Experimental investigation of multi-pass, welding current & arc travel speed on AISI 1020 on weld joint mechanical properties during GMAW

Satish Bhatti[1], Nischal Chhabra[2], Pardeep Singh[3]

[1]Lecturer, Mechanical Engineering Department, CT Polytechnic College, Jalandhar, Punjab, India
[2] Assistant Professor, Department of Mechanical Engineering, DAV University, Jalandhar, Punjab, India
[3] Assistant Professor, Mechanical Engineering Department, R.I.E.T., Phagwara, Punjab, India

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Abstract - *Gas Metal Arc Welding (GMAW) process is widely adopted by industry for the production welding of steel. The innovation in GMAW has made the process very suitable for welding of thin sheet to thick plate. The AISI 1020, low carbon steel grade is used in many industrial applications. The mechanical properties of the above grade is greatly influenced by the number of passes, welding current and arc travel speed as per information available in the literature. Number of experimentations was performed using L9 orthogonal array to find out the influence of three levels of each process parameters and their combination. For L9 orthogonal array, three important parameters with their three levels were selected for the experimental study and the orthogonal array is constructed on the basis of Taguchi methodology. Two trials were repeated along with the main experiments and these experiments were performed on random basis to avoid an error. According to the plot for signal to noise ratio for UTS, the second level of multipass has better result followed by the first and third level of welding current and arc travel speed respectively. Optimum process parameters were selected and experiment was performed to verify the result and found to be 352 MPa. It is observed from the plot for S/N ratio for toughness that the third level of arc travel speed has better result followed by the third and first level of number of passes and welding current respectively. Optimum process parameters were selected and experiment was performed to verify the result and found to be 84 Joule. According to ANOVA, multi pass has more contribution for both of quantitative output, followed by the welding current and arc travel speed.*

Keywords: *GMAW Process, Welding Parameters, toughness, Taguchi method, SN ratio, ANOVA*

Nomenclature	
UTS Ultimate tensile strength	S/N Signal to Noise
GMAW Gas Metal Arc Welding	CO_2 Carbon Dioxide
ANOVA Analysis of Variance	O_2 Oxygen

1. INTRODUCTION

Welding is a widely used process for the fabrications of various components due to its reliability. In this era, the need for joining materials having higher value of tensile strength and toughness has arisen with the present advancement in science and technology. The effect of various welding parameters on the weld joint quality is determined by different researchers by adopting various techniques. The number of passes is also an important parameter along with welding current and arc travel speed for the tensile strength and toughness of the material.

During multipass welding of steel, the different value of heat flows through the heat affected zone which is majorly responsible for the alteration of mechanical properties. The variables that selected in this study are multipass, welding current and arc travel speed. Increasing the value of welding current increased the value of depth of penetration. Other than that, arc voltage and welding speed is another factor that influenced the value of depth of penetration [6].

MIG/MAG provides localized heating, melting and solidification of parent metal with the most suitable filler metal. During solidification phase, there is an uneven contraction which develops stresses in the weld joint and parent metal. Therefore this uneven contraction leads to development of residual stresses and these residual stresses are further linked to the mechanical properties [3].

With the incorporation of automation into the arc welding process, many production companies adopted complete experimental designs and mathematical models to investigate the relevant process parameters to obtain quality weld. The quality of weld is determined through the automation of welding so that there should be minimum variation in the process parameters as it is observed in the manual process. Even some companies use experimental design and mathematical model to find to optimize the process parameters [4].

The effect of multi-pass on low temperature impact toughness was carried out on butt welded high strength steel. The researcher assessed the Charpy impact toughness of the HAZ and the weld metal. The finding was that the selection of appropriate welding process and welding electrode affects the low temperature impact toughness [2]. The change of welding parameters and the shielding gas composition leads to the change in bead formation, size and penetration [5].

2. MATERIALS AND METHOD

2.1 Materials

The material which is widely used in industry is AISI 1020. This material is having wide range of applications that is why it is selected for experimental study. The base material is having a thickness of 10 mm, was cut to the required dimensions. The table numbered 1 and 2 show the chemical composition of the base material and filler material respectively.

Table 1 Chemical compositions of AISI 1020

Designation	Chemical Composition, max wt%				
	%C	%Mn	%P	%S	%Fe
AISI 1020	0.226	.361	0.06	0.04	Balance

Table 2 Chemical compositions of ER 70S-6 (Continuous)

Designation	Chemical Composition, max wt%				
	%C	%Mn	%Si	%P	%S
ER 70S-6	0.06-0.15	1.4-1.85	0.8-1.15	0.025 max	0.035 max

Table 2 Chemical compositions of ER 70S-6

Designation	Chemical Composition, max wt%				
	%Ni	%Cr	%Mo	%V	%Cu
ER 70S-6	0.15 max	0.15 max	0.15 max	0.03 max	0.5 max

2.2 Taguchi Method

Process parameters optimization is the pivotal step in the Taguchi methodology in achieving high quality standards (without increasing costs) and improved performance [8]. Taguchi proposes an organized way of experimentation and with least cost. The orthogonal arrays used in Taguchi approach, organize the parameters at different levels which affect the result tremendously. Full factorial design proposes all the combination of parameters but Taguchi proposes a partial factorial design which not only decreases the cost of experimentation but it increases the effectiveness of experimentation. An L9 orthogonal array having three parameters with three level of each parameter was selected. The three parameters selected in this experiment are multipass, welding current and arc travel speed. The parameters and their level are shown in the table 3, and these parameters are taken based on the trials.

Taguchi's technique is adopted widely in engineering applications [7]. It is the most effective tool through which up gradation of the performance of the product, process and design with significant prediction of cost and time can be achieved [1]. It provides an efficient and systematic technique to determine optimal process parameters. The design given by the Taguchi is so efficient that it operate consistently and optimally over a variety of conditions. The numbers of experiments are reduced tremendously which reduces the cost of experimentation. The Taguchi approach can be used by the person whose knowledge in statistics limited. Therefore it is widely popularized for the optimization of process parameters. Taguchi divide the quality characteristics into three categories of based on Signal to Noise ratio (S/N ratio). They are categorized as (i) the Smaller-the-better (ii) the Larger-the-better and (iii) Nominal-the-better. The S/N ratio for each combination of the process parameters is computed based on Signal to Noise ratio. Out of three categories, one is having higher S/N ratio which means better quality of the product. The optimum level of process parameters has high value of S/N ratio.

Table 3 Selected GMAW variables and their levels

Variables	Level 1	Level 2	Level 3
No. of Passes	1	2	3
Arc Travel Speed (Cm/min)	9	18	26
Welding Current (Amp.)	45	55	65

Table 4 Selected GMAW variables and their levels

Experiment Number	Process variables used		
	Number of passes	Arc travel speed	Welding current
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

MINITAB-16 software is used for design of experiment as well as for ANOVA. A L9 orthogonal array was selected, under this there are 9 trial conditions and for each condition two repetitions were performed. The three parameters used in this experiment are the multipass, welding current and arc travel speed with three levels of each parameter and is shown in the table 3. The parameter and their levels were selected on the basis of trials welding using MAG welding process. The complete L9 orthogonal array is shown in the table 4. It is a good practice to make an edge preparation according to the thickness of the base material and the type of welding process. A joint fit-up was used to minimize the distortion which usually occurs during welding. Before welding, it was ensured that the joint surface area was free from rust, oil, grease etc. The tacking was performed before laying a complete bead on the joint.

The welding setup was made ready by setting the parameters value according to the trial number given in the table of orthogonal array. The gas flow rate is made constant, adjusted and checked for any kind of leakage.

Table 5 Input parameters of orthogonal array and the output characteristics

Trial No.	Input Parameters			Output (strength) Joules		
	Number of Passes	Arc Travel Speed	Welding Current	R 1	R 2	Average
1	1	1	1	300	304	302
2	1	2	2	335	331	333
3	1	3	3	311	313	312
4	2	1	2	342	344	343
5	2	2	3	334	336	335
6	2	3	1	335	341	338
7	3	1	3	311	315	313
8	3	2	1	328	322	325
9	3	3	2	324	332	328

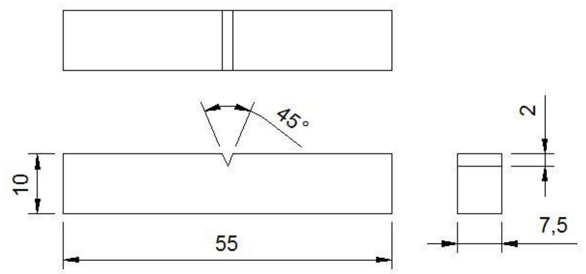

Fig 1 Charpy Sub Size Impact Test Specimen as per "ASTM E23-02a"

The experiments were performed on a GMAW machine with CV characteristics as per experimental layout of L9 orthogonal array for tensile strength and toughness and these orthogonal arrays for the tensile strength and toughness are shown in the table 4 and table 10 respectively. When all the trials were completed with repetition, the reinforcement from all the specimens was flush out. With reference to the ASTM E23-02a, Charpy test specimens were prepared from the different plates as per the drawing shown in Fig 1. The tensile and Charpy test specimens were taken out by following the standards of ASTM. All the tests were carried out at room temperature. The average toughness of the Charpy specimens from two repetitions and average tensile strength from the two repetitions were obtained and shown in the table 5 and table 11 respectively.

3. RESULTS AND DISCUSSION

3.1 Analysis of Tensile Strength

The S/N ratio and mean determined for each experiment gives optimum level of process parameters for high strength of the weld. The S/N and mean ratio for each combination of parameters is calculated through the Minitab 16 software and shown in the table numbered 6 & 7 respectively.

Table 6 Response Table for Signal to Noise Ratios Larger is better

Level	No. of Passes	Arc Travel Speed	Welding Current
1	49.98	50.07	50.14
2	50.60	50.40	50.49
3	50.16	50.26	50.1
Delta	0.62	0.32	0.39
Rank	1	3	2

Table 7 Response table for Means

Level	No. of Passes	Arc Travel Speed	Welding Current
1	315.7	319.3	321.7
2	338.7	331.0	334.7
3	322.0	326.0	320.0
Delta	23.0	11.7	14.7
Rank	1	3	2

The tensile strength of the GMAW welded joint is taken as the output characteristic. The response table for the S/N ratio depicts that the number of passes affect ranks first in the contribution of high tensile strength, while welding current and arc travel speed take the second and third ranks respectively. The same trend has been observed in the response table of mean which are presented in Tables 7.

The responses for the plot of the S/N ratio and Mean are shown in Fig 2 and Fig 3 respectively. The tensile strength was estimated to be the maximum for 2 numbers of passes, 18 cm/min arc travel speed and 55 Amp welding current.

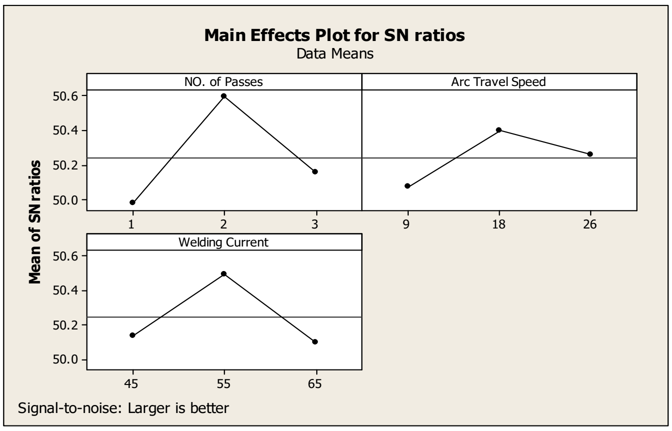

Fig 2 Main Effects Plot for SN ratios

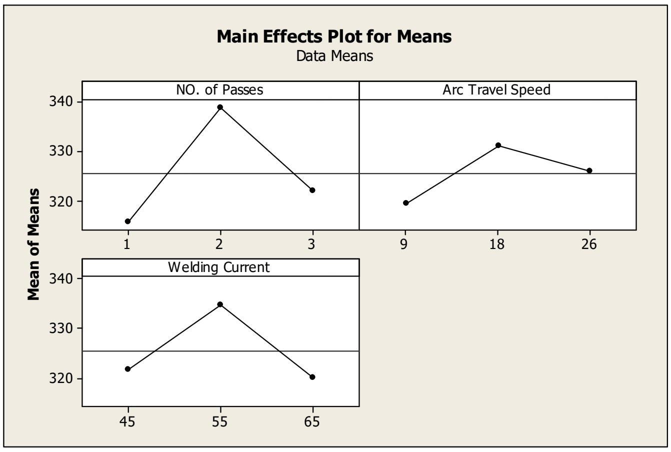

Fig 3 Main Effects Plot for Means

3.2 Analysis of Variance

ANOVA is performed on Minitab-16 software. Through this, individual contribution of the welding parameter on the tensile strength was determined. The relative importance of the welding parameters is shown in Table 8. The analysis of variance for tensile strength shows that the number of passes is the most influential parameter with a percentage of 55.43%, followed by the welding current of 25.55% and arc travel speed of 14.47%.

The optimum parameter obtained can be due to the two following possibilities; either the combination of the process parameters as prescribed may be present in the experimental combination, or may not be present in the combination. The optimum parameter for higher tensile strength obtained by the Taguchi method is presented in Table 9.

The estimated optimized parameters through the Taguchi method were used to determine the maximum tensile strength of the welded joint. Three experiments were conducted and the average tensile strength of the joint obtained with these process parameters is found to be 352 MPa and this value was close to the predicted value. The average tensile strength of the base material was found to 420 MPa and hence the optimized weld has good tensile strength of the welded joint.

Table 9 Optimized result obtained from ANOVA-Minitab

	No. of Passes	Arc Travel Speed	Welding Current	Strength MPa
Taguchi Method	2	18	55	352

3.3 Analysis for Toughness

The Mean and signal to noise ratio are the two effects which influence the response of the factors. The influencing level of each selected welding parameter can be identified.

Table 10 Selected GMAW variables and their levels

Experiment Number	Process variables used		
	Number of passes	Arc Travel Speed	Welding Current
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 11 Input parameters of orthogonal array and the output characteristics

Trial No.	Input Parameters			Output (Toughness) Joules		
	Number of Passes	Arc Travel Speed	Weldin g Current	R 1	R 2	Avera ge
1	1	1	1	62	58	60
2	1	2	2	46	48	47
3	1	3	3	55	49	52
4	2	1	2	60	58	59
5	2	2	3	52	50	51
6	2	3	1	75	81	78
7	3	1	3	62	64	63
8	3	2	1	59	63	61
9	3	3	2	76	72	74

Table 8 Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
No. of Passes	2	0.60652	0.60652	0.30326	12.16	0.076	55.43%
Arc Travel Speed	2	0.15830	0.15830	0.07915	3.17	0.240	14.47%
Welding Current	2	0.27958	0.27958	0.13979	5.6	0.151	25.55%
Residual Error	2	0.04989	0.04989	0.02494			
Total	8	1.09429					

The toughness of the GMAW welded joint is taken as the output characteristic. The response table for the S/N ratio shows that the arc travel speed effect ranks first in the contribution of high joint toughness, while number of passes and welding current take the second and third ranks respectively. The same trend has been observed in the response table of the SN ratio and mean which are presented in Tables 12 and 13 respectively.

Table 12 Response Table for Signal to Noise Ratios
Larger is better

Level	No. of Passes	Arc Travel Speed	Welding Current
1	34.44	35.66	36.37
2	35.80	34.43	35.41
3	36.36	36.52	34.82
Delta	1.92	2.08	1.55
Rank	2	1	3

Table 13 Response table for Means

Level	No. of Passes	Arc Travel Speed	Welding Current
1	53.00	60.67	66.33
2	62.67	53.00	60.00
3	66.00	68.00	55.33
Delta	13.00	15.00	11.00
Rank	2	1	3

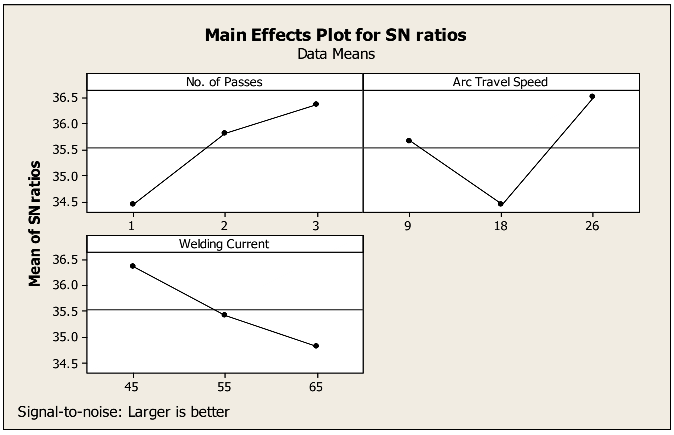

Fig 4 Main Effects Plot for SN ratios

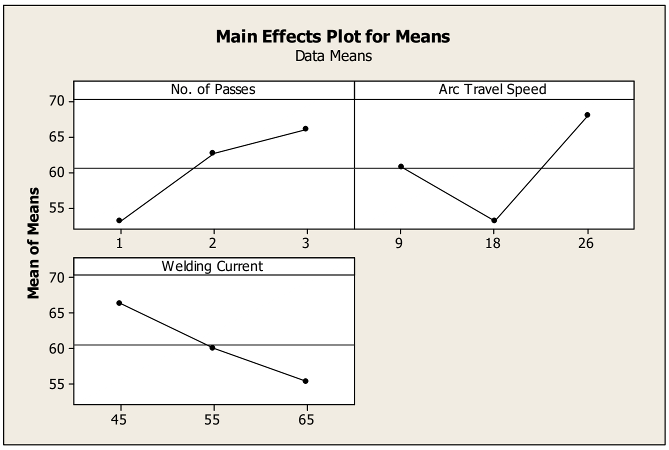

Fig 5 Main Effects Plot for Means

The responses for the plot of the S/N ratio and Mean are shown in Fig 4 and Fig 5 respectively. The toughness was estimated to be the maximum for 3 numbers of passes, 26 cm/min arc travel speed and 45 Amp current; which is optimal from the plots obtained.

3.4 Analysis for Variance

ANOVA is performed on Minitab-16 software. The main aim of the analysis is to estimate the percentage of the individual contribution of the welding parameter on the toughness of the weld, and also give accurately the combination of the process parameters. The relative importance of the welding parameters is presented in Table 14. The analysis of variance for toughness shows that arc travel speed is the most influential parameter with a percentage of 39.19%, followed by the number of passes of 34.85% and welding current of 21.92%.

The optimum parameter obtained can be due to the two following possibilities; either the combination of the process parameters as prescribed may be present in the experimental combination, or may not be present in the combination. The optimum parameter for higher toughness obtained by the Taguchi method is presented in table 15.

The estimated optimized parameters through the Taguchi method were used to determine the maximum toughness of the welded joint.

Table 14 Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
No. of Passes	2	5.8409	5.8409	2.9204	8.61	0.104	34.85%
Arc Travel Speed	2	6.5691	6.5691	3.2845	9.68	0.094	39.19%
Welding Current	2	3.6739	3.6739	1.8369	5.41	0.156	21.92%
Residual Error	2	0.6786	0.6786	0.3393			
Total	8	16.7624					

Three experiments were conducted and the average toughness of the joint obtained with these process parameters is found to be 84 Joules and this value was close to the predicted value. The average toughness of the base material was found to 41 Joules and hence the optimized weld has given better toughness of the welded joint.

Table 15 Optimized result obtained from ANOVA-Minitab

	No. of Passes	Arc Travel Speed	Welding Current	Toughness Joules
Taguchi Method	3	26	45	84

4. CONCLUSION

The Taguchi method has been used to optimize the welding parameters of GMAW process for maximum tensile strength and toughness of 10 mm thick plate AISI 1020

1. The analysis of variance for the strength conclude that the number of passes is the most significant parameter with a percentage of 52.43%, followed by welding current of 25.55% and arc travel speed of 14.47%.

2. The optimum combination of parameters obtained from the main effect plot for the SN ratio and mean for strength are number of passes which ranks first in the contribution of high joint toughness, while welding current and arc travel speed second and third ranks respectively.

3. The analysis of variance for the toughness conclude that the arc travel speed is the most significant parameter with a percentage of 39.19%, followed by the no. of passes of 34.85% and welding current of 21.92%.

4. The optimum combination of parameters obtained from the main effect plot for the SN ratio and mean are arc travel speed which ranks first in the contribution of high joint toughness, while number of passes and welding current take the second and third ranks respectively.

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