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Characteristic analysis of dissimilar metal weld for AISI304 with SA213T22 in super heater coils

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ABSTRACT

Super heater is an inevitable component of any boiler system and failure of super heater leads to breakdown of whole plant. The integration of efficient quality welding technologies for dissimilar metals will be a key component in the successful weld quality for power plant components. In this investigation, an attempt has been made to study the dissimilar material AISI304 and SA213T22 tungsten inert gas welding is performed under different welding conditions current (100, 115, 130 Amps), gas flow rate (6, 8, 10 ltr/min), speed (2, 2.5, 3 mm/sec) and micro structure analysis performed to find influence of fusion heat. The Taguchi analysis is implemented to obtain single response optimization and grey relational analysis used to attain multi response for best yield strength, the ultimate strength, Vickers hardness and the elongation of the metals.

1. Introduction

Super heater is basically a heat exchanger in which heat is transferred from furnace gas to the steam. Improper heat transfer between steam and furnace gas leads to problems of localized heating and damage the welding spots. These coils are made up of alloy steel SA213T22 which has corrosion resistance and it cannot withstand continuous high temperature. The super-heater coils are made up of SA213T22 which can withstand up to 540 °C metal temperatures and final stage super-heater stream temperature of more than 565 °C with the increase in steam pressure with their required dissimilar materials. AISI304 has superior properties such as resistance to fire side corrosion and a stream temperature of 650 °C for final super-heater. Hence, the dissimilar materials are introduced to reduce the damage and an interchange material AISI304 is attempted to replace this super-heated coil. The dissimilar material welding is not possible to make a fusion weld and welding parameters are affecting the welding quality. The dissimilar materials welding have been continuously explored and the related valuable studies presented by the past researchers are given below. Guo Ming et al. [2] studied the dynamic temperature field of laser welding on stainless steel. It was dynamically simulated by the FEA software ANSYS using transient heat conduction equation. Kain et al. [3] studied the failure of a few super heater tubes at localized regions in an atmospheric fluidized bed combustor. Uger esme and Mehim bayramoglu et al. [4] have used AISI 304 Stainless steel plate. TIG welding machine is used. The input parameters are travel speed, current, nozzle plate distance. The output parameters are bead penetration and tensile load. The optimal weld pool geometry has four smaller-the-better quality characteristics, i.e. the front height, front width, back height and back width of the weld pool. The modified Taguchi method is adopted to solve the optimal weld pool geometry with four smaller-the better quality characteristics. Experimental results have shown that the front height, front width, back height and back width of the weld pool in the TIG welding of stainless steel are greatly improved by using this approach. Ahmad et al. [1] investigated excessive hoop stresses are the cause of failure in on a super alloy Inconel-800 super heater tube. Vibhav gupta et al. [6] found primary reason

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Table 1
Chemical composition of the AISI304 and SA213T22.

AISI304								
C	Cr	Fe	Mn	Ni	P	S	Si	Mo
0.08	19	70	2	10	0.045	0.03	1	–
SA213T22								
0.15	2.60	–	0.60	–	0.025	0.025	0.50	1.13

Table 2
Factors and levels for similar and dissimilar welding.

Factor/ Levels	Level 1	Level 2	Level 3
Current (Amps)	100	115	130
Gas Flow Rate (ltr/min)	6	8	10
Speed (mm/sec)	2	2.5	3

for premature failure of super heater tubes led severe oxidation and creep. Gokula Krishnan et al. [5] presented occurrences of phase transformation and formation of alumnide phase such as Ni3Al. Faith Dokme et al. [7] explained that weld zone micro structural analysis exhibited the existence of multi directional grain growth in all specimens on AISI 316L side. Yu Sun et al. [8] found that Iron alloy is exposed to a high temperature oxidation environment, outer layer of super heater will gradually oxidize into stable

Table 3
Experimental result for AISI304 to SA213T22 dissimilar metal weld.

AISI304 TO AISI304 similar metal weld							
Trials	A	B	C	YS (MPa)	US (MPa)	EL (%)	H (Hv)
1	1	1	1	573.20	625.80	17.50	198.9
2	1	2	2	447.50	635.32	27	197.3
3	1	3	3	365	569.45	14.50	196.3
4	2	1	2	429.90	660.60	20	183.5
5	2	2	3	314	511.62	29.50	177.1
6	2	3	1	370.20	594.65	13.50	185.3
7	3	1	3	433	655.81	30	190.1
8	3	2	1	396.80	571.96	17	206.1
9	3	3	2	400.10	599.47	18	230.1

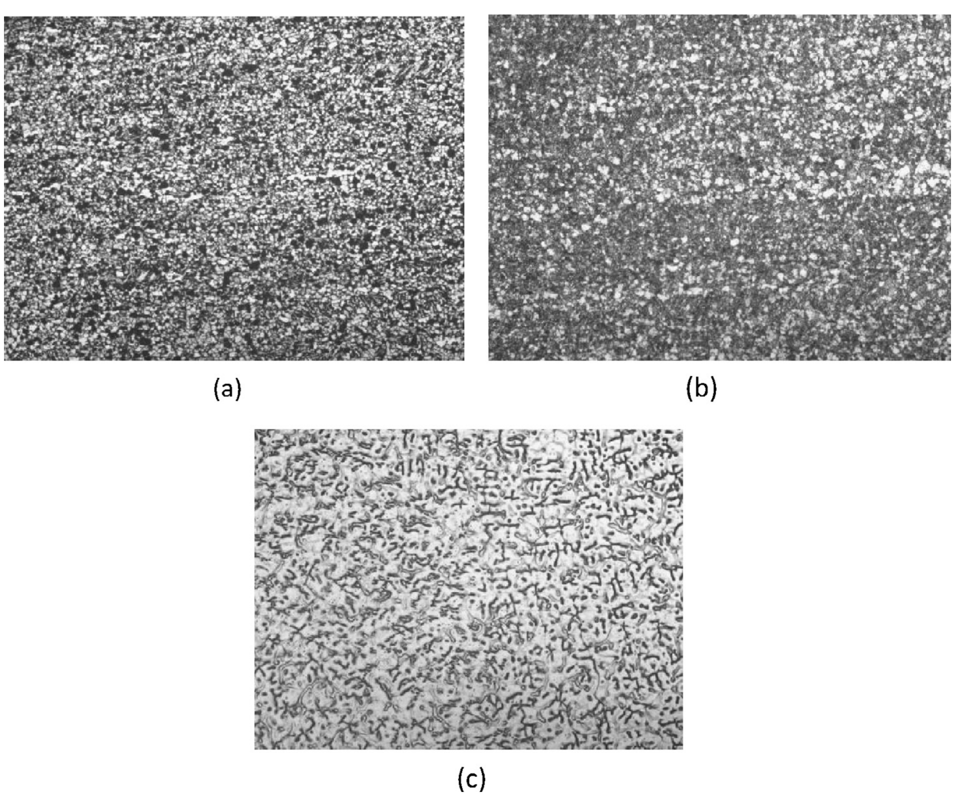

Fig. 1. Micro graph (Mag: 200x) for fusion (a) Parent material of SA213T22; (b) Dissimilar material HAZ of SA213T22; (c) Dissimilar material weld spot.

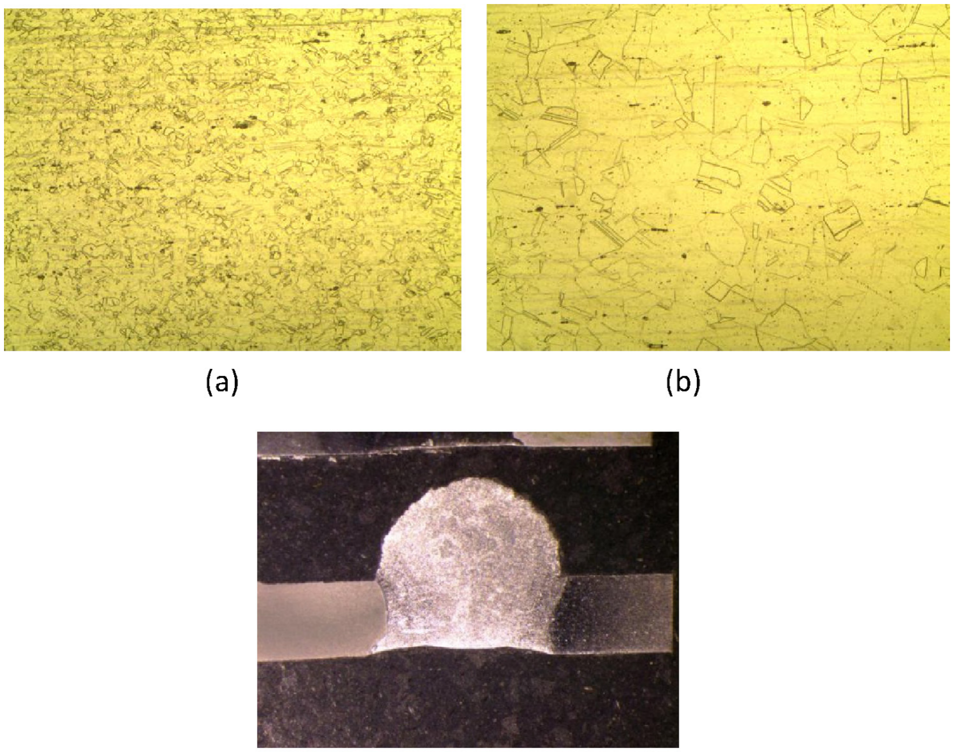

Fig. 2. Micrograph (Mag: 200x) for fusion (a) Parent material of AISI304; (b) Dissimilar material HAZ of AISI304; (c) Macro graph (Mag: 5x) dissimilar material weld spot.

Table 4
Signal to noise ratio for AISI304 to SA213T22 dissimilar metal weld.

AISI304 TO AISI304 similar metal weld							
Trials	A	B	C	YS (MPa)	US (MPa)	EL (%)	H (Hv)
1	1	1	1	55.1661	55.9287	24.8608	45.9727
2	1	2	2	53.0159	56.0599	28.6273	45.9025
3	1	3	3	51.2459	55.1091	23.2274	45.8584
4	2	1	2	52.6673	56.3988	26.0206	45.2727
5	2	2	3	49.9386	54.1790	29.3964	44.9644
6	2	3	1	51.3687	55.4852	22.6067	45.3575
7	3	1	3	52.7298	56.3356	29.5424	45.5796
8	3	2	1	51.9714	55.1473	24.6090	46.2816
9	3	3	2	52.0434	55.5553	25.1055	47.2383

Table 5
Taguchi Analysis: YS & US versus A, B, C.

Level	YS			US		
	A	B	C	A	B	C
1	53.14	53.52	52.84	55.70	56.22	55.52
2	51.32	51.64	52.58	55.35	55.13	56.00
3	52.25	51.55	51.30	55.68	55.38	55.21
Delta	1.82	1.97	1.53	0.34	1.09	0.80
Rank	2	1	3	3	1	2

and dense oxide film. From the study it was observed that flux used as the most significant effect on depth of penetration followed by welding current. Most of the researchers concentrate on the different directions but AISI304 over SA213T22 dissimilar materials weld was not performed yet and hence it is an important to study for the power plant components. Considering all the points into account in this present work. AISI304 to SA213T22 dissimilar TIG welding process is performed under different welding conditions.

2. Experimental details

The paper aims to investigate and identify key improvements in weld mechanical properties and the microstructural compounds of

Table 6
Taguchi Analysis: YS and US versus A, B, C.

Level	EL			H		
	A	B	C	A	B	C
1	25.57	26.81	24.03	45.91	45.61	45.87
2	26.01	27.54	26.58	45.20	45.72	46.14
3	26.42	23.65	27.39	46.37	46.15	45.47
Delta	0.85	3.90	3.36	1.17	0.54	0.67
Rank	3	1	2	1	3	2

Table 7
Normalized- Grey Relational Coefficient and Grey Relational grade.

Trial No.	Normalized values of Z_{ij}				Grey Relational Co-efficient				Grey Relational grade
	YS	US	EL	H	YS	US	EL	H	
1	1.000	0.788	0.325	0.443	0.333	0.388	0.606	0.530	0.464
2	0.589	0.847	0.868	0.413	0.459	0.371	0.365	0.548	0.436
3	0.250	0.419	0.089	0.393	0.667	0.544	0.848	0.560	0.655
4	0.522	1.000	0.492	0.136	0.489	0.333	0.504	0.787	0.528
5	0.000	0.000	0.979	0.000	1.000	1.000	0.338	1.000	0.835
6	0.274	0.588	0.000	0.173	0.646	0.459	1.000	0.743	0.712
7	0.534	0.972	1.000	0.271	0.484	0.340	0.333	0.649	0.451
8	0.389	0.436	0.289	0.579	0.563	0.534	0.634	0.463	0.548
9	0.403	0.620	0.360	1.000	0.554	0.446	0.581	0.333	0.479

Table 8
Main effects on Grey grades.

Levels	1	2	3
Current (Amps)	0.518	**0.692**	0.493
Gas Flow Rate (ltr/min)	0.481	0.606	**0.615**
Speed (mm/sec)	0.575	0.481	**0.647**

dissimilar metals. This information helps lay a baseline for TIG welding process specifications and also demonstrates the significant factors affecting the TIG welding processes on dissimilar metals. The materials selected for dissimilar welding are AISI304 and SA213T22 and the chemical composition is given in Table 1. The diameter of the tube is taken as 60.3 mm, thickness is 4.5 mm and length is 250 mm. The electrode selected for similar welding is E309L whose dimension is 2.4 m in length. The argon is used as gas and its pressure is 3.5 kg/cm^2 during welding. The affecting factors and level selected for dissimilar welding AISI304 and SA213T22 is given in Table 2 and the experimental results of yield strength, the ultimate strength, Vickers hardness and the elongation of the metals is given in Table 3.

The physical properties of two metals are being very different from each other which lead to complexities in the weld pool shape, solidification microstructure and segregation patterns. Fig. 1 shows the micro-structure of the parent, head affected zone and the SA213T22 weld spot at magnification 200x.Fig. 2 shows the macro-structure of the dissimilar materials welding spot at magnification of 5x and the micro-structure of the AISI304 weld spot at magnification 200x. It shows the macro-structure shows the dissimilar materials weld geometry such as reinforcement, width, penetration and weld bead.

3. Taguchi methodology

The main goal of the parameter design is to selecting the best process parameter to improve quality characteristics and to identify the product parameter values under the optimal process parameter values using Taguchi methodology. Moreever implementing that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Since the quality characteristic is to be maximization, the larger the better category is used to calculate the S/N ratio for responses Equation 1 shows the larger the better characteristic.

$$\text{S/N ratio } (\eta) = -10 \log_{10}(1)$$

Taguchi technique is used to find the optimum setting of dissimilar materials weld and experiments are conducted based on the L_9 orthogonal array. The aim function is maximization of the yield strength, ultimate strength, Elongation and Vickers hardness, so experimental results are converted to signal to noise ratio for reduction of variance using Eq. (1). The signal to noise ratio yield strength, ultimate strength, and elongation and Vickers hardness is presented in Table 4. The Taguchi analysis for yield strength and ultimate strength is given Table 5, it clearly shows that the optimal welding parameters for maximization of yield strength is

Table 9
General Linear Model: Analysis of Variance for YS.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	12383.3	12383.3	6191.7	7.98	0.111
B	2	18686.9	18686.9	9343.5	12.05	0.077
C	2	9266.3	9266.3	4633.2	5.97	0.143
Error	2	1551.1	1551.1	775.6		
Total	8	41887.7				

S = 27.8487 R-Sq = 96.30% R-Sq(adj) = 85.19%.

Table 10
General Linear Model: Analysis of Variance for US.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	857	857	429	0.23	0.813
B	2	9308	9308	4654	2.51	0.285
C	2	4313	4313	2156	1.16	0.463
Error	2	3714	3714	1857		
Total	8	18,192				

S = 43.0931 R-Sq = 79.58% R-Sq(adj) = 18.34%

Table 11
General Linear Model: Analysis of Variance for EL.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	6.22	6.22	3.11	0.10	0.911
B	2	139.39	139.39	69.69	2.19	0.314
C	2	116.22	116.22	58.11	1.82	0.354
Error	2	63.72	63.72	31.86		
Total	8	325.56				

S = 5.64456 R-Sq = 80.43% R-Sq(adj) = 21.71%.

Table 12
General Linear Model: Analysis of Variance for H.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	1086.46	1086.46	543.23	5.76	0.148
B	2	286.01	286.01	143.00	1.52	0.397
C	2	376.60	376.60	188.30	2.00	0.334
Error	2	188.65	188.65	94.32		
Total	8	1937.72				

S = 9.71208 R-Sq = 90.26% R-Sq(adj) = 61.06%.

current set as 100 amps, gas flow rate 6 lit/min and welding speed set as 2 mm/sec. Optimal welding parameters for maximization of ultimate strength is current set as 100 amps, gas flow rate 6 lit/min and welding speed set as 2.5 mm/sec. The Taguchi analysis for Elongation and Vickers hardness is given Table 6, it shows that the optimal welding parameters for maximization of Elongation is current set as 130 amps, gas flow rate 8 lit/min and welding speed set as 3 mm/sec. Optimal welding parameters for maximization of Vickers hardness is current set as 130 amps, gas flow rate 10 lit/min and welding speed set as 2.5 mm/sec.

4. Grey relational analysis methodology

In this work, a grey relational approach has been applied to solve multi response optimization of yield strength, ultimate strength, elongation and Vickers hardness using grey relational analysis. The proposed steps can determine effectively the optimal factor level combination for multi response problems. It quantifies all influences of various factors and their relation, which is called the whitening of factor relation. As a result, optimization of the multi responses can be converted into optimization of a single relational grade. In short, there is an ample scope of applying the proposed methodology of grey relational analysis with the multiple responses for the optimization of yield strength, ultimate strength, elongation and vickers hardness.

The objective of the dissimilar material weld AISI304 to SA213T22 is maximization of yield strength, ultimate strength, elongation and Vickers hardness. This was termed as the larger the better type problem where maximization of the characteristic was intended. S/N Ratio was calculated for the responses using the larger the better formula Equations 1. The experimental result and computed S/N ratios for yield strength, ultimate strength, Elongation and Vickers hardness are shown in Table 6. The S/N ratio values were normalized by Eq. (2) and grey relational co-efficient was calculated for the normalized S/N ratio values by using Eq. (3). The grey relational grade was computed from grey relational co-efficient for by Eq. (4). The normalized signal to noise ratio, grey relational co-efficient and grey relational grades are given in Table 7.The main effects were tabulated in Table 8 and considering maximization of grade values in Table 8 the optimal parameter conditions obtained were $A_1B_3C_3$. Multi response optimization of dissimilar material weld AISI304 to SA213T22 for maximization of yield strength, ultimate strength, Elongation and Vickers hardness, current set as 110 amps, gas flow rate 10 lit/min and welding speed set as 3 mm/sec.

In this study, the analysis of variance is used to find the statistically significant welding parameters. The analysis of variance for yield strength is given in Table 9. It clearly shows that the gas flow rate most significantly affects the yield strength with F:P value of 12.05:0.077. The analysis of variance for ultimate strength is given in Table 10. It mention that the gas flow rate most significantly affects the ultimate strength with F:P value of 2.51:0.285. The analysis of variance for elongation is given in Table 11. It represents the gas flow rate most significantly affects the elongation with F: P value of 2.19:0.314. The analysis of variance for Vickers hardness is given in Table 12. It denotes the current most significantly affects the Vickers hardness with F: P value of 5.76:0.148.

5. Conclusion

The function of the super heater coil is transfer heat energy, during transfer of high transfer damage happen in weld spot. So aim of the investigation is to study the performance of the dissimilar material AISI304 to SA213 T22 TIG welding the following are the outcomes

- Optimal TIG welding parameters for dissimilar material maximization of yield strength is current set as 100 amps, gas flow rate 6 lit/min and welding speed set as 2 mm/sec.
- Optimal TIG welding parameters for dissimilar material maximization of ultimate strength is current set as 100 amps, gas flow rate 6 lit/min and welding speed set as 2.5 mm/sec.
- Optimal TIG welding parameters for dissimilar material maximization of Elongation is current set as 130 amps, gas flow rate 8 lit/min and welding speed set as 3 mm/sec.
- Optimal TIG welding parameters for dissimilar material maximization of Vickers hardness is current set as 130 amps, gas flow rate 10 lit/min and welding speed set as 2.5 mm/sec.
- Multi response optimization of dissimilar material weld AISI304 to SA213T22 for maximization of yield strength, ultimate strength, Elongation and Vickers hardness, current set as 110 amps, gas flow rate 10 lit/min and welding speed set as 3 mm/sec.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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