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The effect of graphite precipitates in Ni_3Al/C composite on tribological properties

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Abstract

The study shows the results of investigations of the tribological properties of cast Ni_3Al/C composite and compares them with the properties of pure intermetallic phases of the Ni_3Al type. An inspiration to these studies was a surprising similarity observed between the microstructure of iron-carbon alloys, and specifically of different cast iron grades, and the microstructure of, absolutely different in terms of the chemical composition, nickel-aluminium alloy. Because of carbon present in the alloy, an attempt was made to determine what effect the presence of graphite (acting as a lubricant) might have on the abrasive wear behaviour of alloy during lubricated friction test. Tests were made on a Miller apparatus, used for active testing of the abrasive wear resistance. The specimen loss of mass was determined in function of time.

Keywords: Aluminides; Tribological properties; Abrasive wear resistance;

1. Introduction

Composites based on intermetallic phases from the nickel-aluminium system belong to the group of materials characterised by high functional properties, and as such can be assigned for operation at high temperatures. An important feature of the intermetallic phases is the possibility to obtain the functional properties unattainable in common alloys, owing mainly to a specific combination of the alloying additives and solidification conditions.

In the case of co-acting materials, the degradation observed most frequently is that which occurs during lubricated friction. The said effect is most commonly observed in mating parts of machine tools, e.g. the shaft/bearing or cylinder/piston ring systems. To reduce the effect of friction, different types of lubricants are used. Yet, the most important factor in the abrasive wear behaviour is the structure of material. It should be characterised by the following parameters: low coefficient of friction, the wear-in ability, and the ability to keep on the surface a film of lubricant of the required thickness. Moreover, it is recommended to produce a material that will maintain its satisfactory mechanical properties at high temperatures [7].

The material, which can potentially satisfy all these requirements, seems to be the Ni_3Al/C composite characterised by a non-homogeneous structure with phases of different hardness values. Because of the presence of these phases, the phase which is less resistant to wear, i.e. graphite, tends to form a sort of natural "containers" holding the lubricant and products of the wear.

A surprisingly similar microstructure observed in iron-carbon alloys, and specifically in different grades of cast iron, and in the nickel-aluminium alloys of a totally different chemical composition inspired the authors of this study to undertake further investigations and explain possible effect of graphite on the tribological properties of Ni-Al-C alloy.

Graphite reveals its lubricating properties when the co-acting parts are wearing-in. It prevents the occurrence of seizures – the effect important when parts are expected to run for a long time. After a short time of the co-acting parts operation, graphite is entirely removed from the surface, and at this moment its role as a lubricant practically ends. The crevices (voids) where the graphite was once present are now acting as “containers” holding the liquid lubricant which coats the already ground-in surfaces. The situation is quite different in the case of dry friction, when graphite is turned into a powder which, owing to its lubricating properties, reduces the value of the coefficient of friction, increasing at the same time the resistance to friction wear. At this moment, with the time lapse, the new layers of the graphite-containing metal are gradually exposed, ensuring constant renewal of the thin graphite film, maintained on the co-acting surfaces and effectively preventing the risk of seizure [7].

2. Materials and Methods of Investigations

Two types of materials were used in the tests: a composite material based on the intermetallic Ni_3Al/C phase (Figs. 1 and 3) and pure intermetallic Ni_3Al phase (Fig. 2).

Ni_3Al is characterised by an ordered cubic crystal structure, where the space group has been designated as Pm3m. The elementary cell of Ni_3Al is characterised by an ordered cubic structure in which the atoms of aluminium are located in the corners of the cube and atoms of nickel in the cube walls. The lattice parameter a = 0,357 nm [9].

The Ni-Al-C composite containing aluminium in an amount of 10,5 wt. %, and nickel in an amount of 89,5 wt. % is crystallising as an Ni_3Al phase with graphite precipitates. Figures 1 and 3 show the microstructure of this composite.

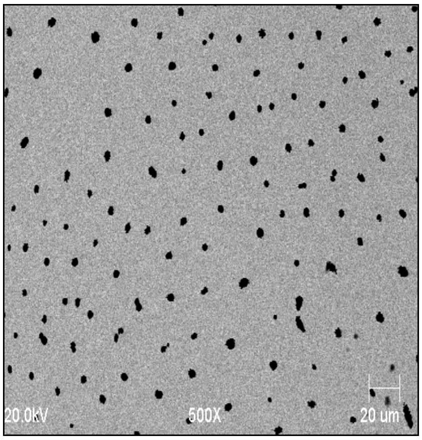

Fig. 1. The microstructure of Ni_3Al/C alloy, 500x; visible are numerous dark precipitates of carbon in the form of black spheres; the light background is Ni_3Al alloy matrix

The tribological properties of the Ni_3Al/C alloy and Ni_3Al phase were determined on a Miller device, where in the four respective sleeves filled with SiC-water slurry the loaded specimens were tested for their tribological behaviour.

Testing of abrasive wear behaviour was conducted on specimens of the 25,4x12,7x9 mm dimensions. During the test, the specimens mounted and loaded at a pressure of 22,24 N were moving with a reciprocating motion against the substrate coated with an abrasive material, which was a composition of silicon carbide particles mixed with water in a 1:1 ratio.

Tests were carried out on the specimens of Ni_3Al/C alloy; the reference sample was made from pure Ni_3Al phase. The abrasive wear test was carried out in three cycles of four hour duration each. The determination consisted in measurement of the loss of mass suffered by the specimen in function of time.

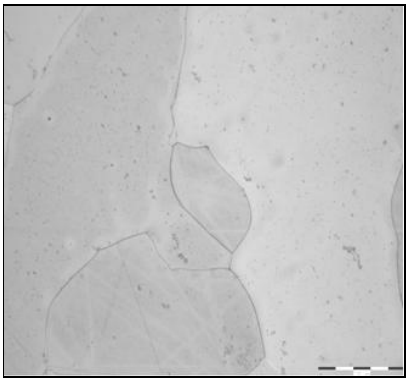

Fig. 2. The microstructure of pure Ni_3Al intermetallic phase, 100x, with well visible grain boundaries

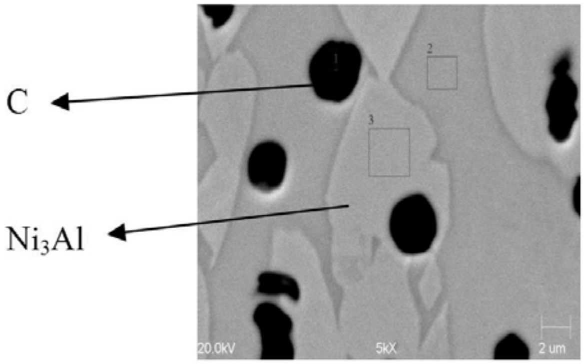

Fig. 3. Scanning electron (SE) topography image of a fragment of the Ni_3Al/C composite specimen surface, magnification 5kX. The selected regions examined by an X-ray microanalysis reveal the presence of two phases, i.e. C and Ni_3Al

3. Tests Results

Figures 4-6 illustrate the results of the measurements taken during the abrasive wear testing of an Ni_3Al/C alloy specimen compared with the reference sample made from pure Ni_3Al phase.

Figure 4. shows changes in the weight of the specimens of Ni_3Al/C and Ni_3Al, observed during the test. With elapsing time of the abrasive wear test, the loss of mass assumes similar values in the specimens prepared from both the Ni_3Al/C alloy and pure Ni_3Al phase.

Figure 5. illustrates absolute loss of mass in specimens during the abrasive wear test. From the drawing it follows that

with elapsing time of the test, the absolute loss of mass increases in both the Ni_3Al/C specimen and its reference counterpart made from the Ni_3Al phase. A tendency appears, which proves the inferior abrasive wear resistance of the Ni_3Al/C alloy specimen.

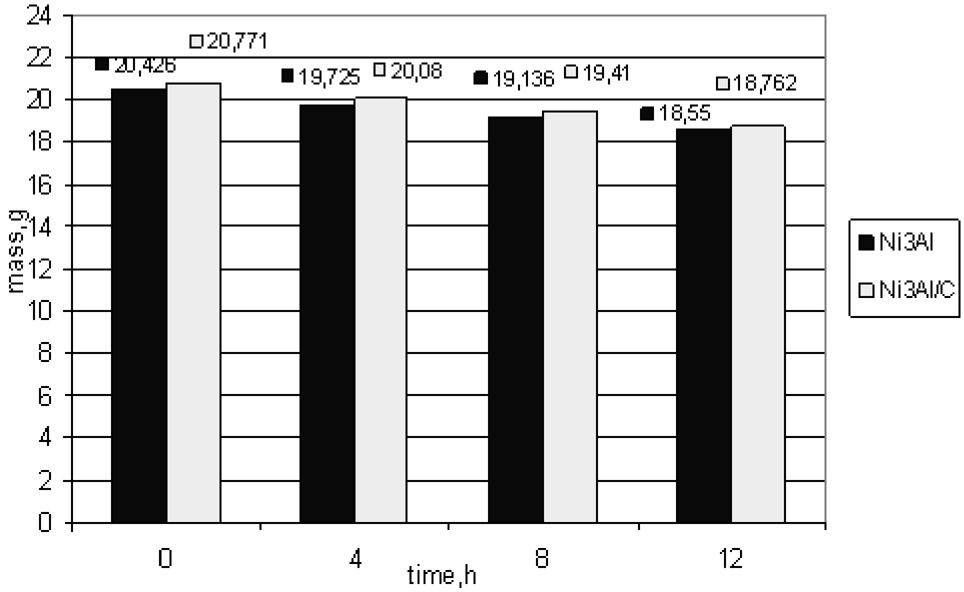

Fig. 4. Mass in function of time m(t) during the abrasive wear test

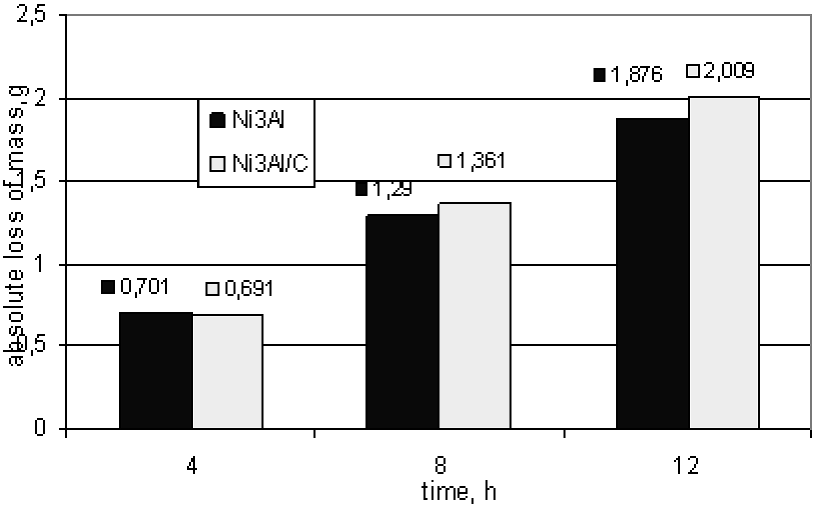

Fig. 5. Plotted relationship between the absolute loss of mass (Δm) and duration of the abrasive wear test

Figure 6. illustrates a relationship between $\Delta m/m_0$ (relative loss of mass in the examined specimens) and the duration of abrasive effect. From the diagram it follows that with the elapsing time of the abrasive wear test, the $\Delta m/m_0$ ratio assumes a linear run.

$\Delta m(t) = m_0 - m_t$ (absolute loss of mass)
$\Delta m(t)/m_0$ (relative loss of mass)
t – the duration of abrasive test
m_i - the final specimen weight
m_0 – the initial specimen weight

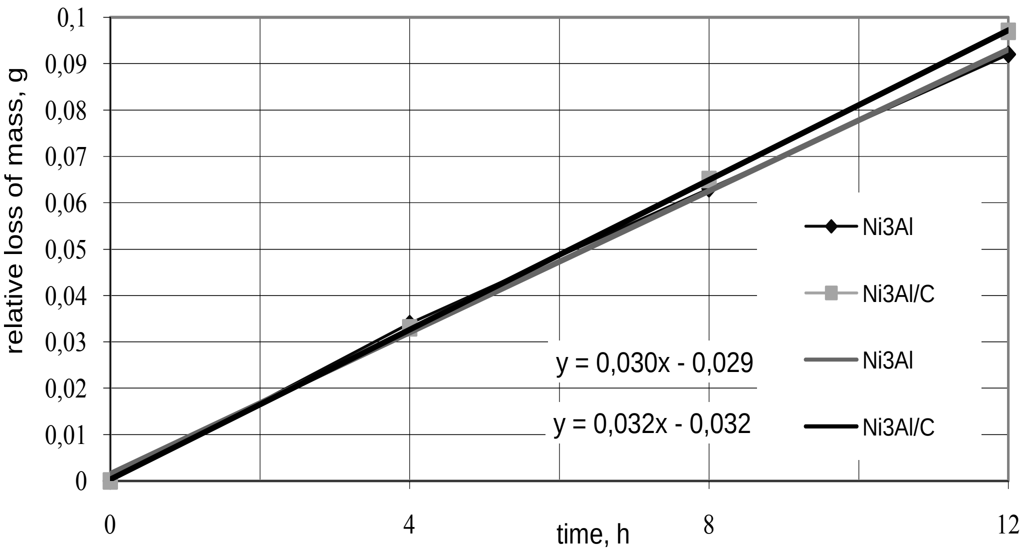

Fig. 6. The relationship $\Delta m/m_0$ (where: Δm- the absolute loss of mass, m_o - the initial weight of specimen) plotted in function of the abrasive wear test cycle duration

4. Conclusions

The investigations enabled the following conclusions to be formulated:

Because of low carbon content (1wt.%), the difference in the abrasive wear rate of the Ni_3Al/C alloy specimen and its Ni_3Al reference counterpart is relatively small, but a tendency has been observed that proves lower abrasive wear resistance of the Ni_3Al/C alloy specimen, thus suggesting a lower coefficient of friction and possible appearance of slip properties due the presence of graphite precipitates of an untypical spheroidal shape.

To verify this conclusion, similar tests should be carried out on alloys with the growing carbon content to examine their abrasive wear behaviour.

Acknowledgments

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