108.5
	40 Volt	71.2	72.9	94.6	97.5

Arc Gap = 1.5 mm, Welding Current = 110 A, Welding Speed = 5 $mm.s^{-1}$

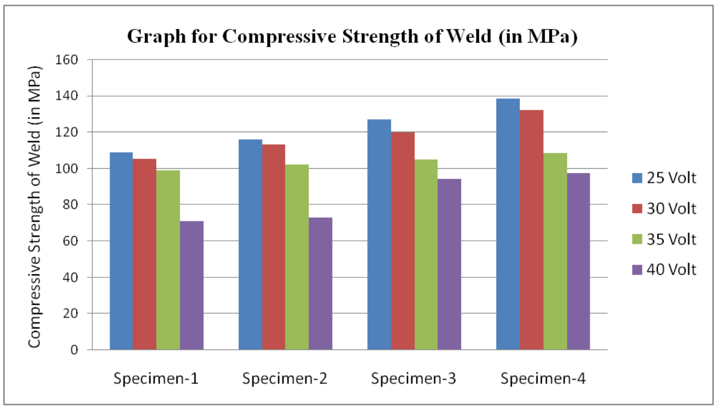

Figure 5.9: Graph for Compressive Strengths of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt

Table 5.10: Impact Energy of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt

		Impact Energy (in Joule)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Voltage (in Volt)	25 Volt	12.0	13.8	16.0	18.4
	30 Volt	10.2	12.8	14.0	16.5
	35 Volt	8.4	9.7	11.3	12.6
	40 Volt	7.1	8.5	9.2	10.0

Arc Gap = 1.5 mm, Welding Current = 110 A, Welding Speed = 5 $mm.s^{-1}$

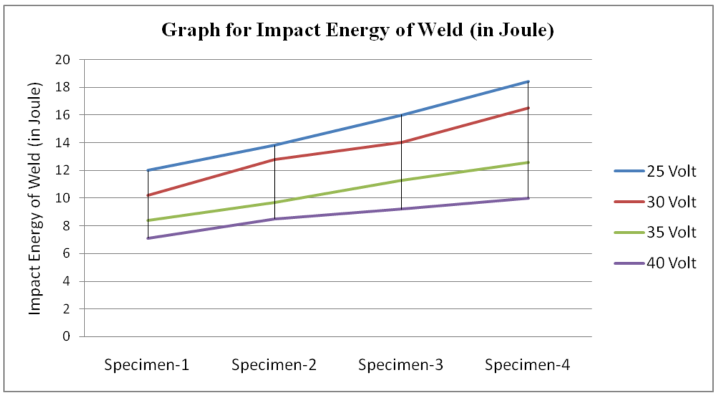

Figure 5.10: Graph for Impact Energy of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt

Table 5.11: Impact Strength of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt:

		Impact Strength (in KJ/m^2)			
		Specimen-1	Specimen-2	Specimen-3	Specimen-4
Arc Voltage (in Volt	25 Volt	333.33	215.62	160.00	127.77
	30 Volt	283.33	200.00	140.00	114.58
	35 Volt	233.33	151.56	113.00	87.50
	40 Volt	197.22	132.81	92.00	69.44

Arc Gap = 1.5 mm, Welding Current = 110 A, Welding Speed = 5 mm.s^{-1}

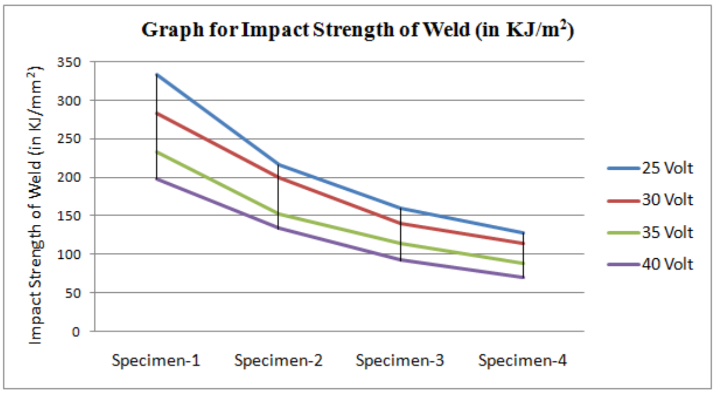

Figure 5.11 Graph for Impact Strength of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt

Table 5.12: Hardness of four specimens for Arc Voltage Ranging from 25 Volt to 40 Volt obtained by Testing in Rockwell Hardness Testing Machine

Arc Voltage = 30 V Welding Current = 110 A Welding Speed = 5 mm.s^{-1}
Applied Load= 250 Kgf Penetrator Type = Diamond Cut (Code used is C)
Hardness Test Method: Rockwell Hardness Test Method (Code used is HR

		Hardness of Weld Specimen			
		Specimen-1	**Specimen-2**	**Specimen-3**	**Specimen-4**
Arc Voltage (in Volt)	25 Volt	HRC 30	HRC 39	HRC 37	HRC 37
	30 Volt	HRC 28	HRC 36	HRC 35	HRC 35
	35 Volt	HRC 25	HRC 33	HRC 32	HRC 31
	40 Volt	HRC 22	HRC 31	HRC 30	HRC 30

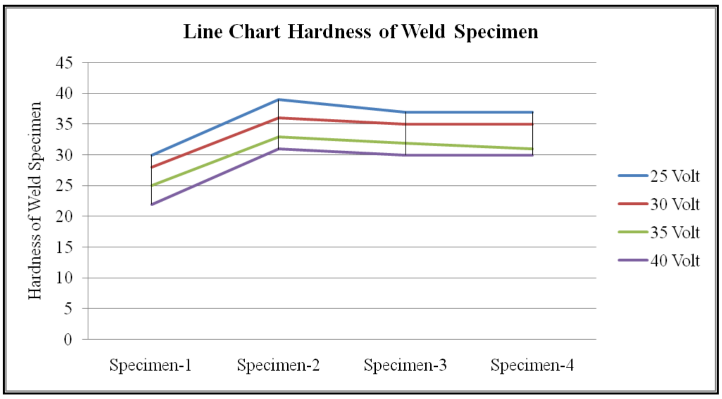

Figure 5.12: Graph for Rockwell Hardness of four specimens from 25 Volt to 40 Volt

6. CONCLUSION :

From the result and graph obtained by comparing the four specimens Tensile & Compressive strengths and weight of the specimen for Arc Gap ranging from 1.5 mm to 3.0 mm, made by welding Mild Steel Square Bar (Specimen Thickness x 150 mm Length) x 2 Nos. welded at the centre (keeping Arc Voltage & welding Speed at constants); and from the result and graph obtained by comparing the four specimens Tensile & Compressive strengths for Arc Voltage ranging from 25 Volt to 40 volt, made by welding Mild Steel Square Bar (Specimen Thickness x 150 mm Length) x 2 Nos. welded at the centre (keeping Arc Gap & welding Speed at constants), the conclusions made are as follows:

1. The Tensile Strength of the weld decreases with increase in Arc Gap & Arc Voltage whereas Tensile Strength increases with decreases in Arc Gap & Arc Voltage. Also, The Tensile Strength of the weld increases with increase in thickness or weight of the specimen whereas Tensile Strength decreases with decrease in thickness or weight of the specimen.
2. The Compressive Strength of the weld decreases with increase in Arc Gap & Arc Voltage whereas Compressive Strength increases with decreases in Arc Gap & Arc Voltage. Also, The Compressive Strength of the weld increases with increase in thickness or weight of the specimen whereas Compressive Strength decreases with decrease in thickness or weight of the specimen.
3. The Impact Energy of weld decreases with increase in Arc Gap & Arc Voltage whereas the Impact Energy of weld increases with decrease in Arc Gap & Arc Voltage. The Impact Energy of the weld increases with increase in thickness or weight of the specimen whereas Impact Energy of the weld decreases with decrease in thickness or weight of the specimen.
4. The Impact Strength of weld decreases with increase in Arc Gap & Arc Voltage whereas the Impact Strength of weld increases with decrease in Arc Voltage. Also, The Impact Strength of the weld decreases with increase in thickness or weight of the specimen whereas Impact Strength of the weld increases with decrease in thickness or weight of the specimen.
5. The Hardness of the weld decreases with increase in Arc Gap & Arc Voltage whereas the hardness of the weld increases with decrease in Arc Gap & Arc Voltage. Also, Hardness of the weld first increases then slightly decreases with increase in thickness & weight of the specimen whereas the hardness of the weld first slightly increases then decreases with decrease in thickness & weight of the specimen.

6. VALIDATION:

Validation of the result obtained is done with the help of ANNOVA Test using MS Excel Data analysis Tool.

Anova: Two-Factor With Replication

SUMMARY	Specimen-1	Specimen-2	Specimen-3	Specimen-4	Total
Tensile Strength (in Mpa) of Weld at Arc Gap 1.5 mm					
Count	4	4	4	4	16
Sum	285.6	308.6	337.7	369	1300.9
Average	71.4	77.15	84.425	92.25	81.30625
Variance	446.02	425.6167	433.9625	385.6967	403.566
Compressive Strength (in Mpa) of Weld at Arc Gap 1.5 mm					
Count	4	4	4	4	16
Sum	354.9	386.9	400.5	436	1578.3
Average	88.725	96.725	100.125	109	98.64375
Variance	274.9292	286.0092	247.9158	299.8467	278.1426
Impact Energy (in Joules) of Weld at Arc Gap 1.5 mm					
Count	4	4	4	4	16
Sum	31.1	39.4	41.7	48.2	160.4
Average	7.775	9.85	10.425	12.05	10.025
Variance	4.9625	5.283333	8.349167	12.65	8.743333
Impact Strength (in KJ/m2) of Weld at Arc Gap 1.5 mm					
Count	4	4	4	4	16
Sum	863.88	615.61	417	334.71	2231.2
Average	215.97	153.9025	104.25	83.6775	139.45
Variance	3829.114	1290.15	834.9167	610.0031	4089.849
Hardness of Weld at Arc Gap 1.5 mm					
Count	4	4	4	4	16
Sum	99	134	129	131	493
Average	24.75	33.5	32.25	32.75	30.8125
Variance	12.91667	9.666667	12.25	7.583333	21.7625
Tensile Strengths (in MPa) at 25 Volt					
Count	4	4	4	4	16
Sum	376.3	388.3	416.5	440.1	1621.2
Average	94.075	97.075	104.125	110.025	101.325
Variance	114.5092	113.8625	100.8225	137.3425	134.4153
Compressive Strengths (in MPa) at 25 Volt					
Count	4	4	4	4	16
Sum	447.5	474.1	475.7	496.8	1894.1
Average	111.875	118.525	118.925	124.2	118.3813
Variance	99.7225	57.44917	134.9492	127.6267	104.351
Impact Energy (in Joules) at 25 Volt					
Count	4	4	4	4	16
Sum	43.4	49.7	49.7	55.8	198.6
Average	10.85	12.425	12.425	13.95	12.4125
Variance	5.283333	8.349167	8.349167	12.65	8.207833
Impact Strength (in KJ/m2) at 25 Volt					
Count	4	4	4	4	16
Sum	1063.88	678.11	497	387.48	2626.47
Average	265.97	169.5275	124.25	96.87	164.1544
Variance	3829.114	1289.785	834.9167	609.9406	5716.708
Hardness of Weld at 25 Volt					
Count	4	4	4	4	16
Sum	105	139	134	133	511
Average	26.25	34.75	33.5	33.25	31.9375
Variance	12.25	12.25	9.666667	10.91667	20.8625
Total					
Count	40	40	40	40	
Sum	3670.56	3213.72	2898.8	2832.09	
Average	91.764	80.343	72.47	70.80225	
Variance	7739.937	3267.712	2084.085	1882.765	

ANOVA

Source of Variation	*SS*	*df*	*MS*
Sample	433185.172	9	48131.6858
Columns	10978.8407	3	3659.61357
Interaction	99917.493	27	3700.64789
Within	50902.7935	120	424.189946
Total	594984.3	159	

Source of Variation	*F*	*P-value*	*F crit*
Sample	113.467295	2.2738E-54	1.9587633
Columns	8.62729916	3.1274E-05	2.68016758
Interaction	8.72403489	1.1848E-17	1.57892389

Results obtained after ANNOVA Test:

Define Alternative Hypothesis: ***Alternate Hypothesis:*** *All the values of parameters obtained by experimental analysis are correct and can be used for the research.*

i.e., $H_1: \mu \leq 0.05$

Define Null Hypothesis: ***Null Hypothesis:*** *All the values of parameters obtained are not appropriate and needs to be corrected.*

i.e., $H_0: \mu > 0.05$

F (Sample) = 113.467295, F-crit (Sample) = 1.9587633
Therefore, F (Sample) > F-crit (Sample) ....Equation (i)

F (Columns) = 8.62729916, F-crit (Columns) = 2.68016758
Therefore, F (Columns) > F-crit (Columns) ....Equation (ii)

F (Interaction) = 8.72403489, F-crit (Interaction) = 1.57892389
Therefore, F (Interaction) > F-crit (Interaction) ....Equation (iii)

P (Sample) = 2.2738E-54 > α (= 0.05) ....Equation (iv)

Also, P (Columns) = 3.1274E-05 > α (= 0.05) ....Equation (v)

Also, P (Interaction) = 1.1848E-17 > α (= 0.05) ....Equation (vi)

From Equation (i), (ii) and (iii); **F > F-crit**

From Equation (iv), (v) and (vi); **P > α**

Therefore, Null Hypothesis ($H_0: \mu > 0.05$) is rejected.

And hence; Alternate Hypothesis i.e. ($H_1: \mu \leq 0.05$) is selected.

Therefore, It is concluded that, "All the values of parameters obtained by experimental analysis are correct and can be used for the research".
Hence, Result is validated.

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