Optimization of Process Parameters for LASER Welded Incoloy 800 HT Joints Using MOORA Technique

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***Abstract*— Multi objective optimization of process parameters helps in quick decision making on operation of a particular process by considering all the necessary criteria required. This paper aims to optimize the process parameters for laser welding of Incoloy 800HT with the help of MOORA(Multi Objective Optimization Using Ratio Analysis) technique. The process parameters taken were focal position, laser power and welding speed and response parameters were the mechanical properties of welded joints like tensile strength, hardness and impact toughness. Metallurgical characterizations like optical microscopy and fractography were done to the specimens which was categorized as best and least from the results of optimization for validation of results. The observations from metallurgical characterization was seen to be in line with the optimization results.The major factor which affects the results of the welding process was found to be the laser speed.**

Keywords*— *Incoloy 800HT, laser welding, mechanical testing, parameter optimization, metallurgical characteristics.

I. Introduction

Super alloys are high performance materials which are superior in resistance to creep deformation and high temperature corrosion[1] . Incoloy belongs to the category of nickel based superalloys with various categories like 800, 800H and 800HT. The difference between 800 and 800 H is their carbon percentage whereas 800HT stands distinct with the addition of 1.20% of Aluminium and Titanium and the high temperature annealing treatment so that it can be used in applications like pressure vessels, ethylene furnace quench boilers and superheaters in powerplants[2]. Solution hardening and precipitation hardening mechanisms can be observed in incoloy 800 H due to precipitation of Al and Ti carbides[3]. Incoloy 800HT has high neutron absorption capacity so it can be used in fuel cladding equipments of nuclear power plants[4].Laser welding is the non-contact welding technique which is used to join two materials. The beams of laser has low divergence since it has high density[5]. It can be used to join materials which are difficult to weld and smaller size materials. The quality of the welded joint in the laser welding was influenced by it's process such as laser power, focal spot, welding speed, beam position etc.., laser welding of austenitic stainless steels were done to prevent the grain boundary precipitation of chromium carbides called sensitization. In laser welding HAZ is very narrow with little amount of thermal distortion and residual stress[6]. Multi objective Optimization is the process of taking decisions in a particular operation by considering various criteria's related to that process which may be beneficial or non beneficial depending upon the particular operation. MOORA is the technique of multi objective optimization which uses ratio approach and the reference point approach[7]. Ratio approach of MOORA deals with the performance measurement of an alternative. The overall performance of an alternative was measured as the difference between the sum of their normalized performances[8]. Reference point approach is where the maximum objective is set as the reference point and the performance of the alternatives were measured in accordance with the reference point. In MOORA the order of preference can be changed according to different normalization methods[9].This paper aims to optimise the process parameters for laser butt welding on Incoloy 800HT by MOORA method. The influence of the controllable process factors (welding speed, laser power and focal position) on the mechanical properties (the ultimate tensile strength, hardness and toughness) of the welded joints was studied. This was based on the correlation between the process factors. By analysing the rank values of MOORA , the most influential factors were determined. Further the metallurgical characteristics of the weldments was analysed by optical microscopy, and fractography analysis of the tensile tested specimens were made.

II. EXPERIMENTAL PROCEDURE

The material under this investigation Incoloy 800HT were procured in the form of plates of dimension 150 x100 x4 mm whose chemical composition was given in the Table-1. The ultimate tensile strength of the material was found to be 540 MPa. The plates were welded by means of a 4 kW capacity laser welding machine which uses CO_2 as shielding gas. Trial runs were conducted to find the desired range of process parameters such as focal position, laser power and welding speed whose levels was shown in Table-2 and the range of parameters were arranged according to taguchi's concept of experimental design. The responses collected were impact toughness, hardness and ultimate tensile strength. Samples for mechanical characterization were prepared according to their recommended standards such as ASME SEC IX for tensile test and ASTM E23-04 for impact toughness. Process parameters along with their resultant values were shown in Table-3. Metallurgical characterization of specimens were done by following suitable procedures such as sectioning, polishing and etching of specimen to reveal the microstructure. Fractographic analysis was to done to study the fracture surfaces of tensile and impact specimen.

TABLE-1 Chemical compositions of the base metal

C	Mn	S	Si	Cu	Cr	Fe	Al	Ti	Ni
0.065	0.688	<0.010	0.094	0.091	20.79	46.60	0.277	0.280	30.65

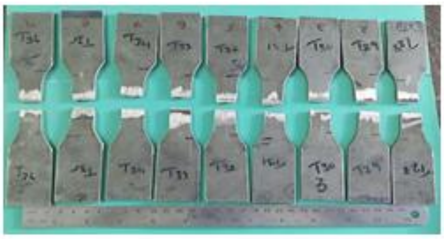

FIGURE-1 Photograph of tensile specimen

FIGURE- 2 Photograph of impact specimen

TABLE 2 Control factors and levels

Factor	Unit	Level 1	Level 2	Level 3
Welding Speed	mm/min	1000	1200	1400
Laser Power	W	2750	3000	3250
Focal position	Mm	-0.3	-0.6	-0.9

TABLE 3 Experimental layout using L_9 orthogonal array and performance result.

Exp. No.	Welding speed (mm/min)	Laser power (W)	Focal position (mm)	UTS (MPa)	Hardness (HV)	Toughness (J)
1	1000	2750	-0.3	602.53	186	64
2	1000	3000	-0.6	605.30	168	62
3	1000	3250	-0.9	612.93	182	72
4	1200	2750	-0.6	604.00	192	54
5	1200	3000	-0.9	622.84	207	68
6	1200	3250	-0.3	605.55	163	70
7	1400	2750	-0.9	558.91	169	64
8	1400	3000	-0.3	598.27	175	60
9	1400	3250	-0.6	601.57	168	62

III. METHODOLGY

The resultant values of mechanical characterization was used to optimize the process parameters using the MOORA method. The steps to be followed while using MOORA method are as follows.

Step I : Initial step of MOORA begins with description of the problem , which was followed by selection of objectives.

Step II: Selection of objectives lead to the construction of decision matrix which was used to represent the resultant values of experiments under their corresponding response parameters which can be represented as

$$D_m = \begin{bmatrix} q_{11} & q_{12} & q_{13} & \cdots & q_{1y} \\ q_{21} & q_{22} & q_{23} & \cdots & q_{2y} \\ q_{31} & q_{32} & q_{33} & \cdots & q_{3y} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ q_{x1} & q_{x2} & q_{x3} & \cdots & q_{xy} \end{bmatrix}$$

Step III: Normalization of decision matrix which can be used to calculate normalized performance rating

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

TABLE-4 Decision matrix value

Exp.no	UTS	Hardness	Toughness	Decision matrix		
				UTS	Hardness	Toughness
1	602.53	186	64	0.333877	0.34561	0.332254
2	605.3	168	62	0.335412	0.312164	0.321871
3	612.93	182	72	0.33964	0.338178	0.373785
4	604	192	54	0.334692	0.356759	0.280339
5	622.84	207	68	0.345132	0.384631	0.353019
6	605.55	163	70	0.335551	0.302874	0.363402
7	558.91	169	64	0.309706	0.314022	0.332254
8	598.27	175	60	0.331517	0.325171	0.311488
9	601.57	168	62	0.333345	0.312164	0.321871

Step IV: Weightage for the normalized matrix was calculated to find the parameter of importance

$$v_{ij} = w_{ij} * r_{ij}$$

TABLE-5 Weighted normalized decision matrix

Exp.no	UTS	Hardness	Toughness	Weighted normalized decision matrix		
				UTS	Hardness	Toughness
1	602.53	186	64	0.11018	0.114051	0.109644
2	605.3	168	62	0.110686	0.103014	0.106217
3	612.93	182	72	0.112081	0.111599	0.123349
4	604	192	54	0.110448	0.11773	0.092512
5	622.84	207	68	0.113893	0.126928	0.116496
6	605.55	163	70	0.110732	0.099948	0.119923
7	558.91	169	64	0.102203	0.103627	0.109644
8	598.27	175	60	0.109401	0.107306	0.102791
9	601.57	168	62	0.11004	0.103014	0.106217

Step V: The benefit and cost criteria rating for each alternative was calculated by taking sum of weighted normalized matrix.

$$S_i^{+} = \sum_{j=1}^{n} v_{ij} \,|j \epsilon J^{max}$$

Where J^{max} is associated with benefit criteria. Similarly, the overall rating of cost criteria S_i^{-} are calculated as:

$$S_i^{-} = \sum_{j=1}^{n} v_{ij} \,|j \epsilon J^{min}$$

Where J^{min} is associated with cost criteria.

Step VI: The overall performance index S_i for each alternative was calculated by taking difference of the values of benefit and cost criteria for each alternative

$$S_i = S_i^{+} - S_i^{-}$$

Step VII : selection of best and least rank experiments from the assessment calculated from performance index

$$A^* = \{A_i | \max S_i\}$$

TABLE-6 Normalized output value of corresponding parameters and normalized assessment

Exp.no	Normalized decision matrix			Normalized assessment	Rank
	UTS	Hardness	Toughness		
1	0.11018	0.114051	0.109644	0.333875	3
2	0.110686	0.103014	0.106217	0.319917	6
3	0.112081	0.111599	0.123349	0.347029	2
4	0.110448	0.11773	0.092512	0.320691	5
5	0.113893	0.126928	0.116496	0.357318	1
6	0.110732	0.099948	0.119923	0.330603	4
7	0.102203	0.103627	0.109644	0.315474	9
8	0.109401	0.107306	0.102791	0.319498	7
9	0.11004	0.103014	0.106217	0.319235	8

IV. RESULTS AND DISCUSSION

Optical microstructure

Microstructural analysis were carried out for the best rank specimens which were obtained from the optimization using MOORA technique. Optical microscope was used to carry out the analysis at 100x magnification. Observation from the microstructure shows the reduction of heat affected zone at the higher welding speed it was supported by the reason that at higher welding speeds the base material acts as the black body. The microstructure of the best rank specimen has been observed to have both cellular and equiaxed grain structure.

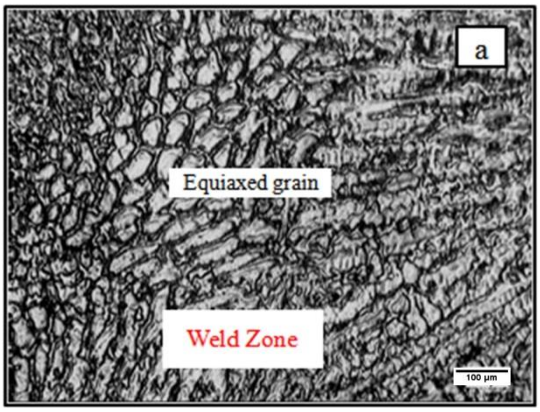

FIGURE-3 Microstructure of the best rank specimen

Fractography

Fractography was used to study the fractured surfaces of tensile and impact specimens which were declared to be of best rank from the optimization results. In general perspective fractography was used as the failure analysis tool of engineering structures and the inputs from the fractography results can be used to develop the properties of the materials. The SEM image of fractured specimen of the best rank was shown in Fig-. from the figure it has been observed that there was a combination of dimples and clevages in large amount. Dimples are black holes which shows that the ductile fracture has occurred in the specimen and also it means that the specimen has high toughness. Presence of white thread like structures called cleavage means that the specimen has high strength.

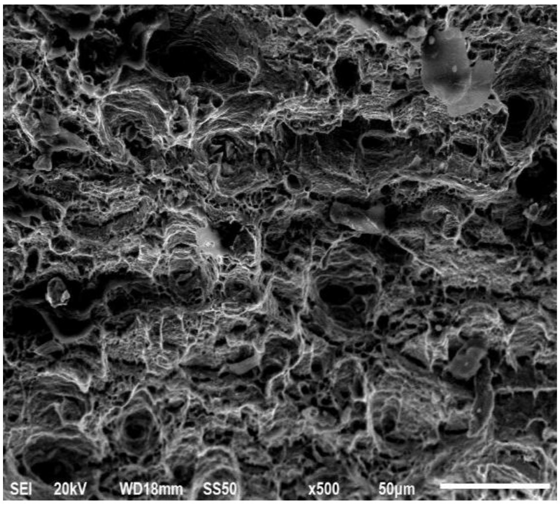

FIGURE-4 SEM image of fractured specimen

V. Conclusion

Multi objective optimization of process parameters for laser welded incoloy 800 HT joints were successfully done and the following conclusions were obtained. Parameters for experiment no:5 was obtained as the optimal parameter with the values of welding speed 1200 mm/min, laser power of 3000W and focal position of -0.9 mm. Microstructural analysis of best ranked specimen shows that the high welding speed caused the reduction of heat affected zone.Fractography analysis revealed that the best ranked specimen has both dimples and cleavages in larger amount which states that the weld joint has both strength and toughness

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