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EFFECT OF CARBON ADDITION ON FUNCTIONAL AND MECHNICAL PROPERTIES OF THE Ni_3Al PHASE

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Casting technology was applied and research was carried out on two alloys based on the Ni_3Al phase with variable carbon content of 0,2 and 1,25 wt. % C, respectively. Resistance to abrasive wear, friction coefficient and Vickers microhardness were determined. Metallographic studies were conducted to examine the macrostructure and microstructure of the investigated alloys. An increase in resistance to abrasive wear and microhardness of alloy containing 1,25 wt. % C was observed. The coefficient of friction was determined, which for the alloy with increased carbon content was much lower than for the alloy containing 0,2 wt. % C. Structural changes were reported to have some effect on functional and mechanical properties of the examined alloys.

Keywords: Ni_3Al, carbon, wear rate, friction coefficient, microhardness.

INTRODUCTION

The Ni_3Al (γ') phase belongs to the group of nickel aluminides and offers very good resistance to corrosion and oxidation at high temperatures [1,2]. However, one of its key features is the anomalous behaviour associated with an increase of strength and abrasive resistance in function of temperature [3,4]. The said properties can be improved quite considerably through reinforcement of the Ni_3Al phase with ceramic particles produced in situ in the alloy melt [5,6]. This property makes the γ' phase commonly used in nickel-based superalloys as one of the two basic structural components. Due to its high brittleness at ambient temperature and low ductility, this phase in nickel superalloys is embedded in soft and plastic fcc γ - matrix [7].

As in many other cases, also in γ' phase, the dissolution of the additives of other alloying effect elements takes place [8-10]. This usually involves changes in the size and basic features of the cells present in a crystal phase. The consequence is the macroscopically observed change in physical, functional and mechanical properties of the alloy, compared with base material. Moreover, during operation, frequent changes are observed to occur in the alloy due to diffusion processes, resulting in e.g. the formation of new phases. Their usual effect is that of deteriorating the material properties. At present, particularly interesting seem to be studies related with the stability of the nickel aluminide-based superalloys of the fourth generation and of the, appearing in them, unfavourable TCP precipitates [11-14].

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The metallographic studies were performed, followed by testing the functional and mechanical properties of two alloys based on Ni_3Al phase, containing 0,2 and 1,25 wt. % C, respectively. The influence of structural changes taking place in the examined alloys on parameters such as the wear rate, the friction coefficient, and Vickers microhardness was examined.

EXPERMINETAL

As part of the work, two alloys based on Ni_3Al intermetallic were prepared and investigated. The alloys contained constant content of nickel and aluminium, which corresponded to the stoichiometry of the Ni_3Al phase and the addition of carbon in an amount of 0,2 wt. % and 1,25 wt. %, respectively. Exact chemical composition of the alloys produced is given in Table 1. The procedure for the preparation of alloys has been described in detail in [15].

Table 1 **Chemical composition of alloys**

Elements	Ni at. %	Al at. %	C wt. %
Alloy M1	75	25	0,2
Alloy M2	75	25	1,25

Metallographic studies were carried out under the light microscope (Laica, Germany) and scanning microscope (Jeol Ltd, Tokyo, Japan).

The friction coefficient μ and the wear rate K were determined with a universal tester for tribology studies of materials (UMT-2MT, Center for Tribology Inc., CA, USA). The dry ball-on-disc test at ambient temperature was carried out. Ball made of ZrO_2 of 0,002 m diameter was used. The disks of 0,010 m diameter and 0,005 m height were made from alloys M1 and M2. All tests

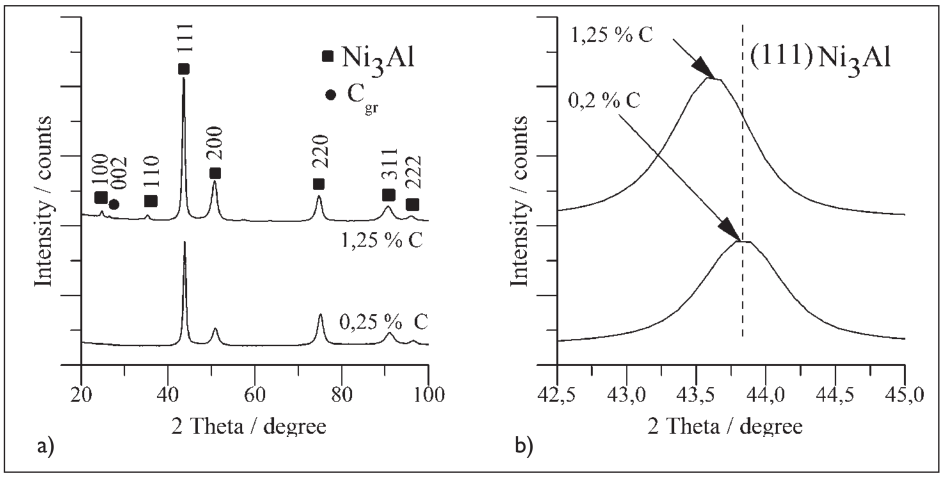

Figure 1 Comparative X-ray diffraction patterns of alloys M1 and M2 containing 0,2 % (a) and 1,25 % (b), respectively

were carried out under a load of 2 N, with the friction radii of 0,002 m, 0,003 m, and 0,004 m, at a rotary speed of 0,1 m/s and with the test duration of 600 s. The friction coefficient was automatically determined during the test from the relationship $\mu = F_t/F_n$, where F_t is the tangent force (in N*)* and F_n is the normal force (in N). When the test was completed, using needle profilometer (PRO500, Cetra), the cross-sectional profile of wear was measured in four places on the circle distant by an equal angle. Then the average cross-sectional area of wear was calculated. The volume of material removed was calculated as the product of cross-sectional area and perimeter length of wear. The worn out surface (wear rate) was calculated from the relationship $K = V/SF_n$, where V is the volume of the worn out material (in mm^3) and S is the total path of abrasion (in m).

Vickers microhardness (MHV) was measured with micro-Vickers hardness tester under a load of 0,1 kg and during the time of 15 s.

Phase composition and structural changes in alloys M1 and M2 taking place with increasing carbon content were discussed in detail in [15]. Figure 1 shows the phase analysis of alloys M1 and M2 (Figure 1a), with an obvious displacement of reflections from planes (111) of the Ni_3Al phase (Figure 1b).

RESULTS AND DISCUSSION

Figure 2 shows the microstructure of alloys M1 and M2 containing 0,2 and 1,25 wt. % C, respectively. Alloy M1 (Figure 2a) has a single-phase microstructure with visible grain boundaries. In the case of alloy M2 (Figure 2b), against the bright matrix background, dark precipitates of spheroidal and lamellar shapes are visible. The precipitates are unevenly distributed in the matrix.

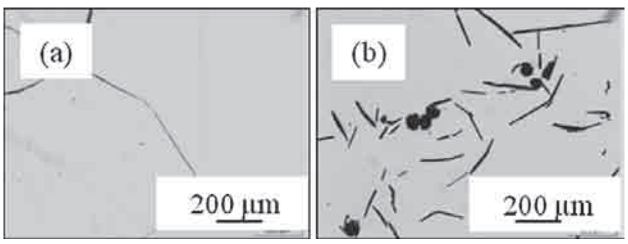

Figure 2 Microstructure of alloy M1 containing 0,2 wt. % C (a) and alloy M2 containing 1,25 wt. % C (b). Image obtained under light microscope

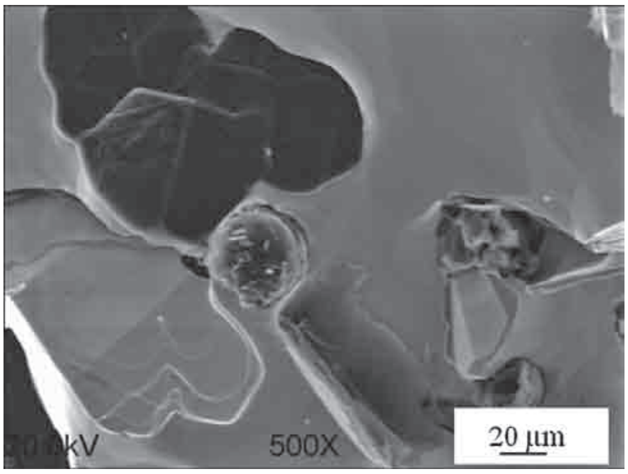

Figure 3 SE image of the fracture of alloy M2 containing 1,25 wt. % C with visible precipitates of lamellar and spheroidal graphite

Figure 3 shows an SE image of the specimen of alloy M2 with well visible precipitates of graphite in lamellar and spheroidal form. Additionally, indentations are visible in the areas of the occurrence of lamellar graphite (the place indicated by an arrow Figure 3), thus proving the epitaxial form of growth.

Figure 4 shows the macrostructure of alloys M1 and M2 with visible places of wear after the abrasion tests conducted. Tracks shown in Figure 6 illustrate the wear effect caused by ZrO_2 ball rubbing against the hard discs made from alloys M1 (Figure 4a) and M2 (Figure 4b). The picture of the worn out surface indicates a significant loss of material in the sample of alloy M1, compared with alloy M2 containing precipitates of graphite.

The tracks visible in Figure 5a, obtained on a sample containing 0,2 wt. % C, have an average width of ~ 580 μm. For the second of the analysed materials, containing 1,25 wt. % C, the average width of tracks is ~ 200 μm (Figure 5b). Comparing the wear test results for al-

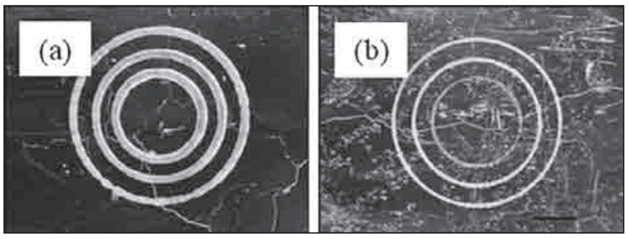

Figure 4 Macrostructure of alloys M1 (a) and M2 (b) with visible tracks left by ball during the ball-on-disc abrasive wear test. 12 x

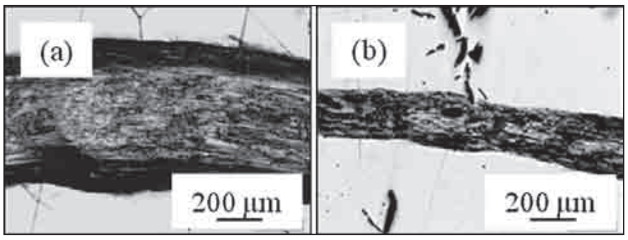

Figure 5 Macrostructure of alloys 0,2 wt. % C (a) and 1,25 wt. % C (b) with visible tracks left by ball during the ball-on-disc abrasive wear test

loys M1 and M2 it can be concluded that the degree of surface degradation determined from the track width has decreased by 64 % in the case of alloy M2. These observations confirm the studies of friction coefficient μ and the K index of the material.

Figure 6 shows friction coefficients μ determined for the alloys designated as M1 (Figure 6a) and M2 (Figure 6b). For alloy M1, the average coefficient of friction μ determined in three trials is at the level of ~ 0,55. The second of the tested materials. i.e. alloy M2, has a much lower coefficient of friction, i.e. ~ 0,15. This significant decrease in the value of the friction coefficient in alloy M2 is due to the presence of graphite precipitates, which during the process of friction enhance the lubricating properties of the examined material.

On the basis of the conducted abrasive wear test, the wear rate index was calculated for alloys M1 (Figure 7a) and M2 (Figure 7b). The wear rate index for alloys M1 and M2, calculated for the friction radius of 3 mm, was ~ 377 and ~ 24 × 10^{-6} mm^3/Nm, respectively. However, with the friction radius of 4 mm it assumed the values of ~ 328 and ~ 22 × 10^{-6} mm^3/Nm for alloys M1 and M2, respectively. This clear difference in the value

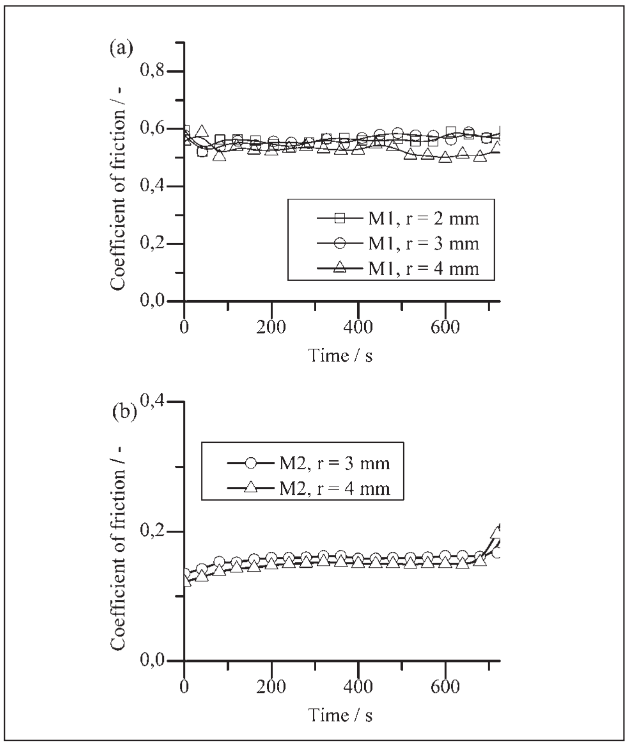

Figure 6 The coefficient of friction determined for alloys M1 (a) and M2 (b).

of K indicates a much higher wear resistance of alloy M2 containing 1,25 wt. % C.

Figure 8 shows the indentation marks left during the microhardness test in alloys M1 (Figure 8a) and M2 (Figure 8b). The average microhardness of alloy M1 is ~ 290 MHV, while in the case of alloy M2 it is ~ 492 MHV. The conducted hardness measurements show significant differences in the mechanical properties of both alloys. The introduced addition of carbon changes in an obvious manner the material parameters of the investigated alloys, increasing the hardness level in alloy M2 by about ~ 70 %. This effect is the result of hardening of the Ni_3Al phase structure by location of carbon atoms in the interstitial spaces.

Considering the results of phase analysis of alloys M1 and M2 (Figure 1) it can be observed that the crystallographic planes of the Ni_3Al phase have shifted towards lower values of the 2θ angles. This effect is connected with the increasing size of the crystal cells of the γ' phase. Therefore hardness increase in alloy M2 is di-

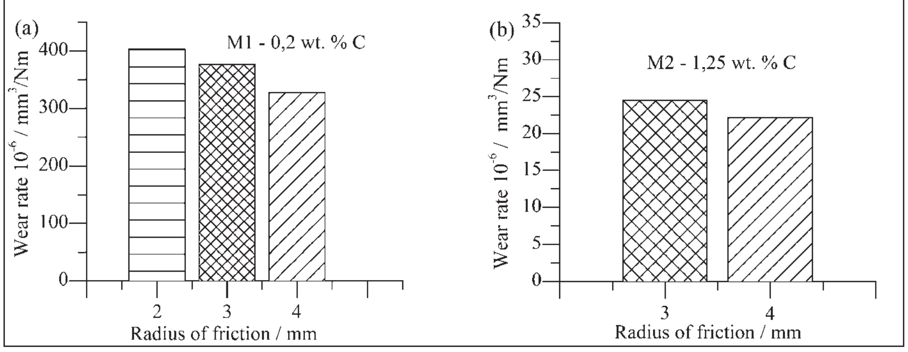

Figure 7 Wear rate under different friction radii determined for alloys M1 (a) and M2 (b)

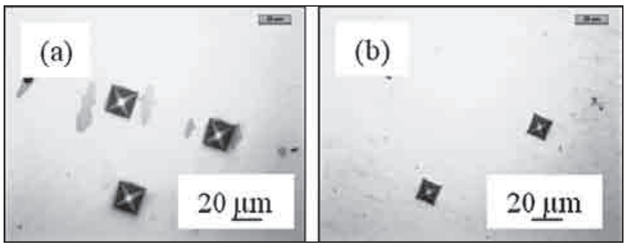

Figure 8 Microstructure of alloys M1 (a) and M2 (b) with visible MHV indentation marks

rectly related with an increase of the atomic carbon content in crystal cells of the Ni_3Al phase.

CONCLUSIONS

Examined in this study, alloys M1 and M2, based on the Ni_3Al phase and containing 0,2 and 1,25 % wt. C, respectively, are characterised by significant differences in both functional and mechanical properties. In terms of the coefficient of friction determined for both alloys, it can be concluded that it assumes values much lower in the case of alloy M2. This effect results from the presence of graphite precipitates in alloy microstructure, which enhance the lubricating properties of the alloy. A comparison of the wear rate K for both alloys shows a few-fold increase in abrasive wear resistance of alloy M2. This result can be linked to structural changes which occur in this material. Along with the increase of carbon content, the Ni_3Al phase undergoes hardening. Finally, the studies of MHV conducted on both alloys have indicated the hardness values increasing in alloy M2 with the increasing carbon content.

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