Abstract

Alloys Ni-22Al-0.24B and Ni-22Al-1B (both in at.%) were prepared by vacuum induction melting and then directionally re-melted in resistance furnace working on the principle of the Bridgman’s method at the rates of 20, 50 and 70 mm h$^{-1}$. The object of this study was assessment of influence of the growth rate on micro-structure of both alloys. Final micro-structures of both alloys were dendritic after directional re-melting in the studied interval of rate of crystallisation. Coarse grains of the phase Ni$_3$Al were oriented in direction of crystallisation and rows of mesh were situated between them in parallel. The mesh was composed of grains of the phase Ni$_3$Al, which surrounded channels. The phases Ni$_3$Al and (Ni) were alternately present inside the channels. Boron formed in the matrix isolated islands of eutectics. Change of the growth rate influenced the primary dendrite arm spacening according to linear equation in such a way, that the distance decrease with an increase of rate for both alloys. Increasing rate caused also changes of volume fractions of the present phases. Increases of fractions of coarse grain of the phase Ni$_3$Al and eutectics were observed, while volume fraction of mesh decreased. This conclusion was identical for both alloys. The study has confirmed that by preparation and appropriate selection of conditions of directional crystallisation it is possible to obtain material with the required structure.

Keywords: alloys Ni-Al-B, growth rate, primary dendrite arm spacing

1. INTRODUCTION

Inter-metallic alloy Ni$_3$Al is applied most frequently at high temperatures, as it shows so called anomalous deformation behaviour. Particularity of this behaviour consists in an increase of the yield strength with temperature up to 800°C, and only then its decrease occurs. The alloy is moreover light and resistance to corrosion, as it is covered with protective layer of aluminium and nickel oxides. The main disadvantage of the alloy in poly-crystalline state is its brittleness. This drawback is partly suppressed by alloying of the alloy by boron, strengthens the alloy in cohesive manner. Other used alloying additions comprise e.g. zirconium, which influences mechanical strength of Ni$_3$Al, and chromium, which suppresses corrosion of the alloy and supports its better creep resistance [1].

Directional crystallisation is one of technological processes, with use of which it is possible to prepare Ni$_3$Al based alloys with suitable combinations of high-temperature properties. This method offers mainly materials with oriented micro-structure that are suitable for applications subjected to tension in direction of orientation. Obtained structure is most often dendritic. Primary dendrite arm spacening $\lambda_1$ [m] in dependence of the growth rate [2, 3] is given by the relation (1):

$$\lambda_1 = KV^n$$

where $K$ [m$^{-1}$•s$^{-1}$] is the constant, $V$ [ms$^{-1}$] is the growth rate of the liquidus-solidus interface and $n$ is power exponent, which in ideal case achieves the value of -0.25.
2. EXPERIMENT

Alloys with atomic composition Ni-22Al-0.24B and Ni-22Al-1B were prepared in vacuum induction furnace LEYBOLD type IS3/1 under inert atmosphere of argon. Cylindrical castings had length 100 mm and diameter 10 mm. After mechanical grinding of the surface layer of oxides always three castings from each alloy were inserted into corundum tubes with a tip and they were directionally re-melted in resistance furnace CLASIC, which works on the principle of the Bridgman's method, at the rates of crystallisation of 20, 50 and 70 mm.h\(^{-1}\). The rate of the tube moving in the furnace corresponded to the growth rate of liquidus-solidus interface. Temperature gradient was 75 K.cm\(^{-1}\).

Re-melted samples were cut longitudinally and the sections were pressed into non-conductive bakelite. After mechanical grinding and polishing on \(\text{Al}_2\text{O}_3\) with particles diameter of 1 \(\mu\text{m}\) the scratch patterns were etched in solution composed of 2 g CuCl\(_2\), 40 ml HCl and 80 ml ethanol. Micro-structure of the scratch patterns prepared in this manner was documented on optical light microscope OLYMPUS GX51 equipped with digital camera OLYMPUS DP12. Image analysis of the phases present after etching was performed by computer program analySIS auto.

3. RESULTS

Structure of the alloys Ni-22Al-0.24B and Ni-22Al-1B was after casting dendritic (Figures 1 and 2). Distribution of dendrites was random and their boundaries were covered with a thick layer of eutectics with boron. Castings contained numerous casting defects, such as pores and cavities. Micro-structure of both alloys after re-melting was again dendritic, but dendrites were arranged in direction of re-melting (Figures 3 and 4). The matrix consisted of long, coarse grains of the phase \(\text{Ni}_3\text{Al}\) (marked hereinafter as \(\gamma'_c\)), through which the so-called mesh ran in parallel rows. The mesh contained minuscule grains of the phase \(\text{Ni}_3\text{Al}\) (\(\gamma'_f\)) surrounded by channels, in which were alternately present the phases (Ni) and \(\text{Ni}_3\text{Al}\) (\(\gamma'_n\)). Indexes \(c\), \(f\) and \(n\) in the phase \(\gamma'\) symbolise its magnitude – \(c = \text{coarse}, f = \text{fine}\) and \(n = \text{particle of nano-dimensions}\). Structure was completed with eutectics and boron.
Coarse grain of the phase $\gamma_c$ and mesh adjoining to it were defined as dendrites. Primary dendrite arm spacing was therefore the width between these two structures taken perpendicularly to the direction of dendrite growth. The values of primary dendrite arm spacing were for the given alloy re-melted at the given rate taken from the photos of their structure taken at magnification 50x. Interval between individual measurements was 250 $\mu$m. The resulting values of primary dendrite arm spacing are for both alloys, which are shown in Fig. 5, very close for the applied rates of crystallisation. Conclusion ensuing from Fig. 5 is the same for both alloys – with increased growth rate the spacing between primary dendrite arms decreases in conformity with the equation (1).

Change of growth rate lead also to the changes of volume fractions of the present phases. Changes of volume fractions of coarse grain of the phase $\gamma_c$, mesh and eutectics with an increased boron content were observed for statistical purposes. They were determined with use of image analysis of photos of structure of individual alloys at given rates, which were taken at magnification 50x. The results are shown in Fig. 6, which documents increments of fractions of coarse grains of the phase $\gamma_c$ and eutectics accompanied by decrease of volume fraction of the mesh. This conclusion was the same for both alloys.
4. CONCLUSIONS

The aim of the work was to assess influence of growth rate of the liquidus-solidus interface on microstructure of the Ni-Al-B alloys. The alloys were prepared by vacuum induction melting and directionally re-melted in resistance furnace working on the principle of the Bridgman’s method at the rates of 20, 50 and 70 mm.h\(^{-1}\). Rate of movement of the sample in the furnace corresponded to the growth rate in the interface. Temperature gradient was 75 K.cm\(^{-1}\).

The resulting micro-structures of both alloys at all three rates were dendritic. Evaluation of dependence of primary dendrite arm spacing on growth rate lead to identical conclusions for both alloys – primary dendrite arm spacing decrease with increasing growth rate. Growth rate influenced moreover also volume fraction of the phase $\gamma'_c$, mesh and eutectics with boron, which were contained in micro-structures of both alloys. Increase of growth rate lead to an increase of fractions of the phase $\gamma'_c$ and eutectics, and to decrease of fraction of the mesh phase.

The study has confirmed that material structure may be modified by preparation and by appropriate selection of conditions of directional crystallisation.

REFERENCES


*The presented results were obtained during solution of the research plan No. MSM6198910013 entitled “Processes of preparation and properties of high-purity and structurally defined special materials”.*