PRODUCTION AND CHARACTERIZATION OF HOT PRESSED Al-Ni ALLOYS

Erdem KARAKULAK, Rıdvan YAMANOĞLU, Muzaffer ZEREN, E. Evren DÜNDAR

Department of Metallurgical and Materials Engineering, Kocaeli University, Umuttepe Campus, Kocaeli, Turkey, erdemkarakulak@kocaeli.edu.tr

Abstract

In this study different amounts (up to 15 wt-%) of pure nickel powders were added to pure aluminium powders. The powders were mechanically mixed using a ball mill for 2 hours. Powder mixtures were sintered at 600 °C for 15 minutes in a hot press under vacuum. Microstructures and fracture surfaces of the specimens were investigated using a scanning electron microscope. The density, hardness and wear properties of the sintered compacts were studied. Density and hardness of specimens increased with increasing nickel content. Maximum wear resistance is obtained with addition of 10 wt-% nickel. Worn surfaces of the specimens were investigated to understand the wear mechanisms.

Keywords: Aluminium, Nickel, Hot Pressing, Sintering

1. INTRODUCTION

Aluminium alloys are very attractive because of their high strength-to-weight ratio, good corrosion resistance and high electrical/thermal conductivity [1-3]. A disadvantage of aluminium and its alloys is their limited application temperature. The research works about intermetallics are increased recently because of their potential application as high-temperature materials. The compounds in Al-Ni system are promising candidates for the use in high temperatures and oxidizing environments such as, automotive parts, fuel cell, biomedicine, turbin blade production and space systems [4,5].

Aluminium can only dissolve very limited amount of nickel atoms at solid state (0.028 % at 600 °C and 0.006 % at 500 °C) and five different intermetallic compound exist in Al-Ni system [6,7]. AlNi and the Al2Ni are the most stable phases in the binary system. These intermetallic compounds have high melting point, low density and high resistance to oxidation at elevated temperatures. The density of Al2Ni is two third and thermal conductivity is about 4-8 times of nickel based superalloys [8]. Some properties of these intermetallic crystals have already been investigated such as; shear modulus, Young’s modulus [9], enthalpies of formation [10-13] or elastic constants [14]. But some other properties such as hardness or wear properties are still lacking in literature. These properties are enormously important about applications of these intermetallic materials. This study aims to investigate hardness and wear properties of Al-Ni alloys produced with powder metallurgy with different nickel contents.

2. EXPERIMENTAL PROCEDURE

Pure nickel and aluminum powders are used in this study to obtain sintered compacts with different chemical compositions. The SEM micrographs of the starting powders can be seen in Fig. 1. As seen in the SEM images aluminium powders have a larger particle size and an irregular shape. Average particle size was 69 μm, 2,5 μm for aluminum and nickel powders respectively. The powder mixtures were mechanically mixed in an alumina container using zirconia balls for 2 hours. Fig 1(c) shows an image of the powders after mechanical mixing. The nickel powders are embedded to the surface of aluminium powders.
Al-Ni powder mixtures were consolidated at 600 °C for 15 minutes under 30 MPa pressure in a graphite die set using hot pressing technique under vacuum atmosphere. After sintering, the densities of the compacts were measured with Archimedes’ technique. To understand the effect of nickel content on the mechanical properties, hardness and wear tests were conducted. Vickers hardness tests were performed using a Future-Tech type vickers hardness tester under 10 kg load and 10 seconds of loading duration. All reported hardness values are based on the average of five measurements. To show the effect of nickel addition on the tribological properties of the sintered specimens, wear tests were conducted at room temperature under dry sliding conditions. Nanovea MT/60/NI type pin-on-disc tribometer was used in the wear tests. All wear tests were carried out under 20 N normal load using AISI 52100 steel balls (5 mm in diameter) as counterfaces. Sliding speed and sliding distance were kept constant at 0.13 m/s and 300 m respectively for all tests. The specimens were thoroughly cleaned with alcohol before and after the wear tests, and then dried with a hot air blower. The weight loss of the alloys was measured using an AND GR200 type microbalance with the resolution of 0.1 mg. The following equation was used to obtain the wear rate of the specimens: \( W = \frac{M}{\rho D} \), where \( W \) is the wear rate \((\text{mm}^3/\text{m})\), \( M \) denotes mass loss \((\text{g})\), and \( \rho \) (\(\text{g}/\text{mm}^3\)) and \( D \) (\(\text{m}\)) are the density and sliding distance respectively [15]. The worn surfaces of the specimens after wear tests were also investigated using scanning electron microscopy.

**Fig. 1** SEM image of starting powders (a) aluminium, (b) nickel and (c) after mixing
3. RESULTS

3.1. Microstructural investigations

Fig. 2 shows the microstructures of the specimens with different nickel additions (2.5-15 wt-%). As seen in the images increasing nickel amount in the specimens causes an increase in the amount of the intermetallic phases. The distribution of nickel containing phases are homogenous in the structure of the sintered compacts. Some micro sized pores were also reported in the microstructures of all specimens.

![Fig. 2 Optical micrographs of sintered specimens](image)

Fig. 2 Optical micrographs of sintered specimens, (a) 2.5 %, (b) 5 %, (c) 7.5 %, (d) 10 %, (e) 1.5 % and (f) 15 %

Fig. 3 shows the change of density as a function of nickel content. As expected density of the sintered specimens increases continiously with increasing nickel content.
Fig. 3 Effect of nickel content on the density of sintered specimens

Fig 4. shows the SEM images of the impact fracture surfaces of the specimens. The connection between metal powders seems to be established. The selected sintering parameters are suitable for this material. The fracture mode of the sintered compacts changes with increasing nickel amount. The cracks are visible in the high nickel containing specimens as a result of high hardness and brittleness.

Fig. 4 Fracture surface of specimens with different Ni additions, (a) Pure Al, (b) 5 % Ni, (c) 10 % Ni and (d) 15 % Ni
3.2. Hardness measurements

Hardness tests were conducted to understand the effect of nickel addition and intermetallic phases on the hardness of pure aluminium. As seen from Fig. 5, hardness of specimens increases with increasing Ni content. The increase of hardness is attributed to the increase in the amount of hard intermetallic phases in the material.

![Fig. 5 Change of hardness as a function of nickel content](image)

3.3. Wear tests

Dry sliding wear tests were applied to the sintered specimens to understand the effect of nickel additions. The obtained wear rate values are depicted in Fig. 6. The wear rate of the alloys increases with nickel addition to a limit value. Minimum wear rate was reported at 10 wt.% nickel addition. Further increasing nickel amount causes a slight increase in the wear rate of the material. The decrease in the wear rate is a result of the increase in the hardness of the material. Although increasing amount of intermetallic phases increases the hardness, they may effect wear properties negatively in some instances. In this case when size of a hard intermetallic increases the tendency for embrittlement and microcracking for that phase increases. The increase in the wear rate after 10 % nickel addition can be explained by this phenomenon.

![Fig. 6 Wear rate change with nickel addition](image)
3.4. Worn surface investigations

After wear tests the worn surfaces of the specimens were investigated to understand the wear mechanisms (Fig. 7). The SEM investigations showed severe plastic deformation on pure aluminium specimen. The aluminum is deformed as layers throughout the wear scar. With increasing nickel content the wear mechanism change to oxidation wear and the fracture of hard intermetallics are evident in Fig. 7 c and d. With further increasing nickel content the hardness and brittleness of the material increases. So the cracks perpendicular to the sliding direction forms and increases wear rate (Fig 7 e).

![Fig. 7 SEM micrographs of worn surfaces](image)

Fig. 7 SEM micrographs of worn surfaces, (a) pure aluminium, (b) 5 % Ni, (c) 10 %, (d) 15 % and 12.5 % Ni at higher magnification
4. CONCLUSIONS

Effect of nickel amount on microstructure, hardness and wear of Al-Ni powder metallurgical alloys was studied. The conclusions drawn are listed below;

- Materials containing Al-Ni intermetallics can be produced using pure powders with mechanical mixing and sintering.
- Increasing nickel amount increases size and amount of intermetallics.
- Hardness increases with increasing nickel content in the alloy.
- Wear rate of specimens are minimum at 10 % Ni and starts to increase in the specimens with higher nickel addition.
- Wear mechanism changes with different nickel amounts.

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