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Stress-rupture Tests of MAR-M-509 Cobalt Alloy Improved by Rapid Solidification

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Abstract

In the paper, results of stress-rupture test applied to MAR-M-509 cobalt alloy specimens, in as-cast condition and with microstructure shaped under rapid solidification conditions are presented. The material for the study were castings of MAR-M509 alloy obtained by means of the investment casting method. The rapid solidification conditions were obtained by means of remelting process carried out with the use of GTAW method. The effect of rapid solidification following the remelting process is a refinement of microstructure in castings of MAR-M509 alloy and significant extension of the time to rupture in stress-rupture test.

Keywords: MAR-M509, Rapid solidification, Stress-rupture test

1. Introduction

MAR-M509 alloy belongs to a group of materials used for manufacturing aircraft engines. It is characterised with high creep resistance and heat resistance as well as good resistance to oxidation and high-temperature corrosion [1]. MAR-M509 alloy is used for segmented seal ring sealing the low pressure turbine in aircraft engines. In the course of varying operation conditions described by the complex engine load spectrum, the ring is subject to interaction of varying temperature and load fields. The load spectrum taken for combat support, fighter, and civil aviation aircraft engines shows that to obtain an instantaneous maximum available thrust value, parameters of the aircraft propulsion system exceed typically allowable limit values [2]. Increasing thrust value is accompanied by rapid increase of exhaust gas temperature followed by equally fast decrease of the parameters. Temperature and pressure changes and the related stress changes intensify the process of the drive unit wear. This means increased significance of new material improvement methods that will allow to improve service properties such as heat resistance and creep resistance in aircraft engines.

Recently, increased recognition is gained by the methods allowing to improve surface of castings by means of surface remelting with the use of concentrated heat stream followed by rapid solidification [3, 4]. Creation of conditions for rapid solidification of surface layer on cobalt alloy castings allows to obtain very fine dendritic grains of cobalt austenite supersaturated with alloy elements as well as superfine precipitation of carbide phases. These properties depend on parameters and morphology of all phases present in the alloy [5].

The objective of the study was to determine the effect of rapid solidification following specimen surface remeltings by means of concentrated heat stream on the time to rupture determined in stress-rupture test.

2. Material and experimental conditions

MAR-M509 cobalt alloy was prepared in Leybold Heraeus vacuum induction furnace. Chemical composition of 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.

Plates cast for the surface remelting test had dimensions $110\times25\times5^{+0.2}$ mm. Moulds for the plate castings were prepared with the use of the investment casting technique.

Plate castings were surface-remelted with the use of concentrated heat stream (GTAW method) at a test set-up allowing for intensification of heat carry-off by washing the plate lower surface with water [6].

The process of remelting was applied to both specimen sides with successive stitches overlapping. For this purpose, FALTIG 315 AC/DC machine was used. Electric current intensity I = 200 A was used and the electric arc scanning velocity v_s = 250 mm/min in protective atmosphere of helium. Such choice of the surface remelting process allowed to obtain remeltings 2.7 mm deep and 13.4 mm wide.

A schematic diagram of specimen surface remelting method allowing to obtain the microstructure characteristic for rapid solidification conditions in the whole specimen volume, is presented in Figure 1.

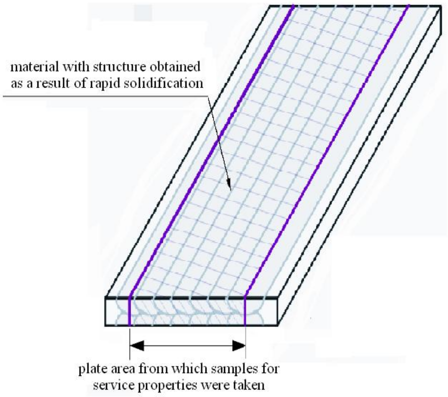


Fig. 1. Schematic diagram of remeltings made on both specimen sides in the form of overlapping stitches, with test specimen cutting-off area marked.

An example microstructure of MAR-M509 alloy in as-cast condition and after surface improvement is presented in Figure 2. The specimens were electrolytically remelted (50 ml HNO_3, 50 ml H_2O, U = 9 V, t = 3 s).

Microstructure of MAR-M-509 alloy includes tantalum-rich carbides (light precipitations) and chromium-reach carbides (dark precipitations) located at cobalt austenite grain boundaries. The effect of surface remelting and rapid solidification following the process is significant refinement of carbide phases and cobalt austenite grains.

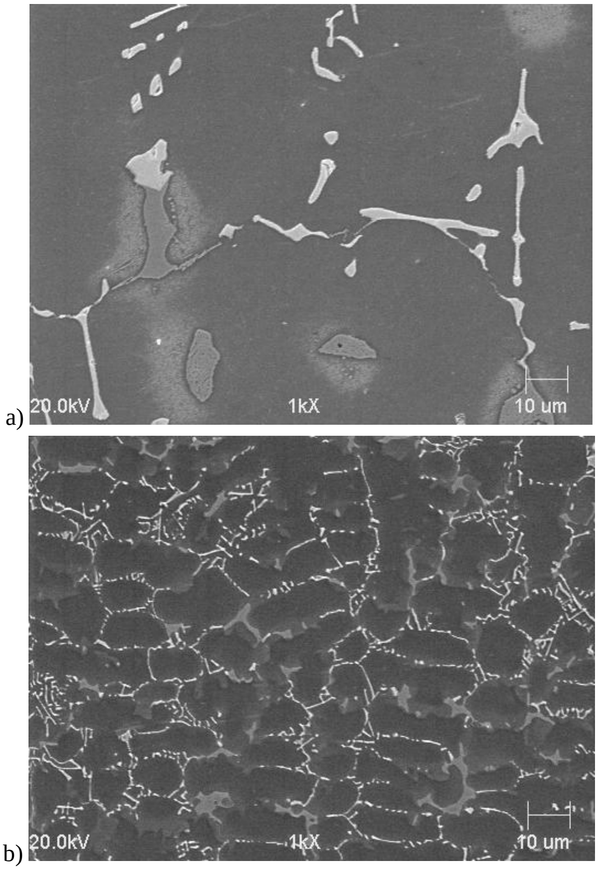


Fig. 2. Microstructure of MAR-M-509 alloy: (a) in as-cast condition and (b) after surface remelting (rapid solidification)

From each of the surface-improved plate castings, three specimens for stress-rupture test were cut-off (Fig. 3).

Stress-rupture tests aimed at determination of the time to rupture were carried out with the use of WPM ZST3/3 creep testing machine equipped with a three-zone heating furnace LAB-TEMP manufactured by Thermcraft Incorporated, USA, offering the maximum heating temperature 1200 °C. Each heating chamber has independent power supply and temperature control system with accuracy of ±3°C.

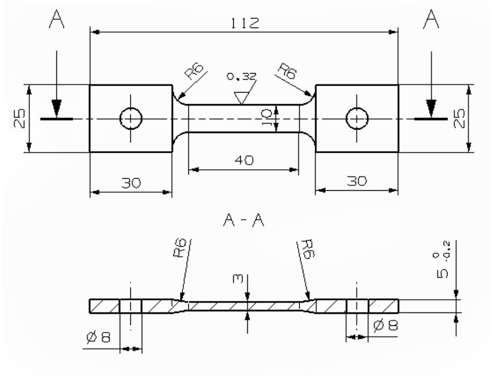


Fig. 3. Shape and dimensions of specimens for stress-rupture test.

The specimens were fastened by means of mandrels in holders fixing their position in the creep testing machine furnace heating chamber (Fig. 4).

Fig. 4. A view of a specimen for stress-rupture test mounted in retaining holders fixing its position in the creep testing machine furnace heating chamber

Stress-rupture tests were carried out at temperature 1095°C under the load of 62 MPa. For each variant of MAR-M-509 alloy, tests were carried out with three specimens, and in the case of distinct deviation, the specimen was being rejected and the tests were repeated on an additional specimen.

The time to rupture values for MAR-M-509 alloy specimens determined in stress-rupture test are presented in Table 1.

Table 1.
The time to rupture for MAR-M-509 alloy specimens determined in stress-rupture test

No	MAR-M-509 alloy	Time to rupture (h)
1	in as-cast condition	29
2	after surface remelting (rapid solidification)	44

So significant increase of the time to rupture observed in MAR-M509 alloy specimens after surface remelting compared to the as-cast condition is the effect of significant refinement of the microstructure.

After completion of stress-rupture test, specimens of MAR-M-509 alloy in as-cast condition and after surface remelting were subject to analysis determining distribution, number, and length of cracks. The analysis was carried out on metallographic section in a 15-mm wide strip adjacent to the fracture profile line (Fig. 5).

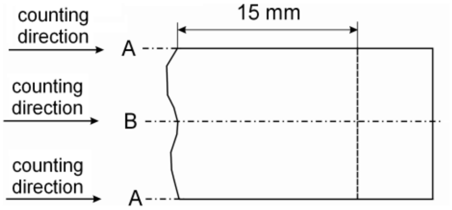


Fig. 5. Definition of areas on metallographic sections and directions along which the cracks were counted

The number of cracks adjacent to specimen edges (line A) was determined as well as the number of cracks located in the specimen width centre (line B). For all the counted cracks, their lengths were estimated.

Results of measurements (according to Fig. 5) characterising cracks on surface of MAR-M-509 alloy specimens in as-cast condition and those with microstructure formed as a result of rapid solidification conditions, both carried out after stress-rupture test, are presented in Table 2.

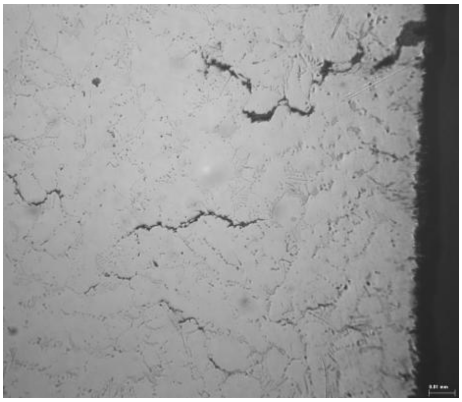
Table 2.
Number (length) of cracks in specimens of MAR-M-509 alloy after stress-rupture test

MAR-M-509 alloy	Number (length in mm) of cracks	
	adjacent to the specimen edge	in the specimen width centre
In as-cast condition	**9** (0.0–0.3) **3** (0.3–0.6) **2** (0.6–0.9) **1** (1.2–1.5)	**5** (0.0–0.3) **3** (0.6–0.9) **1** (0.9–1.2) **1** (1.2–1.5) **4** (above 1.5)
After surface remelting (rapid solidification)	**3** (0.0–0.3) **1** (0.3-0.6)	none

An example microstructure observed on surface of MAR-M-509 alloy specimens in as-cast condition and after surface remelting observed after stress-rupture test is presented in Figure 6.

The obtained results show that in the case of specimens of MAR-M-509 alloy in as-cast condition, cracks adjacent to edges and located in central area of specimens were mainly observed, while in specimens made of MAR-M-509 alloy after surface remelting (and the following rapid solidification), cracks adjacent to specimen edges were only observed. The cracks developed in direction almost perpendicular to the direction of tensile force applied to specimens. Population of the cracks decreased with increasing distance from the fracture surface. The cracks development path followed, in most cases, the γ phase dendrite boundaries, from one carbide precipitate microcrack to another carbide precipitation containing a microcrack.

a)



b)

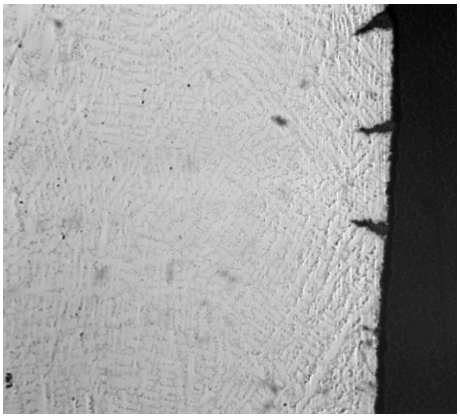


Fig. 6. Microstructure of MAR-M-509 alloy specimen surface (a) in as-cast condition and (b) after surface remelting, observed after stress-rupture test. Magnification ×50.

3. Conclusions

Application of the rapid solidification technique offers the possibility to obtain strong refinement of MAR-M509 alloy

microstructure. The effect is the significant extension of the time to rupture observed in stress-rupture test.

The time to rupture for MAR-M509 alloy specimens improved by the way of rapid solidification is by about 50% longer compared to the time to rupture observed in MAR-M-509 alloy specimens in as-cast condition.

Acknowledgement

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