ARCHIVES

of

FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 14
Special Issue
1/2014
187-192

38/1

Abrasive Wear of Fine-grained Ni_3Al Intermetallic Alloys

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Received 17.03.2014; accepted in revised form 31.03.2014

Abstract

Influence of chemical composition and material structure on the abrasive wear of Ni_3Al intermetallic alloy in loose abrasive was investigated in details. Boron, zirconium and chromium were used as the alloying elements. The alloys are made up of γ' or γ'+γ phases (single-phase, ordered matrix + disordered area). Grain size of the alloys was varied: 5, 20 and 45 μm. Abrasive were experiments were performed with T-07 tester (Norma company) in accordance to the GOST 23.2008-79 standard.

Mechanism of surface layer damaging exposed to the loose abrasive was described on the basis of the obtained structural and topographical experiments. The results revealed that relative abrasive wear in loose abrasive is approximately same for all the investigated alloys with varied grain size.

Keywords: Abrasion, Intermetallic, Wear, Geometric Structure of Surface.

1. Introduction

Abrasive wear in a loose abrasive is a phenomenon during which loose, hard particles are interacting with material's surface. Cutting, scalloping and scratching take place and as a result, damaging of material occurs. Thus, materials loss related to phenomena mentioned above are decreasing productivity, or even destruction of machines' elements. These loose particles of abrasive can be placed on the material's surface or between two surfaces of various materials [1].

Abrasive particles can be transported freely or trapped, by air or liquid causing dry or wet friction. This type of damaging takes place during: crushing, milling, digging, pouring, sieving, shifting and transportation of granular materials [2-3].

This type of wear is common during exploitation of agricultural machines, pouring and storing of granular materials and transportation of liquids [4-6]. Vehicles moving on the sandy and gritty surfaces are exposed to the similar risk, because soil, which is rich in hard mineral particles, especially quartz, behaves like an abrasive.

Intensity of couple nudges damaging during wear in loose abrasive jest usually greater than in comparison to cases when other types of abrasives were applied [7,8]. This phenomenon can also occur in other contacts like piston-sleeve, where products of wear and particles from environment behave like the abrasive [9].

The phenomenon of abrasive wear with loose abrasive occur not only in technology and engineering, but also in many other branches of science like medicine. In dentistry, decay is being removed with a stream of air with alumina particles load with different granularity. In architecture, attrition of the concrete surfaces occurs in trailing debris. In geology, attrition of rocky support by loose rocks also takes place [10-11].

Numerous material features are responsible for abrasive wear of he structural materials, including hardness, elasticity modulus, strength yield, melting point, lattice, topography and geometry of surface layer, microstructure and chemical composition [12-13].

Structural changes in elements of machine can prevent material from exposure to the loose abrasive, as well as materials resistant towards abrasive wear can be applied. Intermetallic alloys from Ni-Al phase diagram are recognized among materials resistant towards abrasive wear. Ni_3Al intermetallic alloys are up-to-date structural material exhibiting transitional properties between metals and ceramics [14-15].

In recent paper, influence of chemical composition and alloys structure of the Ni_3Al intermetallic alloy on the abrasive wear in loose abrasive was studied in details.

2. Material and research methods

Two types of Ni_3Al intermetallic alloys were chosen to the plastic processing and further research. Table 1 presents chemical composition of the alloys.

Table 1.
Chemical composition of the investigated alloys

Alloys Signature	Type of the alloy	Element (% at.)			
		Ni	Al	Cr	Zr
IM	$Ni_3Al(B,Zr)$	76.6	22.95	----	0.45
IM-Cr	$Ni_3Al(B, Zr, Cr,)$	75.41	23.55	0.57	0.47

As cast material was homogenized in air at 1200 °C. Next, the material was rolled to the deformation of 60% and recrystallized at 900, 1100 and 1200 °C, to obtain material with varied grain size: 5, 20 and 40 μm respectively.

Structural analysis was performed with analytical scanning electron microscopes: Philips XL30 (LaB_6) and Quanta 3d FEG.

Micro-hardness measurements were done with Shimadzu M with Dorernst Company software. Load of 0.98 N was being used (HV0.1) for 10 seconds.

Roughness analysis of the intermetallic samples was done with contact method using TOPO 01P profilometer. 2D profiles of the samples were taken then. Additionally, 3D profiles (stereometric) were also done and primary isometric view and roughness view of the analysed surfaces were taken.

Abrasive wear tests were performed with T-07 tester (Norma Company) in accordance to the GOST 23.2008-79 standard. The concept of the experiments was an interaction of loose abrasive with material. The abrasive was tighten to the material's surface by the rotating rubber roll (Fig. 1).

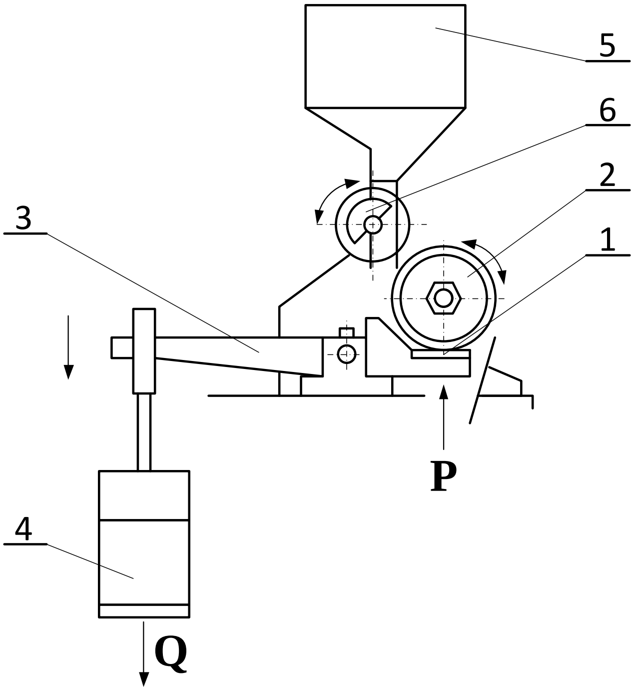

Fig. 1. Scheme of the applied tester (1-sample, 2- rubber roll, 3-lever, 4- extenders, 5- containers, 6- feeder)

In this method abrasive wear of the investigated sample is referred to the abrasive wear of the standard. Comparison of these two values allows to asses and estimated the abrasive wear resistance towards the loose abrasive. The standards were made of 45 steel according to the PN-75/H-84019 standard. Hardness of the standard specimens 180 ÷ 190 HB.Surface roughness R_a 0.63 ÷ 0.32 μm.
Abrassive corundum.

Relative abrasive wear resistance K_b of the investigated materials was estimated according to the following equation:

$$K_b = (Z_{ww} \cdot q_b \cdot N_b)/(Z_{wb} \cdot q_w \cdot N_w) \qquad (1)$$

where:

Z_{ww} – mass wear of the standards

Z_{wb} – mass wear of the researched samples

q_w – density of the standards,

q_b – density of the researched samples,

N_w –number of rubber roll rotations during testing of the standards,

N_b - number of rubber roll rotations during testing of the researched samples.

The mass wear of the researched samples is in the denominator of the equation presented above, hence the greater value of the relative abrasive wear resistance Kb, the more resistant towards abrasive wear is the material.

3. Study results and discussion

Metallography revealed that plastic processing (deformation equal 60%) and heat treatment allow to fragment the structure of the researched alloys. Recrystallization of the deformed material in 900, 1000 and 1200 ^{o}C for 1 hour allow to fragment γ’ phase (ordered secondary Ni$_3$Al based solid solution) or γ+γ’ (γ - disordered solid solution of aluminum in the nickel lattice) to grain size of approximately: 5, 20 and 40 μm respectively (Fig. 2-4). Micro-hardness of the γ’ areas is ranging from 310 to 330 HV0.1. Additionally, it was found that bi-phasal areas have elevated micro-hardness (360 HV0.1). Hardness of the researched alloys, independently from the grain size, was below 400 HV10. Signs of abrasion noticeable in the micrographs allows to asses mechanism of surface layer damaging (Fig. 5).

Pockets shown in Fig. 6a reveals that damaging of the surface layer undergoes via scratching and scalloping. Additionally, small secretions of the second phase are being tear off by the abrasive and these are responsible for additional damages, intensifying the tribological wear of the material.

During analysis of the surface profiles done with profilometer and cross-sections of the pockets’ profiles in three various sites (on the head, in the middle and at the end of the pocket), it was found that the greatest size is on the head of the pocket.

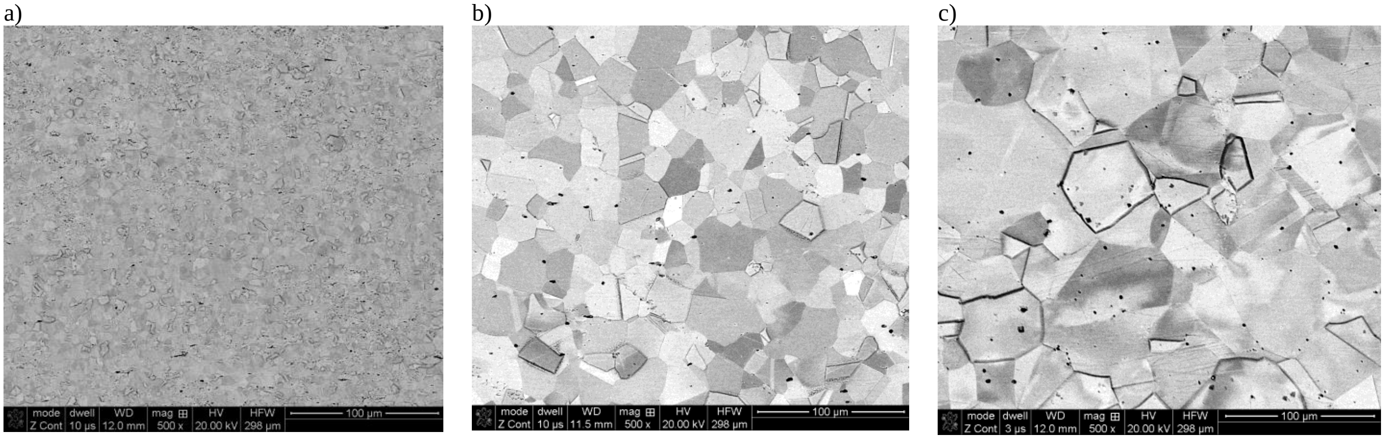

Fig. 2. Microstructure of the single-phase Ni$_3$Al intermetallic alloy – the IM alloy
a) grain size of approximately 5 μm, b) grain size of approximately 20 μm, c) grain size of approximately 40 μm

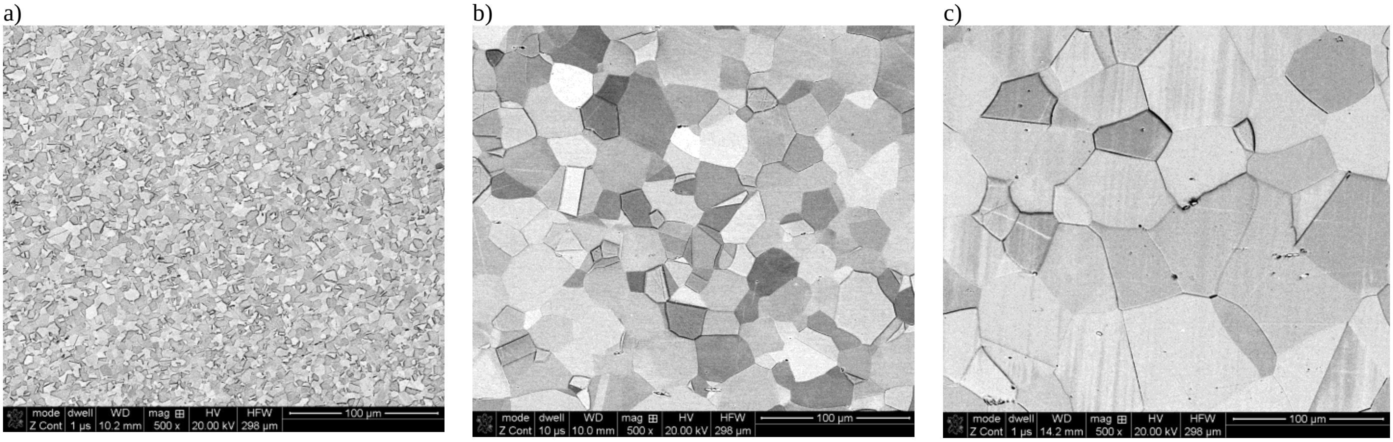

Fig. 3. Microstructure of the single-phase Ni$_3$Al intermetallic alloy – the IM/Cr alloy
a) grain size of approximately 5 μm, b) grain size of approximately 20 μm, c) grain size of approximately 40 μm

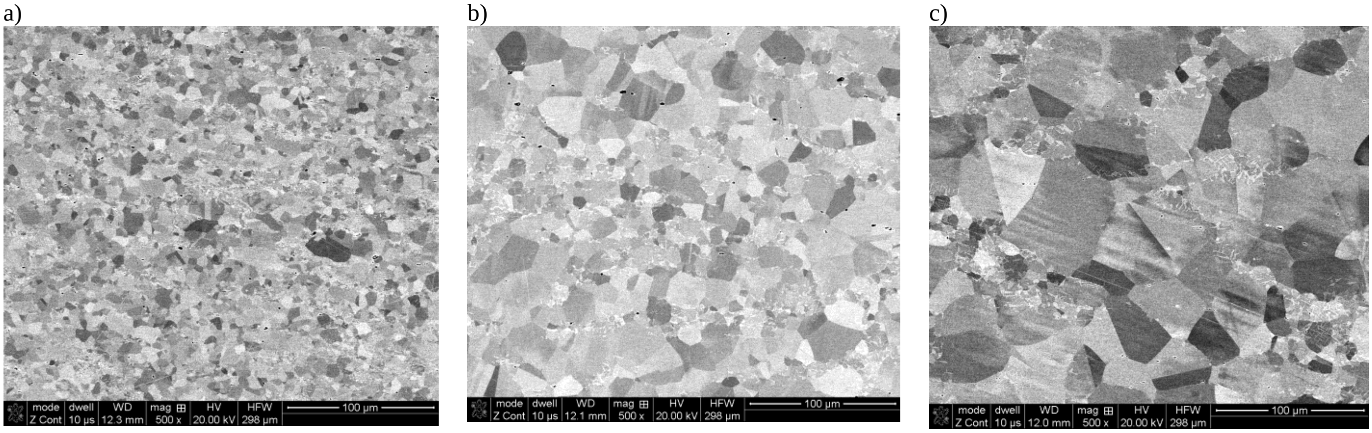

Fig. 4. Microstructure of the bi-phasal Ni_3Al intermetallic alloy – the IM/Cr alloy
a) grain size of approximately 5 µm, b) grain size of approximately 20 µm, c) grain size of approximately 40 µm

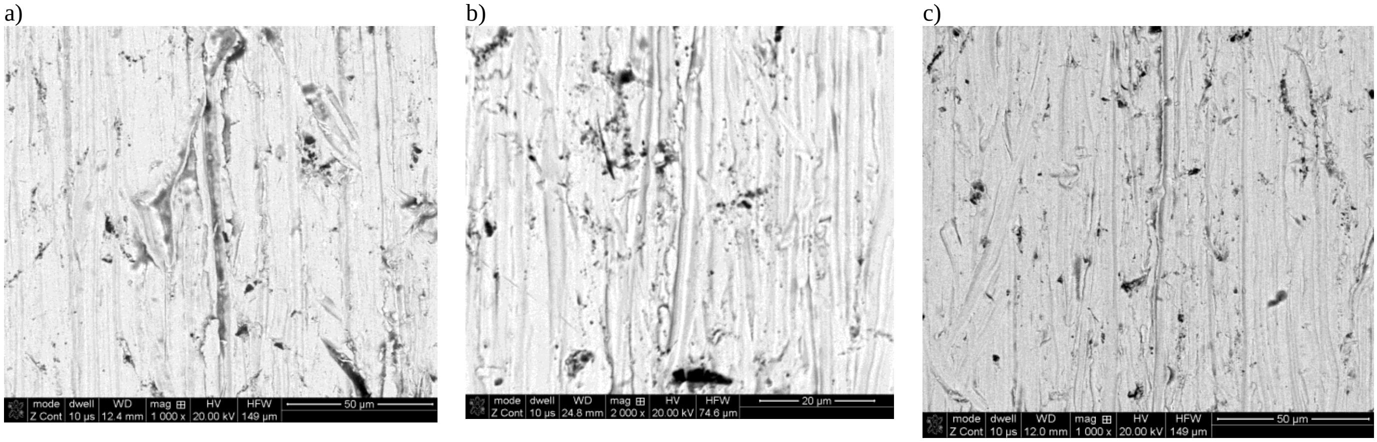

Fig. 5. Signs of wear of IM/Cr bi-phasal intermetallic alloy; a) EDC 5µm, b) EDC 20µm and c) EDC 40µm

The abrasive wear tests in loose abrasive revealed the best resistance towards abrasion for IM alloy with grain size equal d=40µm (Fig. 6).

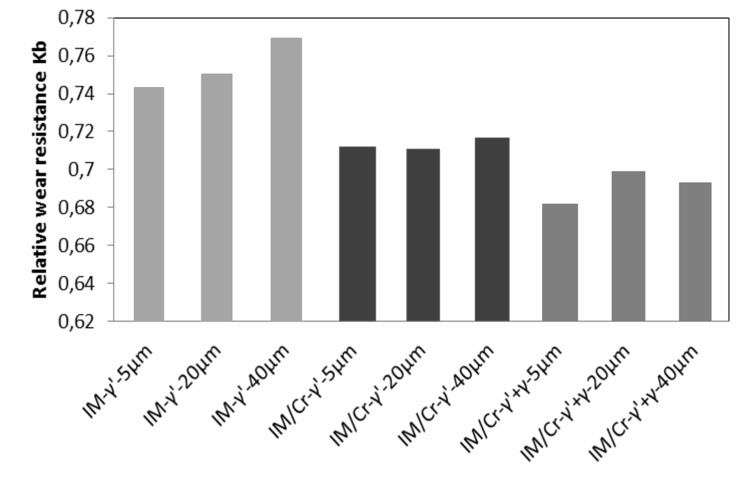

Fig. 6. Abrasive wear resistance changes of Ni_3Al intermetallic alloys

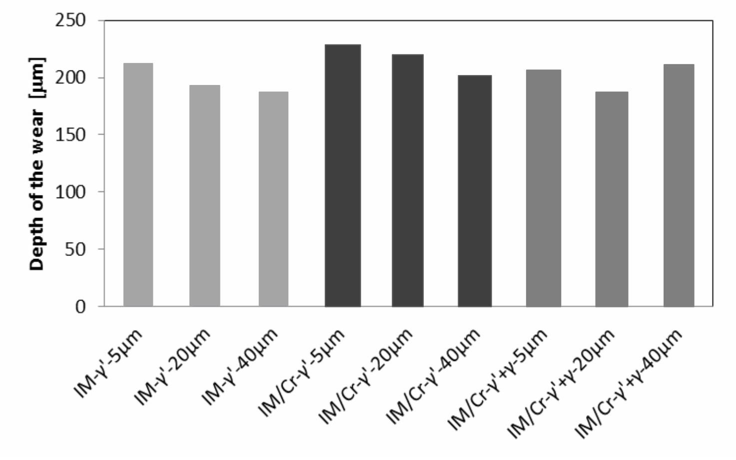

Fig. 7. Depth of the wear signs of Ni_3Al intermetallic alloys

It is worth to note that this alloy is made of one phase and has the smallest hardness among the analyzed alloys. It was also noticed that IM/Cr alloy has similar values of relative abrasive wear resistance independently from phase composition and grain size (Kb is approximately 0,7 – Fig. 6). the same tendency was denoted for influence of grain size on the depth of wear signs for this alloy (Fig. 7). However, abrasive wear resistance of the Ni_3Al intermetallic alloys is about 0,1 less than the analogous as-cast alloys and alloys after homogenization [15].

Surface geometry measurements brought information that average arithmetic deviation of the roughness profile Ra and height of the roughness of 10 points of Rz profile are directly related to the grain size of the analyzed alloys. It was found that the greatest grain size the smaller roughness of the wear sign at its bottom. It is clearly seen for single-phase IM/Cr alloy (Fig. 8).

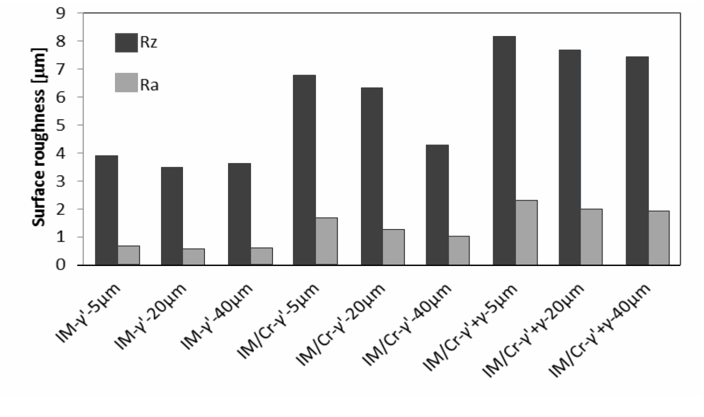

Fig. 8. Surface roughness at the bottom of the wear signs

Summary

Basing on the results of abrasive wear in loose abrasive following conclusions can be listed as following:

- Controlled rolling and Recrystallization allow to obtain desired grain size of the Ni_3Al intermetallic alloy;
- The smallest abrasive wear resistance in loose abrasive was for alloy with homogeneous structure (single-phase IM alloy) and grain size with EDC=40µm;
- Scratching and scalloping are the major damaging processes of the surface layer of the researched alloys;
- Shape of the pocket is caused by destructive interaction of material with loose abrasive and the greatest size is on the head of the pocket;
- The greater grain size the shallower signs of the abrasive wear;
- Relative abrasive wear resistance of the fine-grained Ni_3Al intermetallic alloys is about 0.1 smaller than analogous as-cast alloys and homogenized alloys;
- Surface roughness at the wear sign bottom decreases with Ni_3Al intermetallic alloy grain size increase.

Acknowledgements

Scientific work is funded by the Ministry of Education and Science in the years 2011 ÷ 2014 as a research project No. N N507 231 040.

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