An investigation to the Effect of Copper Addition on the Characteristics of Ni-Ti Shape Memory Alloy

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Abstract

The effect of Cu addition on the physical and mechanical properties of Nickel-Titanium (weight percentage) shape memory alloy were investigated , density , porosity , compression strength ,Shape Effect (strain recovery), ,micro-hardness , Conducted to estimate the Cu effect ,a Different amount of Cu (2%,5%,10%) weight percent were added with different compacting

Pressure (450MPa and 600MPa). Significant effect on master alloys properties especially the alloys that have 5%Cu and 10%Cu has been observed.

Keywords: Shape Memory Alloys, Powder Metallurgy, marten site, austenite

Introduction

Shape Memory Alloys (SMAs) are a group of metallic materials having ability to return to a previously defined shape when subjected to appropriate thermal procedure The shape memory effect occurs due to a temperature and stress dependent shift in the material's crystalline structure between two different phases, marten site (low temperature phase) and austenite (high temperature phase). The temperature, where the phase transformation occurs, is called the transformation temperature. In austenite phase, the structure of the material is symmetrical; each "grain" of material is a cube with right angles.

When the alloy cools, it forms the marten site phase and collapses to a structure with different shape [1]. Nickel–titanium (Ni-Ti) alloys are commonly used in shape memory applications, although many other kinds of alloys also exhibit shape memory effects. These alloys can exist in final product form in two different temperature-dependent crystalline states or phases [2], the manufacturing and the technology associated with both of the two commercial classes of shape memory alloys are quite different as are the performance characteristics. Therefore, in applications where a highly reliable product with a long fatigue life is desired, the nickel–titanium alloys are the exclusive materials of choice which have been used in medical tools like arch wire for dental correction, eye glass frames and tissue

Separator for surgery uses In medical, highly reliable biological and chemical characteristics are very important. Nickel–titanium shape memory alloys have also been employed in artificial joints such as in artificial hip joints.

These alloys have also been used for bone plates, for marrow pins for healing bone fractures, and for connecting broken bones. Also this kind of alloy has been used in electric switches and actuators. However, if high performance is not mandated and cost considerations are important, then the use of copper–based shape memory

 Alloys can be recommended, also they are applied to hip replacements, considering the high level of super-elasticity, Typical applications of this kind include safety devices such as temperature fuses and fire alarms [3]. Ni–Ti shape memory alloys (SMAs) are attracting more and more attention, because of their unique characteristics such as shape memory behavior and super elasticity, especially in medical and aerospace applications. In addition, NiTi alloys are biocompatible properties and have good corrosion resistance, stiffness and damping characteristics. Shape memory and super elasticity of these alloys are due to thermoplastic martensitic transformation from high temperature austenite phase (B2) to low temperature marten site phase (B19). Cu addition results in enhancing the thermo elasticity, increased stability of characteristic temperature after mechanical deformation, narrow transformation hysteresis, decreasing the martensitic yield strength, reducing the composition sensitivity of martensitic start temperature, improvement in the fatigue resistance during thermal cycling, and prevention of the precipitation of Ti_3Ni_4 precipitates. However, addition of higher amount of Cu (higher than 10 at %) reduces the formability and fatigue life of the alloy. It is clear that the properties of the ternary TiNi Cu shape memory alloys are closely related to the martensitic transformation sequences, which obviously depend on the Cu content [4]
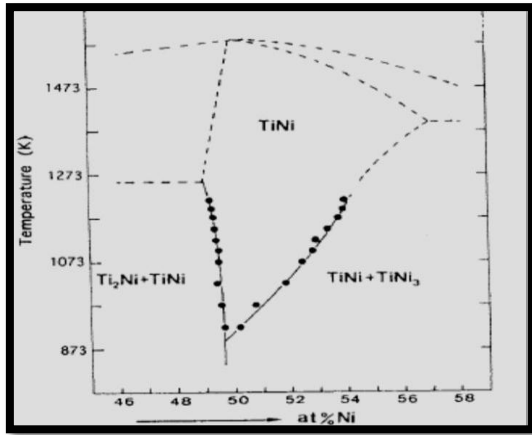
Figure.1: Equilibrium phase diagram for Nickel-Titanium binary phase diagram in the vicinity of Ni-Ti [1].
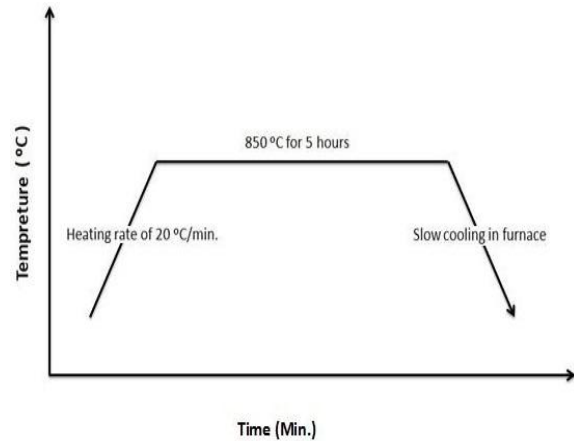
2. Experimental Work
2.1 Sample Preparation

All elemental powder which has been used in this study has been imported from (Sky Spring Nanomaterial's , Inc. USA) with the purity of 99.9 % and an average particle sizes of 45 micron (-325 mesh).The powders in percent were mixed by an electrical parallel mixer with 70 rpm for 5hr. One elemental powder additives (Cu) were used in four different weight percentage which are listed in Table 1.

Table 1: Sample with alloying element.

Ni%	Ti%	Cu%
50	50	0
48	50	2
45	50	5
40	50	10

Two types of samples from powder were prepared in the same die with a cross section of (14mm diameter and 5 mm thickness) and (11mm diameter and 16.5 mm length) as shown in fig. 3. The samples were pressed at (450 and 600) MPa in a computerized uniaxial press machine with a load capacity of 100KN, with a displacement rate of 1mm/minutes and a holding time of 4 minutes.

The sintering process of green compacts was performed in a vacuum tube furnace. Sintering process consists of heating to 850°C for 5hr and then the sintered sample is left to cool in furnace. A heating rate of 20°C/min is maintained for the sintering stage
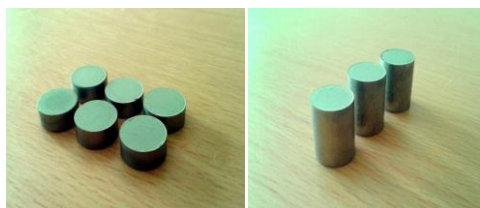

Figure 2: Green samples.

Figure.3: Diagram of sintering procedure.

2.2 Sample Testing

Porosity test was carried out by using Archimedes' rule by using Hock balance devise to weighting the sample in air and then weighted it in the basket hugging in distilled water full container then socking it for 24hr in distilled water and weighting it after dried by clothes from the water and calculate the apparent porosity and bulk density according to the equations 1 and 2 respectively[5].

Vickers micro hardness TH-715 china devise was used to conduct compression strength test on all samples with a holding time of 25 second. More than three readings of hardness were taken for each sample to get the mean value which represents the hardness.

$$Apparent\ porosity = \frac{Ws-Wd}{Ws-Wn} * 100 \qquad ..... (1)$$

$$Bulk\ density = \frac{Wd}{Ws-Wn} * pd \qquad ..... (2)$$

Where:
Wd : weight of dried sample .
Ws : weight of sample in the basket .
Wn : weight of sample after 24hr socking in distilled water .
pd : distilled water density.

Shape effect test was done to study the shape effect and the percentage of maximum strain back after heating by using uniaxial compression device, which was done by computing the actual length of samples before compressing ($L_\circ$), then it was compressed to 6% strain (max strain back for copper base) and release, then the resulting length (L_1) was computed, after heating it to 250°C for 5 min , finally the resulting length would be measured (L_2) .By measuring these lengths the shape memory effect will be computed by using the following equation :

$$\textbf{Strain recovery (shape effect)} = \frac{L2-L1}{L0-L1} *100\%$$

$$.... (3)$$

Where:
L_0: normal sample length

L_1: sample length after 0.06% length compacted
L_2: sample length after heating 110°C for 5 min.

3. Results and Discussion

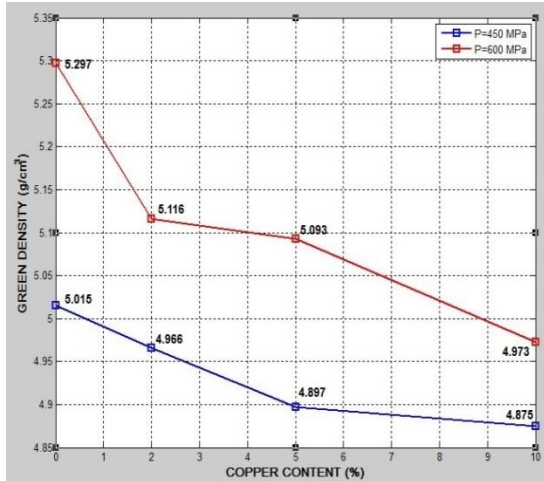1- The effect of copper content on the green density of master alloy is shown in Figure 4:

Figure 4: Green density as a function of copper content for compacting pressure 450 and 600 MPa.

The density of copper (8.95 g/cm3) slightly differs from nickel (8.90 g/cm3), As it is seen in figure Increase in percentage of copper from 0% to 10% would reduce the density with few reduction percent up to 2% at the compacting pressure of 450MPa and 6% when compacting pressure 600MPa, so green density increases with decreasing of copper content [6].

The density of the powder mass increases by increasing the compacting pressure because the total amount of porosity in the mass decreases. The uniform compacting stress applied to the upper punch when a single level cylindrical compact is pressed from one direction as used in this study, is not transmitted uniformly for both direction and magnitude of the stress throughout the compact. This leads to variation in density in the pressing direction due to the friction between the die wall and the powder. This friction is reduced by cleaning the dies after each process of compaction with acetone. Fig.(5) show Green porosity as a function of copper content for 450 and 600 MPa compacting pressure
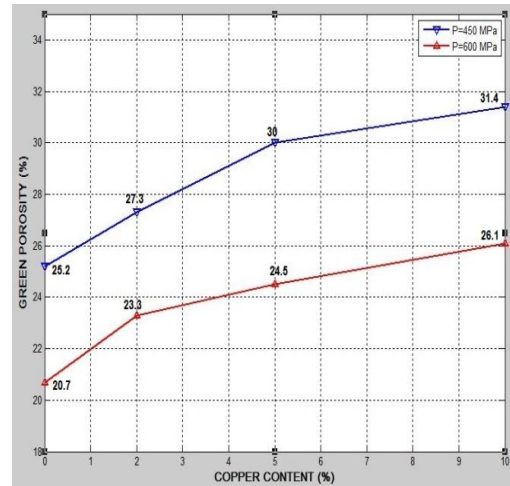

Figure 5: Green porosity as a function of copper content.

Porosity increased by 24.6% when compacting pressure was 450MPa, and increased by 26% when compacting pressure was 600MPa.
Fig.(6) shows Density after sintering as a function of copper content for compacting pressure 450MPa and 600MPa.
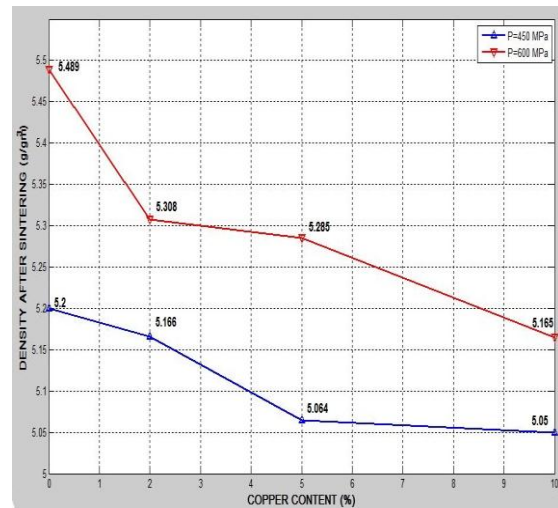

Figure 6: Density after sintering as a function of copper content for compacting pressure 450MPa and 600MPa.

The density after sintering is higher than the green density for all values of compacting pressure. The increase in density was about 3.5%, this increase is likely due to the shrinkage of the original pores during sintering. With increasing sintering time, the shrinkage of the original pores increases [7].
Sintering at 850C for 5 hours causes significant decrease of the density for every studied composition. Decrease of the density is closely leads to increase of the porosity after sintering as shown in Fig.(7).
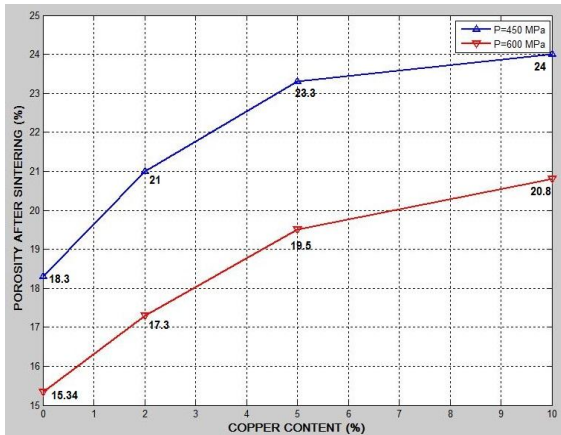
Figure 7: Porosity after sintering as a .
function of copper content for compacting
pressure 450MPa and 600MPa.

This increasing caused from that the diffusion of copper atoms in titanium is several times higher than diffusion of nickel atoms in titanium. Also, the diffusion ratio of copper and nickel atoms in titanium is higher than titanium in copper or nickel. As a consequence, titanium particles create a base for an alloy, where first copper atoms diffuse-in and second – nickel. In this manner, the volume of the pores increases. Using this mechanism, pores with smaller size can be created at the border between titanium particles and copper/nickel

Increase of the sintering temperature intensifies the diffusion while the average size of the pore also increases.

2-Effect of copper addition on the hardness of master alloy: Master alloy result was compared with the result of 2% , 5% and 10% copper addition. Figures 8 and 9 shows decrease in Vickers micro hardness with increasing in copper content.

Figure 8: Vickers micro hardness as a
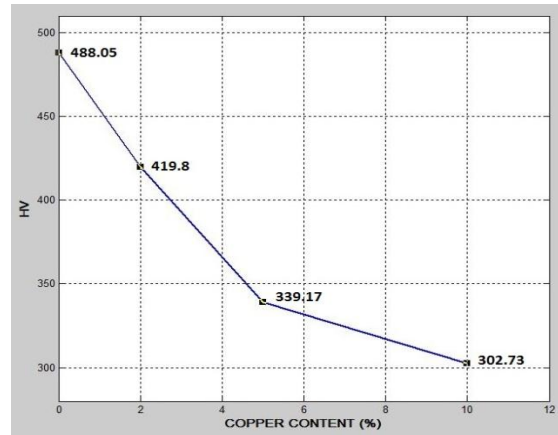function of copper content for compacting
pressure 450MPa.

Figure 9: Vickers micro hardness as a
function of copper content for compacting
pressure 600MPa.

Master alloy presented higher hardness values in comparison with 2% , 5% and 10% copper and so increase the copper content cause a decrease in hardness. The reduction was about 40% with an increased amount of copper from 0% to 10% when compacting pressure was 450MPa, and about 37% when compacting pressure was 600MPa. This reduction of hardness for the Ni–Ti–Cu in relation to Ni–Ti alloy can be associated to the change of microstructure morphology induced by copper addition. In fact, the lower level of hardness in Ni–Ti–Cu is expected since it is known that the copper addition makes the material more ductile by reducing the stress to induce or reorient variants of marten site [8].

3- Effect of copper addition on the compression resistance: All samples were placed under compression force until failure was determined as follow:

For the Cu addition in 450MPa and 600MPa compacting pressure, represented in Figures 13 and 14 . It shown an increase in applied force to start failure in the 2% , 5% and 10% additive.

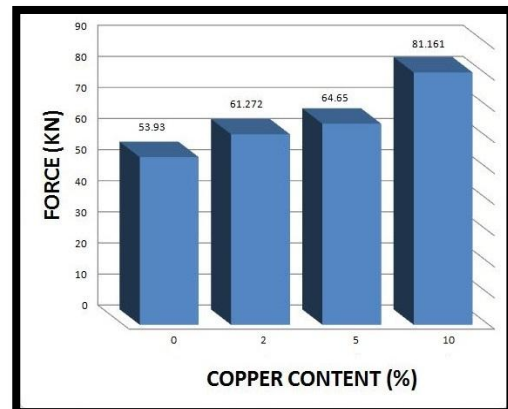Figures 10 and 11 shows Compression failure as a function of copper content.

Figure 10: Compression failure as a function
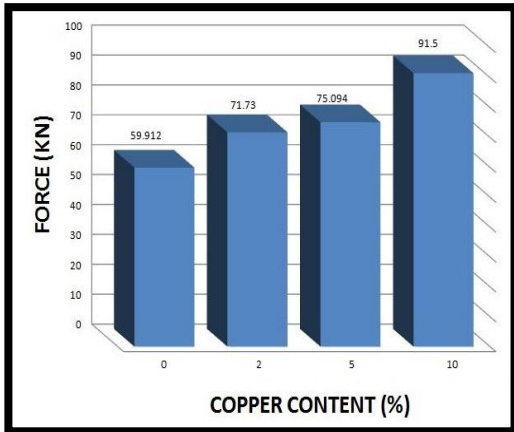of copper content for 450MPa.

Figure 11: Compression failure as a function of copper content for 600MPa.

As it is seen the compression strength results show that increasing compacting pressure from 450MPA to 600MPA and copper percent to 10%wt, leads to improve the compression strength of master alloy. This behavior might be due to the increase in compacting pressure and the copper addition makes the material more ductile, and improves the compression strength of the master alloy due to the decreases in the defects such as pores and micro cracks which act as a stress concentration region and may cause early failures of the alloy [9]

4- Effect of copper addition on strain recovery: Figures 12 and 13 show the retaining length recover percentage as a function of copper content for both 450MPa and 600MPa compacting pressure.
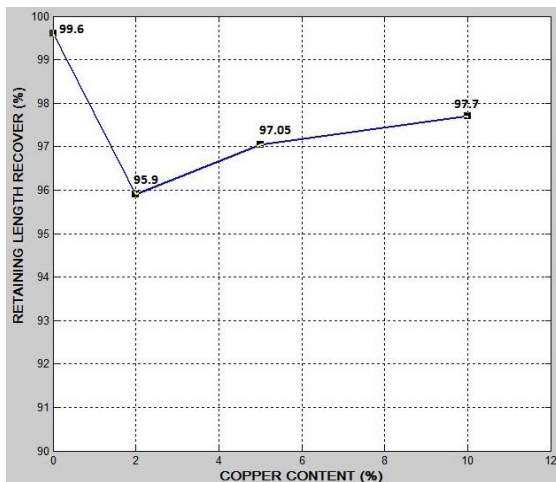

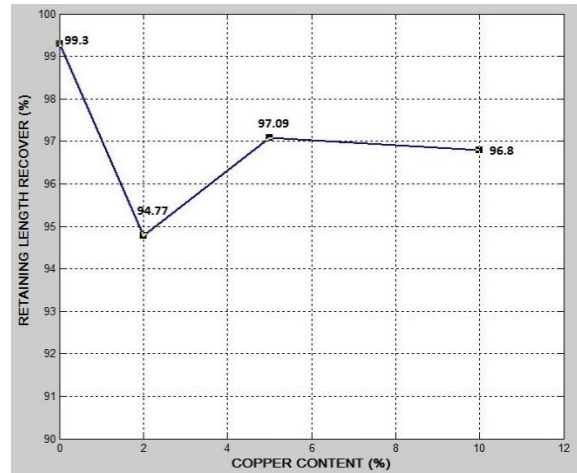**Figure 12:** Shape effect as a function of copper content for 450MPa

Figure 13: Shape effect as a function of copper content for 600MPa.

Shape effect ranged between 95.9% to 99.6% for 450 MPa , and 94.77% to 99.3 % for 600 MPa , that means this element made a good martensitic structure , which is then transformed to good austenite phase.

4. Conclusion

1. The suitable pressure force for powder compacting process is 600 MPa , this is obtained by using (450MPa and 600MPa) pressure force for sample compacting. The best density and apparent porosity values are at this pressure.
2. Volumetric percent of porosity is decreased with increasing compacting stress.
3. Hardness is decreased with increasing copper content.
4. Compression strength is increased with increasing copper content, also 600 MPa Compacting pressure gives high compression strength compared with 450 MPa.
5. All the rates of copper content (2% , 5% , and 10%) have a good martensitic structure , which is then transformed to good austenite phase according to shape effect test

5. References

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دراسة تحقيقية لتأثير إضافة النحاس على خصائص سبيكة نيكل – تيتانيوم العائدة للذاكرة

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الخلاصة:

تمت دراسة تأثير إضافة النحاس على الخصائص الفيزيائية والميكانيكية لسبيكة نيكل – تيتانيوم العائدة للذاكرة حيث تمت الإضافة بنسب وزنية، أجريَت إختبارات الكثافة، المسامية، مقاومة الإنضغاط، نسبة الرجوعية نسبة الرجوعية والصلابة لمعرفة تأثير إضافة النحاس حيث أضيفت بنسب مختلفة وهي (2٪، 5٪، 10٪) كنسب وزنية، كما تم كبس العينات بضغط كبس (450 و600)MPa . تمت الوصول الى نتائج تثبت تأثر هذه الخصائص على السبيكة الأساس خاصة عند إضافة نسب نحاس 5 % و 10 %.

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