Multi Response Optimization In Cold Metal Transfer Welding

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ABSTRACT-
For single response process parameter optimization, Taguchi analysis is used. By varying the settings, the user may obtain variable results that always depend on selected data parameters. Hence optimization of multi responses and their characteristics is the solution. Mechanical properties and their improvements are critical for Cold Metal Transfer Welding. In this paper, a multi-response objective optimization process, the DEAR approach is proposed for Stainless steel welding using the CMT process. Various process parameters for this type of welding are, Nozzle to tip distance is varied to test the multiple responses like Tensile test, Surface Roughness. Taguchi L8 Orthogonal Array was picked up to acquit the experiment. Various parameters were optimized for the butt- welded specimens by decided approach and each process parameter, and its percentage contribution in the outcome was identified.

Keywords: CMT Welding, Optimization, L8 Orthogonal Array, DEAR approach, Taguchi Analysis.

1. INTRODUCTION

In 2004, Fronius of Austria developed a modified form of Metal Inert Gas (MIG) welding, which initiated a novel theme of using a short circuiting-transfer process acknowledged as Cold Metal Transfer welding (CMTW). The mechanical droplet cutting method plays a key role in this CMT Welding where it differs from MIG/MAG welding. Short-circuiting was done by a decrement in current and heat input and the main features of this process which is done in an assured static manner.

Setu. G, et al. [1] performed test T Joint made of Al-64430 alloy which was fabricated by stir casting process. Later hardness and microstructure analysis was conducted on the specimen at nugget zone using brinnell hardness test and optical microscope. The results reveal that the hardness value was decreased by the enhancement of speed in rpm, but it doesn’t exhibit any influence on number of passes of welding. Satyanarayana. G, et al. [2,14] simulated a welded butt joint made of Zirconium alloy E110 by Nd:YAG pulsed laser welding process with three dimensional heat and fluid flow model and results are compared with analysis made by numerical model and deduced that the numerical results are well suited with simulation results. Suresh. A and Diwakar. G [3] used plasma arc welding to weld mild steel plates with varying thickness by 50:50 distilled water and acetone by volume, and the specimens are examined and tested for hardness using microhardness tester and weld strength. The tests are conducted by both destructive and non-destructive tests to find the defects in the welded joint. Seung Hwan Lee et al. [4] modelled the wire and arc additive manufacturing process (WAAM) parameters using Gaussian process regression (GPR) and developed an optimized model with improved shape and quality of deposition and compared the optimization results with experimental results. Guodong DU et al. [5] investigated about the welded joint made of aluminium AA6061-T6 to galvanised DP590 steel which is welded with AlSi-5 wire as filler material. By following orthogonal array, weld joint was made with process parameters like wire feeding speed, welding speed and arc length, later the tensile and metallographic test was conducted to test the strength of weld joint. Results show that wire feed rate influences the thickness of layer of weld joint. Rahmad Wisnu Wardhana et al. [6] investigated about the best suited welding process to repair a shredder hammer by using data envelopment analysis and probust technique, by following six types of welding process with various process parameters. Later the sensitivity analysis of the regret value was predicted for the welded joint for three proposed cases. Gaurav Kumar et al. [7] analysed about a welded joint of AISI 304 steel with process parameters like welding current, voltage, and speed and checked the strength and quality of joint based on Taguchi method followed by evaluation Signal to noise ratio of the analysis. Satyanarayana G et al. [8,13] predicted about the weld geometry and temperature fields by CFD simulation generated in and around the melt pool, when an end plate was welded to fuel rod in forming a fuel bundle with a three-dimensional non- linear thermo fluid analysis using Zirconium alloy E110 and validated the results with experimental results. Later the results are compared by optimization technique using Taguchi method. Singh L et al. [9,10] made analysis on welded joint made with AISI-304 steel using grey relational analysis (GRA) of principal component analysis and Taguchi analysis was used to predict the optimal performance characteristics of joint for selected process parameters, where the results predicts the short peening process parameters when preparing a welded joint. Prasad V et al. [11] studied about the disposition of spiking in ETP copper plates by using various process parameters related to welding joint, and results described about the spiking inclination for the selected material. Raghav B

V. et al. [12] discussed about the effects of electron beam butt welding on microstructure and microhardness of welded zone of Cu-Cr-Zr with two welding schedules, and results show that heat input exhibits major effect on grain size of welded zone. Gupta S et al. [15] conducted experiment based on optimisation technique using SAW welding on A36 carbon steel with selected process parameters and predicted the quality of welded joints in terms of strength, max. temperature, heat input etc. Kodati Teja et al. [16] prepared specimens of Al-6061 plates welded with ER-4043 wire by Wire Arc Additive Manufacturing (WAAM) process with CMT technique by following Taguchioptimization technique with selected process parameters. Later the specimens are tested for various mechanical and metallurgical tests to predict the maximization of ultimate tensile strength. Microhardness, and the influence of process parameters on welded specimens.

2. METHODOLOGY AND MATERIALS

TaguchiMethod:
From decades in manufacturing, Taguchi method plays a vital role in designing a product or a process with its Quality Characteristics (QC) which attracts industrialists and researchers. This QC alters the properties by their enhancement or decreases according to the utility of method. In Taguchi method algorithm, the distinctive calculation exchanges the quantitative assessment of particular QC into signal to noise ratio (S/N ratio).

This S/N ratio is the quantitative value of the target ability for a QC while reduces the variation related to the outcome for a specific experimental condition. In manufacturing, the applications of Taguchi method have been extremely fruitful followed by its advantages like optimisation of fabricating process and methodology to make a product which reduces the time, manpower and cost of product.
A special set of arrays used in Taguchi method called orthogonal arrays. For conducting the minimum number of experiments, with full information of all factors which affect the performance parameters, these standard arrays are used.

Stainless SteelAlloy
Austenitic Stainless-Steel alloy (304L), a T-300 series, contains min. 18% Cr and 8% Ni by wt.%. From the series of all weldable steels, the austenitic stainless steels which are high-alloyed steels and can be welded by all types of welding processes. Alloy 304L is versatile and widely used alloy in the stainless-steel family. It finds its applications mostly in domestic and industries fields, with attractive features like excellent corrosion resistance, high ease of fabrication, outstanding formability are the highlights for this alloy 304L.

In the present work, 304L plates of 5mm thickness are welded using Stainless-Steel-304L MIG wire., and the apparatus setup was shown in Fig-1.

Fig-1: Cold Metal Transfer Apparatus setup

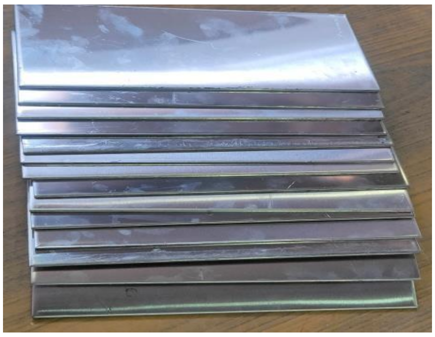

Fig-2(a): SS-304L Plates

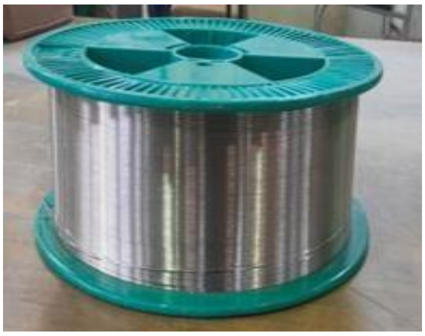

Fig-2(b): SS-308 MIG Wire

Fig-2: Weld Material and Filler material

Table-1:
Chemical Composition ofMaterials

ELEMENT	CHEMICAL COMPOSITION (Weight %)	
	304L	**308L**
Carbon, C	0.019	0.018
Silicon, Si	0.50	0.32
Chromium, Cr	18.20	19.70
Nickel, Ni	8.04	10.10
Sulphur, S	0.030	0.01
Manganese, Mn	1.53	1.90
Phosphorous, P	0.030	0.017
Iron, F	Balance	Balance

Table-2:
Mechanical Properties ofMaterials

PROPERTY	VALUE	
	304L	**308L**
Shear strength	370-680 MPa	380 MPa
Tensile strength, ultimate	540-1160 MPa	580 MPa
Tensile strength, yield	190-870 MPa	230 MPa
Poisson's Ratio	0.28	0.28
Modulus of Elasticity	200 GPa	200 GPa

The chemical composition and mechanical properties of SS-304L and SS-308L are mentioned in Table-1 and Table-2 respectively, where it exhibits that the Poisson's ration and Modulus of Elasticity is same for both materials. The plates and filler material to prepare the weld joint are shown in Fig-2(a) and 2(b).

Data Envelopment Analysis based RankingMethod

Data Envelopment Analysis (DEA) is a mathematical tool implemented where more inputs and more than one outputs are needed and relation and comparison between them which makes make the comparison unmanageable and hard to understand [3]. This technique generally depends on Linear Programming (LP) utilised to estimate the relative efficiency for a set of experiment, when each experiment is taken as units for decision making.

In this method, to achieve the optimized levels as outcome, certain proportion of original responses are considered as input and mapped based on input parameters, where these outcome responses of ratio are considered as MRPI value to estimate the best combination of input process parameters.

Various steps followed in Data Envelopment Analysis based Ranking Methodology are explained below [6]. MRPI is the ratio between the summation of larger the better data to the summation of smaller the better data.

- **Step-1,** Check the weights(w) of each response for all experiments, where this weight of response is taken as the proportion between response at any run to the addition of all replied outcomes.
- **Step-2,** Convert this data of response in terms of weighted data which arrives by multiplying the observed data with its ownweight.
- **Step-3,** Separate the total data into parts, where data as larger the better and with smaller the better.
- **Step-4,** Consider these values as Multi Response Performance Index(MRPI).

In the present study, the following Eq-1, has been used to find the MRPI value where P, Q and Rare just variable denotations.

$$MRPI = (P+Q)/R \qquad (1)$$

3. EXPERIMENTATION

3.1. Cold Metal Transfer Welding:

Various properties of Austenitic Steel plate (304L) and filler material (308L) are described in Table-1 and Table-2. In Cold Metal Transfer Welding, various process parameters viz Voltage, current, nozzle to tip distance, arc length, wire feed rate, layer thickness etc. are considered which influences the properties of welded zone due to heat generated and chemical process occurred.

In the present work, an austenitic steel (SS-304L) in the form of plates with 3mm thickness, 200mm length and 200mm width are considered to make a weld joint. These two plates are butt welded by (SS-308L) MIG wire which acts as filler material. To perform this work, CMT Welding is considered with Current, Nozzle to Tip Distance and Weld Speed as various process parameters by following L8 Orthogonal Array of Taguchi method. A mixture of both

Argon and CO2 was used as shielding purpose to avoids the occurrence of oxidation reaction at weld zone and the flow of the shielding gas was maintained at flow rate of 18 lt. /min.

3.2. Orthogonal Array:

The number of experiments were performed according to L8 Orthogonal Array which is listed in Table-3. According to the Table-3 shown, eight number of samples are fabricated by using WAAMprocess with 3 process parameters at 3 levels each where Table-4 lists the selected process parameters according to Taguchi method. These parameters were adopted based on initial trials, literatures and references. Pure Argon gas was used for shielding to avoid oxidation, and the metal deposition rate was kept steady at 0.75 kg/hr.

Table-3: - L_8 Orthogonal Array

Experiment	**A**	**B**	**C**
1	1	1	1
2	1	1	2
3	1	2	1
4	1	2	2
5	2	1	1
6	2	1	2
7	2	2	1
8	2	2	2

Table-4: - Process Parameters and their levels

Process Parameter	**Level 1**	**Level 2**
Current (A)	95 Amp	105 Amp
Nozzle to Plate Distance (B)	6 mm	10 mm
Weld Speed (C)	4.03 mm/s	5.817 mm/s

3.3 Performance Characteristics

According to ASTM standards, the specimens, that are cut from the welded zone into required shape and size with the help of wire EDM. A total of eight tensile test specimens and hardness test specimens are subjected to testing.

Tensile test was done at normal room temperature on the welded zone using Micro tensile testing machine according to ASTM Standards.

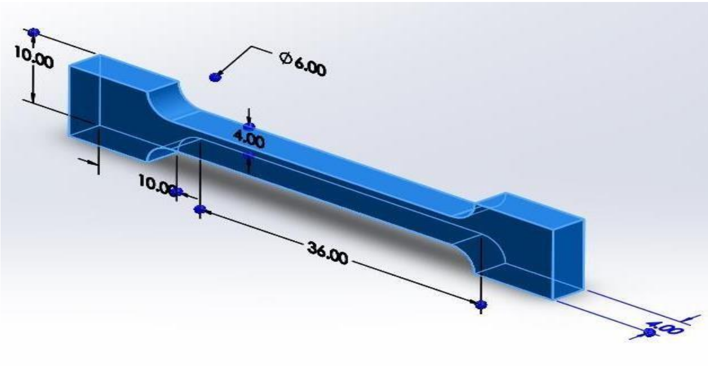

Figure-3: Tensile test specimen with ASTM standards

Fig-4(a): Tensile test specimen and welded specimen

Fig-4(b): Micro tensile testing machine

Fig-4 Test Samples and Tensile Testing machine

Hardness of material is defined as the resistance offered by the material to the externally applied load which avoids the occurrence of scratches, worn out of material, and wear of materials. In the present work, the hardness test was conducted with Brinell Hardness Testing machine shown in Fig-5(a) and Surface Roughness was tested for the specimen using roughness testes shown in Fig-5(b).

Fig-5(a): Hardness testing Machine

Fig-5(b): Roughness tester

Fig-5: Equipment for Hardness test and Surface Roughness

3.4 Optimal Performance Characteristics

The obtained values of tensile strength, hardness of the specimen after completion of experiment are tabulated in Table-5. In this section, the use of the Orthogonal Array with the DEAR approach for determination of the optimal machining parameters, are mentioned by step by step, where multiple performance characteristics are obtained along with optimal parameters for CMT welding are verified.

By using DEAR method, weights of each responses were calculated and generated data were transformed into weighted data and mentioned in Table-6 as response weights. The Weighted data which is the ratio of larger the better type to the smaller the better type data was shown in Table-7.

Table-5

Experimental layout using L8 OA and performance results

Expt. No.	**Levels of Parameters**			**Tensile Strength (MPa)**	**Hardness (BHN)**	**Surface Roughness(μm)**
	Current (A)	**Nozzle to TipDistance (mm)**	**Weld Speed (mm/sec)**			
1	1	1	1	327.75	66.5	8.885
2	1	1	2	383.24	71	22.8
3	1	2	1	314.71	85.5	16.496
4	1	2	2	394.79	71	18.683
5	2	1	1	542.64	78.5	28.797
6	2	1	2	240.60	84	33.64
7	2	2	1	513.97	69.5	20.027
8	2	2	2	277.09	82	22.58

Table-6: Response Weights

Expt.	Tensile Strength (MPa)	Weightage	Hardness Value (BHN)	Weightage	Surface Roughness (μm)	Weightage
1	327.75	0.109440061	66.5	0.109375	8.885	0.262214303
2	383.24	0.127968906	71	0.116776316	22.8	0.102183074
3	314.71	0.105085832	85.5	0.140625	16.496	0.141232668

4	394.79	0.131825604	71	0.116776316	18.683	0.124700213
5	542.64	0.181194675	78.5	0.129111842	28.797	0.080903361
6	240.6	0.080339523	84	0.138157895	33.64	0.069256067
7	513.97	0.171621382	69.5	0.114309211	20.027	0.116331657
8	277.09	0.092524017	82	0.134868421	22.58	0.103178657

Table-7: Weighted responses and MRPI

Expt. No.	**Tensile Strength X Weightage(P)**	**Hardness(BHN) X Weightage (Q)**	**Surface Roughness X Weight (R)**	**MRPI = (P+Q) / R**
1	35.86897996	7.2734375	2.329774086	18.51785447
2	49.04280354	8.291118421	2.329774086	24.60921954
3	33.07156231	12.0234375	2.329774086	19.35595391
4	52.04343012	8.291118421	2.329774086	25.89716699
5	98.32347831	10.13527961	2.329774086	46.5533369
6	19.32968923	11.60526316	2.329774086	13.27809103
7	88.20824195	7.944490132	2.329774086	41.27126861
8	25.63747979	11.05921053	2.329774086	15.75117971

4. RESULTS AND DISCUSSION

The Optimal results were identified treating MRPI as a single response. Input factors consolidated Multiple Responsive Performance Index with all the levels is tabulated in the below Table-8. MRPI values corresponding to each process parameter level are added to get the final value. The optimal level of input parameters is given by the maximum value of each process parameter in determining the performance characteristics.

Table -8: Level totals of MRPI

Process Parameter with notation	LEVELS		Max-Min
	1	2	
Current (A)	88.38	116.8538763	28.47
Nozzle to Plate Distance (B)	102.9585019	102.2755692	0.682932724
Weld Speed (C)	125.6984139	79.53565728	46.16275661

4.1 Discussion:

- From table-8, the first row was obtained at Current- 105Amp, Nozzle to tip distance-6mm, and weld speed-4.03mm/sec as the process parameters, and indicates the large difference between Level-1 value(88.38) and Level-2 value(116.85) which is nearly double indicates that the obtained value was greatly influenced by selected process parameter.

5. CONCLUSIONS

Taguchi method based on DEAR and it's response table has been proposed for studying the optimization of CMT welding process parameters for SS 304. A total of eight number of trial runs based on L8 Orthogonal Array was conducted.

The conclusions which are drawn from this experiment are as follows.

- An optimal value, current-105 Amp, nozzle to tip distance- 6mm, and weld speed - 4.03mm/sec gives better tensile strength, hardness and better surface finish and from the experiment, it is found that values are obtained for Trial-5.
- Also, the combination of weld speed with these multiple characteristics has a greater effect onoutcome.

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