Argon Gas Metal Arc Welding Process Parameters with Regard to Tensile Strength for AISI 310 Stainless Steel

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Consultancy Research Paper

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Argon Gas Metal Arc Welding Process Parameters withRegard to Tensile Strength for AISI 310 Stainless Steel Using Taguchi Technique

Abstract. Gas metal arc welding (GMAW) is the leading process in the development of arc welding process for higher productivity and quality. In this study, the effect of process parameters of argon gas welding on the strength of T type welded joint of AISI 310 stainless steel is analyzed. The Taguchi technique is used to develop the experimental matrix and tensile strength of the welded joint is measured using experimental method and finite element method. Optimization of input parameter is performed for the maximum tensile strength of welded joint using ANOVA. The results showed that welding speed is the most significant factor affecting the tensile strength followed by voltage in argon gas metal arc welding (AGMAW) process. Argon gas welding process performance with regard to the tensile strength is optimized at voltage: 18.5 V, wire feed speed: 63 m/min and welding speed: 0.36 m/min.

1. Introduction

Welding is the process of fusing multiple pieces of metal together by heating filler metal to liquid state. Gas metal arc welding (GMAW) is an arc welding process which produces coalescence of metal by heating them with an arc between continuously fed filler metal electrode and the work piece. This method incorporates inert gas to protect the liquefied metal pool. Gas metal arc welding process has higher electrode efficiency, usually between 93% and 98%, when compared to other welding processes [1].

Stainless steel is an engineering material widely used in all the fields. They exhibit excellent corrosion resistance, high strength and fabrication characteristics. They are preferred over other material for welding because of their superior performance in any environment and can be fabricated by most of the fabrication techniques [2, 3].

Stainless steel is used in fluidized bed combustors, radiant tubes, tube hangers for petroleum refining and steam boilers, coal gasified internal components, lead pots, thermo wells, refractory anchor bolts, burners and combustion chambers, retorts, muffles, annealing covers, food processing equipment, cryogenic structures. Components of blowers, turbine are exposed to corrosive, abrasive, and other damaging influences, which cause them to crack, pit, erode, and otherwise degrade generally at welded joints. GMAW plays an important role in such conditions [2, 3].

The experimental optimization of any welding process parameters is often a very costly and time-consuming task, due to many kinds of non-linear events involved. One of the most widely used methods to solve this problem is the Taguchi technique. It is effective for various welding technologies, investigating the effect of process parameters on weld quality in terms of weld bead geometry and mechanical properties [4, 5]. Again, the effect of influential welding parameters depends largely on several factors such as material type, joint type, as well as welding process involved and has to be researched separately for each new component, material as well as for welding process [6]. Therefore, in this paper, analysis of tensile strength of T-joint of AISI 310 stainless steel material made with argon gas metal arc welding (AGMAW) process was performed.

using Taguchi based experimental method and finite element method. The optimization of AGMAW process parameters was achieved using analysis of variance (ANOVA).

M.M. Khan, et al. [2] studied experimental design approach to parameter optimization in laser welding of ferrite/austenitic stainless steels in a constrained fillet configuration. Laser power, welding speed, and incident angle are the factors that affect the weld bead characteristics significantly. A focused beam with laser power and welding speed respectively in the range of 860– 875 W and 3.4– 4.0 m/min and an incident angle of around 12° were identified as the optimal set of laser welding parameters to obtain the stronger and better welds. R. Dhasharat [7] has studied stages of development of the model, design of experiments and optimization of parameters using ANOVA. Experiments were conducted using Taguchi L9 orthogonal array considering four input parameters, namely welding speed, accelerating voltage, beam current, distance between guns to work. The performance of electron beam welding was measured in terms of weld strength and weld penetration levels. The weld penetration was measured using non-destructive testing methods. The researcher concluded that the optimum condition of welding is accelerating voltage of 50 kV, beam current of 60 mA, weld speed of 1 m/min and distance between guns to work of 200 mm. K.Y. Benyounis, et al. [8] investigated the tensile strength and impact strength along with the joint- operating cost of laser-welded butt joints made of AISI 304.

The relationships between the laser- welding parameters such as laser power, welding speed and focal point position and the responses like tensile strength, impact strength and joint-operating cost were established. Researcher found that welding speed is the most effective parameter in the optimization of response output parameters. H. Naffakh -Moosavy, et al. [9] investigated characteristics of dissimilar metal weld between AISI 310 and Inconel 657 alloy. These two dissimilar welds were joined together with 75 degree V groove with the help of argon tungsten welding.

Welding process was carried out using different filler metal in GTAW and SMAW. It was found that Inconel A and Inconel 82 weld metals are the best choices for the dissimilar welds of AISI 310 and Inconel 657. S. Kršćanski [10] determined FEM stress concentration factor for fillet welded CHS plate T-joint. Researcher modeled fillet welded T-joints with FEM and analyzed with finite element method. Stress concentration factors calculated by finite element model analysis were found to be higher than those interpolated from the experimental data.

Y. H. P. Manurung, et al. [11] investigated welding sequence effect on induced angular distortion using FEM and GMAW experiments. The 3D thermo-elastic-plastic FEM analysis shows a good agreement with the experimental results with regards to weld distortion. Based on the results of experiment and simulation, it was found that the first welded side shows more angular distortion than the later welded one. P. K. Palani [12] investigated the effect of TIG welding process parameters on welding of Aluminium-65032. Response Surface Methodology was used to conduct the experiments. Researcher concluded that welding speed has most significant effect on both UTS and percentage elongation followed by welding current. However, gas flow rate has least significant influence on both UTS and percent elongation. R. Kassab [13] analyzed T-joint with V groove for AISI 1018 steel plate using experimental and finite element method for determination of deformations, distortions and residual stresses resulting from the welding of plates. E. A. Al- Bahkali, et al.

[14] studied the elastic-plastic stress distribution in weld-bonded joint made from austenitic stainless-steel (AISI 304) sheet and epoxy adhesive araldite 2011 subjected to axial loading. It was concluded that failure of spot attachment occurred at the interface between weld- nugget and HAZ. I. A. Ibrahim, et al. [15] studied the outcomes of different parameters on welding penetration, microstructures and hardness using the robot fuel metallic arc welding and observed that arc voltage and welding speed influenced considerably on the value of weld penetration.

2. Materials and Method.

2.1 Experimental Design.

AISI 310 stainless steel was selected as work piece material in AGMAW process, as it is widely used in applications involving high temperature and severe conditions. The control and constant.

input process parameters were selected as shown in Table 1. The levels and orthogonal array for conduction of experiments were developed using Taguchi method [16, 17]. The range and levels for process parameters were chosen as shown in Table 2, based on the literature review and the practice in the welding industry. The L9 orthogonal array was developed for the conduction of experiments in terms of the natural values, as shown in Table 3. This was generated by MINITAB software [18], where systematic error was evaded by random parameter assignment.

Table 1: Process parameters

Control parameters	Constant parameters
Voltage	Work piece material: AISI 310
Wire feed speed	Electrode material: ER 310
Welding speed	Electrode diameter: 1 mm
	Gas flow rate: 20
	LPM Current: 115 Ampere

Table 2 Range and levels of process parameter

Process parameter	Level 1	2	
Voltage (Volt)	18	18.5	
Wire feed speed (m/min)	60	63	
Welding speed (m/min)	0.23	0.28	0.

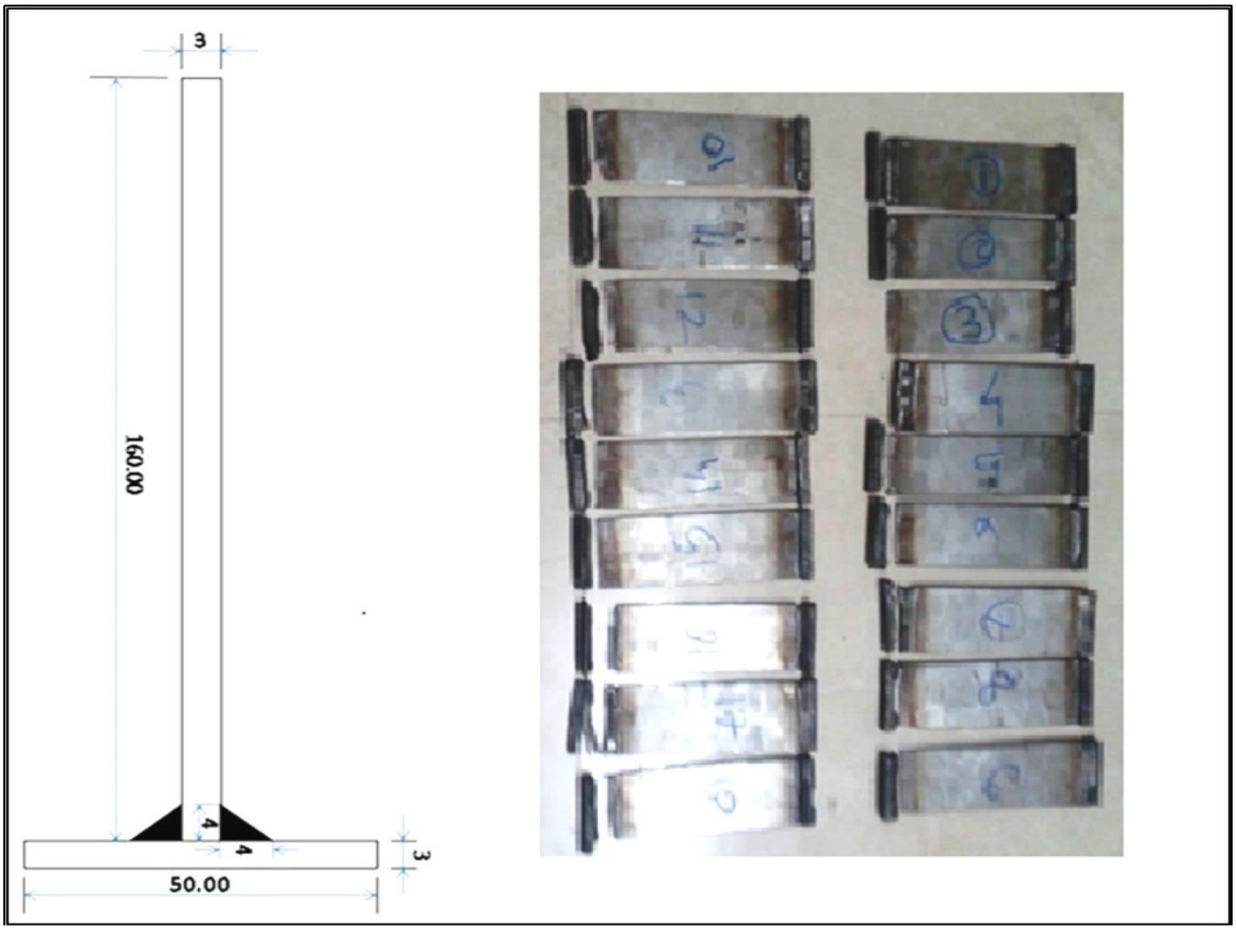
Table 3: Orthogonal array

Exp.	Voltage	Wire feed speed	Welding speed

No.	(V)	(m/min)	(m/min)
1	18	60	0.23
2	18	63	0.28
3	18	66	0.36
4	18.5	60	0.28
5	18.5	63	0.36
6	18.5	66	0.23
7	19	60	0.36
8	19	63	0.23
9	19	66	0.28

T joint was selected as it is generally preferred in blades of pump, blowers, rotaryengines, utensils, construction joints [10]. The T joint welded specifications were selected as given in Fig.1. 100% argon gas was selected as the shielding gas in AGMAW process. Then AGMAW was performed using Sigma weld welding machine with single pass on weld plate for 18 work piece samples of two trials as per Table 3.

Fig. 1: T joint specifications and tested samples on UTM



1.Results.

1.1 Experimental Method.

Tensile strength of welded joint of samples (Fig.1) was measured on Universal Testing Machine (UTM) with gradually applied tensile load. Tests were carried out as per IS 1608 standard on UTM machine. The results of the tensile strength are shown in Table 4.

Table 4: Experimental results

From the results, maximum tensile strength was observed to be 498.43 MPa (experiment no. 5), wherein the parameter settings were; voltage: 18.5 V, wire feed speed: 63 m/min and welding speed: 0.36 m/min.

Ex. No.	Input parameter			Output parameter		Avg .tensile strength
	Voltage	Wire feed speed	Welding speed	Tensile strength (MPa)		
	(V)	(m/min)	(m/min)	Trial 1	Trial 2	(MPa)
1	18	60	0.23	352.50	360.00	356.25
2	18	63	0.28	446.25	442.50	444.37
3	18	66	0.36	405.00	411.26	408.13
4	18.5	60	0.28	443.75	453.75	448.75
5	18.5	63	0.36	493.75	503.12	498.43
6	18.5	66	0.23	440.00	446.87	443.43
7	19	60	0.36	409.65	414.72	412.18
8	19	63	0.23	456.25	459.37	457.81
9	19	66	0.28	410.62	421.87	416.25

2.2 Finite Element Method.

The model of T joint weld was prepared by using UG NX CAD software. This model was meshed using tetrahedron type of meshing in ANSYS software. Material properties were assigned to the model. The input parameter was given in term of net heat input. As per European system (EN ISO 1011-1 and PD ISO /TR 18491), net heat input (Hnet) during the welding was obtained using Eq. 1 [19].

Hnet = ηa x (VI / S), kJ/mm

Where V is arc voltage (V), I is welding current (A), S is welding speed (mm/sec) and (ηa) is the arc efficiency indicating the fraction of heat generated and transferred to the plate. Here, arc efficiency was taken as 0.80 for GMAW process [19]. The calculated heat values for each experiment are given in Table 5. These input conditions were applied to the model and results were obtained as shown in Table 5. The tensile strength of sample experiments is shown in Fig.3 and Fig.4. Maximum tensile strength of 494.92 MPa was observed for the combination of process parameters of experiment no. 5.

Table 5: Finite element analysis results

Ex. No.	Current (A)	Voltage (V)	Wire feed speed (m/min)	Welding speed (m/min)	Net heat input (KJ/mm)	Tensile strength (MPa)
1	115	18	60	0.23	540.00	351.62
2	115	18	63	0.28	443.57	443.17
3	115	18	66	0.36	345.00	386.43
4	115	18.5	60	0.28	455.89	447.15
5	115	18.5	63	0.36	354.58	494.92
6	115	18.5	66	0.23	555.00	440.52
7	115	19	60	0.36	364.16	388.25
8	115	19	63	0.23	570.00	464.40
9	115	19	66	0.28	468.21	417.96

From Fig.3 and Fig.4, it was observed that the maximum stress value points are shifted away from the weld area towards the edge of the joint with base plate. Also, maximum stress value areas are very small and scattered. Comparison of the results between

the experimental method (Table 4) and finite element method (Table 5) show that the predicted tensile strength by FEM agreed well with the measured tensile strength. Deviations were between -0.014% and 6.16%. Therefore, experimental results of the tensile strength of T- type welded joint prepared by AGMAW process are acceptable [1].

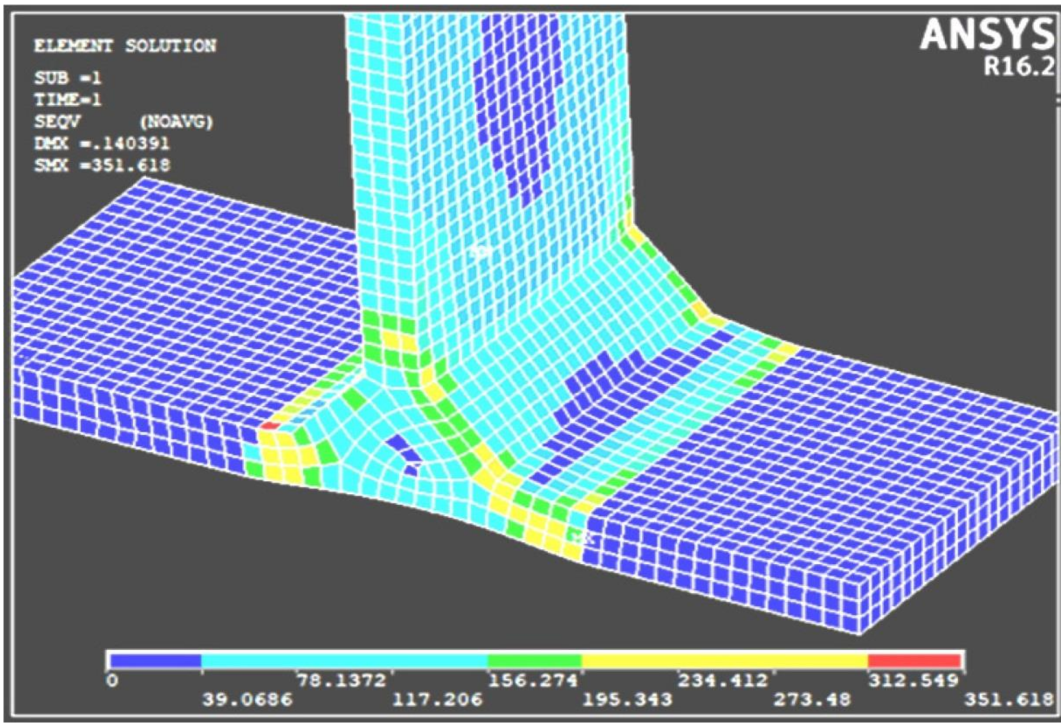


Fig. 3: Tensile strength at H=540 KJ/m (Experiment no.1)

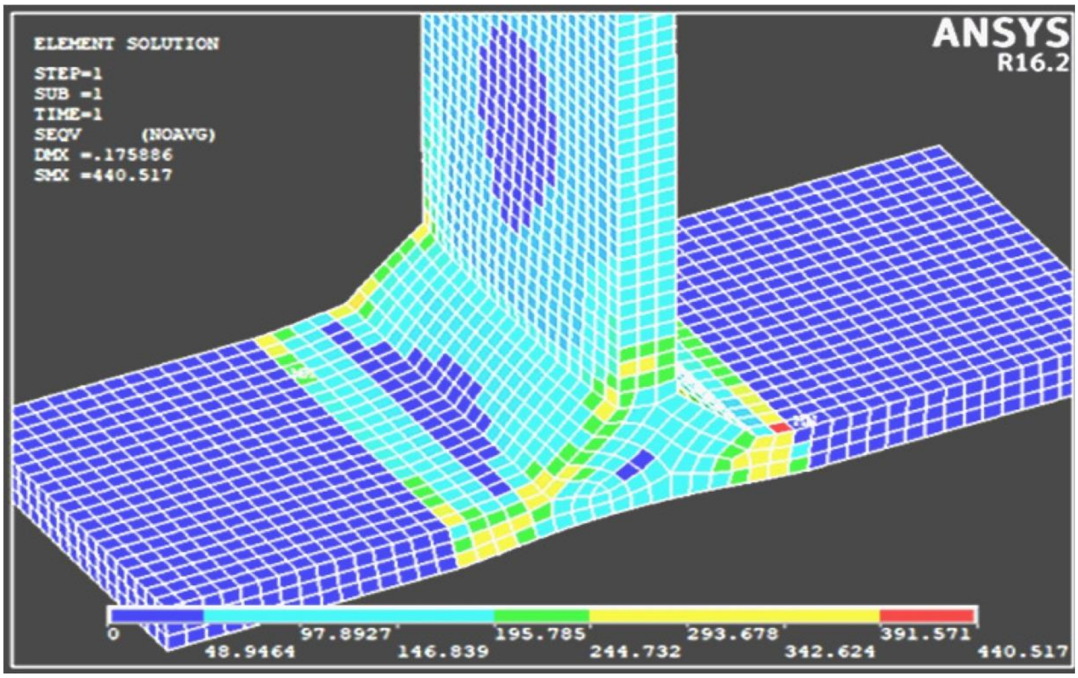


Fig. 4: Tensile strength at H=555 KJ/mm (Experiment no. 6)

3. Optimization of Process Parameters.

As the experimental results were validated, optimization of AGMAW process parameters was performed using Taguchi technique. Using the experimental data in Table 4 and Minitab software, S/N ratio, response table for S/N ratios, main effect plots for mean and analysis of variance for the tensile strength were obtained as shown in Table 6, Table 7, Fig.5, and Table 8 respectively. As tensile strength should be higher, the "Larger is the better" characteristic was selected during the analysis.

Table 6; S/N ratio for tensile strength

Ex. No.	Tensile Strength (MPa)	S/N ratio for tensile strength
1	356.25	51.03
2	444.37	52.95
3	408.13	51.59
4	448.75	53.03
5	498.43	53.95
6	443.43	52.93
7	412.18	52.03
8	457.81	53.21
9	416.25	52.38

Table 7: Response Table for S/N ratio for tensile **strength**

Level	**Voltage**	**Wire feed speed**	**Welding speed**
1	**392.9**	**419.2**	**385.7**
2	**463.5**	**436.5**	**466.9**
3	**408.7**	**409.6**	**412.6**
	70.6	**26.9**	**81.1**
Rank	**2**	**3**	**1**

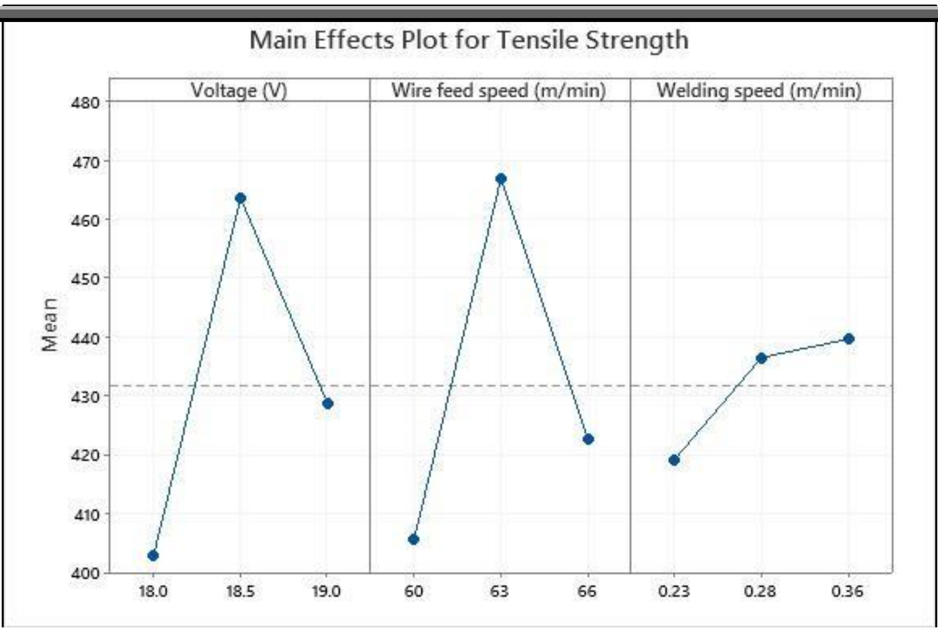


Fig.5: Main effects plot for tensile strength

Table 7 shows the orderly significance of the effect of process parameters on the tensile strength. The rank indicates the order in which process parameters affect the tensile strength. It was observed that the welding speed significantly affect the tensile strength followed by the voltage and then wire feed rate in AGMAW process. It can be observed from Fig. 5 that tensile strength increases with increase in the voltage level up to the optimum value of 18.5 V and thereafter it starts decreasing. As wire feed speed increases, tensile strength increases initially up to the optimum value of 63 m/min of wire feed speed and thereafter it starts to decrease. In GMAW process, low heat input

results in higher tensile strength as compared to high heat inputs [5, 20]. As voltage and wire feed speed increases [21] arc penetration and heat input increases. However, heat input is still low and hence cooling rate is high which results in fine grained structure in welded part. Hence the tensile strength increases. When voltage and wire feed rate crosses the corresponding optimum values, heat input became too high causing formation of coarse grains due to slow cooling rate [22] and hence tensile strength decreases. With increase in the welding speed, tensile strength increases at a faster rate up to the optimum value of 0.36 m/min of welding speed and then it continues to increase but with reduced rate. When welding speed increases, heat input decreases and hence tensile strength increases [23]. When welding speed became high, deposition of molten electrode, penetration and heat input is too low causing reduction in the rate of increase of the tensile strength. Thus, optimum values of process parameters for maximum tensile strength of welded joint in AGMAW process are voltage: 18.5 V, wire feed speed: 63 m/min and welding speed: 0.36 m/min.

Table 8: Analysis of variance for tensile strength

Source	DF	Adj. SS	Adj.MS	F	P	% contribution	Remark
Voltage	2	4120	4120	23.58	0.041	42.03	Significant
Wire feed speed	2	556.7	556.7	3.19	0.239	5.68	In-significant
Welding speed	2	5125.8	5125	29.33	0.033	52.28	Most significant
Error	2	174.8	174.8				
Total	8						

From analysis of variance (Table 8), welding speed has shown highest percentage contribution followed by the voltage on the welded joint strength. Hence, welding speed is the most significant factor affecting the tensile strength followed by the voltage in AGMAW process.

4.Conclusions.

The following conclusions were drawn from the present investigation.

i. The maximum error between the experimental results and FEM results is 6.16 %, which is acceptable. Thus, the experimental results for the tensile strength of T type welded joint produced by AGMAW were validated.

ii. In AGMAW process, maximum tensile strength of welded joint by the experimental method and FEM was 498.43 MPa and 494.92 MPa, respectively.

iii. Welding speed has shown 52.28 % contribution and voltage has shown 42.03 % contribution on argon gas welding joint strength. Hence welding speed is the most significant factor affecting the tensile strength followed by the voltage in AGMAW process.

iv. Optimum values of process parameters for the maximum tensile strength of T type joint were obtained as, voltage: 18.5 V, wire feed speed: 63 m/min and welding speed: 0.36 m/min in AGMAW process.

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