The Physical and Mechanical Properties of a Shape Memory Alloy Reinforced with Carbon Nanotubes (CNTs)

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Abstract

The shape Memory Alloy (SMA) (Copper-Aluminum-Nickel) was prepared in the research by Powder metallurgy (PM) in component percentage (Cu-13% Al-4% Ni), pressure of (500 Mpa) in one direction, and sintering in (800°C) with Nitrogen gas for three hours. (CNTs) was added in percentage (0.0,0.5,1.0,1.5,2.0,2.5)% as a volumetric ratio at the relatively of the copper ratio to obtain advanced composites for Carbon Nanotubes with a distinct effect on properties. The elements of the alloy were analyzed using the (EDS) system attached to the Scanning Electron Microscopy (SEM) and study the X-ray Diffraction (XRD) to definition the elements and compounds formed after the process of sintering while imaging the microscopic structure by both Optical Microscopes and (SEM). The physical characteristics were studied as the results showed that by increasing the content of the Carbon Nanotubes (CNTs), The Bulk Density values of the (Cu-13% Al-4% Ni) decrease by ratio (23.5%) for content of Carbon Nanotubes (0%) to (2.0%) associated with an increase in True Porosity with the increase of the (CNTs) content at the same ratio (27.85%) and the impact is reversed when the content is increased to (2.5%) as it corresponds to the Water Absorption. The decrease in thermal conductivity corresponds to the increase in the True porosity ratio while slightly improving the amount Thermal Conductivity at an add (2.5%) percentage (2.0%) of the (CNTs). Some Mechanical properties, such as Hardness and Compressive Strength, have been reduced by increasing the content of the (CNTs) to (2%) While there has been a slight improvement in these two characteristics at the corresponding ratio.

1-Introduction

The alloy memory of the shape is part of the smart material that has the ability to re-order its dimensions when the thermal stress or mechanical strain external is removed and to be the beginning of the temperature transformation phase. The term alloy memory of the shape (SMAs) is called on the metal materials that has the ability to re Its shape and its initial size were prior to proceeding thermal and mechanical processes, and that property is not limited to metals only but appeared in polymers and ceramics [1,2]. Those Alloys (SMAs) of a unique category of metallic alloys that can be recovered when heated to certain temperatures and the (SMAs) pass to the two phases first a stable phase at the high temperature are called Austenite for the English scientist (William Chandler Austen). The second stage is at low temperatures and is called martensite for the German scientist (Adolf Martens) [3-5]. Those Alloys(SMAS) are classified into two types controlled by the base material, namely, The Nickel-Titanium alloys and copper-based alloys of their multiplications, their distinctive characteristics and their lesser cost. A copper-based alloys (SMAS) have been developed for high-temperature engineering applications such as remote sensors, engines and because of its ability to work at temperatures close to (200°C) instead of the Ni-Ti alloys that operate at maximum temperature is (100°C). These alloys are
widely used; they are much cheaper than Ni-Ti alloys and do not require any complex processing during their manufacture and are carried out for the memory alloys of the shape. Moreover, these alloys have a small hysterics and the possibility of switching in high temperatures compared to other alloys [6,7]. Those Alloys (SMAs) consists of minerals that show some unique and distinctive properties which are (Superplastic)(SE) and (Shape Memory Effect) (SME) which can be obtained through the change of phase in the solid state of reordering the atmosphere. The idea can be represented in a simplistic way, as it usually gets in the stage when the material becomes from solid to liquid or from liquid state to gas is the re ordering of atoms and molecules but the particles in the solid state remain closely interconnected by the act of the connections [8].

The research aims to prepare (Cu-13% Al-4% Ni) Shape Memory Alloys (SMAs) and its parameters are recognized by Powder Metallurgy (PM). The effect of the reinforcement in variable ratio of the (CNTs) on certain physical properties.

2- Methods technology and materials used
Samples prepared for research by Powder Metallurgy (PM), which are copper-Aluminum-Nickel the format and its parameters using (copper, aluminum and nickel powders) and reinforcement by the Carbon Nanotubes (CNTs) and The Table (1) shows the powders used in the search and their parameters.

<table>
<thead>
<tr>
<th>No.</th>
<th>Materials</th>
<th>Density (gm/cm³)</th>
<th>Purity(%)</th>
<th>Particle Shape</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Copper(Cu)</td>
<td>8.94</td>
<td>99.8</td>
<td>Dendritic</td>
<td>England</td>
</tr>
<tr>
<td>2</td>
<td>Aluminum (Al)</td>
<td>2.71</td>
<td>99.0</td>
<td>Dendritic</td>
<td>Germany</td>
</tr>
<tr>
<td>3</td>
<td>Nickel(Ni)</td>
<td>8.90</td>
<td>99.9</td>
<td>Dendritic</td>
<td>England</td>
</tr>
<tr>
<td>4</td>
<td>Carbon Nanotubes (CNTs)</td>
<td>2.10</td>
<td>95.0</td>
<td>Multiwall Tubes</td>
<td>USA</td>
</tr>
</tbody>
</table>

A special breach was used to ascertain the size of the particles in the work and because of the large variation in the density of the antigen, it was introduced consideration in the initialization of the alloy and the size of the volumetric ratios and by The Table (2) using a delicately sensitive electric balance (0.0001) grams.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Chemical Composites %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu</td>
</tr>
<tr>
<td>A</td>
<td>83.0</td>
</tr>
<tr>
<td>B</td>
<td>82.5</td>
</tr>
<tr>
<td>C</td>
<td>82.0</td>
</tr>
<tr>
<td>D</td>
<td>81.5</td>
</tr>
<tr>
<td>E</td>
<td>81.0</td>
</tr>
<tr>
<td>F</td>
<td>80.5</td>
</tr>
</tbody>
</table>

The constituent powders of each sample are mixed with a one-hour laboratory mixing device to ensure homogeneity and blend in a metal mold with a (10 mm) diameter and (5 mm) a height, Press pressure (500 Mpa) was pressed using a test machine (Universal Testing machine) and then sintering by temperature (800 °C) for three hours and existence Nitrogen Gas and then leave the samples inside the oven as gas continues to flow to the temperature of the room and to ensure that the oxidation does not get the samples are placed inside layers of the graphite powder and cast iron chip as well as covered with fire clay and this is all Subject in a metal container allocated for this purpose while allowing the flow of Nitrogen gas within it during the sintering process which as shown in Figure (1), and as Figure (2) chart the flow diagram of the experimental part of the search.
Sintering in Furnace at (800 °C) for three hours and Nitrogen gas

Figure (2) chart Flow Diagram for Experiment part.
3- Physical Measurements

3-1 Microstructure Examination
For the purpose of microscopy, the samples were smoothed using paper containing granules (SiC) and a continuous water current. The samples were then polished with polishing cloth and diamond paste. The polishing process was done manually. After each stage of polishing and polishing, the samples were washed with water and alcohol as well as drying, so that the samples are prepared for Microstructure Examination using optical microscope and Scanning Electron Microscope (SEM) as well as analysis of elements in the EDS system.

3-2 Porosity, density and water absorption
Physical tests consisting of bulk density, apparent density, true porosity, apparent porosity and water absorption were performed by following Archimedes base according to the global Standard (ASTM C373-88) using a sensitive electrical balance, as the samples dried for one hour using an electric oven at a degree heat (150 °C) and left to cool inside the furnace, then weight each the sample after taking it out of the oven and this weight is called Dry Weight (Wd). The samples were placed in boiled water for five hours and then transported to a bowl containing distilled water at room temperature for 24 hours and after the removal of the samples the surface water was removed, the samples are then weighed in saturated weight (Ww). The sample is weighed and suspended and immersed in distilled water with a sensitive balance and weight is (Ws) then each of the bulk density is calculated (B.D.), apparent density (A.D.), the true porosity (T.P.), apparent porosity (A.P.) and Water (W.A.) Use of the following relations [9-12]:

\[ T.D. = \sum_{i=1}^{n} (\rho_i X_i) \]  

(1)

\[ B.D. = \frac{Wd}{Ww-Ws} \times \rho w \]  

(2)

\[ A.D. = \frac{Wd}{Ww-Ws} \times \rho w \]  

(3)

\[ A.P. = \frac{Ws-Wd}{Ww-Ws} \times 100\% \]  

(4)

\[ T.P. = \frac{T.D.}{B.D.} \times 100\% \]  

(5)

\[ W.A. = \frac{Ww-Wd}{Ww} \times 100\% \]  

(6)

\( \rho w \): Water density (gm/cm³)

\( X_i \): The ratio of each element (%).

\( T.D. \): theoretical density.

3-3 Thermal conductivity
Thermal conductivity is defined as the rate of hypothermia during the unit of space for the unit of time. (when there is a thermal difference between the two surfaces, the temperature is transported from the high temperature surface to the surface with low temperature) [13]. Thermal conductivity was calculated using a Hot Disc system and factory from the Swedish company (Keithley), shown in Figure (3).

Figure (3) Thermal conductivity measuring device.

3-4 X-Ray Diffraction (XRD)
X-ray diffraction device produced by Japan-based “SHIMADZU” was used and the target used in the tube is (CuKα) It obtained the spacing of atomic levels values (d) for each sample. At the same time, the phases created through the use of the software (Match2) were obtained.

3-5 Mechanical Measurements
3-5-1 Hardness
Hardness is a measure of material resistance to corrosion and corrosion on the outside surface, which is exposed to each of these effects, the Vickers method was used to measure the hardness using a microscopic Vickers hardness device and the rigidity can be calculated theoretically according to the following equation [14]:

\[ \text{Hardness Vickers} \text{(H.V.)} = \frac{2F \sin \left( \frac{180}{12.25} \right)}{d^2} \approx 1.85 \frac{F}{d^2} \]  

(7)

F: The strength of the needle pressure on the model surface (kg. Strength) (Kgf).

\( d \): the distance between the diameters (d1, d2) (mm).

3-5-2 Compressive strength
Known as the body’s resistance to external stresses and calculated from the following relationship [15]:

\[ \sigma = \frac{2F}{nhD} \]  

(8)

\( \sigma \): Compressive strength (Mpa).

F: Force exerted on the sample (N).

h: Sample height (mm).

D: Sample diameter (mm).

4- Results and Discussion
4-1 Physical Properties
The relationship between the bulk density (B.D.) and the content of the (CNTs) in figure (4) and shows that the increase in the content of the (CNTs) has led to a decrease shown in the density of the shape memory alloy (Cu-13% Al-4% Ni) until it reaches (2%) of the content of the CNTs as it decreases by the amount of (23.5%). This behavior is due to the low intensity of the (CNTs) used in the research as it is (2.1 gm/cm³) as compared to copper so increasing the content of the (CNTs) reduces the density of the overlapped as well as the slope of the (CNTs) to the conglomerate around each other and the distances Interfaces between overlapping components resulting in the impairment of the proliferation of the components and the acquisition of the merger (Consolidation), thereby decreasing the proportion of the formation of rigid solutions in the solid state during the sintering process and thus weaken the correlation between the components and with it the bulk density is reduced and this is agreed with [16-17] For other alloy-based copper-fortified alloys and
tracers. And since the (CNTs) It has unique physical and mechanical properties of its kind, and has increased bulk density at the rate of addition (2.5%) by (7.87%) than it is at (2%) for the content of the (CNTs) This behavior may indicate that the increase in the percentage of CNTs (2%) has an opposite effect as it leads to increased density of Volumetric and this is agreed with [20] for composite copper reinforced with carbon nanotubes and for the content (CNTs) variable. The figure (5) shows the relationship between the apparent density and the content of the (CNTs), noting through a decrease in the amount of apparent density when increasing the content of the (CNTs), At the rate of Add (CNTs) (2.5%), a rise in the value of the virtual density corresponds to the observed behavior and content in the figure (4) which is also agreed with the conduct with [20] copper-reinforced ratios of the (CNTs).
The True porosity ratio increases by increasing the content of the (CNTs) (Cu-13% Al-4% Ni) by ratio (27.85%) for (CNTs) (0-2.0)% This corresponds to the practical results we have achieved in figures (10) and (11) this agreed with [16,17] for alloys Other metal parameters are in the graphite, while at the percentage of content (2.5%) There is a shift in the previous concept as the true porosity decreases by (9.24%) compared with overlapping (2%) (CNTs) which corresponds to the behavior of densities at the same ratio and agreed with [21]. The relationship between the apparent porosity and the content of the CNTs is shown in Figure (11). During the form, an increase in the apparent porosity ratio is observed by increasing the content of the CNTs (2.0%) to an additional limit (22.8%), and then the ratio of (20.0%) to the content of (CNTs) (2.5%). And that this behavior is compatible with True porosity behavior as the factors that control the closed pores are the same as those that control the open pores and that the mechanisms of these two types of porosity are the same and this behavior is agreed with [16,17,20] for copper-alloy alloys, as well as carbon nanotubes.

The relationship between the rate of water absorption and the content of the (CNTs) is in figure (13) As we note the increase in absorption by increasing the content of the (CNTs) (2%) by (44.90%).
The relationship between thermal conductivity and the content of the (CNTs) is noted in Figure (14), as the thermal conductivity and reinforced (CNTs) corresponds to the behavior of both bulk density and apparent density and at the same ratio while the behavior is opposite to what is found in the pores because of their The role in lowering the conductivity whether thermal or electrical this is consistent with what it found [18-19] for alloys and copper-based and fortified with garages and carbon nanotubes. At the rate of (CNTs) (2.5%) the thermal conductivity increases by (5.04%) compared to the content (2%) due to high conductivity for the carbon nanotubes that reach (1812 W/M.K) which may have an impact on increasing the percentage of pores and this in turn will positively reflect on the improvement Thermal properties are consistent with [20-21] copper-reinforced carbon nanotubes.

4- Mechanical properties
4.1 Vickers Hardness
Figure (15) shows the relationship between the amount of Vickers microscopic prayer and the CNTs content of the (Cu-13% Al-4% Ni). The shape describes the behavior of the decrease in the amount of hardness by increasing the content of the CNTs (56.81%) for the CNTs content from (0%) to (2.0%). This is agreed with [13] the behavior of other compositions. The increase of (CNTs) from (2%) to (2.5%) makes a slight improvement in the value of Vickers hardness and this is consistent with the [20,21] copper alloy reinforced with (CNTs).

Conclusions
1) The bulk density, the apparent density, and thermal conductivity are decrease with increase the content (CNTs).
2) The True porosity, the apparent porosity, and the water absorption are increase with increase the content (CNTs).
3) The mechanical properties such as, Vicker's hardness and compressive strength are decrease with increase content (CNTs).
4) The ratio of the addition of (2.5%) from carbon nanotubes changes in physical and mechanical properties in comparison with the ratio (2.0%) from (CNTs).
References


الخواص الفيزيائية والميكانيكية لسبيكة ذاكرة لمشكل مقواة بأنابيب الكاربون النانوية

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المتخص

الخواص الفيزيائية والميكانيكية لسبيكة ذاكرة لمشكل مقواة بأنابيب الكاربون النانوية

خُضِعَت سبيكة ذاكرة لمشكل (Cu - Al - Ni) في بحثنا هذا بنقادة ميتالورجيا الساحيق (PM) ونسبة مكونات (PM) ونسبة مكونات (PM) ونسبة مكونات (PM) (500 Mpa) باتجاه واحد والتبديل بدرجة حرارة (800°C) لمدة ثلاث ساعات ووجود غاز النيتروجين (N₂) وكانت إضافة أنابيب الكاربون النانوية (CNTs) بالنسبة (0,0,5,1,5,2,0,5,1,5,2) كنسية حجمية على حسب نسبة النحاس للحصول على متراكبات متقدمة لما لأنابيب الكاربون النانوية من تأثير متميز على الخواص.

تم تحليل العناصر للمسبكة ومتراكباتها باستخدام منظومة (EDS) ودراسة جيود الأشعة السينية (SEM) لتحديد العناصر والمركبات المتكونة بعد إجراء عملية التلقيح وتصوير البنية المجهرية بكل من المجهر الضوئي (Optical Microscope) و المجهر الإلكتروني الماسح (SEM) و دراسة حيود الأشعة السينية (XRD).

درست الخصائص الفيزيائية إذ أظهرت النتائج أنه بزيادة محتوى أنابيب الكاربون النانوية (CNTs) نخفضت قيمة الكثافة الحجمية للمسبكة (Cu - 13% Al - 4% Ni) ومتراكباتها بنسبة مقدارها (23.5%) لخفضت تزايد الكثافة السماوية (2.0%) وترافت زيادة زاوية المحمولة (9%) و كما أظهرت زيادة مقدارها (27.8%) وزيادة محتوى الميكانيكية على متراكباتها (0.5%) عند ذات النسب بنسبة مقدارها (2.5%)، إذ يتطابق السبب مع قابلية استغلالية الماء، وأما الموصية الحرارية فإن سلكها يتطابق مع سلك الكثافة السماوية وفي ذات النسب، وانخفضت بعض الخصائص الميكانيكية كالصلادة ومقاومة الانضغاط بزيادة محتوى الذ (CNTs) إلى نسبة (2%) بينما حسب دراسة طيف تلك الخصائص عند النسب المتوقعة.