Morphology of graphite solidified in Ni$_3$Al/C intermetallic

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Abstract

The study presents the results of microstructural examinations of the Ni-Al-C alloy forming a natural Ni$_3$Al/C composite, in which the precipitates of graphite are acting as a lubricating, slip phase. Different forms of graphite were described, starting with the fibrous shapes and ending in spheroidal forms, identical with the spheroidal graphite present in cast iron. The morphologies of graphite precipitates in the Ni$_3$Al phase were compared to similar precipitates observed in ferrous alloys with high carbon content.

Keywords: Composite; Intermetallic phase; Graphite; Eutectic; Fibrous eutectic;

1. Introduction

In the past few years, a lot of research works have been published on the intermetallic based on Ni$_3$Al and FeAl phases, reinforced with ceramic particles, like borides or metal carbides [1-4].

Choosing as a matrix, the intermetallic phase from an aluminium – nickel equilibrium diagram was dictated, among others, by the possibility to make this phase more plastic with a microaddition of boron, and by the possibility to obtain the best value of the coefficient of the specific tensile strength ($R_{m}/\gamma$), high oxidation resistance in a wide range of temperatures, as well as the mechanical properties growing with temperature increasing in the range of 923-1123 K.

This combination of the very interesting properties of the Ni$_3$Al matrix with lubricating and damping capacity of graphite can be of quite a spectacular character, and this fully justifies calling the newly developed material the material of the third generation.

Thus fabricated composite material can be used for the structural elements, which are expected to offer high tribological properties and high strength within a wide range of temperatures.[5-8] So far, only Fe – C, Ni – C and Co - C alloys with high carbon content have been observed to contain free graphite.

Similar as in these alloys, various graphite forms have been observed to occur in Ni-Al alloy containing 88wt.% Ni and 12wt.% Al, which corresponds to the atomic content of 75% Ni and 25 % Al, respectively. The alloy solidifies as an intermetallic phase, i.e. nickel aluminide Ni$_3$Al.

The aim of this study is showing that graphite crystallisation is also possible in Ni$_3$Al intermetallic.

2. The results

From a „Y” wedge-shaped ingot two specimens were cut out, one from the riser and one from the casting body. They were designated with symbols A and B, respectively, Fig.1.

After surface etching, the specimens were subjected to metallographic examinations carried out under an optical Leica microscope. Numerous metallographic photographs was taken, and the results are shown in Figures 2 to 13 below.

Observations carried out under the microscope revealed a two-phase structure of the examined material. The light background forms alloy matrix, and it is the Ni$_3$Al phase. The dark phase has...
different morphologies, since it crystallises in several different geometrical configurations forming:

- fine precipitates of oblong shapes appearing at grain boundaries,
- spheroidal precipitates, which are traces of intersection of the fibres of eutectic cells with a normal plane,
- larger precipitates of a fuzzy spheroidal phase resembling temper carbon in cast iron,
- graphite of perfectly spheroidal shape in the form of polycrystals, composed of the conically coiled layers growing in radial directions,
- graphite of perfectly spheroidal shape, contrary to the radial model of growth indicated by other authors, growing in a circumferential direction.

The morphologies of these precipitates are shown in figures below. Figures 4a, 4c, 5a, 7 to 9 show metallographic structures, which appear in specimen A cut out from the riser, while Figures 3a, 5b, 6b, 10 show photographs of microstructures observed in specimen B cut out from the casting body.

Fig. 1. Schematic representation of a „Y” letter-shaped ingot from which specimens were cut out for the metallographic examinations and SEM observations

Fig. 2b. Microstructure of Fe-V-C alloy of eutectic composition with fibrous eutectic (BEC) [7]

Fig. 2c. Eutectic fibres after deep etching with aqua regia (SE image) [7]

Cast iron vs Ni₃Al – C

Figures below show photographs of microstructures observed in different grades of cast iron (courtesy of the Staff of the Chair of Cast Alloys and Composites Engineering) compared with the Ni-Al-C alloy which, subjected to synthesis for the needs of this study, was solidifying into a specific type of Ni₃Al/C composite. The photographs show the morphology of the precipitated phases present in totally different material.

Fig. 2a. Microstructure of Ni-Al-C alloy. One of a region of sample. Visible is structure similar to that shown in Fig. 2b. (The microstructure indicating hypoeutectic composition)
Another type of graphite present in both materials.

Fig. 3a. Ni$_3$Al-C alloy. Specimen B, 200x. Visible are numerous precipitates of a dark phase assuming the shape of spheroids resembling graphite in Fig. 3b

Fig. 3b. „Spheroidal” graphite cast iron, 200x. Visible are numerous dark precipitates of graphite in the form of spheroids

Fig. 4a. Ni$_3$Al-C alloy. Specimen A, 500x. Visible are the precipitates of fuzzy graphite resembling the „exploded” type in (b)

Fig. 4b. „Exploded” graphite in cast iron, 500x. Visible are large dark precipitates of graphite

Fig. 4c. Ni$_3$Al-C alloy. Specimen A, 500x. Visible are dark precipitates of spheroidal graphite (fracture)

Fig. 4d. Schematic representation of the circumferential growth of spheroidal graphite [9]

A comparison of different graphite forms observed in another type of cast iron and in Ni$_3$Al/C composite.
Fig. 5a. Specimen A, 500x. Visible are numerous dark carbon precipitates of spheroidal shape, the light region is Ni$_3$Al phase.

Fig. 5b. Specimen B, 1500x. The light region is the phase forming alloy matrix, i.e. Ni$_3$Al, while the dark region is the phase of a morphology resembling that of temper carbon in cast iron.

Fig. 5c. Schematic representation of the growth of spheroidal and flake graphite [9]

Fig. 6a. Cast iron (graphite precipitates visible in interdendritic spaces) 100x

Fig. 6b. Ni$_3$Al-C alloy (precipitates of graphite fibres visible in interdendritic spaces) 200x

Fig. 7. Specimen A, 250x. The visible light region is Ni$_3$Al phase, forming alloy matrix. The large dark precipitates appearing in the central part of image are pure carbon, i.e. graphite
Similar examinations were carried out on specimens designated as A and B, taken from the casting body. Figures 8 to 10 show microstructures of the material examined at different magnifications.

Fig. 8. Specimen A, 250x. The visible light region is Ni$_3$Al phase, forming alloy matrix. The fine dark precipitates appearing along the grain boundaries are pure carbon in the form of graphite precipitates

Fig. 9. Ni$_3$Al-C alloy. Specimen A, 1000x. Visible are the grain boundaries along which fine graphite precipitates are distributed

Fig. 10. Specimen B, 500x. Visible are numerous regular carbon precipitates in the form of black spheroids; the light region is an intermetallic Ni$_3$Al phase

Summary, different morphology of graphite in Ni$_3$Al phase.

Fig. 11. Ni$_3$Al-C alloy. „Spheroidal” graphite. Nodule eutectics.

Fig. 12. Ni$_3$Al-C alloy. Flake and spheroidal graphite. Lamellae eutectics

Fig. 13. Ni$_3$Al-C alloy. Fiber form of graphite. Fibrous eutectic.

3. Conclusions

It was discovered in this study that graphite can crystallise in the Ni$_3$Al intermetallic in the form of fibres, lamellae and nodules.
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References


