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THE INTERMETALLIC COMPOUND Ni_3Al AS A BASE FOR A HIGH-TEMPERATURE ALLOY

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The possibility of obtaining thin-wall castings of a complex shape by the method of directed crystallization from an alloy based on the intermetallic compound Ni_3Al alloyed by 0.5% Co, 0.28% Ce or 0.5% Co, 0.28% Ce, and 6.4% Mo is considered. The additives improve the technological and strength properties of the intermetallic compound.

Alloys based on the intermetallic compound Ni_3Al are used in structures produced by methods of equiaxial casting and powder metallurgy [1]. It should be noted that Ni_3Al obtained by equiaxial casting has diminished characteristics of high-temperature and mechanical strength due to the presence of too many intergrain boundaries in its structure. An Ni_3Al alloy obtained by the method of directed crystallization has higher properties. The design and improvement of the methods of making castings from this alloy is accompanied by a study of promising methods of powder metallurgy that include preparation of nanopowders based on Ni_3Al and creation of materials on their base which possess unique properties [2].

At the present time an alloy based on this intermetallic compound is produced by two methods: (*1*) casting into molds with equiaxial crystallization, when the alloy is alloyed with B, Hf, and Zr, and (*2*) using directed crystallization of an intermetallic compound with a composition close to the stoichiometric one and alloyed with B, Hf, Si, Co, Ce, Mo, Nb, W, and Ta. Alloys based on Ni_3Al produced by method *1* can operate at 800 – 900°C, and those made by method *2* can operate at 1200 – 1300°C. It should be noted that unalloyed Ni_3Al manufactured by directed crystallization withstands a load of 20 – 40 N/mm^2 at 1200 – 1300°C and an alloy with 0.5% Co, 0.28% Ce and refractory elements (up to 7%) withstands at most 20 N/mm^2.

We studied the structure and properties of an alloy based on Ni_3Al and alloyed with 0.5% Co, 0.28% Ce, 4.6 – 9.6% Mo and that contained no additives.

The highest strength characteristics and structural stability were observed in the unalloyed variant of Ni_3Al (12% Al) possessing a directed structure (Fig. 1). Fracture of specimens of Ni_3Al with such a structure has been described in detail in [3]. An intermetallic compound with a directed structure can be manufactured given that the temperature and time regimes of heating and cooling are observed strictly. By adding cobalt and cerium to the intermetallic compound, we increased the degree of dendrite orientation at a uniform crystallization rate. Additives of refractory elements increased the deformability of the material at room temperature and improved the mechanical processability, especially in drilling. The tensile tests have shown that the strength characteristics of the "pure" alloy (without additives) depend on the geometry of the specimen. The use of this special feature makes it possible to widen the range of application of Ni_3Al alloys. It is known [3] that standard cylindrical specimens of Ni_3Al subjected to short-term rupture tests at from room temperature to 1200°C fracture by different mechanisms. At $t_{test} < 800°C$ the specimen deforms in two mutually perpendicular directions and

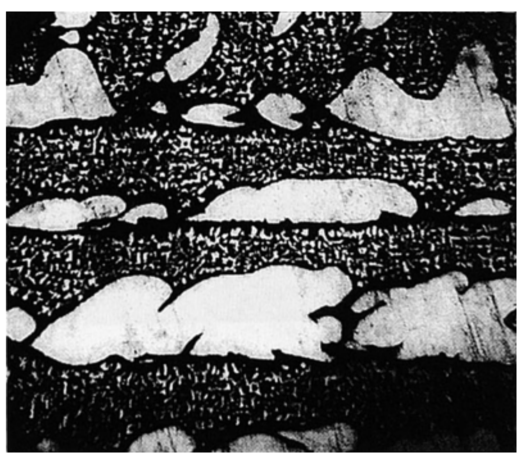

Fig. 1. Microstructure of an alloy based on Ni_3Al over the direction of crystal growth attained by dosed feeding of the mother solution into the growing casting, × 100.

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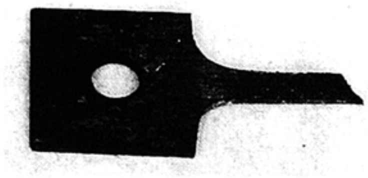

Fig. 2. Appearance of a broken lamellar specimen of Ni_3Al after a tensile test at 1200°C (the microstructure is presented in Fig. 1).

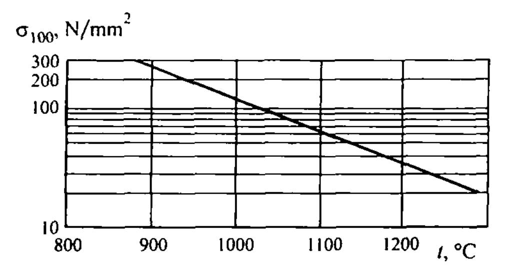

Fig. 3. A long-term strength curve (100-h hold) for lamellar specimens of alloy Ni_3Al.

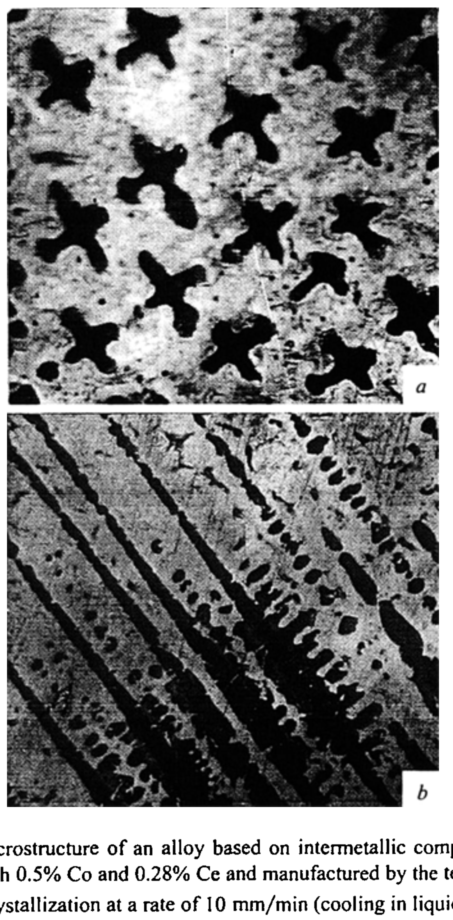

Fig. 4. Microstructure of an alloy based on intermetallic compound Ni_3Al alloyed with 0.5% Co and 0.28% Ce and manufactured by the technology of directed crystallization at a rate of 10 mm/min (cooling in liquid tin), × 100: *a*, *b*) in transverse and longitudinal sections relative to the direction of the growth of the casting, respectively.

fractures (without forming a neck) in a middle region equal to 2/3 of its functional part. The specimen fractures over the {111} plane. At $t_{test} > 800$°C the fracture mechanism is conventional (with the formation of a neck). The strength of the specimens decreases markedly, and the ductility increases. When the tested specimen is plane and has the size and shape described in our previous works, fracture occurs by a quite different mechanism. Beginning from room temperature and up to 1200°C these specimens undergo ductile fracture over the {111} plane (Fig. 2).

The results of tests of plane specimens for long-term strength in a temperature range of 800 – 1200°C (100 h) are presented in Fig. 3. It has been established that the strength of plane specimens is much higher than that of cylindrical ones.

In contrast to round specimens, tensile tests of plane specimens are not accompanied by changes in the slip planes in the entire temperature range [3]. It could be that the strength of plane specimens at $t_{test} > 1000$°C decreases less rapidly for this reason too. After the tests at room temperature the surface of the functional part of plane specimens did not exhibit transverse cuts in the source of fracture, as has been observed in tensile tests of round specimens [3]. In plane specimens with a cross-section of 1 × 3 mm the proportion of the area to the perimeter $S : P = 0.37$. Round specimens with a diameter of the functional part equal to 5 mm have $S : P = 1.3$. The interaction between mobile dislocations in the {111} slip plane and boundary dislocations in specimens of these two kinds seems to differ markedly. When stretching round specimens at room temperature the process can be observed visually on the surface in the form of ellipsoidal bulges positioned in the zone adjoining the fracture plane [3]. This does not occur in plane specimens.

The specific elongation of plane specimens $\delta = 10 - 15\%$, which is considerably lower than in round specimens in the tested temperature range. The long-term ductility of plane specimens at 1200°C is also lower ($\delta_l = 15 - 20$ %) than in round specimens. An analysis of the obtained data has shown that the method of directed crystallization is especially efficient for the Ni_3Al alloy in the production of thin-wall (1 – 3 mm) parts with a structure possessing a highly stable heat resistance when heated to a high temperature. The production of large castings with a complex geometry from aluminum nickelide by this method is restricted by the sizes of the functional space of the furnace for directed crystallization and the difficulties arising when a directed structure must be obtained in different regions of the part.

In order to improve the structural stability of the directed structure, we studied the possibility of alloying aluminum nickelide with cobalt (0.5%) and cerium (0.28%). It has been established [4] that the given additives provide preforms with a strict orientation of the crystals along the direction of the growth in a very wide range of hardening rates. The microstructure of such an alloy exhibits a clear differentiation of the γ and γ' phases in cross-sections both longitudinal and transverse to the direction of the crystal growth. Our study has shown that the addition of cobalt and cerium to aluminum nickelide provides castings with a complex geometry and a stable orientation of the crystals (Fig. 4).

In order to establish the properties of alloys based on Ni_3Al (without an additive and with adding 0.5% Co, and 0.28% Ce) we fabricated hemispherical specimens with a radius of 10 – 15 cm and a wall thickness $h = 2$ mm. The spherical surface had multiple openings and bulges that complicated the directed growth of the crystals. However, we obtained castings with a structure that consisted of one, two, and three crystals with well defined phase directions (Fig. 5). A similar structure has been obtained in thin-wall tube specimens with a wall thickness of 0.8 – 1 mm. It should be noted that the hemisphere fabricated from Ni_3Al alloyed with Co and Ce did not have hot shrinkage cracks. In hemispheres fabricated from Ni_3Al without additives we observed cracks up to 4 – 5 cm long positioned in meridional planes. The cracks pass through both the γ and γ' phases. In the structure of Ni_3Al with Co and Ce microadditives the shrinkage stresses seemed to relax on interphase boundaries, the yield of which eliminated the possibility of the formation of cracks. The hemispheres fabricated by the method of directed crystallization were subjected to a technological cycle of mechanical treatment under industrial conditions, and their adaptability to manufacture corresponded to the specifications.

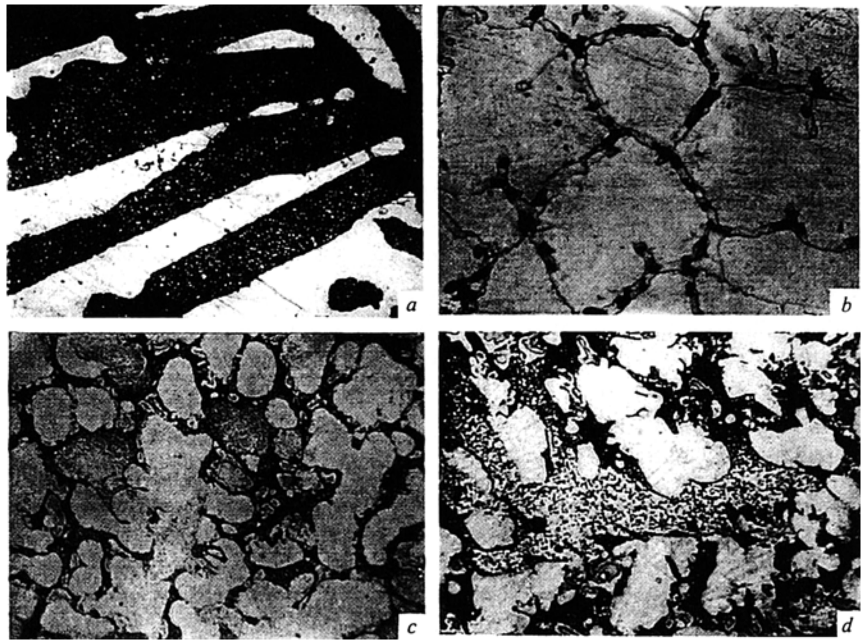

Fig. 5. Microstructure of thin-wall castings prepared by the technology of directed crystallization from Ni_3Al alloyed with different elements, × 100: *a*) 0.5% Co, 0.28% Ce; *b*) 0.5% Co, 0.28% Ce, 4.6% Mo, *c*, *d*) 0.5% Co, 0.28% Ce, 9.6% Mo, *a* – *c*) cross-section of the casting; *d*) longitudinal section.

Fine cracks and other defects formed in some cases in castings manufactured by the method of directed crystallization are weldable by an argon-arc method with an after-charge of a material of a similar composition but melted by the method of rapid crystallization at a rate of 218 mm/min with cooling in liquid tin. We used after-charge electrodes 3 mm in diameter and 150 – 200 mm long. The technology for manufacturing the electrodes is described in detail in [4].

In order to improve further the adaptability to manufacture of castings of thin-wall parts from an alloy based on Ni_3Al and alloyed with 0.5% Co and 0.28% Ce, we studied the effect of the addition of refractory elements using molybdenum as an example. We added 4.6, 6.4, and 9.6% Mo to the studied material. The microstructure of the alloy with Mo additives is presented in Fig. 5*b* – 5*d*. We established that as the molybdenum content is increased from 6.4 to 9.6%, an excess phase is segregated in the alloy (Fig. 5*d*).

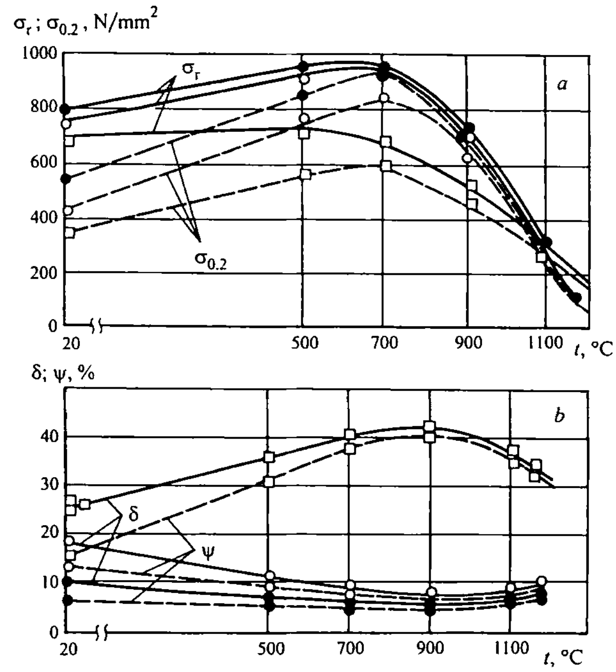

Fig. 6. Temperature dependences of the mechanical properties of an alloy based on Ni_3Al and alloyed with 0.5% Co, 0.28% Ce and different amounts of molybdenum: □) 4.6% Mo; ○) 6.4% Mo; •) 9.6% Mo.

We tested round specimens of Ni_3Al with different contents of Mo for short-term strength from room temperature to 1200°C. It turned out that the temperature dependences of $\sigma_{0.2}$ and σ_r behave similarly for the alloy with 6.4 and 9.6% Mo (Fig. 6). At 4.6% Mo the temperature dependence of σ_r and $\sigma_{0.2}$ is defined much more poorly than in the case of the other two modifications. The maximum strength characteristics are observed at 9.6% Mo. The temperature dependences of the ductility characteristics of the studied compositions are more complex (Fig. 6). In virtually all studied alloys the ductility changed the most substantially in a temperature the greater the decrease in the ductility. The ductility was minimum at about 900°C for the alloys with 6.4 and 9.6% Mo. On the contrary, in the alloy with 4.6% Mo at this temperature the ductility increased.

In casting of parts from an alloy based on Ni_3Al and containing 0.5% Co, 0.28% Ce, and 6.4% Mo the frequency of the formation of cracks was preserved at approximately the same level as in the alloy without molybdenum. However, the process of crack welding by an argon-arc method in parts from the molybdenum-containing alloy became much more complicated, and the weld could contain shrinkage microcracks. For this reason, castings for thin-wall parts used at 1200 – 1300°C under a load of at most 20 N/mm^2 should not contain molybdenum.

CONCLUSIONS

1. The maximum strength is exhibited by plane specimens based on the intermetallic compound Ni_3Al without additives and manufactured by the method of directed crystallization.

2. Plane specimens of Ni_3Al tested for elongation in a 20 – 1200°C temperature range fracture by the same mechanism. Fracture occurs in a $\{111\}\langle 110\rangle$ octahedral slip system in the entire test range.

3. Inconsiderable additives of cobalt (0.5%) and cerium (0.28%) increase the susceptibility of the alloy to directed growth at a constant crystallization rate and improve the resistance to the formation of hot cracks in thin-wall castings.

4. Alloying intermetallic compound Ni_3Al containing 0.5% Co, 0.28% Ce, and more than 4.6% Mo decreases markedly its ductile properties.

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