Optimization of Metal Inert Gas Welding with Taguchi Method

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Abstract. Welding parameters affected to weld joint performance. Optimize welding parameter of Metal Inert Gas (MIG) welding is not many studied. This study discussed Optimization from welding parameter of MIG welding used Taguchi Method. Tensile strength of weld joint was affected by welding speed significantly. Factor level welding current 100A, wire speed 65 inch/min, welding speed 6 mm/sec could get the optimize tensile strength. The value of tensile strength optimize when the average 44.07 kg/mm2 of Confirmation experimental and an average value 43.79 kg/mm2 based on Taguchi experiment.

1. Introduction

Welding technology is still common used in industries however performance of a weld joint decrease because of welding process[1]. Heat input of welding technology is affected by welding process parameter. Welding process parameters were importance to get weld joint quality[2]. Each welding technology has difference process parameter.

Wiryosumarto and Okumara said that once of welding process of Metal used manufacture industries the arc welding. Gas arc welding is welding process using the gas protecting to protect arc and metal when melting condition to welding defect. Metal Inert Gas (MIG) is one of some welding methods using Argon and CO_2 as a protecting. MIG was used to weld height strength steel, stainless steel and also no Ferro metal that can be welded by another method.

Muzakki et al studied parameter welding of micro Resistance Spot Welding with leveling welding current, welding time[3]. MIG process welding parameters also importance and were studied in this study. The MIG parameter which was studied and was discussed in this study such as welding current, arc stress, welding speed, and arc gas. Patil and Waghmare laso used welding speed, welding current, and arc stress.

Performance or weld joint quality was studied by testing and measurement the mechanical properties in this study such as tensile strength, and optimize parameters used Taguchi method. Not many researchers studied optimize welding parameters of metal joint MIG weld with TAGUCHI method.

2. Material and Method

ST 37 steel sheet was used in this study, the steel was cut based on ASTM E 8/ E 8 M dimension standard. Detaille specimen dimension represent by figure 1.

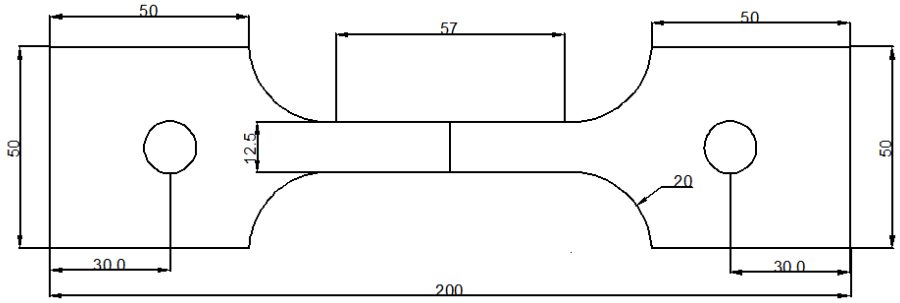

Figure 1. Shape and dimension of tensile test specimen

This welding process used a Millernmatic 180 Auto-set welding machine, specification and shape of welding machine were shown in Figure 2, and table 1 for presenting the specification machine.

Figure 2. MIG Welding Machine
(Source : https://www.millerwelds.com/equipment/welders/mig-gmaw)

Welding parameter used the machine specification such as welding current, arc stress.

Tabel 1. Specification of Welding Machine

Tipe Solid/stainless	**Tipe Flux Cored**		Length : 444mm, Width : 273mm, Height : 400mm
0,24-0,35 in	0,30 - 0,45 in		**Weight of Machine**
(0,6 - 0,9 mm)	(0,8 - 1,2 mm		72 Lb (32,7 kg)
Wire Speed			**Welding Current**
60-540 Ipm (1,5 - 13,7 m/min)			30-180 A

Welding process was worked by arm robotic, the type of robot is Scorbot Er 9Pro. The arm robotic was used to welding process to get the constant welding speed. Scorbot Er 9Pro and specifications of arm robotic were represented by figure 3 and table 2.

Figure 3. Scorbot Er 9Pro

Specification of the robot was shown in the table 3 which can be represented the performance of the robot.

2.1. Tensile Test

"Zhejiang Geotechnical" Tensile Test Machine was used in this study, this machine was used to practicum and experiment in the laboratory at Mechanical Engineering Department. Maximum capacity and dimension of machine were 300 KN and 750 mm x 600 mm x 2100 mm.

2.2. *Method*

2.2.1. Data collection. The tensile strength became respond variable for this study. Tensile test of specimens was welded with the welding process parameter combination. Treatment factor variable or the level of welding process parameter represented the level of welding speed, wire speed, and welding current for this study. Each factor was leveled three values which could represent the effect of welding parameter to weld joint quality. Treatment factor variable was presented in table 4.

This study discussed Taguchi method so the data used Orthogonal Matrix to get accurate data. Soejanto said that when the Orthogonal Matrix was used, degree of freedom value from experiment and matrix have to attend. The matrix value was shown in table 5.

Table 5. Orthogonal Matrix $L_9(3^3)$

Eksperimen	**Threatment Factor**		
	A	**B**	**C**
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

Orthogonal matrix L_9 (3^3) could be known that 9 specimen were tested and 3 replicated so 27 values.

2.2.2. Taguchi method stages. Frist, Varian Analysis or Analysis of Varian (ANOVA) is account to measure the contribution each level to result. Second, S/N Ratio was used to know the levels characteristic. Third, polling up is the clustering factor that is not significant (error) which were resulted from ANOVA.

3. Result and Discussion

Results of experimental have gotten and stages of Taguchi have been done. Each data was represented in tables and figures. Tensile Test for each welding parameter combination according to Design of Experimental (DOE) was shown in table 6.

Table 6. Result of Experiment

No	Design of Experiment			Treatment Factor Combination			Experimantal Repetition			Everage (kg/mm2)
	Amp	inch/ min	mm/sec	Current	Wire Speed	Welding Speed	1	2	3	
1	1	1	1	80	55	5	43.6968	39.7718	45.4359	42.9682
2	1	2	2	80	60	6	41.0603	42.9393	43.0446	42.3481
3	1	3	3	80	65	7	40.3271	42.8272	44.7326	42.6290
4	2	1	2	90	55	6	39.8166	40.0010	45.8786	41.8988
5	2	2	3	90	60	7	40.9672	49.8095	42.5944	44.4570
6	2	3	1	90	65	5	41.7322	50.9957	44.3812	45.7030
7	3	1	3	100	55	7	48.7992	38.8600	39.5662	42.4085
8	3	2	1	100	60	5	49.5307	51.4116	42.0044	47.6489
9	3	3	2	100	65	6	49.6225	40.6784	41.0070	43.7693

Table 6 sawn that welding current 80 A, wire speed 55 inch/min, and 55 mm/sec could achieve 45.4359 kg/mm^2 tensile strength. Combination of welding parameter 90 A for welding current, 65 inch/min of wire speed, welding speed 5 mm/second resulted tensile strength 50.9957 kg/mm^2. 51.4116 kg/mm^2, the highest tensile strength could be achieved when welding process parameter 100 A, 60 inch/min, and 5 mm/second. Each parameter combination had the highest and the lowest value so optimize and the real value of welding parameter can be achieved with Taguchi Method.

Taguchi method has some stages the first stage is an Analysis of variant. The results of ANOVA were presented in table 7.

Table 7. ANOVA Ultimate Tensile Strength (UTS)

Source	df	SS	MQ	F
SSA	2	6.07098106	3.03549053	12.270
SSB	2	8.92839984	4.46419992	18.045
SSC	2	13.08117005	6.54058502	26.439
ERROR	2	0.49477660	0.24738830	
Total	8	28.57532755		

Analysis of Varian presented in table 7, SSC has Sum of Square the highest of 13.08117005 and also F value 26.439. Based on the ANOVA's result used to adjust the signification contribution with welding current represented SSA. Hypothesis such as: H_0 that welding current has not significant effect to tensile strength. H_1 that welding current significant affect to tensile strength. Effect of wire speed to tensile strength, H_0 that wire speed did not significant affect to the tensile strength. H_1 affect significant to tensile strength. SSB represent that wire speed affects to tensile strength. Effect of Welding speed to tensile strength was represented by SSC so H_0 don't significant effect to tensile strength and H_1 significant effect to tensile strength. Reject H0 if F account > F

table. F table in this study (0,05,2,2) is 19. Welding speed affected significant to tensile strength. To know optimize tensile strength of tensile strength will be gotten, it need next stage of Taguchi method.

Calculation of S/N ratio each treatment factor combination with repetition of tensile test was shown in table 8.

Table 8. S/N Ratio Value

No	Design of Experiment			Repetition-1 (Kg/mm2)	Repetition-2 (kg/mm2)	Repetition-3 (kg/mm2)	Average (kg/mm2)	S/N Ratio
	Amp	Inch/min	mm/sec					
1	1	1	1	43.697	39.772	45.436	42.96818499	32.6220
2	1	2	2	41.060	42.939	43.045	42.348058405	32.5305
3	1	3	3	40.327	42.827	44.733	42.62896781	32.5705
4	2	1	2	39.817	40.001	45.879	41.898772067	32.3887
5	2	2	3	40.967	49.810	42.594	44.45704235	32.8677
6	2	3	1	41.732	50.996	44.381	45.70302696	33.1086
7	3	1	3	48.799	38.860	39.566	42.40848646	32.4136
8	3	2	1	49.531	51.412	42.004	47.648892732	33.4591
9	3	3	2	49.623	40.678	41.007	43.7692974	32.7161

Based on table 8, S/N ratio was analyzed with ANOVA to know significant contribution to tensile strength of weld joint. Result of ANOVA was represented with table 9.

Table 9. ANOVA S/N Ratio Based on Calculation

Source	df	SS	MQ	F
SSA	2	0.1347	0.0673	5.9951
SSB	2	0.3567	0.1783	15.8768
SSC	2	0.4725	0.2363	21.0354
ERROR	2	0.0225	0.0112	
Total	8	0.9864		

F value of SSC is 21.0354 and F table 19 so welding speed has significant affect to tensile strength. Plotting mean value of average each parameter with welding parameter combination which used Minitab software 17. The plotting was shown figure 4.

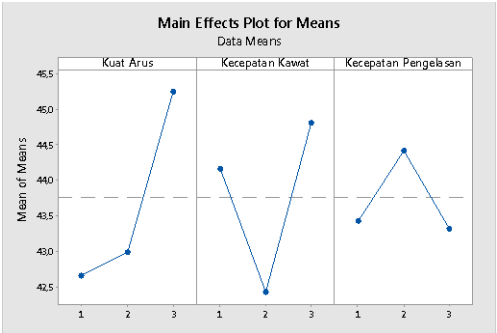

Figure 4. Factor Combination Vs Optimize level based on Mean

Figure 4 explains that mean of factor treatment for welding current more than 42.5 kg/mm^2, level 2 is around 43 kg/mm^2 however level 3 so difference more than 45 and less than 45.5 kg/mm^2. Wire speed at level 1 is around 44.25, it is near with average 43.75 kg/mm^2. Value of level 2 and were 3 42.75 and 44.25 both of far from average. Level 1 and 3 of Welding speed under average value were 43.5 and 43.25 and level 2 was upper than average at 44.5 kg/mm^2.

Plotting S/N ratio of main tensile strength versus each level for welding parameter or factor combination based on table 8. The results of Minitab software was represented by figure 5.

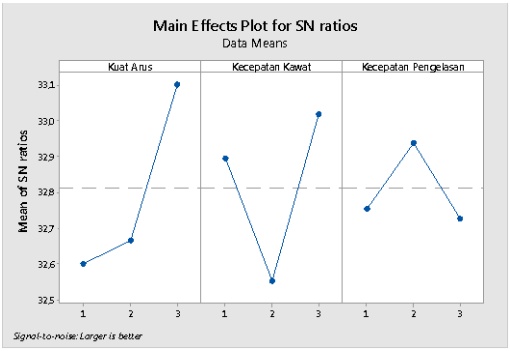

Figure 5. Factor Combination Vs S/N Ratio based on Mean

Figure 5 explains that plotting pattern from S/N ratio data tend to similar with Figure 4 optimize to mean each mean level, however the value tend to decrease. Average for all data is more 32.8, S/N ratio of welding current level 1 and level 2 under average value 32.6 and less than 32.7 and level 3 higher 33.1 it is the highest S/N ratio more higher than another S/N ratio. S/N ratio of wire speed level 1, it is 32.9 near with average value. Value of level 2 from wire speed is 32.55. It is the lowest value for S/N ratio. Level 3 is far from S/N ratio average. Value from all level of welding speed is near with S/N ratio average value. Level 1 and level 3 under average were 32.775 and 32.75. Level 3 is not more than 32.9. Next stage is polling up.

Polling up of each factor has done, the objective of polling up is to know significance contribution for treatment factor. Joining the factor to error is strategy of polling up. Polling up for welding current so sum square of welding current was joined with sum square of error. The wire speed F value change because of the structure from ANOVA result has changed, moreover F table value was also change (0.05, 2, 4), F table value is 6.94. Based on F value was lower than F table so wire speed factor is not significance contribute to tensile strength because 2.720 value of F value calculation lower than 6.94 of F table value. Wire speed has sum square value higher than welding current so wire speed became next polling up. Welding current value was 1.288521149 of calculation value. It is less than 6.94 of table value. Welding current was not significant affected to tensile test strength.

The Polling up of welding speed factor from ANOVA that F value of polling up of welding current and wire speed factor less than F value of table. F value of welding current was 0.894373147 and F value of wire speed was 1.3153263, F value table was 6.94. The F value of welding current 0.894373147 less than 6.94 so welding current factor was not significant to tensile strength. The F value of wire speed factor when welding speed become polling the F value of wire speed less then value table so wire speed was not significant effected to tensile strength.

Polling up factor of welding current from S/N value which was resulted by ANOVA represented 4.539 of F value from SSB or Wire Speed Factor. It explained that SSB was not significance affected to tensile strength because of F value lower than F table. The result of ANOVA from SSC or Welding speed factor of S/N value shows that F value was 6.014. SSC did not affect significant to tensile strength because the table value is 6.94. F table was higher than F value. The results of ANOVA when polling was SSB or wire speed factor. SSA as welding current factor had F value 0.710. This value was lower than 6.94 of table so wire speed factor did not affected significant to tensile strength of welding joint. SSC represented as welding speed factor from S/N calculation, the result of ANOVA shows that F value was 2.492822249. F table value is 6.94 so welding speed factor is not significance affected to tensile strength. Welding speed factor or SSC was become as polling for S/N calculation. The results of ANOVA can be explained that SSA and SSB value were lower than F table value. The F value of SSA of welding current factor was 0.544133383 based on ANOVA. The tensile strength was not affected significantly because the F value was lower than F table value. SSB as wire speed factor had F value

lower than F table value so wire speed factor did not effect to tensile strength significant because of SSB F value was 1. 441024542 and F table value is 6.94.

Each factor contribution based on average value of tensile tests from each specimen welded by welding parameters combination was shown by table 10.

Table 10. Contribution each factor based on mean (%)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	SS'	ρ (%)
Welding Current	2	6.070981	3.035491	12.270146	13.38	5.576204	19.51405
Wire Speed	2	8.9284	4.4642	18.045315	28.9	8.433623	29.51365
Welding Speed	2	13.08117	6.540585	26.438538	41.01	12.58639	44.04637
Error	2	0.494777	0.247388			1.979106	6.925927
Total	8	28.57533				28.57533	100

Table 10 shown that effect of welding current to tensile strength was 19.51%, tensile strength of weld joint was affected by wire speed 29.51 %, and welding speed affected to tensile strength 44.04 %. Welding speed had effect to tensile strength was higher than wire speed and welding current. Calculation of contribution each factor in present was shown in table 11.

Table 11. Contribution Each Factor (%)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	SS'	ρ (%)
Welding Current	2	0.1347	0.0673383	5.995102	0.834	0.112212	11.3765
Wire Speed	2	0.3567	0.1783315	15.87679	0.858	0.334199	33.8823
Welding Speed	2	0.4725	0.2362743	21.03541	0.75	0.450084	45.6312
Error	2	0.0225	0.0112322			0.089858	9.1101
SST	8	0.9864				0.986353	100

Table 11 explained that contribution each factor in percent based on calculation was presented that effect of welding current to tensile strength 11,37 %, effect of wire speed 33,88 %, and welding speed affected to tensile strength 45,63%.

Calculation of confidence interval of Taguchi Method used to the prediction and optimize values, the results of calculation was shown in table 12. Confirmation experiment value must on around confirmation confident value.

Table 12. Result of Calculation Taguchi Method

Respond (Maximum Tensile Strength/UTS)		Prediction	Optimize		
Taguchi Experiment	Average	43.79676	43.797	±	1.887
	S/N Rasio	32.72276	32.723	±	0.402
Confirmation Experiment	Average	44.07681	44.077	±	1.887
	S/N Rasio	32.86844	32.868	±	0.402

Average value of Taguchi Experiment was 4.797 optimize value and 43.79676 of prediction value. Confirmation experiment had prediction value in average was 44.07681 and average value of optimize was 44.077. Average value of confirmation experiment was higher than Taguchi experiment.

4. Conclusion

Based on result and discussion, conclusion of this study represented that:

1. ANOVA test, welding speed was significant effect to tensile strength. Presentation effect of S/N ratio based on counting to the tensile strength was 45.63%.
2. Combination level of treatment process factor, the best factor level welding current 100A, wire speed 65 inch/min, welding speed 6 mm/sec).
3. Tensile strength optimal could be achieved based on average 44.07 kg/mm^2 and average based on 43.79 kg/mm^2.

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