Structural studies of partial meltings of casting surfaces made of cobalt alloy MAR-M509

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Abstract

The results of structural studies of partial meltings of casting surfaces of plates made of cobalt alloy MAR-M509 have been presented. The partial meltings were formed with argon or helium plasma beam generated in electric arc. Observations of microstructure revealed presence of phase $\gamma$ and carbides. X-ray diffraction has shown phase $\gamma$, carbide types MC and $M_23C_6$ and scanty amount of hexagonal phase $\varepsilon$.

Keywords: cobalt alloy MAR-M509, GTAW method, microstructure, X-ray diffraction phase analysis

1. Introduction

Precise castings made of high resisting cobalt alloy MAR-M509 are used in aircraft jet turbine engines as segments of sealing rings in a high-temperature part of a turbine. Those segments are exposed to the influence of high temperature (above 1000°C), erosion and corrosion interactions of combustion gases with flow velocity 150 – 300 m/s and pressure 0,93-1,0 MPa [1].

Due to those factors the segments of sealing rings are being damaged easily (Fig. 1) [2].

Microstructure of castings of sealing ring segments made of alloy MAR-M509 are characterized by big dendritic grains of cobalt austenite $\gamma$ with an irregular ternary eutectic placed on their boundaries ($\gamma + M_23C_6 + MC$) [3,4]. Such a microstructure leads to deterioration in functional quality (especially high resisting properties) of those castings.

Application of plasma beam generated in electric arc (GTAW method) enriches the microstructure of castings made of alloy MAR-M509 through partial meltings and rapid crystallization [5]. Because of good susceptibility of castings made of that alloy to surface partial melting [6,7] enrichment with plasma beam causes refinement of grains and change of morphological features of eutectic.

The aim of this article is to present the results of X-ray studies (application of X-ray diffraction) of partial meltings of casting surfaces of plates made of alloy MAR-M509.

2. Material and applied methodology of studies

Plates with dimensions: 4x20x90 mm, casted from alloy MAR-M509 of chemical constitution: 0,60% C; 22,83% Cr; 10,0% Ni; 7,12% W; 3,77% Ta; 0,36% Zr; 0,18% Ti;
0.007% B; the rest is Co, were used for studies. Plates were obtained in multilayer ceramic moulds where liquid alloy of temperature ca 1500±5°C was poured in. Casting into a ceramic mould of initial temperature ca 1000°C was executed in a vacuum ca 2.9 Pa, in a pair vacuum induction furnace Leybold-Heraeus JS30/SP. Such casted plates were melted partially on the surface with argon or helium plasma beam generated in electric arc. Partial meltings formed at constant velocity of dislocation of plasma beam, \( V_p = 400 \) mm/min, constant current intensity \( I = 150 \) A and constant electric arc length \( l_e = 3 \) mm and partial meltings in argon formed at \( V_p = 200 \) mm/min, \( I = 200 \) A, \( l_e = 3 \) mm were used for structural and X-ray studies.

X-ray diffraction was performed on metallographic specimens parallel to the direction of partial melting by exposing to monochromatic radiation of a Cu target tube (\( \lambda = 1.54 \) Å) with X-ray diffractometer Siemens D500.

3. Study results

Macrostructures and microstructures of partial meltings of casting surfaces of plates made of alloy MAR-M509, which cross-section along the direction of the surface partial melting were observed, are shown in Fig. 2. Macrostructure of partial melting formed with argon plasma beam is shown in Fig. 2a and with helium plasma beam is shown in Fig. 2b. Both partial meltings were executed under the same conditions (\( V_p = 400 \) mm/min, \( I = 150 \) A, \( l_e = 3 \) mm).

Diffraction patterns of partial meltings are shown in Fig. 3. Examples of diffraction patterns of the surface layer of partial meltings (argon, \( V_p = 200 \) mm/min, \( I = 200 \) A, \( l_e = 3 \) mm, Fig. 4) obtained for a grazing incident geometry, different effective penetration distances and the Bragg–Brentano geometry are shown in Fig. 5 and 6.
Diffraction patterns of partial melting (area 1, fig. 4) and the casting (area 2, fig. 4) are shown in Fig. 6.

Fig. 6. Diffraction patterns of areas 1 and 2 (Fig. 4) obtained for the Bragg – Brentano geometry

4. Discussion

Microstructure of the surface layer of castings made of cobalt alloy MAR-M509 might be formed with argon or helium plasma beam generated in electric arc. Partial meltings are characterized by fine, oriented, cellular-dendritic grains which on their boundaries have a continuous, thin eutectic that consists of carbides type MC (rich in tantalum) and type M23C6 (rich in chromium). The cellular-dendritic grains of cobalt austenite $\gamma$ of partial meltings have a scanty amount of phase ($\epsilon$) plates. The growth directions of the grains depend on parameters of partial melting process, especially on plasma-forming and shielding gas (Fig. 3). Cobalt austenite (phase $\gamma$) has a low value of SFE. Low SFE supports phase transitions and influences the course of strengthening, spatial configuration of the dislocation structure and sort of texture that is being formed [8]. Reconstruction of stacking fault structure that leads to elastic stress reduction, is possible during fast crystallization of partial meltings of casting surfaces made of alloy MAR-M509. According to Nutting [9] SFE might be treated as a formation energy of phase $\epsilon$ plate.

Fig. 4. Macrostructure of plate casting in a longitudinal section that is cut along the direction of partial melting with marked areas showing slide of X-ray diffraction phase analysis. (1) partial melting, (2) casting material. Parameters of partial melting: argon $V_p = 200$ mm/min, $I = 200$ A, $l = 3$ mm

Fig. 5. Diffraction patterns of partial melting 1 (Fig. 4) obtained for a grazing incident geometry $\alpha = 2^\circ$, $\alpha = 9^\circ$ and the Bragg – Brentano geometry
Literature


