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GRAIN SIZE INFLUENCES THE CORROSION AND CAVITATION OF Ni_3Al INTERMETALLIC ALLOYS

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Influence of grain size on corrosion and cavitation of the Ni_3Al - based intermetallic alloy was studied in recent paper. The research was conducted on Ni_3Al - based intermetallic alloy doped with boron and zirconium. The initial grain size of 6, 20 and 45 μm the investigated samples was obtained through cold rolling followed by recrystallization annealing. It was found that initial grain size does not influence the breakthrough potential neither repassivation potential. On the other hand, various types of pits were found for alloys with different grain size during corrosion tests in sodium chloride solutions. It was found that increase of grain size results with reducing the depth of cavitational pits. However, surface area of the pits increases with increasing grain size.

Key words: Ni_3Al alloy, corrosion, grain size/metallography, cavitation wear,

INTRODUCTION

Structural materials are exposed to a corrosive and cavitation environments during their exploitation. Damaging of even one crucial element of constantly working construction exposes one to the serious economic losses.

The phenomenon of a cavitation is based on mechanical damaging of the sample via implosion of the cavitation bubbles in the nearby or on the surface of the material, implying marials loss. A cumulative stream with velocity exceeding 100 m/s may appear in critical conditions [1, 2]. As a results of pressure pulses, strengthening of the surface layer takes place, however microcracks, materials losses and changes in the microstructure are also commonly observed [3-5].

Ni_3Al based intermetallic alloys are potentially attractive due to their physical and mechanical properties [6-8]. These materials exhibit a high yield strength and stiffness, high corrosion resistance and cavitation and abrasive wear in various environments. Moreover, their price is quite competitive in comparison to the classical heat-resistant nickel-based alloys.

Ni_3Al based intermetallic alloys with diversity of properties can be obtained by selection of the manufacturing technology, alloying elements, conditions of crystallization and processing technology [9]. Therefore, these materials have a potential to be applied in metallurgy, automotive, chemical and aviation industries in the next few years [10].

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EXPERIMENTAL RESEARCH

The material investigated was a Zr - and B – doped nickel aluminide with following chemical composition Ni-22Al-0.26Zr-0.1B (atomic %). Material in as-cast condition was subjected to cold-rollin to 60 % of thickness reduction followed by 1-hour recrystallization annealing. Temperature of recrystallization annealing (900 °C, 1 100 °C, 1 200 °C) was adjusted to obtain preassumed grain sizes of the investigated material.

Investigation of the structure and changes of the surface layer was carried out with Philips XL 30 (LaB_6) and Quanta 3D FEG scanning electron microscopes.

Geometrical topography measurements of the surface of the investigated alloys were carried out by a contact method with TOPO 01P v3D profilometer. Three dimensional analysis of a primary profile, a waviness profile and a roughness profile were taken.

Corrosion tests were conducted using anodic polarization. The experiments were conducted in 0,3 M and 0,9 M NaCl water solutions. Potential of the specimens were measured with saturated calomel electrode (SCE). A platinum grid was used as a counted electrode. During experiments the solution was stirred. To stabilize the open cell potential, the specimens were being immersed in the solution for 15 minutes before the polarization. The polarization was started from -600 mV and continued with 1 mV/s rate till reaching repassivation potential. Each specimen was investigated for five times, in order to obtain reproductive results.

STUDY RESULTS AND DISCUSSION

Results of SEM microsturcture evaluation revealed that applied thermomechanical treatment (cold rolling and recrystallization) allows to structure refinement of the alloy. Recrystallization annealing of the cold deformed alloy at 900 °C, 1 100 °C and 1 200 °C for 1 hour gives grain size of the γ' phase (ordered secondary solution based on Ni_3Al intermetallic alloy) equal 6 µm, 20 µm i 45 µm, respectively (Figure 1). Presence of biphase areas, being a mixture of γ' and γ phases (γ is a disordered solution of aluminum in a fcc nickel lattice). The phase composition of the materials was estimated basing on the chemical composition micro analysis supported also by the Ni-Al phase diagram. The energy dispersive spectroscopy EDS analyses revealed increased content of nickel in the biphase areas. Micro-hardness experiments have shown higher values of hardness of the biphase areas (hardness of γ'+ γ regions was approximately 360 HV since hardness of γ' grains was 320 HV), being probably an effect originating from strengthening impact of boundaries between phases.

Ni_3Al intermetallic alloy reveals typical behavior for nickel alloys during anodic polarization in aqueous solution of sodium chloride, what indicates on high corrosion resistance. It was found that grain size has no prominent impact on the value of the breakthrough potential. For all the specimens the breakthrough potential was approximately Ep = 300 mV in both electrolytes (0,3 and 0,9 M NaCl). Repassivation potential was also the same for all investigated specimens and equal to Es = 100 mV.

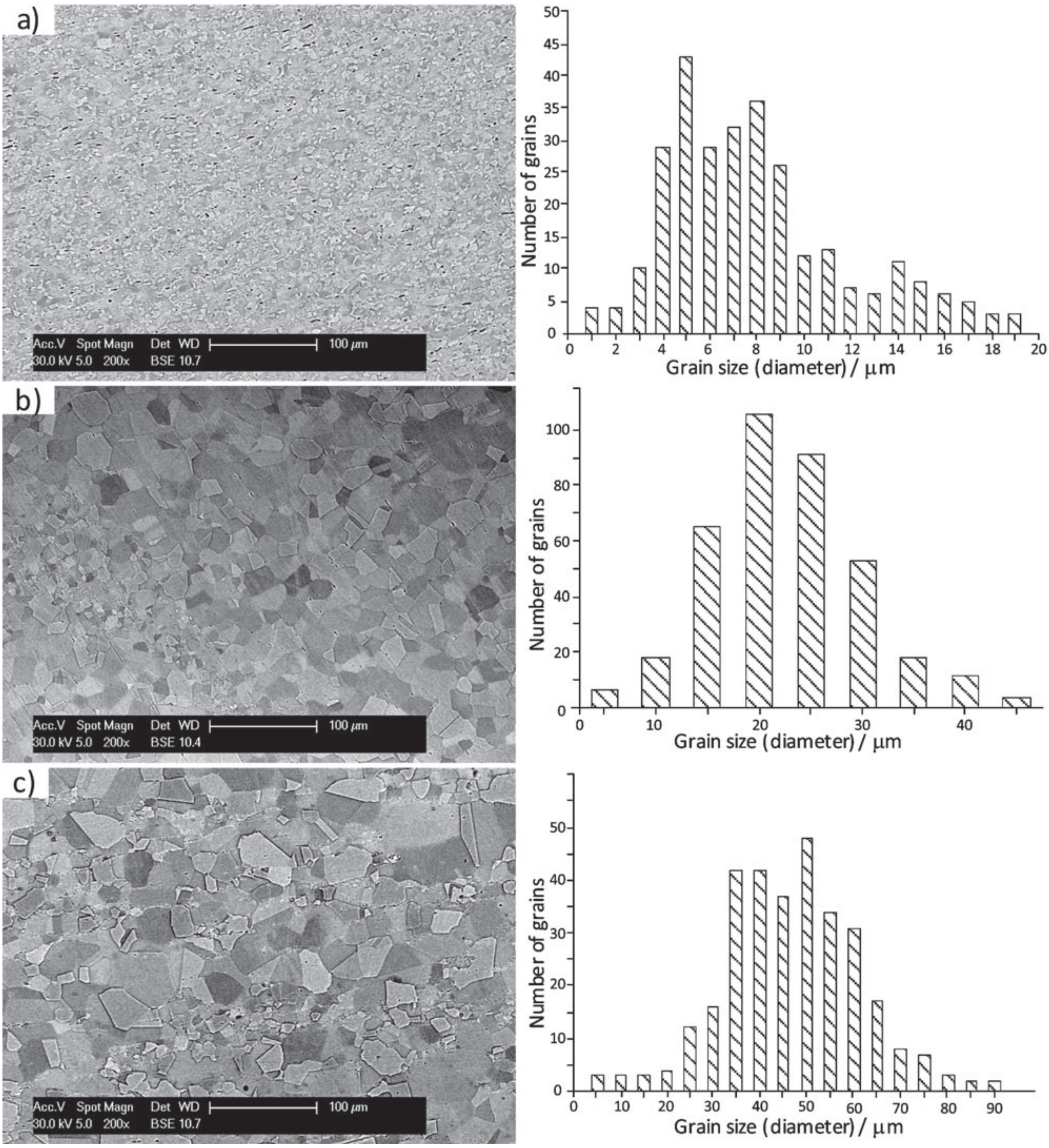

Figure 1 Ni_3Al alloy microstructure and matrix grain size histogram after cold-rolling and recrystallization at: a) 900 °C, b) 1 100 °C or c) 1 200 °C

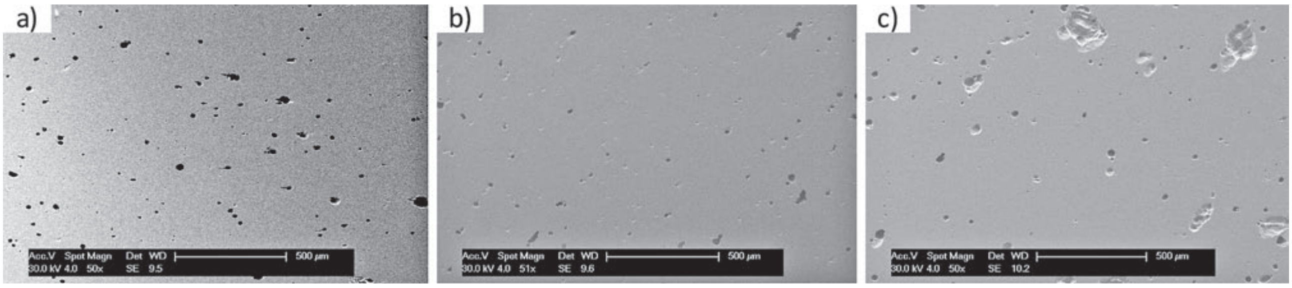

Figure 2 Effect of corrosive material loss of the Ni_3Al intermetallic alloy in 0,3 M water solution of NaCl for materials with varied ECD: a) 6 μm, b) 20 μm and c) 45 μm

Corrosive damaging of the material starts in the grain boundaries regions, or in the triple contact points. Consequently, compressive stresses occur which decrease corrosion resistant of the Ni_3Al matrix.

It was also found that the corrosion pits are different for investigated material with different grain sizes (Figures 2 and 3). The pits observed for material with a grain size of 6 μm are deeper, however they occupy smaller area of the surface (Figure 2). The depth of the pits was 6 μm and 28,7 μm for polarization in 0,3 and 0,9 M NaCl, respectively. Surface area occupied by the pits was 1,8 % (0,3 M NaCl) and 17,2 % (0,9 M NaCl). For specimens with grain size of 20 μm the pits had 9,6 μm (0,3 M NaCl) and 19,8 μm (0,9 M NaCl) depth. The pits occupied 4,3 % and 19,8 % of specimens surface area while the samples are polarized in 0,3 M and 0,9 M NaCl, respectively. The pits appearing in the specimens with a grain size of 45 μm have the smallest depth, however they occupy the greatest surface area of the specimen. Depth of the pits was 9,3 μm (0,3 M NaCl) and 15,7 μm (0,9 M NaCl). Surface area occupied by the pits was 5,4 % (0,3 M NaCl) and 22,8 % (0,9 M NaCl).

The results show that the greater is grain size the shallower are corrosive pits, on the other hand the greater is grain size the greater are surface area occupied by the pits. Analysis of the 3D waviness profiles confirm the aforementioned conclusion. It directly indicates that surface area occupied by the pits is increased for the when the initial grain size of the alloy is also increased. It also shows that the pits depth is inversely proportional to the equivalent grain diameter of the material.

The effects of the cavitation in deionized water on the surface of the Ni_3Al intermetallic alloy with various equivalent grain diameter (6 μm, 20 μm, 45 μm) are observed in the form of traces of plastic deformation in single crystallites of the matrix as well as traces of "etching out" of the microstructure in the surface layer of the alloy (Figure 3).

The greatest resistance towards cavitation wear in demineralized water, measured as a mass loss, possess the alloy with the smallest grain size. It lost 0,3 mg after 60 minutes exposure to the working medium (Figure 4a). The alloy with the medium grain size underwent to the greatest mass loss during the cavitation wear experiments (1,2 mg / 60 min) (Figure 4a). Obtained results of cavitation wear in 0,3 M NaCl in the open system revealed the smallest cavitation resistance for the specimens with EDC = 20 μm (about 2 mg / 60 min), however the specimens with EDC = 6 μm and EDC = 45 μm have similar cavitation wear resistance at the level of about 3 mg / 60 min (Figure 4b). Inversed tendency was noted for cavitation wear experiments in 0,3 M NaCl with applied breakthrough potential (EDC = 6 μm = 2,5 mg / 60 min, EDC = 45 μm = 3 mg / 60 min and EDC = 20 μm = 4 mg / 60 min) (compare Figure 4b to Figure 4c).

Extensive pitting was found to be an effect of cavitation wear of the Ni_3Al intermetallic alloys in 0,3 M NaCl (for both: with open cell and with application of breakthrough potential). The damaging process started in the grain boundaries or in the triple contact points. In these sites "uplifts" of the grains caused by the compressive stresses was commonly observed on the alloy surface.

Corrosion and cavitation cause appearance of micro-cracks of the material in the grain boundaries. These cracks lead to the initial mass losses in the triple contact points – noticeable pits are observed in these areas.

Gradual development of the micro-cracks leads to an appearance of arrays of craters along the grain boundaries. A depth of the craters causes increase of rate of the crushing or loss of all grains or presence of a

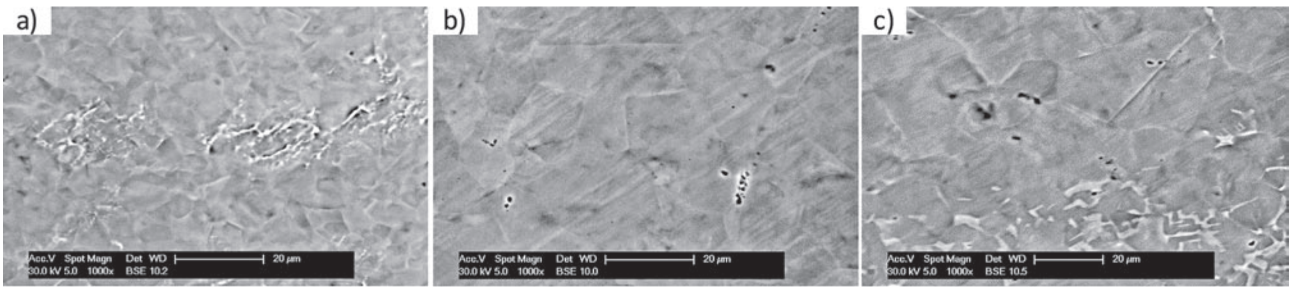

Figure 3 Effects of cavitation of Ni3Al intermetallic alloy in deionized water with varied ECD: a) 6 μm, b) 20 μm and c) 45 μm

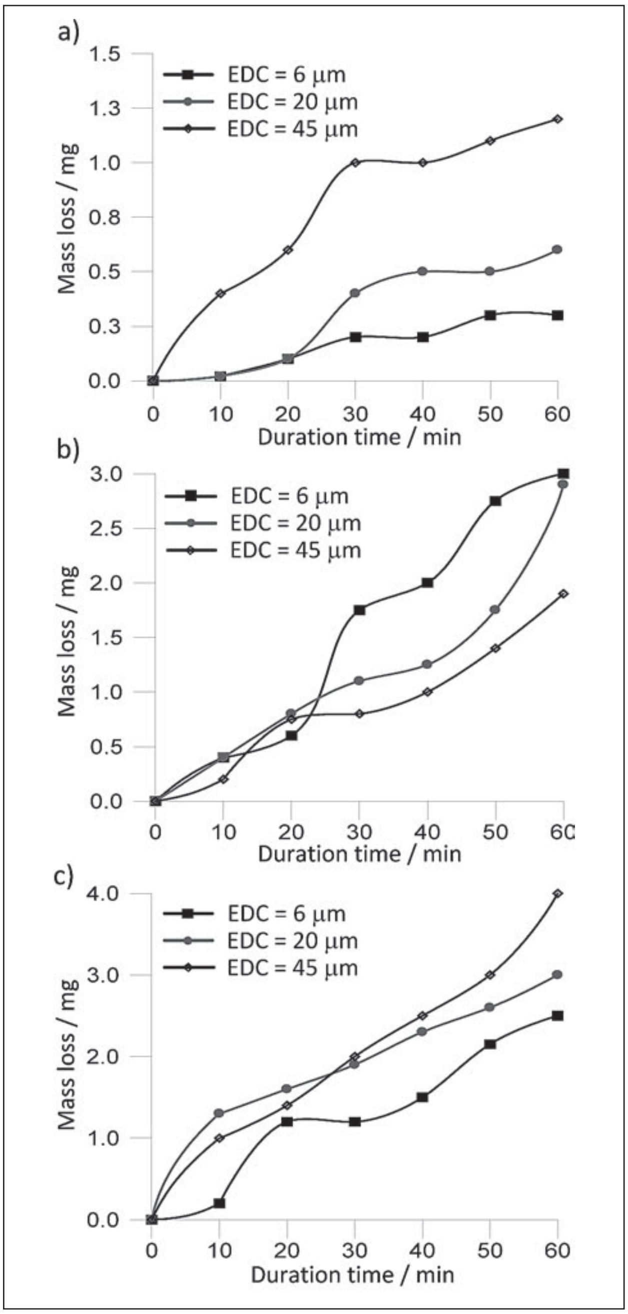

Figure 4 Cavitation wear of the Ni_3Al intermetallic alloy: a) in deionized water, b) in 0,3 M NaCl in open cel and c) in 0,3 M NaCl with applied breakthrough potential

critically strengthened areas. Grains orientation and fatigue stresses are the major factor influencing the mechanism of corrosive and cavitation wear of the material, what was confirmed by the observed fatigue stripes on the craters' walls and loss sites.

SUMMARY

Basing on the obtained experimental results following conclusion can be pointed out:

- Selection of proper rolling and recrystallization parameters allow obtaining Ni_3Al intermetallic alloy with desired grain size.
- Grain size of the Ni_3Al intermetallic alloys does not affect the breakthrough potential.
- Repassivation potential does not depend on the grain size of the Ni_3Al intermetallic alloys.
- Increase of the grain size cause decrease of the depth of the corrosive pits.
- Surface area occupied by the corrosive pits increases with increase of an equivalent grain diameter of the investigated alloy.
- Results have not revealed direct relationship between the grain size and cavitation or cavitation-corrosive wear of the investigated alloy.
- Micro-cracking initialize in the grain boundaries and triple contact points during the corrosive-cavitation wear.
- Crushing and losses of critically strengthened parts of grain or all grain takes place.
- Noticeable fatigue damaging and crushing after longer period of working medium interaction with alloys surface have been found.

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