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AGNIESZKA SZCZOTOK*

METALLOGRAPHIC STUDY OF POROSITY IN IN713C SUPERALLOY IN AS-CAST AND AFTER CREEP TEST

BADANIA METALOGRAFICZNE POROWATOŚCI W NADSTOPIE IN713C W STANIE LANYM I PO PRÓBIE PEŁZANIA

Abstract

The paper summarizes the results of observation and quantitative analysis of porosity in IN713C superalloy in as-cast and after the creep test. The sources of porosity in castings are shortly described and the methodology of pores measurement is circumscribed. The results of pores in as-cast and after the creep test were shown and, finally, the interpretation of the result was presented.

Keywords: metallography, porosity, microstructure, map of pores distribution, image analysis, microstructure

Streszczenie

W artykule przedstawiono wyniki obserwacji i badań ilościowych porowatości występującej w nadstopie IN713C w stanie lanym i po próbie pełzania. Scharakteryzowano pokrótce źródła powstawania porowatości w odlewach. Metodyka pomiaru porów opisano i przedstawiono uzyskane wyniki pomiarów wraz z ich interpretacją.

Słowa kluczowe: metalografia, porowatość, mikrostruktura, mapa rozkładu porów, analiza statystyczna wyników

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* Ph.D. Eng. Agnieszka Szczotok, Institute of Materials Science, Faculty of Materials Science and Metallurgy, Silesian University of Technology.

1. Introduction

Porosity may be the most persistent and common complaint of casting users. Porosity in castings contributes directly to customer concerns about their reliability and quality. Controlling porosity depends on the understanding of its sources and causes [1]. The most well-known methods for the control of porosity are by means of X-Rays [2].

Formation of pores can have many sources. One of the pore sources is an air bubble trapped in a casting during the pouring process, which is unable to escape before solidification. Closely related to air bubbles trapped during filling are gas bubbles that are blown into the liquid from a core or mold. Much of the porosity in castings is not a result of excess gas pressure forming blowholes or gas solubility forming pinholes, but a result of oxides. In fact, most of the surface or subsurface porosity is likely due to oxide formation. Solidification shrinkage occurs as the liquid metal becomes a more dense solid. When feeding is cut off and metal continues to solidify, the pressure in the remaining metal pool decreases while segregation causes the gas content to increase [1].

Gas and shrinkage porosity is a cause of mechanical properties lowering turbine blades and vanes applied to a jet engine. These properties include: creep strength, durability, impact strength resistance, elongation and tensile strength [3, 4].

2. Methodology

Carrot-shape IN713C superalloy castings were produced in an investment casting cluster mould and creep test samples (Fig. 1) were then prepared from the castings.

Creep test cylindrical samples with a diameter and length of 6 and 100 mm, respectively, were prepared. The creep tests were conducted according to the requirements of the recipient.

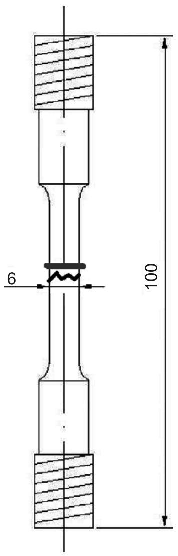

Fig. 1. Creep test sample scheme with a marked sampling way with red line

The tests were performed by means of a Zwick/Roell Kappa 50DS creep-testing machine, which placed each tensile specimen under a constant load of 151.7 MPa maintained at a constant temperature of 982°C up to fracture.

The resultant macro- and microstructures were observed and characterized after the creep tests by means of a light microscope (LM) and *Hitachi S-4200* scanning electron microscope (SEM) equipped with EDS.

The creep specimens were sectioned longitudinally along the gauge length and prepared for the microstructural examination. Firstly, the porosity was examined on the ground, polished, and the unetched metallographic samples by means of LM. Then, the specimens were lightly etched in a solution containing 3g MoO_3, 100 ml HNO_3, 100 ml HCl and 100 ml H_2O and observed by means of the SEM technique.

3. Microscopic observation

The metallographic observations have shown that the investigated Ni-based superalloy in as-cast state, as well as after the creep test, contain gas and shrinkage porosity (Fig. 2). The increased porosity observed in the specimens after the creep tests relative to that of the as-cast material indicates that porosity can result from cracking propagation along the pores.

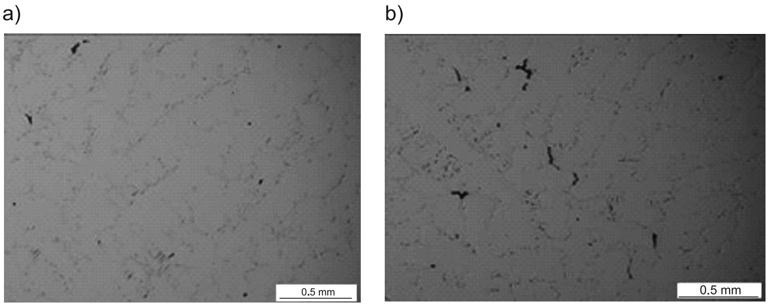

Fig. 2. Microstructure of IN713C Ni-based superalloy with pores visible on the unetched sample: a) as-cast state, b) after the creep test. LM, BF

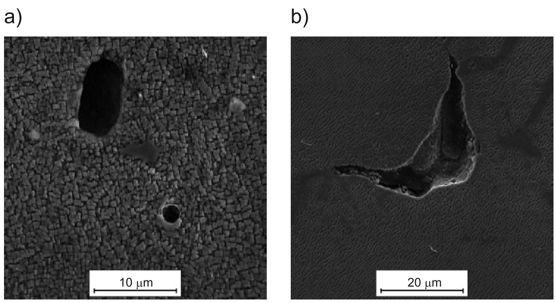

Fig. 3. Microstructure of IN713C with porosity on the etched samples: a) as-cast state, b) after the creep test. SEM, SE

Interdendritic areas are the places of privileged formation of shrinkage porosity. Gas porosity seems to be evenly distributed. It should be noted that propagation of microcracks from the initial casting pores is considered to be the critical life-limiting factor.

On the etched surface of sample using higher magnification (SEM) you can observe the morphology of pores and cracking propagation in consequence of pores presence in the case of the creep test sample (Fig. 3).

4. Measurement of porosity

A series of 15 images were taken by means of LM equipped with a digital camera to evaluate the area fraction of the pores and other parameters describing the pores. The most important part of the image analysis of the pores was performed by means of the Met-Ilo image analysis program to automate pore detection and their measurement. The measurements were carried out on the binary images of the pores (Fig. 4b). An example of pores detection is presented in Fig. 4.

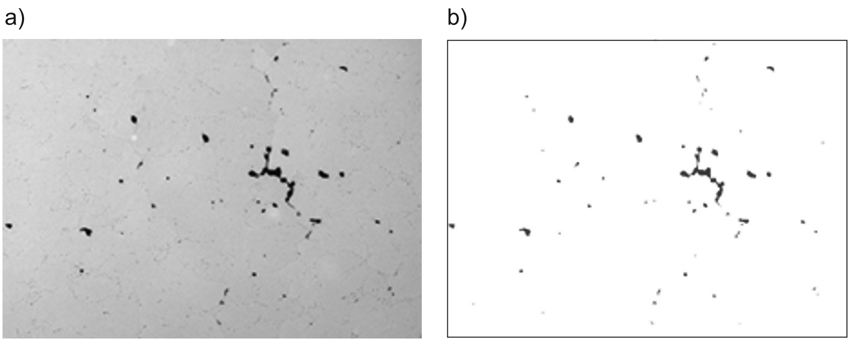

Fig. 4. Detection of pores on unetched sample in the Ni-based superalloy: a) grey initial image, LM, BF; b) and binarization of pores

The evaluation of the mean plane section area of pores and other parameters which describe their morphology was performed. In Table 1 the selected parameters are presented.

Table 1

Results of pores measurement in as-cast state and after creep test

Parameter	**After creep**	**As-cast**
Area fraction of pores A_A [%]	0.62	0.14
Mean plane section area of pores $\bar{A}$ [μm^2]	26.08	32.43
Coefficient of variation of plane section area v (A) [%]	242.6	128.9
Mean value of nondimentional shape factor	0.83	0.87
Coefficient of variation of nondimentional shape factor [%]	34.18	33.36

Fine pores predominate in both cases (Fig. 5). You can see that only small fraction of pores makes up pores with greater plane section area. The mean value of nondimentional shape factor could indicate that pores have a shape close to a circle (for a circle value equals 1), but it should be remembered that it is a mean value – in both cases there are gas as well as shrinkage pores.

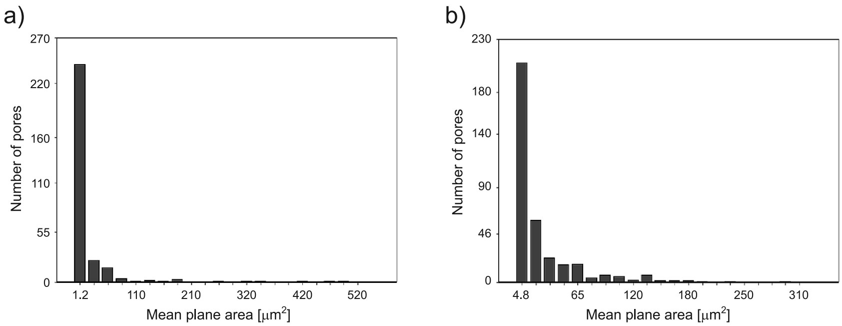

Fig. 5. Histograms of plane section area with the number of pores: a) after the creep test, b) as-cast

The comparison of two graphs in Fig. 5a, b and 5c, d indicates that after the creep test pores with greater plane section area are present. The maximum value after the creep test amounts to 525 μm^2, and for the as-cast maximum value is only 305 μm^2.

5. Summary

On the basis of the obtained results, the following observations were made:

- gas and shrinkage porosity are present in as-cast and after the creep test in IN713C superalloy;
- the area fraction of pores is higher in the case of material after the creep test (0.62 %) in comparison with as-cast state (0.14%);
- the mean plane section area of pores is smaller after the creep test than in the as-cast, but after the creep test greater pores have been noted (with higher plane section area – Fig. 5), and, moreover, the coefficient of variation of plane section area is higher after the creep test than the as-cast;
- the mean value of the nondimentional shape factor of the pores in both cases range from 0.83 to 0.87, simultaneously both gas and shrinkage pores are present in the as-cast and after the creep test.

Propagation of microcracks from the initial casting pores is observed in the material after the creep test and it can explain higher evaluation of area fraction of pores after the creep test than in the as-cast state. It is very hard to distinguish the difference between pores on 2D microstructure image and propagation of cracking from the initial pores, which is why the evaluation of pores after the creep test can be overestimated.

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