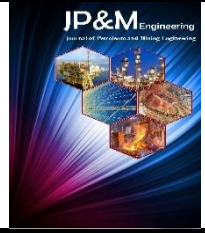




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## Fabrication of Aluminum Matrix Nanocomposites by Hot Compaction

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### Abstract

In this investigation, five aluminum matrix nanocomposites were obtained by the hot pressing at 800 MPa and 600 °C. The electrolysis coating technique was utilized to prepare the nano-nickel powder. The fabricated nanocomposites were characterized by studying their chemical composition, microstructure, hardness, and thermal expansion coefficient. The scanning electron microscope of the microstructure of the electroless nickel powder shows that the Ni particles have nano-size where it was less than 100 nm. The EDAX analysis of the fabricated composite that contains 25 wt. % (Al<sub>2</sub>O<sub>3</sub>) in different regions was established. No elements rather than Al, Cu, Ni, and O were observed. The hardness of the aluminum matrix increases as the content of the Al<sub>2</sub>O<sub>3</sub> increases. In addition, the thermal expansion coefficient was reduced by increasing the Al<sub>2</sub>O<sub>3</sub> content for reasons related to the low thermal expansion of the alumina reinforcement 7.2 x10<sup>-6</sup> mm/°C compared with aluminum that has 23.1x10<sup>-6</sup> mm/°C.

### Introduction

A composite material is a combination of two or more elements insoluble in each other. It can be fabricated by casting, or by extrusion, or by powder metallurgy techniques. Composite materials consists of a matrix and reinforcement. Based on the matrix of the composite, it can be classified into three types that are metal matrix composite (MMC), polymer matrix composite (PMC), ceramic matrix composite (CMC). reinforcements are used according to the needs application to achieve the required properties [1-3].

To add the reinforcement to the matrix and distributed it in a good manner without any agglomerations, the powder metallurgy technique is considered a good choice to achieve that. It is also a

cost-effective method for producing complex-shaped parts. In this process no need for melting the materials to produce the product where the production process proceeded at a temperature less than the melting temperature of the constituents that make the elements keeping its properties without any changes [4-7, 16].

In hot consolidation technique temperature and pressure are applied respectively to sinter a metal matrix. This process is performed to get a product with no porosity. When used for producing a diamond reinforced metal matrix to avoid the graphitization of diamond particles, it presents the advantage to strictly control the processing parameters (temperature, pressure and time). It seems like a spark plasma sintering process, but this process established without

power, where no need for current to pass it between two electrodes [8-11].

The automobile piston is exposed to severe working conditions from high heat and high impact forces as a result of gas exposure so that it needs to be manufactured from materials that have enormous strength and heat resistance properties. also, it is required to be lightweight and rigid to minimize energy consumption. [12].

Because of the lightweight of the aluminum metal, it was the preferred choice for fabricating the automobile piston. The aluminum metal suffers from its low wear rate and low strength so that it needs to be reinforced with a suitable material to improve its properties like alumina, silicon carbide, and or titanium carbide. Not only the morphology and properties of the reinforcement that affect the properties of the matrix, but also the bonding between the constituents has a great effect [13-15].

Rahimian et al. [17, 18] have studied the effect of alumina particle size and concentration on the properties of the aluminum matrix at different sintering temperature and sintering time by the powder metallurgy method. The results illustrate that using finer alumina particles and sintering temperature of 600 °C attributed to producing composites with high relative density (96.5 to 99%) and enhanced the mechanical properties.

This experimental investigation aims at explore the impact of the Al<sub>2</sub>O<sub>3</sub> content on the microstructure, density, thermal expansion, and hardness of the aluminum matrix.

## Materials and Methods

Aluminum powder 99.8% purity, copper powder of 99.8% purity, electro-less deposited Ni, and the Al<sub>2</sub>O<sub>3</sub> of the particle size 5-10µm (Lobo Chemie) are used as raw materials.

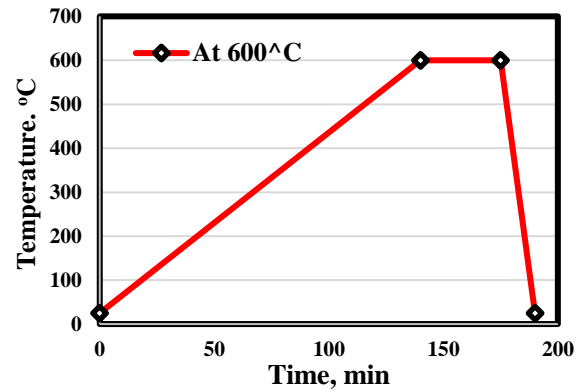
The alumina Al<sub>2</sub>O<sub>3</sub> power is cleaned and coated with 5 wt. % of Ag from a chemical composition contains 2 g/l AgNO<sub>3</sub>, 400 ml/l formaldehyde, pH=11, and 33% ammonia solution [5].

The deposition of the nano-nickel metal powder chemical composition is shown in table 1 [2].

**Table 1** Chemical composition bath of the electro-less nickel deposition.

Chemical	g/l
NiCl <sub>2</sub> , 6H <sub>2</sub> O	100 (g/L)
KNaC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ·4H <sub>2</sub> O	80 (g/L)
NH <sub>4</sub> Cl	50 (g/L)
pH	11
NaPO <sub>2</sub> H <sub>2</sub>	90 (g/l)
Heat	96 °C

The consolidation process is performed by hot pressing at 800 MPa and at 630 °C. Figure 1 shows the heating cycle.

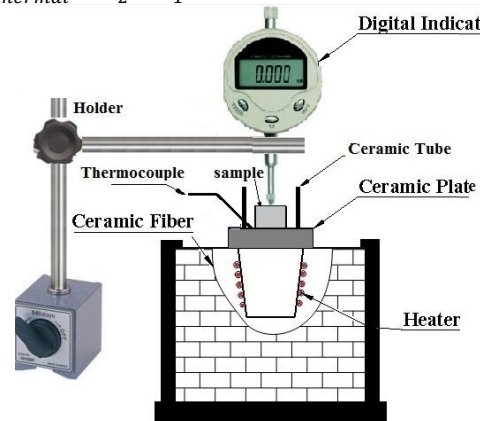


**Figure 1** Heating cycle

In order to characterize the microstructure of the fabricated composites, their surfaces are prepared by the grinding, and polishing processes. the scanning electron microscopy (SEM) QUANTA FEG250-EDAX is used to evaluate the microstructure. Also, the EDAX analysis and mapping are performed for the consolidated composites.

The thermal strain is measured according to the experimentally step-up shown in figure 2, at a temperature ranged from 150 to 450 °C. the thermal strain is determined from the following equation.

$$\epsilon_{thermal} = L_2 - L_1 \quad (1)$$



**Figure 2** Schematic diagram of thermal strain measurements [6]

The composites macro-hardness is measured using the Vickers hardness tester of the model 5030 SKV England, at 5 kg<sub>f</sub> load and 15 sec holding time.

## Results

Figure 3 shows the morphology of the used raw material powders. It is shown that the raw Al<sub>2</sub>O<sub>3</sub> powder is irregular with 1-5µm particle size. The raw Al, Cu, and nano-nickel Ni are nearly spherical.

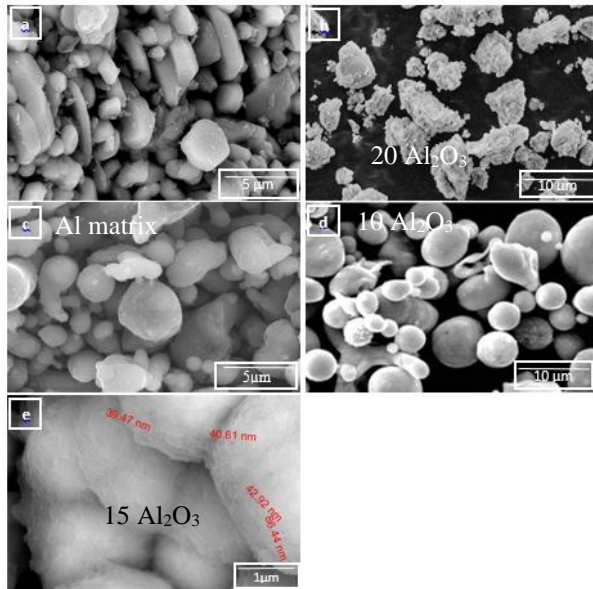


Figure 3 SEM micrograph of the used powders.

### Microstructure of Fabricated Composites

The microstructures of the fabricated composites reinforced with 0, 10, 15, 20, and 25 wt. %  $\text{Al}_2\text{O}_3$ , are shown in figure 4. As shown in the figure the reinforcements, which are Cu, Ni, and  $\text{Al}_2\text{O}_3$ , are homogeneously distributed in the Al matrix. Good adhesion between the different elements of the composite is observed. The main reason for improving the contact between the ceramic  $\text{Al}_2\text{O}_3$  and the Al matrix may be attributed to the coating of  $\text{Al}_2\text{O}_3$  with nano-particles layer of Ag [4-7].

The EDAX analysis of the fabricated composite sample that contains 25 wt. % ( $\text{Al}_2\text{O}_3$ -3Ag), is shown in figure 5. The analysis is performed in different regions to detect the type of the different elements and any new phases. No elements rather than Al, Cu, Ni, and O were observed.

### Hardness Evaluation

Figure 6 illustrates the effect of the ( $\text{Al}_2\text{O}_3$ -3Ag) on the hardness of the aluminum matrix. the figure shows that the hardness of Al/10Ni/10Cu increases with increasing the weight percent of the ( $\text{Al}_2\text{O}_3$ -3Ag). the highest value for the hardness is achieved at 25 wt. ( $\text{Al}_2\text{O}_3$ -3Ag). G. Abouelmagd [20] studied the effect of  $\text{Al}_2\text{O}_3$  additions and the hot deformation by the extrusion on the hardness and compressive strength of the pure aluminum and showed that the hardness was increased as the percentage of the  $\text{Al}_2\text{O}_3$  increases.

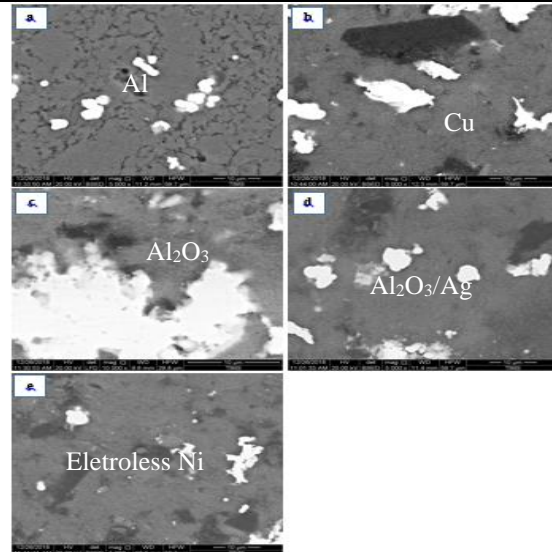


Figure 4 SEM of fabricated Al matrix non-composite

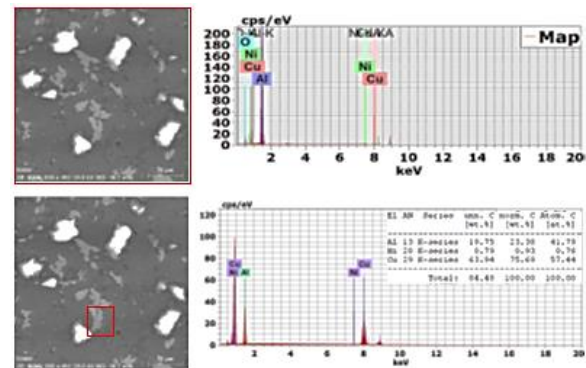


Figure 5 EDAX analysis of the fabricated Al/10Ni/10Cu/25wt.% $\text{Al}_2\text{O}_3$  nano-composites

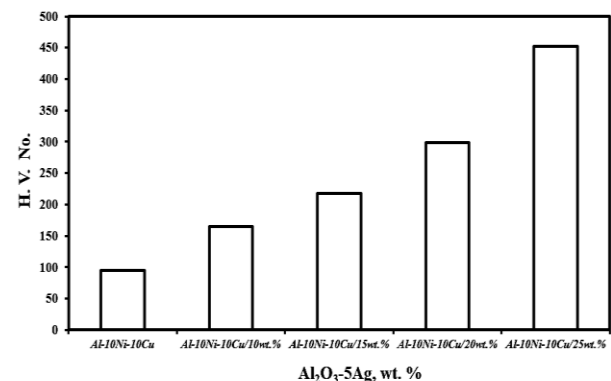
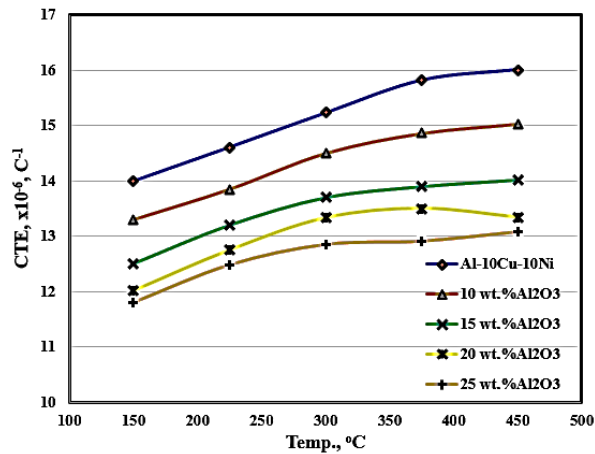


Figure 6 Micro-hardness of the fabricated nano-composites.

### Thermal Expansion

The effect of reinforcing (Al-10Cu-10Ni) nano-composites matrix with different percentages of  $\text{Al}_2\text{O}_3$  and the variation of temperature on the thermal expansion coefficient is shown in figure 7. As the figure shows, the CTE increases as the temperature increases. On the other hand, the CTE decreases with increasing the  $\text{Al}_2\text{O}_3$  content.



**Figure 7** Coefficient of thermal expansion of the different nano-composites

## Conclusions

- (Al-10Cu-10Ni)/X Al<sub>2</sub>O<sub>3</sub> nano-composites were successfully fabricated by the hot press method.
- The hardness of the aluminium matrix nanocomposite was increased gradually with increasing the percentage of the Al<sub>2</sub>O<sub>3</sub>.
- The thermal expansion coefficient was dramatically decreased by increasing the percentage of the Al<sub>2</sub>O<sub>3</sub>.

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