THE MICROSTRUCTUAL ANALYSIS OF TURBINE BLADE FROM ALLOY INCONEL 713 LC

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MIKROSTRUKTURNÍ ANALÝZA TURBÍNOVÝCH LOPATEK ZE SLITINY INCONEL 713 LC

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Abstrakt

Inconel 713 LC patří mezi lité polykrystalické niklové superslitiny, které jsou užívány k výrobě oběžných kol malých spalovacích turbín pro pomocné energetické jednotky v leteckém průmyslu. V provozních podmínkách spalovacích turbín proudových motorů jsou lopatky oběžných kol namáhány časově, teplotně a napěťově proměnnými cykly zatěžování. Během provozu jsou lopatky vystaveny řadě degradačních vlivů, zejména vysokoteplotní korozi, únavovým procesům a creepu.

Cílem předložené práce je studium změn mikrostruktury lité slitiny na bázi niklu Inconel 7I3 LC po provozních zkouškách. Strukturní změny byly studovány pomocí světelné a elektronové transmisní mikroskopie.

Abstract

Inconel 713 LC belongs to the cast poly-crystalline nickel super-alloys which are used for the production of circulating wheels of small combustion turbines for supplementary energetic units in aviation industry. In operational conditions of combustion turbines as part of turbo engines, blades of the circulating wheels are stressed in time, temperature and stress variable cycles during the loading procedure. The blades are exposed to a series of degradation factors such as high-temperature corrosion, fatigue processes and creep during the operation.

The current knowledge obtained through structural analyses of operational impellers does not rely, save for some exceptions, on a sufficiently detailed investigation of structural, chemical and dendriteform non-homogeneity of the above-mentioned material as found after exposure to the operational conditions. Also a comparison study of exposed versus fresh materials is still to be performed.

The aim of presented work is to study the microstructure of cast nickel-base alloy Inconel 713 LC after testing at the exploitation temperature. The structural changes were studied using light microscopy and transmission electron microscopy (TEM).

Key words: cast nickel alloys, exploitation temperature, colour metallography, light-electron microscopy, microstructure

1. Introduction

When exposed to the operation conditions as encountered in gas turbines of jet engines, the turbine blades have to withstand loading cycles featuring different temperature, stress and time patterns. Such operation exposes the blades to a number of degrading factors, particularly to the high-temperature corrosion, fatigue processes and creep [1, 2]. Short-term overloading associated with the peak values of temperatures and stresses, as experienced e.g. during the takeoffs, landings, or possibly due to some other irregularities met in the jet engine operation, may induce irreversible changes in the blade microstructure and hence in its properties. Faster diffusion processes lead to local dissolution causing in turn the precipitation of hardening phases while eliminating the dendritic segregation of elements typical of the initial microstructure and properties of cast blades [3, 4, 5, 6, 7]. This paper aims to generate overall information on chemical, structure-related mechanical, and application-related properties of INCONEL 713 LC, cast refractory nickel-based superalloy used to manufacture blades and cast impellers of gas turbines for aircraft engines.

The paper concentrates on the investigation and assessment of macro and microstructures performed in reliance on optical and electron microscopy. The observations presented herein have been derived from two turbine blades, a new one and a blade with the history of 1992 service hours.

2. Experimental material & technique

The experiments were conducted on turbine blades dismounted from an aircraft engine manufactured by the Walter a.s. company. Their chemical compositions were determined using the *LECO SA2000 spectrometer* (see Table 1) on the PBS Velká Bíteš a.s. premises.

Table 1 Chemical composition of INCONEL 713LC blades (all values in wt.%)

Cr	Mo	C	Co	Fe	Zr	Nb	Al	B	Ti	Ni
11.90	4.57	0.05	0.08	0.19	0.10	1.96	5.75	0.013	0.7	balance

To obtain the samples needed, the blades were cut (with the DISCOTOM no-deformation saw from STRUERS Comp.) perpendicular to the leading edge, (1) at a place distanced 1/3 of the blade length from the tip of the blade platform and (2) at the blade root. When embedded into an elastomeric material using the LABOPRESS-2 from STRUERS Comp., the metallographic samples were being prepared by the common methods, i.e. wet grinding and mechanical polishing (both diamond and oxidic polishing) using the DAP-7 device fitted with the PEDEMIN-2 driving coupler from STRUERS.

To make the samples suitable for metallographic analysis by means of an optical microscope, they were etched with HCl + H_2O_2 + ethyl alcohol. The OLYMPUS GX 71 optical microscope was employed to study the cast structure, the eutectics, the primary carbides, and the degree of dendritic segregation in reliance on the Nomar's method of differential interferential contrast.

The JEOL JEM 100C Transmission Electron Microscope (TEM), utilizing the acceleration voltage of 100 kV, was used to observe the collodion-carbon replicas. Moreover, the samples taken from the blades were analyzed on a PHILIPS XL 30 Scanning Electron Microscope (SEM), utilizing the acceleration voltage of 20 kV. The devices worked in the secondary and backscattered electron modes of operation. Local microanalysis of particles was performed on the EDAX spectrometer.

3. Results

The turbine blades made of Inconel 713 LC nickel-based superalloy exhibit a pronounced dendritic segregation (see Figures 1a, b). The dendrites observed in the blade root were substantially larger than those encountered in the shaped part of the blade (see Table 1); this observation can be ascribed to the higher rate of cooling experienced in the thin wall of the shaped blade part. The sizes of dendrites were determined on sections cut parallel to the sample axis; the length of the primary dendrite axis was measured.

Table 2 Sizes of dendrites

Sample	Dendrite sizes [mm]		
	min.	max.	mean
Root	1.3	4.3	2.3
Blade (flat part)	0.3	2.9	0.8

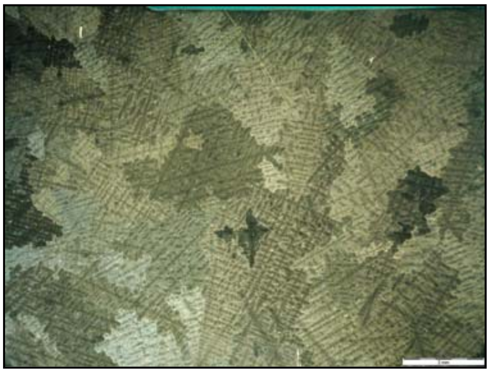

Fig.1a Macrostructure of the lock turbine blades with dendritic segregation

Fig.1b Macrostructure of the surface turbine blades with dendritic segregation

The comparison of a new blade with a blade of some operation history using the Olympus GX-71 optical microscope showed no marked differences in structures. Obviously, the times of thermal and stress expositions were too short to bring about any substantial changes. At large magnification (1000x) it became apparent that small-size γ‘ precipitates undergo partial agglomeration and form larger structures (see Figure 2a). The change was observed in the already operated blade at the grain boundaries, where a small population of secondary carbides precipitated (see Figure 2b).

The samples cut from the blades were also treated to chemical microanalysis using EDS. The main structure constituents were thus analyzed, namely matrices, γ´ precipitates, γ-γ´ eutectics and carbides. The matrix was found to contain a sizeable quantity of dissolved Cr and the precipitated γ´ phase particles were observed to contain Al and Ti. The primary carbides (see Figure 3a) comprised primarily Nb, Zr and Mo; therefore it can be supposed that the carbides observed are complex carbides of the MC type. As obvious from Figure 3a, two carbide spots were analyzed. The light-color spot contained all the three elements mentioned above, while the dark-color spot contained just Nb and Mo. In addition, the microanalysis confirmed that the eutectic is composed of γ´ particles and γ matrix (see Figure 3B). As follows from Figure 3b and from the microanalysis performed, the dark eutectic background (area 1) consists of the intermetallic phase of Ni_3Al with the embedded γ matrix (the light-color stripes).

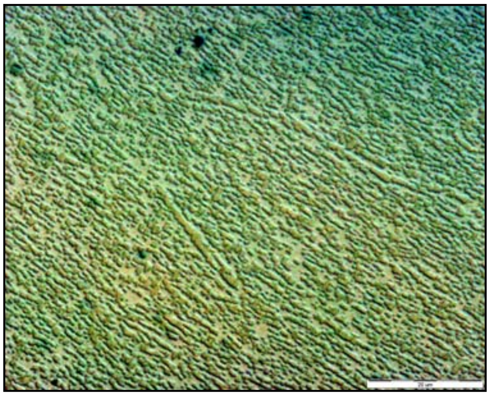

Fig.2a Microstructure of the lock turbine blade after aircraft service (1992 hours)

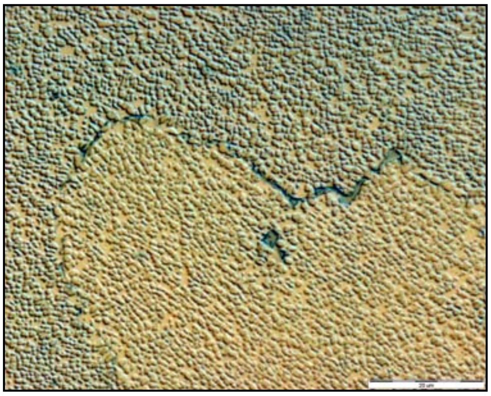

Fig.2b Microstructure of the surface turbine blade after aircraft service (1992 hours)

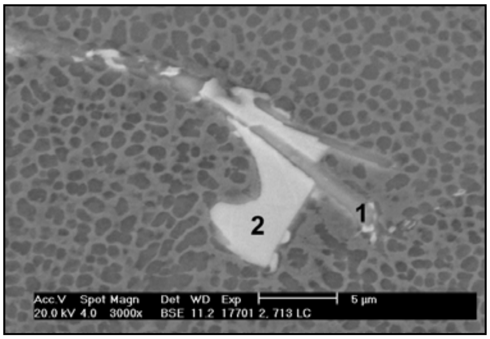

Fig.3a Primary carbides on the base Nb, Zr, Mo (REM)

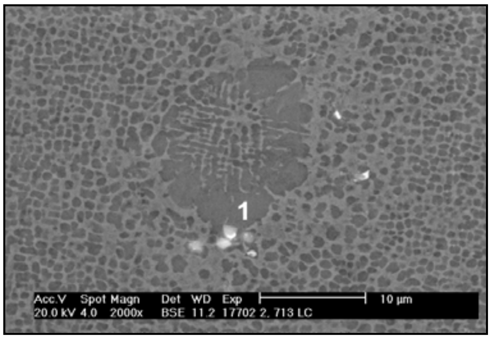

Fig.3b Detail of the eutectic with γ´ phase particles and γ matrix (REM)

4. Conclusions

The comparison of the new blade and the used blade yielded these conclusions:

1. The structure of sample exposed to 1992 hours of airborne operation exhibited some changes in the morphology of the hardening γ´ phase. The modified morphology showed what is known as the raft pattern, a structure substantially impacting on the creep properties.
2. Moreover, carbide precipitation on grain boundaries was observed.

The microanalysis relying on EDS confirmed adequacy of these assumptions:

3. The matrix contains a sizeable quantity of dissolved Cr and the precipitated γ′ particles (Ni_3AlTi) contain, apart from Al, also Ti.
4. The primary carbides are created mostly by Nb, Zr and Mo.
5. The eutectic is formed by γ′ phase particles and γ matrix.

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