



Effect of micro-alloying chromium on the corrosion resistance of nanocrystalline nickel aluminide intermetallic produced by mechanical alloying process

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ABSTRACT

In this study, $\text{Ni}_{50}\text{Al}_{50-x}\text{Cr}_x$ nanocrystalline intermetallic compound was synthesized by using the high energy mechanical milling of pure Ni, Al and Cr elemental powders for 16 h. The morphological investigation was done by using the optical and scanning electron microscope. The corrosion behavior of the samples was studied by using the electrochemical impedance spectroscopy in 3.5% NaCl solution. The results showed that when the micro-alloying Cr content is increased, the particles distribution is modified and the size of particles is decreased. Therefore the passive film which is formed on the surface of samples is less porous, so the corrosion resistance is increased.

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1. Introduction

High temperature oxidation and corrosion resistance properties have made NiAl as a material with high temperature potential [1–4]. But its weak ductility at room temperature limits its applications. Therefore, numerous efforts have been done in recent years to overcome this problem by adding the micro-alloying elements. Among the various micro-alloying elements which examined to improve the room temperature ductility of NiAl, Cr could be a suitable additive [4–8].

Mechanical alloying (MA) is known as a proper tool for synthesis of nanocrystalline intermetallics [9]. It has been reported that, in the materials which are prepared by MA, due to the extensive deformation, the internal energy of them increases and consequently their reactivity increases too. So, the corrosion behavior of alloys made by MA is different with alloys which are produced by other methods. For this reason, investigation of corrosion behavior of mechanically milled alloys can be useful. Some researchers have investigated the effect of Cr as alloying element on the corrosion behavior of nanocrystalline NiAl intermetallic [10–12]. But the main goal of this work is to investigate the effect of Cr as a micro-alloying element on the corrosion resistance of nanocrystalline NiAl intermetallic produced by the MA process.

2. Experimental procedure

High purity Ni, Al and Cr elemental powder blends were mechanically mixed for 16 h in a high energy planetary ball mill under Ar

atmosphere at a milling speed of 250 rpm. Various elemental blends with the composition of $\text{Ni}_{50}\text{Al}_{50-x}\text{Cr}_x$ (where $x = 0, 0.25, 0.75, 2.25$) have been studied. Hardened chromium steel balls were used and the ball to powder ratio was 20 in mass. The small amount of ethanol was added to prevent welding of powders to the steel balls and container.

X-ray diffraction with a D8 Bruker diffractometer (40 kV and 40 mA) and $\text{Cu}_{K\alpha}$ radiation ($\lambda = 0.154 \text{ nm}$) was used to analyze the crystal structure. The crystallite size and lattice strain variations were calculated by Williamson-Hall method.

The milled powders were compacted uniaxially with pressure of 400 MPa at room temperature to obtain cylindrical samples with diameter of 16 mm. For increasing the final density, the samples were

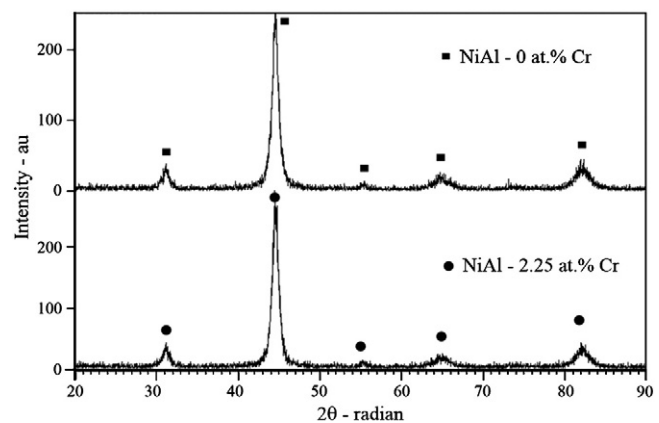


Fig. 1. The XRD pattern of the samples with 0 and 2.25 at.% of Cr.

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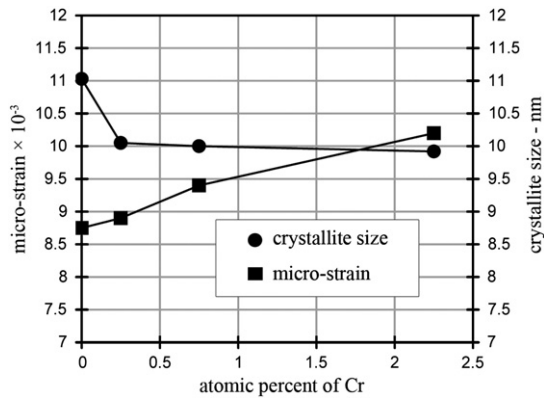


Fig. 2. The lattice strain and crystallite size of NiAl as functions of micro-alloying Cr.

hot pressed at 800 °C with pressure of 500 MPa. Finally, the samples were sintered in the Ar atmosphere at 1100 °C for 7 h.

Electrochemical impedance spectroscopy (EIS) tests were carried out in a 500 ml volume of 3.5% NaCl solution. These tests were done by using an EG & G 236A potentiostat coupled with a frequency analyzer system. A cell kit with a platinum counter electrode and a saturated calomel reference electrode was used. The samples with 1 cm² surface area were used as working electrodes. The potential amplitude was set to 5 mV in open-circuit and the frequency range was 102 to 105 Hz. Measurements for EIS tests began after an initial delay of 30 min for the sample to reach a steady state condition.

3. Results and discussions

Fig. 1 shows the XRD pattern of the samples including minimum (0 at.%) and maximum (2.25 at.%) amount of micro-alloying Cr. As it can be seen, the samples only show NiAl intermetallic phase.

Fig. 2 shows the crystallite size and lattice strain as functions of micro-alloying Cr contents. With increasing the Cr from 0 at.% up to

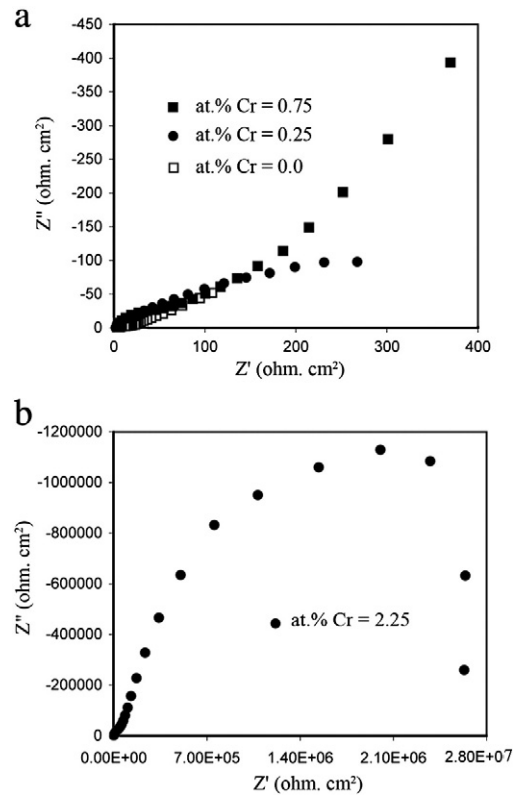


Fig. 4. Comparisons between EIS results of samples with various micro-alloying Cr.

0.25 at.%, the crystallite size of NiAl particles decreases from 11.03 nm to 10.5 nm and after that would be almost constant. Also the lattice strain increases from 0.87% to 1.02%.

Fig. 3 shows the surface image of samples with various micro-alloying Cr which were compacted uniaxially with the pressure of 400 MPa. It can be seen that, the samples with lower micro-alloying

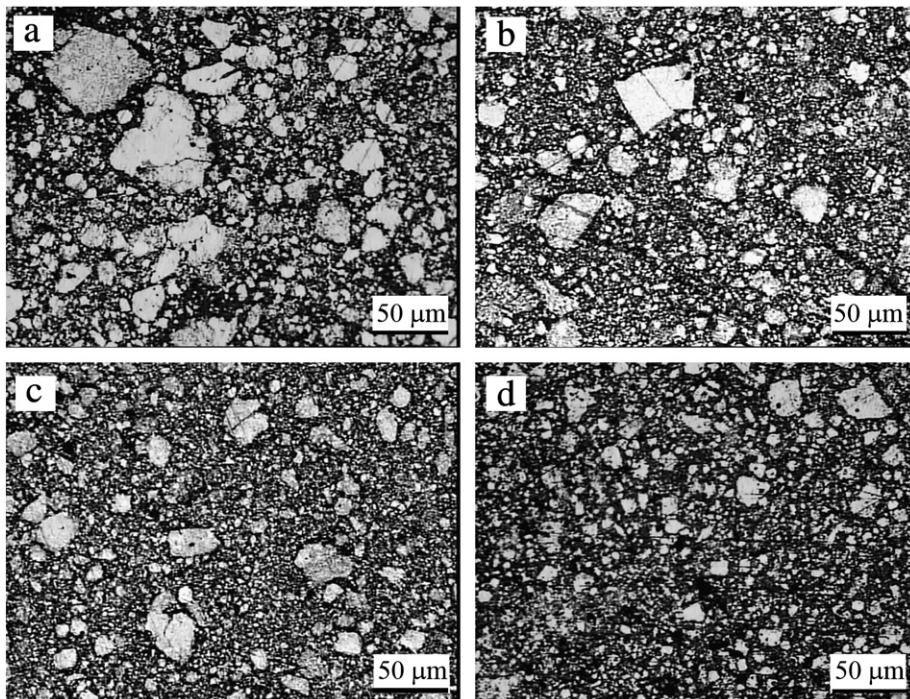


Fig. 3. The surface image of samples with various micro-alloying Cr: (a) 0 at.% Cr, (b) 0.25 at.% Cr, (c) 0.75 at.% Cr, (d) 2.25 at.% Cr.

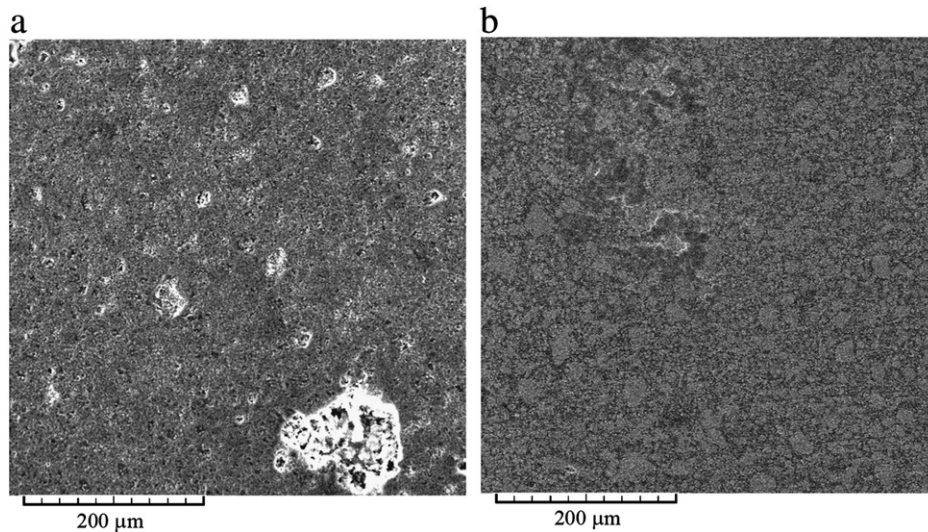


Fig. 5. The surface SEM images of the samples with (a) 0 at.% Cr and (b) 2.25 at.% Cr.

Cr include some great particles beside the finer particles. In fact, Cr dissolution in Ni is an exothermic process. The heat which is released from this reaction accelerates the reaction of Ni with Al. Hence, increasing the micro-alloying Cr accelerates formation of nickel aluminide [13]. Therefore, the nanocrystalline NiAl particles with higher micro-alloying Cr experience the higher milling times than the samples with lower micro-alloying Cr. So, the particle size of nanocrystalline NiAl in the samples with higher micro-alloying Cr decreases.

Fig. 4a and b compares the EIS test for the samples with various micro-alloying Cr via Nyquist diagrams. These figures show that the diameter of the capacitive curve for the samples with 2.25 at.% Cr is higher than other samples. This behavior means that the samples with 2.25 at.% Cr has a better corrosion resistance than the other samples. In fact these diagrams evidence that more micro-alloying Cr tends to improve the corrosion resistance of nanocrystalline NiAl.

The crystallite size of NiAl does not follow the micro-alloying Cr content (see Fig. 2), so the observed corrosion behavior of the nanocrystalline NiAl synthesized during MA process cannot be due to crystallite size. According to Fig. 2 the micro-strain of the nanocrystalline NiAl is raised with increasing the micro-alloying Cr. Thus logically the corrosion resistance must be decreased with increasing the micro-alloying Cr. According to Fig. 3, increasing the micro-alloying Cr improves the particles distribution of nanocrystalline NiAl. In fact, decreasing the particles size made better densification during compacting and sintering. Therefore, the passive film is more homogenous.

Fig. 5 compares the SEM images of the samples surfaces with 0 and 2.25 at.% Cr. As it can be seen the sample with 0 at.% Cr exhibits a porous surface while the sample with 2.25 at.% has a relatively dense surface. This means that, by increasing the micro-alloying Cr the passive film which is formed on the sample surface includes less porosity. For this reasons, the samples with higher micro-alloying Cr show the corrosion resistance better than the samples with lower micro-alloying Cr.

4. Conclusion

Although the corrosion resistance of nanocrystalline NiAl is improved in the presence of 0.25 and 0.75 at.% Cr, but a great improvement in the corrosion resistance take place in the 2.25 at.% Cr. Increasing the micro-alloying Cr leads to homogeneous distribution of nanocrystalline NiAl particles which exhibits the better compaction and sintering. So the samples with low micro-alloying Cr include larger porosity after sintering which act as places for corrosion initiation. The passive film on the samples with higher micro-alloying Cr is less porous than the passive film on the samples with lower micro-alloying Cr. Therefore the sample with 2.25 at.% Cr shows better corrosion resistance.

Acknowledgments

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