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Experimental Analysis on TIG welding process parameters of dissimilar metals SS304-SS202 using Taguchi Method

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Abstract

This paper presents an effect of welding process parameters on the mechanical and microstructural properties of dissimilar SS304-SS202 joints welded with TIG welding process with Inconel625 filler wire of diameter 3.2mm. The input parameter chosen were the welding current, welding speed and gas flow rate. The mechanical properties (output responses) chosen were- impact toughness and bending strength. A plan of experiments based on L_9 orthogonal array (OA) of Taguchi method has been used to acquire the data. Statistical techniques- analysis of variance (ANOVA) and signal-to-noise (S/N) ratio have been employed to investigate the welding characteristics of dissimilar metal joint & optimize the welding parameters. The maximum values of impact strength and bending strength were found to be 7.3KJ/mm^2 and 962.79N/mm^2 respectively. The optimal combination of parameters was determined as $A_2B_1C_3$ i.e. welding current at 115 Amp, welding speed at 1.5mm/sec and gas flow rate at the 12lit / min for impact strength and $A_2B_3C_3$ i.e. welding current at 115 Amp, welding speed at 2.5mm/sec and gas flow rate at 12lit/min respectively for bending strength. The structure-property relationships on these dissimilar weldments were evaluated using the SEM /EDS and XRD analysis technique.

Keywords: Optimization, Orthogonal array, S/N ratio, ANOVA

1. INTRODUCTION

Welding has made a significant impact on the large number of industries by raising their operational efficiency, productivity and service life of the plant and relevant equipment. But with the widespread applications of welding, technology needs constant upgrading [1]. To consistently produce high quality of welds, welding technique requires experienced welding personnel. One reason for this is the need to properly select welding parameters for a given task to provide a good weld quality which identified by its micro-structure and the amount of spatter, and relied on the correct bead geometry size. Therefore, the use of the control system in arc welding can eliminate much of the "guess work" often employed by welders to specify welding parameters for a given task. A Lot of research work has been done on optimum choice of welding parameters. Ibrahim et al. [2] studied the effect of different MIG welding process parameters on hardness and depth of penetration. Bharath et al. [3] optimized TIG welding process parameters of 316 Stainless Steel using Taguchi Technique. Chuaiphan and Srijaroenpramong [4] studied the effect of welding speed on microstructures, mechanical properties and corrosion behavior of GTA-welded AISI 201 stainless steel sheets. Srirangan and Paulraj [5] applied Multi-response optimization technique for optimization of TIG welding process parameters of Incoloy 800HT by Taguchi gray relational analysis. Bilga et al. [6] applied Taguchi method for optimization of energy consumption response parameters for turning operation.

This research studies the influence of various input parameters on the impact toughness and bending strength of SS304-SS202 welded joint. The influence of current, speed and flow rate is identified by ANOVA method.

2. EXPERIMENTATION

Stainless steel plates of SS304 and SS202 having size of 150×100×4 mm were used in this investigation. The input process parameters used for welding with their levels are - welding current (95-135) Amp, welding speed (1.5-2.5) mm/sec and gas flow rate (8-12) Lit/min. The Taguchi L9 orthogonal array was selected, and the experiments were carried out accordingly. SS304 and SS202 dissimilar metal plates were butt welded using Inconel 625 of 3.2 mm diameters as filler wire. The objective function chosen were the impact toughness and bending strength. The impact test was carried out according to ASTM standards – E23.The measured values of bending strength and impact toughness are presented in Table 1. Three trials on the weldments were carried out to check the reproducibility of the results.

Table 1 experimental value of output responses

S.NO	Impact toughness ($kg/mm^{2)}$	Bending Strength ($N/mm^{2)}$
1	5.5	893.25
2	5.2	746.53
3	6.1	935.52
4	6.9	826.72
5	7.3	946.25
6	6.8	962.79
7	7.1	897.13
8	6.0	782.43
9	5.9	770

3. ANALYSIS OF RESULTS

The Results of analysis of variance (ANOVA test) for bending strength are shown in Table 2. The value of p greater than 0.05 for welding current and welding speed indicates that it has not statistically significant effect on response bending strength. On examination of the Delta values from Table 3, gas flow rate (C) is found to be the most significant factor, next is welding current and then followed by welding speed. The main effect plots have been made using MINITAB 16 software as shown in Figure 1. Bending strength increases first with increases in current from 95Amp to 115Amp, then decreases with an addition in welding current. With the increase in welding current, the temperature rises in the welding zone. As with rise in temperature, grain growth in weld microstructure also increases. This increase in grain growth, decreases the grain boundaries, this may lead to different welding defects such as dislocation, line defect and so on. These defects are the major reasons in the variation of the bending strength of welded joints. With the increase in welding speed, first bending strength decreases, with further increase in welding speed, bending strength increases. This may be due to change in the structural behavior of welded joint during solidification and chance of forming the defects in different conditions of welding. With the increase in welding speed, first bending strength decreases, with further increase in welding speed, bending strength increases. This may be due to change in the structural behavior of welded joint during solidification and chance of forming the defects in different conditions of welding. With the increase in gas flow rate, bending strength first decreases, then increases with further addition in gas flow rate.

Table 2 ANOVA for bending strength

Source	DF	Seq SS	Adj SS	F	P
A	2	13718.7	13718.7	15.38	.061
B	2	6671.4	6671.4	7.38	.118
C	2	32962.9	32962.9	36.95	.026^{A}
Error	2	892.1	892.1		
Total	8	54245.2			

As bending strength is “the higher-the better” type quality characteristic, from the main effects plot Fig.1, the second level of A, third level of B, third level of the C results in maximum value of bending strength. A_2, B_3, C_3 is optimal levels for bending strength. The results of analysis of variance (ANOVA) for impact toughness are shown in Table 4.

Table 3 response table for S/N ratio

Level	A	B	C
1	58.63	58.81	58.85
2	59.18	58.28	57.85
3	58.22	58.94	59.33
Delta	.96	.66	1.49
Rank	2	3	1

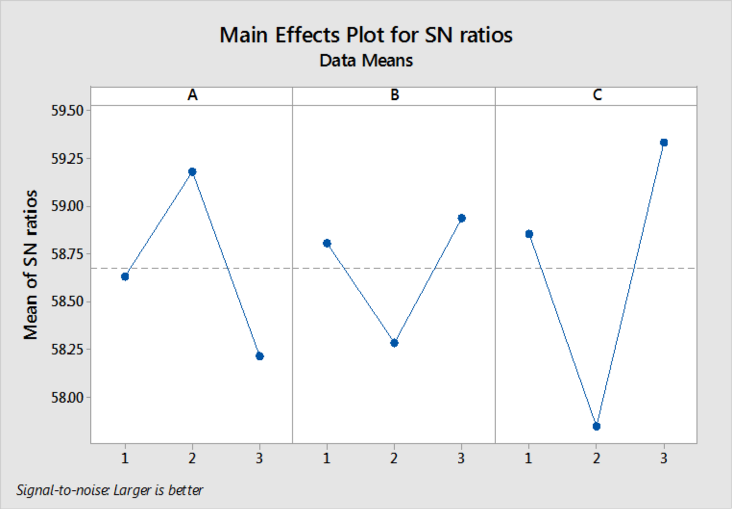


Fig.1 Main effect plot for bending strength

It is found from Table 4 that P values for welding speed is greater than rate 0.05. This means that the both welding current and gas flow rate has a significant effect on the impact strength at 95% confidence level. The significant factors are indicated by superscript $^{a\ b}$ in the AVOVA Table 2 and Table 4 respectively. On examination of the Delta values from table 5, welding speed (B) is found to be the most significant factor, next is gas flow rate and followed by welding current. From main effects plot as shown in figure 2, the increase in welding current causes impact toughness increases first. With further increase in welding current, impact toughness decreases. With the increase in welding speed, first impact strength decreases, with further increase in welding speed, impact toughness increases. Finally, the impact toughness decreases as the welding speed increases due to the relatively smaller weld pool size obtained as a result of the high cooling rate, which reduces the weld toughness and make them more brittle. With the increase in gas flow rate, impact toughness first decreases from 8L/Min to 10L/Min, then increases from 10L/Min to 12L/Min. This may be due to changes in the structural behavior of welded joint during solidification and chance of forming the defects in different conditions of welding. These defects are the major reasons in the variation of the impact toughness of welded joints.

Table 4 Analysis of variance for impact strength

Source	DF	Seq SS	Adj SS	F	P
A	2	2.94	2.94	101.85	0.010^{A}
B	2	0.17	0.175	6.08	0.141
C	2	1.24	1.24	43.00	0.023^{B}
Error	2	0.02	0.02		
Total	8	4.38			

Table 5 Response table for S/N ratio

Level	A	B	C
1	14.94	16.20	15.67
2	16.90	15.72	15.50
3	16.00	15.92	16.67
Delta	1.95	0.49	1.16
Rank	1	3	2

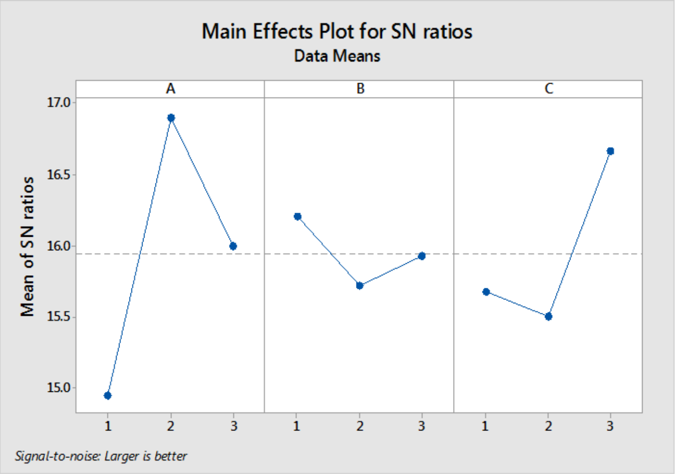
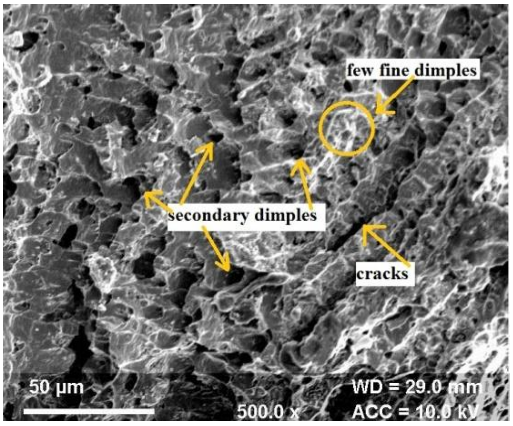
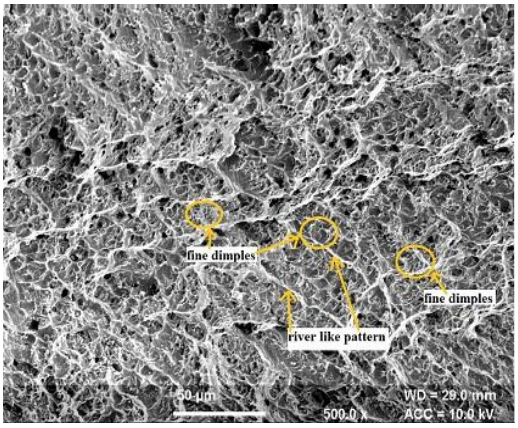


Fig 2: Main effect plot for impact toughness

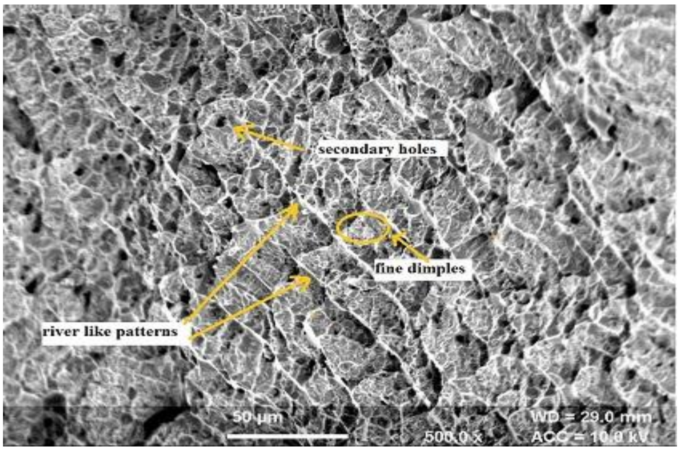
The effect of the most of the parameters is similar to the results reported by Bhavsar and Patel (2016) [8]. Impact toughness first increases with addiction of current, then decreases with further increases in current. As impact toughness is "the higher-the better" type quality characteristic, from the main effects plot Fig.1, the second level of A (115Amp), the first level of B (1.5mm/sec) and third level of the C (12lit/min) results in maximum value of impact toughness. Consequently, the optimal factor/level combination A_2, B_1, C_3 was approved for impact toughness. In Microstructural analysis of impact fractured specimens, the fracture surface of the weld joints as shown in figure Fig. 3 (a), (b), (c), shows a dimple pattern in the whole width which confirms the ductile mode failure of the joints. However, an appreciable difference in fracture pattern was found. Fine and secondary dimples are the key features of superior impact strength of the joint (from fig b) as compared to other joints. In fig 3(a), there is a presence of few fine dimples; also there is a presence of secondary holes.



(a)-lowest impact strength



(b)-highest impact strength



(c) Average impact strength

Fig 3. SEM Fractographs of impact specimens (a, b, c)

From EDS analysis, It was found that the weld zone has higher in Ni, Cr, C and Fe. The presence of the other elements such as S, Nb, Mo, Mn, Si, Al and Ti are also being noticed. The difference in the weld metal compositions of nickel, chromium, and manganese in the impact fractured specimens has a large influence on the toughness. Nickel (Ni) Increases the toughness by refining the grains, while enhancing corrosion resistance without sacrifice strength. Nickel reduces the ferrite content of the weld and also stabilizes the austenitic structure against the formation of Martensitic. The alloying content of manganese and nickel are very important in the solidification process of high strength steel weld metals. An effect of manganese is that it provides strengthening through solid solution hardening and grain refinement by lowering the austenite to ferrite transformation temperature. Grain refinement also leads to increased toughness. [11]

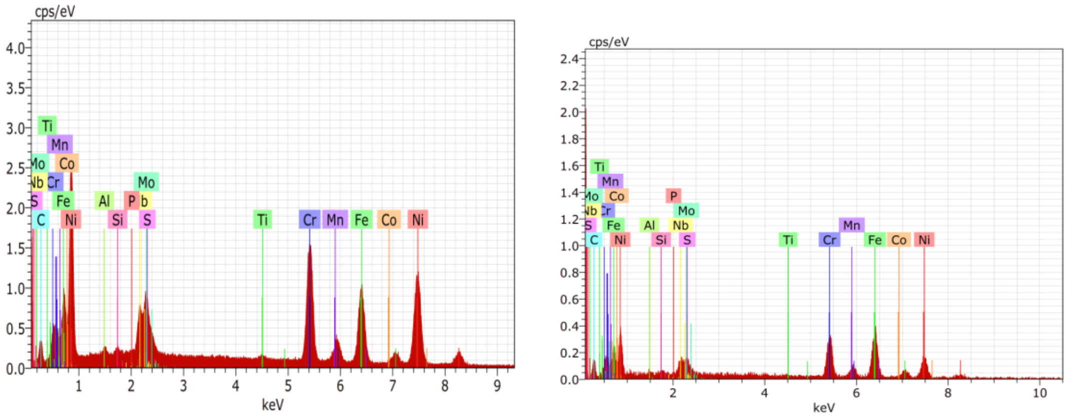


Fig 4: EDS spectrum of distribution of elements

From XRD analysis (as shown in fig5), the Characteristics peaks of impact fractured specimens are indexed, a cubic system with reflection peaks of (111), (200), (220), (300), and (311) were found. Sharp and characteristics strong peak at $2\Theta=42.4$. Which indicate the presence of base material Ni. The miller indices calculated at angle $2\Theta = 42.4^0$ is (111) which indicate the F.C.C structure.

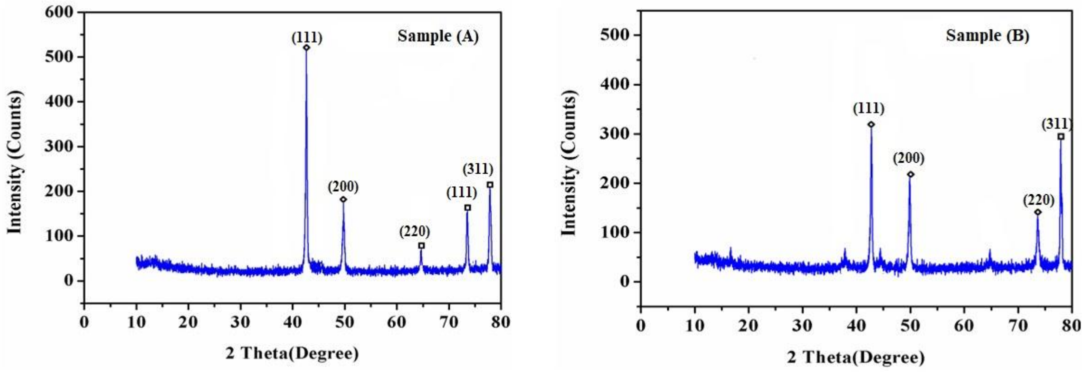


Fig. 5 XRD patterns of impact fractured specimens

Comparative analysis -

The results show that predicted values for each combination of experiment are close to experimentally measured values and there is no significant difference between experimental data and predicted data

Table9. Predicted values of impact and bending strength

S.No	Output responses	Predicted	Experimental	Diff%
1	Impact strength	17.87	17.26	.61
2	Bending strength	1003.07	962.79	40.28

5. CONCLUSIONS

In this study, the Taguchi L9 array has been used to optimize process parameters. The effects of welding current, welding speed and gas flow rate on the microstructure and mechanical properties of TIG dissimilar metals between AISI304 and AISI202 were investigated. The following important conclusions were derived:

i. For impact strength, welding current of (115Amp), welding speed of 2.0mm/sec and gas flow rate of (12lit/min) is optimized parameters.
ii. An optimum combination of three test parameters is found to be welding

current of 115A, welding speed of 2.5mm/sec and gas flow rate of 12lit/min for bending strength.

iii. If the dimple size is fine, the strength and ductility of the respective joint are higher. The size variation of dimples and the presence of micro-pores and secondary cracks might be the reason for the drop of impact energy absorption.

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