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EVALUATION OF CARBIDES IN TURBINE BLADE MADE OF IN713C SUPERALLOY AFTER HOT ISOSTATIC PRESSING

The IN713C is nickel-based superalloy, used to produce low pressure turbine blades in a process of investment casting. However, porosity which is formed during the casting, decreases mechanical properties of IN713C. Therefore, to eliminate porosity, a process of hot isostatic pressing was applied. Nonetheless, HIP also least to some changes in the microstructure of tested material. The main aim of this paper is to characterize the morphology of carbides before and after hot isostatic pressing. Microstructural characterization was carried out with the use of a scanning electron microscope equipped with an energy dispersive X-ray spectrometer and an electron backscatter diffraction detector. The size and shape of carbides were evaluated by quantitative metallography methods methods. The results show that the amount, size and heterogeneity of arrangement of the carbides increased after application of HIP treatment.

Keywords: IN713C superalloy; Hot isostatic pressing; Turbine blades; Qualitative and quantitative analysis of carbides

1. Introduction

Due to technological and economic conditions, a lot of blades are still produced from the polycrystalline nickel-based superalloys made in the investment casting process. The most commonly used polycrystalline nickel superalloy is IN713C. IN713C alloys is strengthened by γ' precipitates and carbides. Thanks to its low price, inherent castability, microstructural stability and high strength with ductility at high temperatures, IN-713C is still used to production of blades for low pressure turbine [1]. Turbine blades operate at difficult conditions in aircraft engines. In addition, they are exposed to high temperatures, high pressure and corrosive environments. Good properties of the superalloy at high temperature depend on its microstructure (especially the morphology of γ' phase and carbides) and casting defect [2-4]. Because of the fact that IN713C alloy was produced in the process of investment casting, it is difficult to avoid the porosity during solidification. These defects lead to reduction of mechanical properties of the superalloy, especially creep resistance and fatigue strengths at high temperatures [1].

The hot isostatic pressing (HIP) is the effective industrial method used to remove casting porosity, improve fatigue, creep and tensile properties. The HIP process is a thermal treatment, which puts alloys under combination of various factors like high temperature and high pressure [5-9]. In case of superalloys, the HIP treatment is usually carried out before thermal treatment, at the temperature slightly below the γ'-solvus temperature. The typical conditions of HIP treatment for nickel superalloys are 150-175 MPa for 2-4 hours [5,6,8]. Additionally, HIP treatments caused microstructural changes, especially in amount, size and heterogeneity of arrangement of the carbides.

The purpose of the work was to evaluate the microstructure (especially amount and morphology of carbides) of turbine blades made of the IN713C nickel-based superalloy, which was subjected to HIP treatment.

2. Material and methodology

Two polycrystalline turbine blades with equiaxed grains were material subjected to investigation. The blades had been made of IN713C nickel superalloy, which chemical composition is presented in Table 1. One of the blade was examined in the as-cast state, while the second one was subjected to hot isostatic pressing (HIP) treatment.

TABLE 1

The chemical composition of IN713C alloy (in wt. %)

Cr	Mo	Nb	Al	**Ti**	**C**	**B**	**Zr**	**Ni**
12.5	4.2	2	6	0.8	0.12	0.012	0.1	balance

The research was carried out in the middle of airfoils and roots (Fig. 1). A qualitative evaluation of the microstructure before and after HIP treatment was performed with the use of the scanning electron microscope (SEM) Hitachi S-3400N equipped with the energy dispersive X-ray spectrometer (EDS) (Thermo Noran) and the electron backscatter diffraction detector (EBSD)

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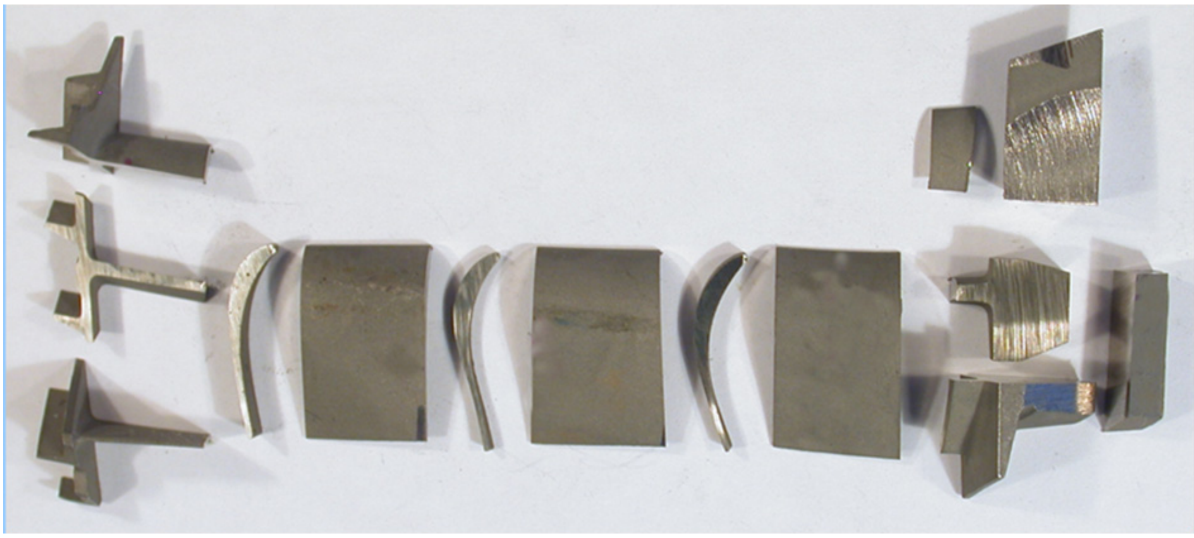

Fig. 1. The turbine blade made of IN713C alloy with the marked places of execution of metallographic specimens (red squared)

(INCA HKL Nordlys II with Channel 5 software). A quantitative analysis of carbides morphology was carried out with Met-Ilo software. The image analysis was carried out on backscattered electron image in accordance with procedures described in [12]. The microstructure of superalloy for the research was revealed by electrochemical etching in a solution consisting of 10% oxalic acid at 6 V.

3. Results

The microstructure of IN713C superalloy in mid-airfoil and root of the as-cast blade is shown in (Figs. 2, 3). The microstructure of the as-cast blade in mid-airfoil and root consists of γ' phases in γ matrix, MC carbides and small amount of γ/γ' eutectics. The morphology of γ' particles is significantly different

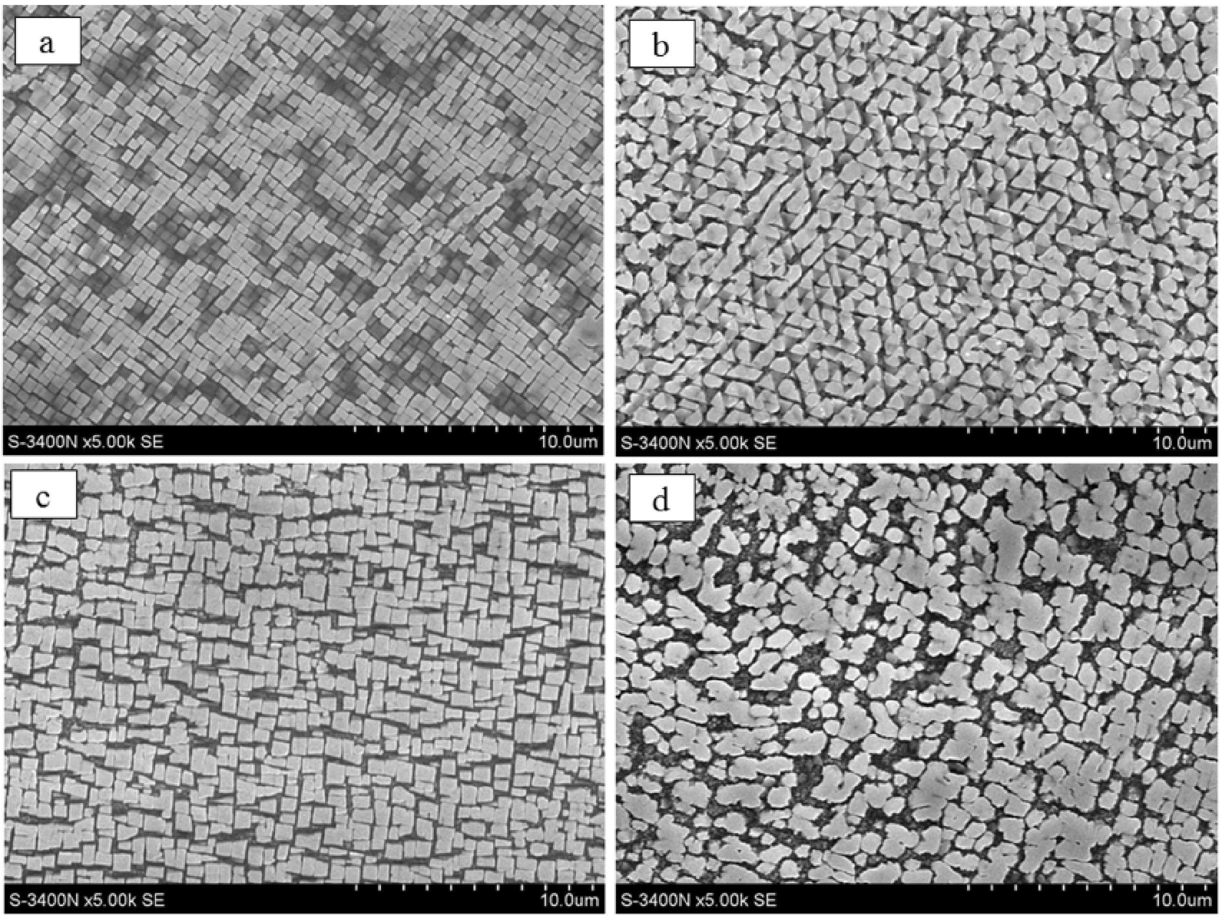

Fig. 2. SEM images of γ' particles in the as-cast blade in mid-airfoil (a, b) and root (c, d): (a, c) dendrite; (b, d) interdendritic area

in the dendrite cores and the interdendritic areas (Fig. 2). This applies to both mid-airfoil and root of blade. In the dendrite cores, the γ' phase is characterized by regular cubic shape. However, particles of γ' phase have an irregular shape in the interdendritic areas. In both cases, the size of the γ' precipitates is bigger in the interdendritic areas than in the dendrite cores. The primary carbides MC appeared mainly along the grain boundaries and in the interdendritic areas, in which the characteristic systems, so-called "Chinese script", were formed (Fig. 3). The MC carbides have the typical blocky and irregular shape. Their chemical composition contained mainly Nb and Ti (Fig. 4).

After HIP treatment, the microstructure of IN713C has been changed in the mid-airfoil as well as in the root (Figs. 5 and 6). The characteristic feature is the change of the γ' particles morphology. Above all, shape of γ' particles was changed from cubic to irregular in the interdendritic areas. The presence of

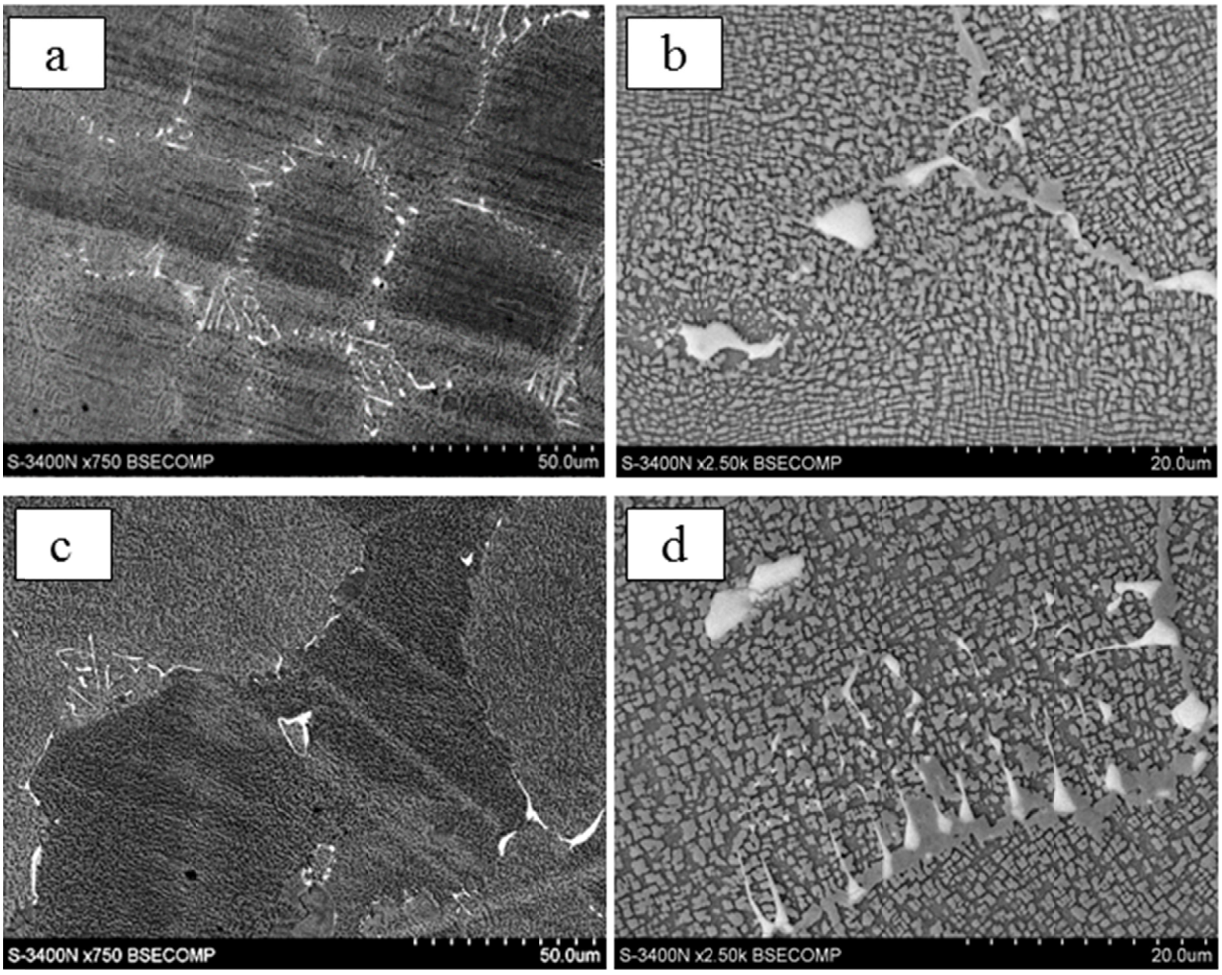

Fig. 3. SEM images of MC carbides in the as-cast blade in mid-airfoil (a, b) and root (c, d)

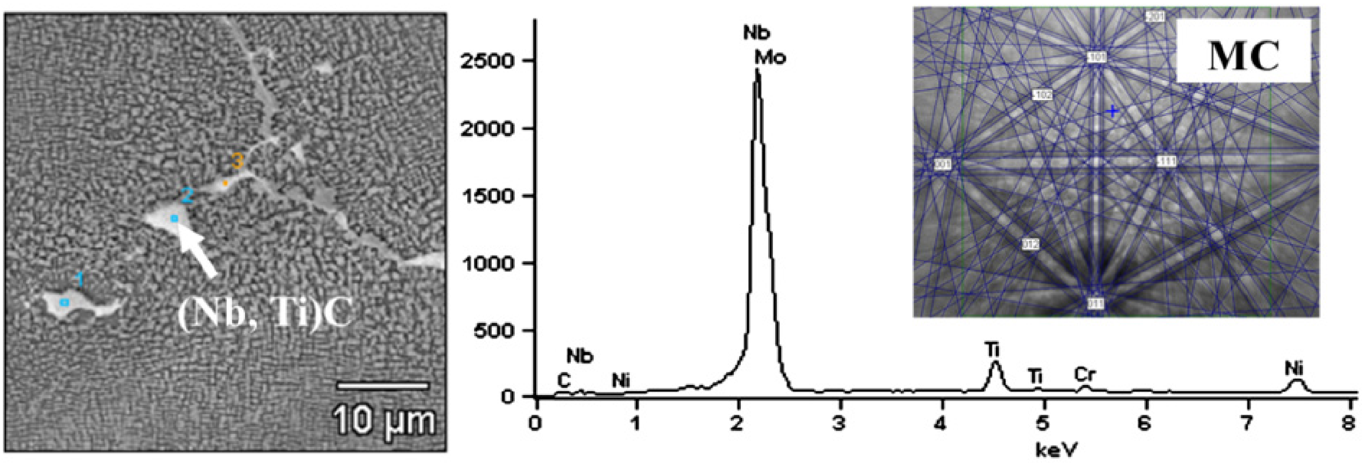

Fig. 4. The chemical and phase composition of MC carbide in as-cast IN713C superalloy

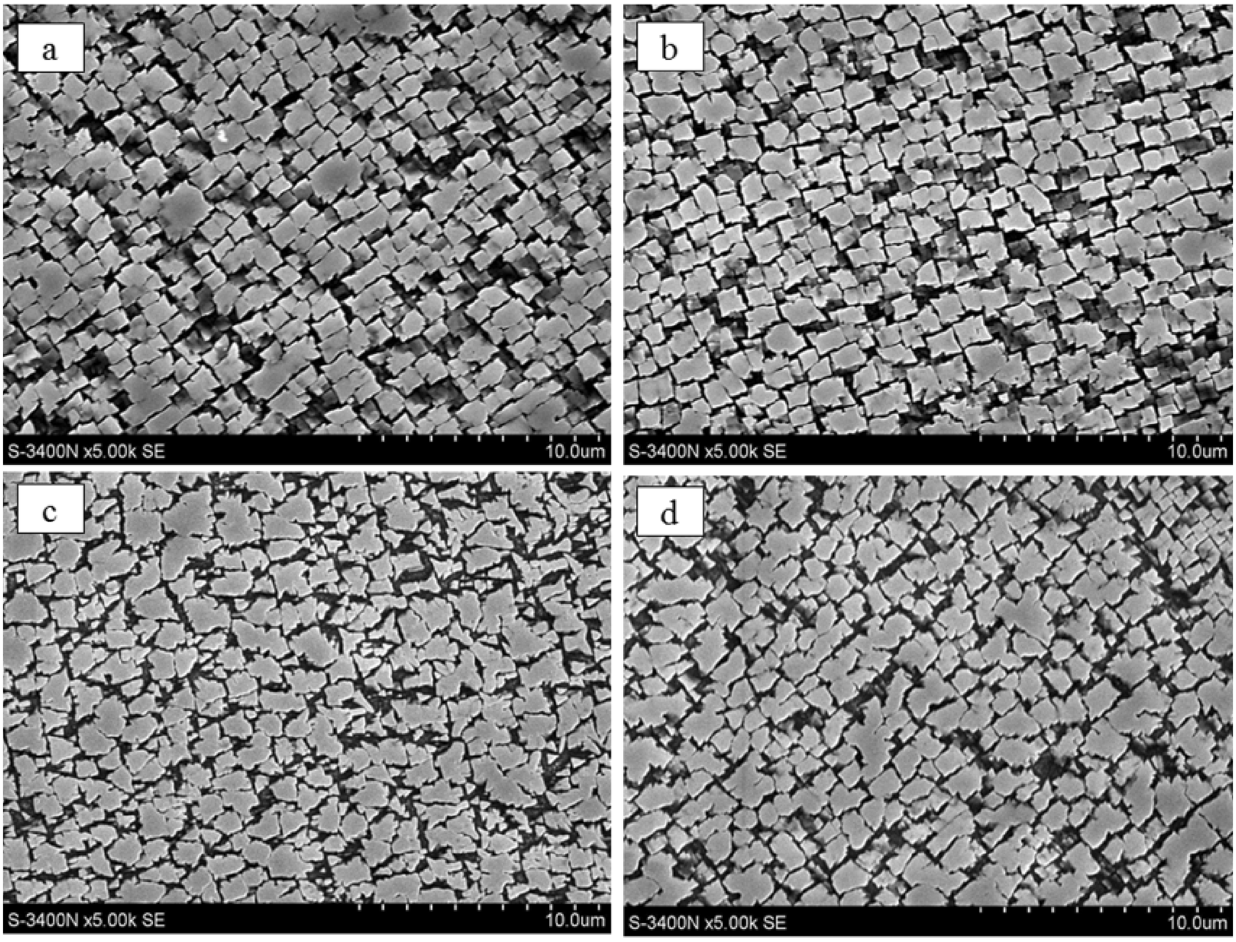

Fig. 5. SEM images of γ' particles in the blade after HIP treatment in mid-airfoil (a, b) and root (c, d): (a, c) dendrite; (b, d) interdendritic area

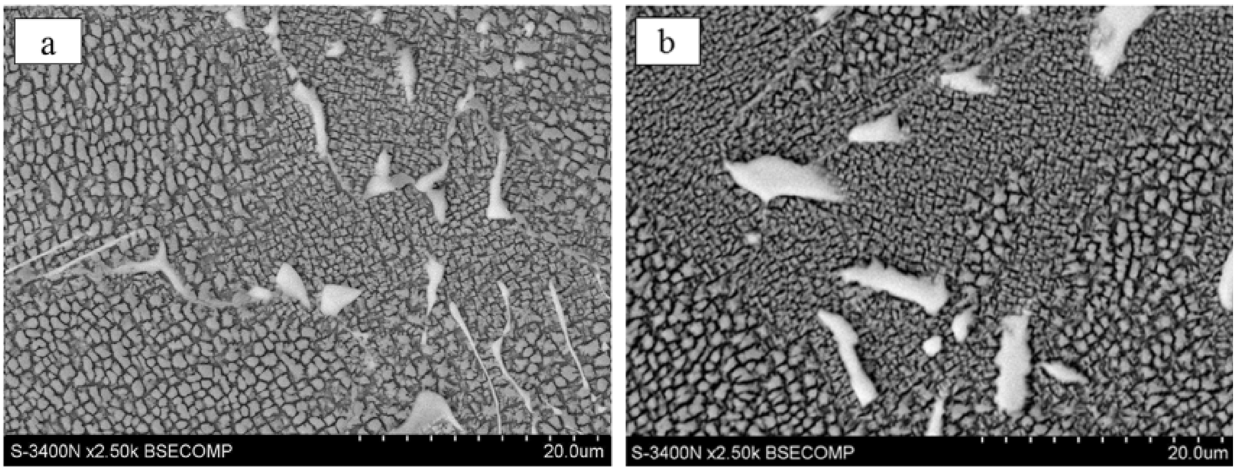

Fig. 6. SEM images of MC carbides in the blade after HIP treatment in mid-airfoil (a) and root (b)

heterogeneity in size of the precipitates of γ' phase, surrounded by the primary MC carbides, was also found. In the areas of where MC carbides appeared particles of γ' phase became significantly smaller than in the areas without presence of MC carbides. There was also observed the change of shape – from irregular to cubic. In addition, the particles of MC carbides also increased. We could observe the occurrence of larger particles of MC carbides in comparison to the as-cast state of blade. The large MC carbides occurred mainly in the interdendritic areas, in the surroundings of fine γ' phases (Fig. 7). The changes of the carbides shape was not observed. The MC carbides still remained in the form of irregular and blocky particles. During the process of investigation, the MC-type carbides has only been identified within the alloy in HIP state. Probably, the changes in morphology of γ' phases and carbides are the result of diffusion that occurs between these phases.

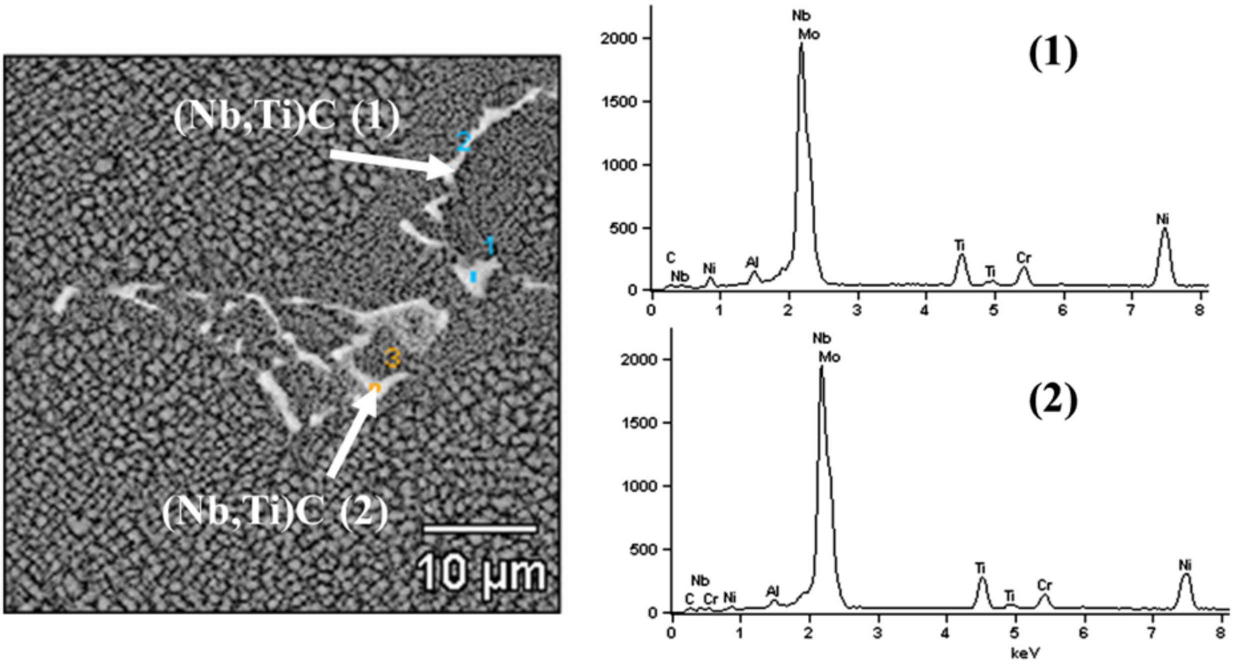

Fig. 7. The chemical and phase composition of MC carbide in IN713C superalloy HIP treatment

The measurements of MC carbides before and after HIP treatment were carried out. The morphological parameters of the carbides in mid-airfoil and root of the blade are shown in Tables 2 and 3.

TABLE 2

Quantitative evaluation of carbides in mid-airfoils before and after HIP treatment

Parameters of quantitative metallography	**as – cast state**	**HIP state**
Number of carbides		
Area fraction of carbides A_A; %	0.54	0.66
Number of carbides per µm N_A; mm^{-2}	10256	10256
The size of carbide		
Mean area of plane section A; µm^2	0.53	0.73
The maximum value of mean area $A_{(max)}$; µm^2	20	32
Feret's diameter of plan section D; µm^{-2}	0.80	0.95
The shape of carbides		
Non-dimensional shape factor ξ	0.89	0.87
Non-dimensional elongation factor δ	1.98	2.02
Heterogeneity of the placement of carbides		
The area fraction variation coefficient $v(A_A)$; %	44	87
Heterogeneity of the size of carbides		
The shape fraction variation coefficient $v(A)$; %	247	245

The quantitative evaluation of carbides, carried out with the use of image analysis methods, revealed an increase of the amount of carbides after application of HIP treatment, which was measured by the area fraction. The amount of carbides in the mid-airfoil is A_A = 0.66%, while in the root is A_A = 0.65% (Fig. 8). Applied HIP treatment caused precipitation of new carbide particles in the investigated superalloy. The size of carbides also increased, which was measured by the mean area of plane section, in the mid-airfoil is 0.73 µm^2 and in the root is 0.95 µm^2. The examined microstructure of IN713C after HIP, revealed the occurrence of large carbides with a maximum value of mean area is 32 µm^2 for the mid-airfoil and 44 µm^2 for the root. By contrast, the shape of carbides did not change. The non-dimensional shape factor of the carbides in the mid-airfoil is 0.87 and for the root is 0.89. The HIP application causes a slight increase in heterogeneity of carbides arrangement, measured by the area fraction variation coefficient, for the mid-airfoil is 87% and for root is 53%.

TABLE 3

Quantitative evaluation of carbides in roots before and after HIP treatment

Parameters of quantitative metallography	**as – cast state**	**HIP state**
Number of carbides		
Area fraction of carbides A_A; %	0.45	0.65
Number of carbides per um N_A; mm^{-2}	5938	6785
The size of carbide		
Mean area of plane section A; µm^2	0.76	0.95
The maximum value of mean area $A_{(max)}$; µm^2	29	35
Feret's diameter of plan section D; µm^{-2}	0.98	1.06
The shape of carbides		
Non-dimensional shape factor ξ	0.89	0.89
Non-dimensional elongation factor δ	2.02	1.93
Heterogeneity of the placement of carbides		
The area fraction variation coefficient $v(A_A)$; %	51	53
Heterogeneity of the size of carbides		
The shape fraction variation coefficient $v(A)$; %	285	248

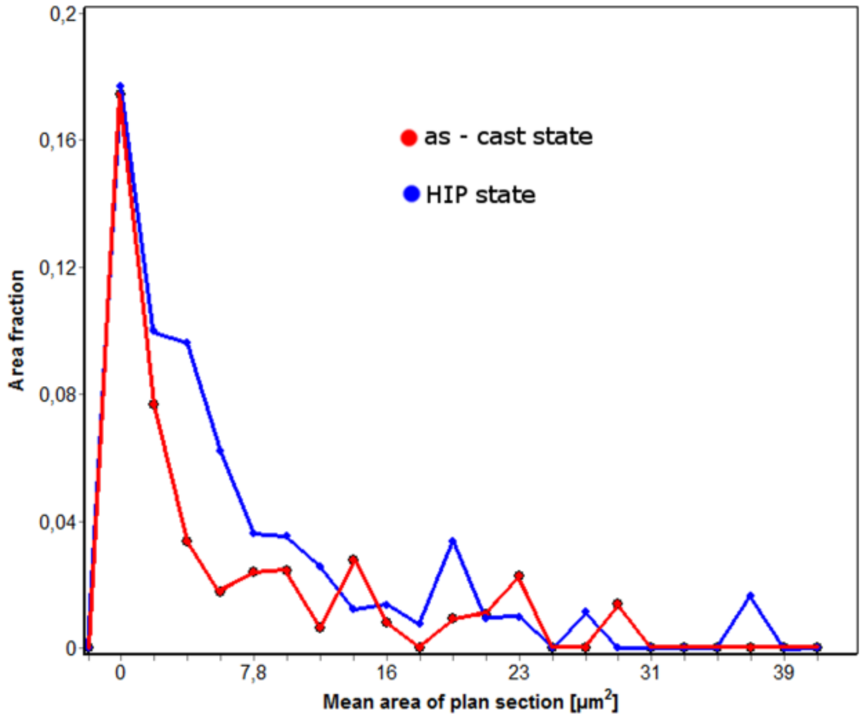

Fig. 8. Area fraction as function of plane section area of carbides in root before and after HIP

4. Conclusions

The application of the hot isostatic pressing has an impact on the change in size and shape of the *γ'* phase in the mid-airfoil and the root. The most significant difference is the change of the shape of *γ'* phase in dendritic cores. The *γ'* phase lost the shape of regular cubes after HIP treatment and is now characterized by irregular edges, which resemble the shape of *γ'* precipitates in the interdendritic areas of the mid-airfoil, as well as in the root. In addition, fine particles of *γ'* phase appeared in surrounding carbides. In the as-cast and HIP state, MC carbides occurred along the grain boundaries and in the interdendritic areas, chemical composition of which contained mainly Nb and Ti. In both states only MC carbides were observed. The MC carbides have irregular and blocky shape. After HIP treatment, the shape of carbides did not change. The amount and size of carbides increased after application of HIP treatment. During HIP, a precipitation of new MC carbides was observed, as well as a growth of already existing particle, resulting from diffusion between carbides and the *γ'* phase.

Acknowledgements

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