

Geometry of Remeltings and Efficiency of the Surface Remelting Process Applied to Cobalt Alloy Castings

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Abstract

The paper summarises results of measurements of remelting area geometry, thermal efficiency and melting efficiency characterising the surface remelting process applied to castings of MAR-M-509 cobalt alloy. The remelting process was carried out with the use of GTAW (Gas Tungsten Arc Welding) method in protective atmosphere of helium, at the electric current intensity in the range from 100 A to 300 A, and the electric arc scanning velocity v_s in the range from 200 mm/min to 800 mm/min. The effect of current intensity and electric arc scanning velocity on geometrical parameters of remeltings, thermal efficiency, and melting efficiency characterising the remelting process has been determined.

Keywords: MAR-M509 alloy, Surface remelting, Remelting geometry, Thermal efficiency, Melting efficiency

1. Introduction

In the last ten or fifteen years, intensive development in the area of heat resistant and creep resistant materials can be observed. This is true particularly with the reference to the aircraft industry where range of application for such materials is the widest [1, 2].

Expansion of aviation as a means of public transport and haulage of goods, is a result of a large number of scientific studies concerning establishment of an optimum chemical composition, best manufacturing practices, and

methods allowing to improve service properties of cobalt alloy castings [3, 4].

One of the promising methods allowing to improve service properties of castings consists in shaping the fine-grained structure of their surface layer. To this end, the casting surface remelting technique can be used. Using for this purpose such high-energy heat sources as laser beam, electron beam, or electric arc plasma stream, allows to remelt the surface of a casting that is followed by rapid solidification. As a result, a refinement of microstructure occurs and improvement of service properties of the castings [5–9].

Surface improvement of castings with the use of concentrated heat stream requires knowledge on the amount of heat intercepted by a casting in the course of being heated up as the parameter has a decisive effect on the remelting area geometry, solidification rate, and microstructure.

The objective of the study was to determine the effect of technological parameters characterising the surface remelting process carried out with the use of GTAW method on geometry of remeltings, thermal efficiency and melting efficiency when applied to MAR-M509 cobalt alloy castings.

2. Material and experimental conditions

Plate castings with dimensions of 200 mm × 50 mm × 16 mm were prepared for the tests. Melts were carried out in the Balzers vacuum furnace. The moulds were prepared with the use of the investment casting method. Chemical composition of the MAR-M-509 alloy included: 0.57% C, 0.001% S, 0.13% Si, 0.04% Mn, 10.31% Ni, 23.10% Cr, 7.10% W, 0.17% Ti, 0.18% Fe, 3.78% Ta, 0.34% Zr, 0.01% B, rest Co.

Plate castings of MAR-M509 alloy were surface-remelted by mean of GTAW method with the use of FALIG 315 AC/DC welding machine. Electric current intensities $I = 100, 150, 200, 250,$ and 300 A were used. The used electric arc scanning velocities were $v_s = 200, 400, 600,$ and 800 mm/min. Remeltings were carried out in the atmosphere of helium. Tungsten electrode with diameter $\varnothing = 3.0$ mm was used, at the electric arc length of 3.0 mm.

Evaluation of the quantity of heat intercepted by the casting specimen was performed with the use of a set-up for calorimetric tests [10].

Thermal efficiency and melting efficiency

Thermal efficiency of the GTAW process η was calculated from the formula:

$$\eta = \frac{Q_k}{U \cdot I \cdot t} \quad (1)$$

where Q_k is the amount of heat intercepted by the heated material determined experimentally with the use of calorimeter (J), U — electric arc voltage (V), I — electric current intensity (S), t — electric arc scanning time (s).

The melting efficiency η_m was calculated from the following formula:

$$\eta_m = \frac{V_n \cdot Q_H}{Q_k} \quad (2)$$

$$Q_H = \rho(Q_f + \int_{T_0}^{T_1} c_p dT)$$

where V_n is the remelting volume (mm^3); Q_H — amount of heat required to heat up a unit volume of the alloy from temperature T_0 to a temperature T_1 and melt it (J/mm^3); Q_f — the specific heat of fusion (J/g), c_p — specific heat (J/gK), and ρ — alloy density (g/cm^3).

Geometry of remeltings

Geometry of the obtained surface remeltings was examined on a cross-section perpendicular to the longitudinal axis of remeltings (Fig. 1). Specimens were cut on the metallographic cut-off machine Labotom 3 of Struers brand using Supra TRD 15 cut-off wheel at the linear velocity of the wheel edge displacement of 37.2 m/s. The wheel was advanced with velocity of about 10 mm/min, at several intervals. In the course of cutting-off the specimens, the wheel was intensively cooled with water. Specimen surfaces selected for observations were prepared with abrasive papers with grit size grades of 150, 500, and finally 1000 at the polishing pad rotational velocity of 150 rpm. In the course of specimen preparation, abrasive papers were wetted with a water stream.

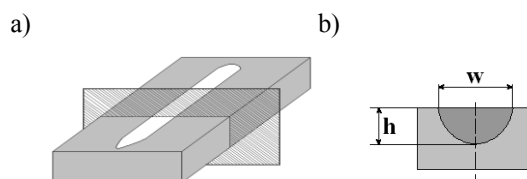


Fig. 2. (a) Schematic diagram showing the method used to cut off specimens for remelting geometry measurements; (b) geometric parameters of remeltings: width w , depth h

Measurements of geometrical parameters characterising the remeltings were carried out by means NEOPHOT 2 optical microscope equipped with VIDEOTRONIC CC20P video camera, with the use of advanced image capture and analysis system Multiscan v. 08. Width w and depth h of remelted areas were measured. The adopted method allowed to read out values of the parameters w and h with accuracy of 0.01 mm.

Results or measurements of remelting geometry (width and depth) and calculated values of the heat efficiency and the melting efficiency are presented in Table 1.

3. Conclusions

Based on the obtained test results it was found that with increasing electric current intensity and decreasing electric arc scanning velocity, both width and depth of surface remeltings increase. The largest width $w = 17.8$ mm and

depth $h = 3.2$ mm was obtained at the electric current intensity $I = 300$ A and scanning velocity $v_s = 200$ mm/min. The smallest width $w = 3.5$ mm and depth $h = 0.7$

mm of remelting was obtained for the electric current intensity $I = 100$ A and scanning velocity $v_s = 800$ mm/min.

Table 1.

Results of measurements of remelting geometry (width and depth) and calculations of thermal efficiency and melting efficiency characterising the process of surface remelting process applied to castings of MAR-M-509 cobalt alloy

No.	Current intensity I (A)	Scanning velocity v_s (mm/min)	Voltage U (V)	Remelting geometry		Efficiency	
				width w (mm)	depth h (mm)	thermal η	of fusion η_m
1	100	200	18.0	6.0	1.2	0.48	0.02
2	150		18.5	8.2	1.8	0.42	0.03
3	200		19.0	10.6	2.3	0.38	0.04
4	250		19.5	13.4	2.7	0.36	0.04
5	300		20.0	17.8	3.2	0.34	0.05
6	100	400	18.0	4.6	1.1	0.37	0.04
7	150		18.5	6.3	1.6	0.32	0.06
8	200		19.0	8.3	2.1	0.29	0.08
9	250		19.5	10.3	2.5	0.27	0.11
10	300		20.0	13.2	3.0	0.26	0.12
11	100	600	18.0	3.9	0.9	0.31	0.08
12	150		18.5	5.7	1.4	0.25	0.11
13	200		19.0	7.1	1.9	0.23	0.15
14	250		19.5	9.4	2.3	0.21	0.19
15	300		20.0	11.4	2.8	0.19	0.23
16	100	800	18.0	3.5	0.7	0.24	0.12
17	150		18.5	4.9	1.0	0.19	0.18
18	200		19.0	6.2	1.5	0.17	0.25
19	250		19.5	7.5	1.9	0.16	0.33
20	300		20.0	8.5	2.3	0.15	0.41

In the adopted range of the GTAW process parameters, the remelting width is more sensitive to the current intensity changes than to variation of the electric arc scanning velocity.

Any change in technological parameters characterising the surface remelting technique applied to MAR-M509 alloy castings results in significant differences in thermal efficiency and melting efficiency of the process. Higher current intensities and lower electric arc scanning velocities result in increased amount of heat generated in the electric arc. Accordingly, the amount of heat absorbed by the warmed-up casting also increases. The rate of increase of the heat amount intercepted by the casting related to increase of the current intensity is lower than the respective rate of increase of heat generated in electric arc. The effect is a reduction of the thermal efficiency.

The increase of the current intensity and the electric arc scanning velocity results in increased melting efficiency. Higher current intensity means higher energy of the electric energy, and higher scanning speed shortens duration of the remelting process and therefore thermal losses related to heating the specimen up to temperature just below the melting temperature are less.

The obtained results allowed to determine relationships between the thermal efficiency, melting efficiency, and

geometrical parameters of remeltings on one hand and technological parameters of the remelting process on the other.

The relationship between the thermal efficiency on one hand and the current intensity and the electric arc scanning speed on the other is described by formula:

$$\eta = 0.0006 \cdot I - 0.0004 \cdot v_s + 0.57 \quad (3)$$

Statistical parameters of the equation: $R = 0.98$; $R^2 = 0.96$; $F = 242.1$; $\Delta\eta = 0.018$; $\alpha = 0.05$.

The relationship between the melting efficiency on one hand and the current intensity and the electric arc scanning speed on the other is described by formula:

$$\eta_m = 0.0007 \cdot I + 0.0004 \cdot v_s - 0.19 \quad (4)$$

Statistical parameters of the equation: $R = 0.92$; $R^2 = 0.86$; $F = 53.5$; $\Delta\eta_m = 0.041$; $\alpha = 0.05$.

The relationship between the remelting width on one hand and the current intensity and the electric arc scanning speed on the other is described by formula:

$$w = 0.04 \cdot I - 0.008 \cdot v_s + 4.28 \quad (5)$$

Statistical parameters of the equation: $R = 0.96$; $R^2 = 0.92$; $F = 103.1$; $\Delta w = 1.05$ mm; $\alpha = 0.05$.

The relationship between the remelting depth on one hand and the current intensity and the electric arc scanning speed on the other is described by formula:

$$h = 0.009 \cdot I - 0.0013 \cdot v_s + 0.69 \quad (6)$$

Statistical parameters of the equation: $R = 0.99$; $R_2 = 0.98$; $F = 730.4$; $\Delta h = 0.08$; $\alpha = 0.05$.

The obtained formulas, characterised with high values of statistic coefficients, can be used effectively in industrial practice for assessment of thermal efficiency and efficiency of fusion in the surface remelting process applied to castings of MAR-M509 alloy and geometry of the obtained remelting patterns based on technological parameters of the surface remelting process carried out by means of the GTAW method.

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