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INFLUENCES OF THE HEAT INPUT ON A 2205 DUPLEX STAINLESS STEEL WELD

VPLIV VNOSA TOPLOTE V ZVAR DUPLEKSNEGA NERJAVNEGA JEKLA 2205

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In arc welding, the energy is transferred from the electrode to the base metal via an electric arc. The energy transferred per unit length is measured as the heat input. The heat input is an important factor that influences the cooling rate and affects the metallurgical and mechanical properties of welds. In this study, the flux-cored arc-welding process was used to join duplex stainless steel. The experiment was conducted on the basis of a three-factor, five-level central composite rotatable design using the full-replication technique. A mathematical model was developed for the heat input. The effects of the welding-process parameters on the heat input are discussed. Metallographic techniques were employed to study the microstructure produced at low, medium, high and optimum heat-input conditions.

Key words: heat input, FCAW, duplex stainless steel, microstructure

Pri obločnem varjenju se energija prenaša iz elektrode na osnovno kovino z električnim oblokom. Energija, prenesena na enoto dolžine, se meri kot vnos toplote. Vnos toplote je pomemben faktor, ki vpliva na hitrost ohlajanja, na metalurške in mehanske lastnosti zvara. V tej študiji je bilo za spajanje dupleksnega nerjavnega jekla uporabljeno varjenje pod praškom. Eksperiment je bil izvršen na osnovi treh faktorjev in petnivojske centralno vrtljive izvedbe s polno možnostjo ponovitve. Za vnos toplote je bil razvit matematični model. Obravnavan je bil vpliv parametrov varilnega procesa na vnos toplote. Za študij mikrostrukture, nastale pri nizkem, srednjem, velikem in optimalnem vnosu toplote, so bili uporabljeni metalografski postopki.

Ključne besede: vnos toplote, FCAW, dupleksno nerjavno jeklo, mikrostruktura

1 INTRODUCTION

The flux-cored arc welding (FCAW) is widely used by industries because it produces welds with better and more consistent mechanical properties and fewer weld defects, it is a high-deposition-rate process and suitable for stainless steel. Generally, FCAW produces a stronger weldment than SMAW at room temperature.[1] Duplex stainless steel (DSS) is widely used in industrial applications due to its excellent corrosion resistance and its strength that is higher compared to types 316 and 317 of austenite stainless steel.[2] It is a combination of 50 % austenitic and 50 % ferritic steels. In the present study, 2205 DSS was used as the base metal for the experiment and a diameter 1.2 mm (E2209T1-4/1) filler wire was used for depositing the metal. For the shielding purpose, a combination of 75 % argon plus 25 % CO_2 was used as the welding gas for horizontal-position welding. 2205 DSS was procured from Outokumpu Stainless AB, Sweden.

2 EXPERIMENTAL SETUP

The FCAW setup available at the Welding Research Centre of Coimbatore Institute of Technology (CIT), Coimbatore, India was used to conduct the experiments. The welding setup consists of a power source, namely, INDARC 400 MMR, a unit feeding the filler wire with the shielding-gas-flow control, a welding gun and a welding manipulator that helps to deposit the filler metal on the desired area as shown in **Figure 1**.

The selection of significant FCAW process parameters helps us to get the desired weld-bead quality.[3] In accordance with the available literature, the welding current (I), the welding speed (S) and the open-circuit voltage (OCV) were taken as the significant process parameters. The trial runs were conducted by varying

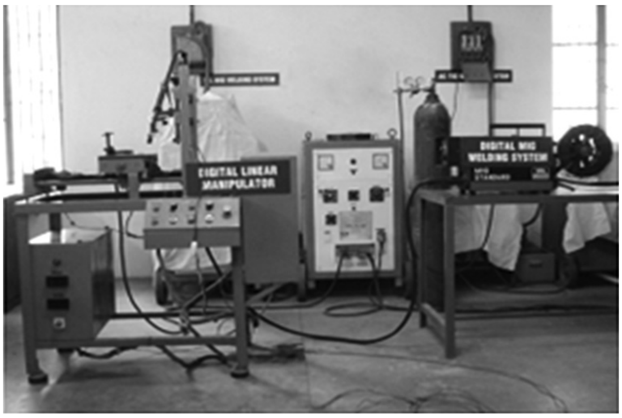

Figure 1: FCAW experimental setup
Slika 1: Eksperimentalni sestav FCAW

one process parameter while keeping the other two parameters constant. The working range was selected, by visual inspection, on the basis of the appearance of the weld bead with respect to how smooth and continuous it was, and with respect to the absence of defects like porosity, undercut, etc. The welding parameters and their levels are given in **Table 1**. The experiment was conducted as per the design matrix and 20 runs were made by varying the process variables as shown in **Table 2**.

Table 1: Welding parameters and their factor levels
Tabela 1: Parametri varjenja in faktorji njihovih nivojev

S. No.	Parameter/unit	Factor level				
		–1.682	–1	0	1	1.682
1	Welding current (A)	170	182	200	218	230
2	Welding speed (cm/min)	25	27	31	35	37
3	Open-circuit voltage (V)	28	30	32	34	36

Table 2: Design matrix and the observed heat-input values
Tabela 2: Postavitev matrice in opažene vrednosti vnosa toplote

Sp. No.	*I*/A	*S*/ (cm/min)	*OCV*/V	*U*/V	H_I/ (kJ/cm)
1	–1	–1	–1	28.7	9.87
2	1	–1	–1	24.35	10.03
3	–1	1	–1	27.75	7.36
4	1	1	–1	27.7	8.80
5	–1	–1	1	31.55	10.85
6	1	–1	1	31.35	12.91
7	–1	1	1	30.9	8.19
8	1	1	1	29.35	9.32
9	–1.682	0	0	31.25	8.74
10	1.682	0	0	31.8	12.03
11	0	–1.682	0	32	13.06
12	0	1.682	0	32.55	8.97
13	0	0	–1.682	24.7	8.13
14	0	0	1.682	34.5	11.35
15	0	0	0	32.85	10.81
16	0	0	0	32.25	10.61
17	0	0	0	31.75	10.45
18	0	0	0	29.4	9.67
19	0	0	0	30.6	10.07
20	0	0	0	27.45	9.03

3 DEVELOPMENT OF A REGRESSION MODEL FOR THE HEAT INPUT

The heat input could not be measured directly; however, with the help of the welding current, the arc voltage and the welding speed it could be calculated. The arc voltage was measured with the voltmeter of the welding transformer, the welding current was determined on the basis of the wire feed rate and the welding speed on the basis of the movement of the table. The heat input was calculated as the ratio of the power to the velocity of the heat source:

$$H_I = 60\ UI\eta\ /1000\ S \tag{1}$$

where H_I = heat input (kJ/cm), U = arc voltage (V), I = current (A), S = travel speed (cm/min) and η = arc efficiency accounting for the heat dissipation to the surrounding as a result of the convection and radiation (0.85). The observed heat-input values are shown in **Table 2**.

The response function representing the parameters is expressed with the following equation:

$$Y = f\,(X_1, X_2, X_3) \tag{2}$$

where Y = heat input, X_1 = current (I), X_2 = speed (S) and X_3 = open circuit voltage (V).

The second-order polynomial equation represents the response for K factors given in equation:[4]

$$Y = b_0 + \sum_{I=1}^{K} b_i X_i + \sum_{ij=1}^{K} b_{ij} X_i X_j + \sum_{\substack{I=1 \\ i\neq j}}^{K} b_{ii} X_i^2 \tag{3}$$

For the three factors, the above polynomial equation can be expressed as:

$$Y = b_0 + b_1 I + b_2 S + b_3 V + b_{12} IS + b_{13} IV + b_{23} SV + b_{11} I^2 + b_{22} S^2 + b_{33} V^2 \tag{4}$$

where b_0 = free term, coefficients b_1, b_2, b_3 = linear terms, coefficients b_{12}, b_{13}, b_{23} = interaction terms and coefficients b_{11}, b_{22}, b_{33} = quadratic terms. The developed regression model in the coded form is given below; adequacy was checked with the ANOVA method.

Heat input:

$$H_I = 10.213 + 0.756I - 1.235S + 0.778V - 0.294V^2 - 0.314SV \tag{5}$$

4 RESULTS

Figure 2 depicts the effects of the process parameters on the heat input. The welding speed shows a significant effect on the heat input. The heat input increases up to 12.67 kJ/cm with the lower welding speed of 25 cm/min and it gradually falls down to 8.52 kJ/cm at the higher

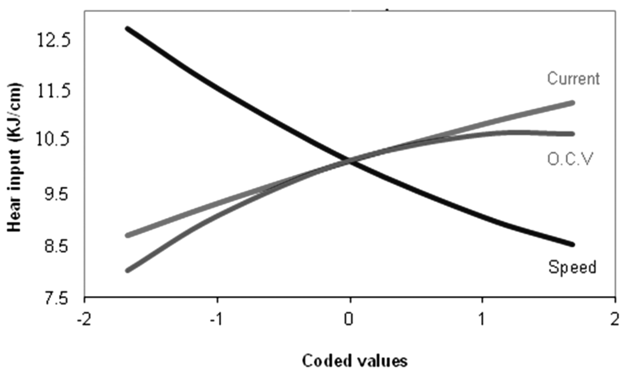

Figure 2: Effects of process parameters on the heat input
Slika 2: Vpliv parametrov procesa na vnos toplote

Figure 3: Microstructure of the weld metal zone at different conditions: a) low heat input (H_I = 7.36 kJ/cm), b) medium heat input (H_I = 10.45 kJ/cm), c) high heat input (H_I = 13.06 kJ/cm); magnification: 400-times

Slika 3: Mikrostruktura zvara v različnih razmerah: a) nizek vnos toplote (H_I = 7,36 kJ/cm), b) srednji vnos toplote (H_I = 10,45 kJ/cm), c) visok vnos toplote (H_I = 13,06 kJ/cm); povečava 400-kratna

welding speed of 37 cm/min. At the lower welding speed, the heat input per unit length of the weld is higher resulting in large heat-affected zones and causing a severe distortion. The heat input increases from 8.01 kJ/cm to 11.24 kJ/cm with the increasing welding current and open-circuit voltage. Obviously, the higher voltage and the higher current increase the discharge and elevate the heat input.

In **Figure 3a**, the ferrite phase is shown in white color. The presence of a columnar dendrite structure represents a faster cooling rate due to the low heat-input condition.[5] It is evident from **Figure 3b** that a vermicular structure is observed in the weld metal at the magnification of 400-times. The delta ferrite is pale yellow, the austenitic regions are greenish blue, and the final-solidification regions are bluish. In **Figure 3c**, the microstructure reveals the presence of ferrite (white) and austenite (dark). The coarse austenite grains found in the microstructure may be due to the higher heat input during the welding.

5 CONCLUSION

At the higher welding speed, the heat input per unit length of the weld decreases.

A higher heat input reduces the weld quality and increases the distortion.

The microstructure study reveals the morphology of 2205 DSS welds at various heat-input conditions.

6 REFERENCES

[1] Z. Zhang, A. W. Marshall, G. B. Holloway, Flux cored arc welding: the high productivity welding process for P91 steels, Proceedings of the 3rd conference on advances in materials technology for fossil power plants, The Institute of Materials, University of Wales Swansea, London, 2001, 267–282

[2] I. Alvarez-Armas, Duplex Stainless Steels: Brief History and Some Recent Alloys, Recent Patents on Mechanical Engineering, 1 (**2008**), 51–57

[3] K. Y. Benyounis, A. G. Olabi, Optimization of different welding processes using statistical and numerical approaches – A reference guide, Adva. Engg. Software, 39 (**2008**), 483–496

[4] K. M. Carley, Response surface methodology, CASOS Technical Report, Carnegie Mellon University, 2004

[5] J. Elmer, S. M. Allen, T. W. Eagar, Microstructural development during solidification of stainless steel alloys, Metallurgical Transactions A, 20A (**1989**), 2117–2131