EFFECT OF COOLING RATE ON SOLIDIFICATION BEHAVIOUR OF IN 738LC NICKEL BASED SUPERALLOY

Jana Dobrovska[1], **Frantisek Kavicka**[2], **Simona Zla**[1]

[1]VSB - Technical University of Ostrava, 17.listopadu 15, 708 33 Ostrava , Czech Republic
[2]Brno University of Technology, Technicka 2, 616 69 Brno, Czech Republic

Introduction

Nickel based superalloys are widely used in turbine blades and other engine parts [1]. IN 738LC is a modified version of superalloy IN 738 with enhanced carbide stability, castability and ductility, achived by lowering the carbon content. IN 738LC alloy is well known alloy, however, not many studies have been reported on microsegregation of elements during solidification and on effect of cooling rate on microsegregation.
The paper deals with the impact of cooling rate on chemical and structural micro-heterogeneity of nickel superalloy IN 738LC by proprietary experimental research followed by processing of experimental data.

Experiment

Chemical composition of as-received superalloy IN 738LC was (in wt.%): 0.010B, 0.114C, 3.46Al, 3.41Ti, 16.17Cr, 0.23Fe, 8.49Co, 0.05Zr, 0.87Nb, 1.76Mo, 1.798Ta, 2.73W, balance nickel. Altogether 4 samples with height of approx. 3 mm and diameter of approx. 3 mm were mechanically cut from the casting.
These samples were submitted to controlled heating (up to the temperature of approx. 1350 °C) and immediately after melting they were cooled by controlled rate by DTA method. Marking of samples and used cooling rates (CR) were the following: **A** (1 °C min^{-1}), **B** (5 °C min^{-1}), **C** (10 °C min^{-1}), **D** (20 °C min^{-1}).
Then the microstructure was studied with use of light microscope. Microanalysis of minority phases was performed in electron micro-probe and photo documentation of microstructure of individual samples was taken with use of scanning electron microscope.
Subsequently concentration distribution of selected elements (Al, Ti, Cr, Co, Ni, Nb, Mo, Ta and W) in selected regions of structure of individual samples was determined by method of energy dispersion X-ray spectral micro-analysis and by electron scanning microscope. For experimental details see [2].

Results and Their Discussion

DTA Analysis. Fig. 1 presents DTA curves obtained for the individual samples during cooling with different cooling rates. The phase transformation temperatures (see Table 1) were determined from these curves: 1 – liquidus, 2 – the MC carbide formation temperature, 3 – the γ/γ' eutectic formation temperature, 4 – the final solidification temperature (solidus), 5 – the γ' precipitation temperature from the γ matrix.

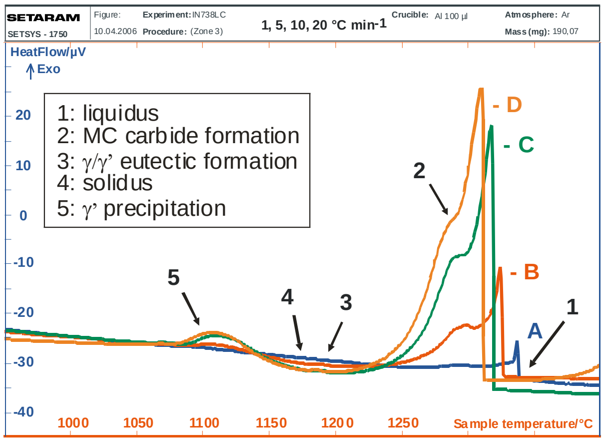

Fig. 1 The DTA curves of samples A, B, C and D.

Table 1 Temperatures of phase transformations (PT)

CR (°C/min)	**Temperature (°C)** (see Fig.1)				
	PT1	**PT2**	**PT3**	**PT4**	**PT5**
1	1342	1332	1291 ?	1241 ?	1095
5	1331	1300	1191	1183	1103
10	1323	1297	1192	1183	1109
20	1315	1294	1189	1179	1111

The effect of the undercooling on the cooling curves is significant, mainly in case of liquidus temperatures and the beginning of MC carbide formation. It was very difficult to determine the values of transformation temperatures for cooling rate 1 °C min^{-1}. For this reason some uncertain values are marked by question mark.
The values of transition temperatures for cooling are usually lower than these obtained for heating as the undercooling reduces any smearing effect [3]. This may be due to the many precipitates and different phases that are evolving during solidification. There is a relation between the cooling rate and the amount of undercooling achieved: the slower the cooling rate, the less undercooling there will be.

Structural Heterogeneity. Discontinuous meshes of non-metallic particles were observed in metallic matrix of samples in polished state. It was established that these are complex carbides of Ta, Nb and Ti of type MC.

It was verified after etching of samples that carbidic meshes are situated in segregated interdendritic regions. Their formation is connected with exceeding of the limit of solubility of individual carbide-forming elements in segregated regions during cooling. Dimensions and distribution of MC carbides corresponded to applied cooling rates – as increasing solidification rate the carbide morphology changed from the blocky and script type to fine script type and spotty type, see Figs. 2 and 3 (projection of the phase MC in reflected electrons).

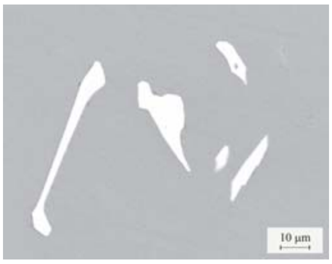

Fig. 2 Morphology of MC carbides, CR 1 °C min^{-1}.

Fig. 3 Morphology of MC carbides, CR 20 °C min^{-1}.

In interdendritic regions of all samples there occurred moreover micro-structural objects formed by coarse particles (phase $(Ti,Al)Ni_3$) of precipitates with related elliptic formation, in which very fine particles of precipitates were observed. Frequency of occurrence of discussed micro-structural objects was the highest in the sample D with the highest cooling rate and it declined with decreasing cooling rate of samples [2]. This suggests that micro-structural objects are related to chemical heterogeneity of original material.

It was also determined that these micro-structural objects have slightly increased contents of Nb and Ti, and on the contrary decreased contents of Cr and W. Very fine particles of precipitate $(Ti,Al)Ni_3$ were segregated in metallic matrix of elliptic objects.

Segregation Behaviour of Analysed Elements. On the basis of EDX analysis conducted on all samples it was established that during solidification of this alloy Cr, Co, W and Mo segregated to the dendrite core. Elements such as Ni, Ti, Al, Ta and Nb segregated in the inverse way, i.e. they enriched the interdendritic regions during solidification.

Fig. 4 illustrates the ratio of compositions (partition coefficient) between dendrite cores and interdendritic regions of the experimental samples. No segregation occurs when this ratio equals one; the higher is the deviation from the number 1, the higher is the segregation ability. It can be seen from Fig. 4 that increasing cooling rate has different influence on the segregation behaviour of analysed elements.

As found out above, the MC carbide-forming elements in this Ni-base superalloy are Ta, Nb and Ti. These elements have a strong tendency to segregate in residual liquid during solidification. Thus, as the solidification proceeds, interdendritic liquid becomes a preferential site for MC carbide formation.

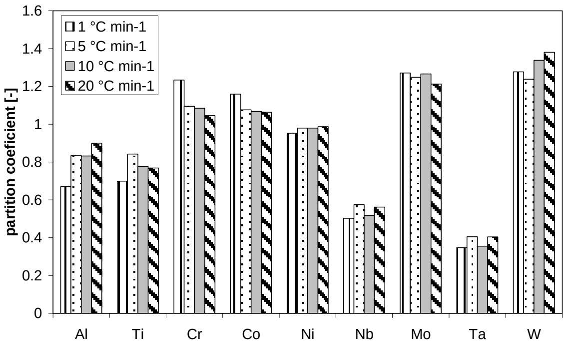

Fig. 4 Ratio of average composition in dendrite cores to interdendritic regions (by EDX) in four samples.

Conclusion

The transition temperatures for all analysed samples were determined and it was also found out the main results: (*i*) as the solidification rate decreased, the precipitations and particles are more coarsed; (*ii*) as increasing solidification rate the carbide morphology changed from the blocky and script type to fine script type and spotty type; (*iii*) Cr, Co, W and Mo segregated to the dendrite core, while Ni, Ti, Al, Ta and Nb enriched the interdendritic regions during solidification; (*iv*) Ta, Nb and Ti have a strong tendency to segregate in residual liquid during solidification.

Acknowledgement

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