ISSN: 1813 – 1662 (Print)
E-ISSN: 2415 – 1726 (On Line)

TJPS

TIKRIT JOURNAL OF PURE SCIENCE

Journal Homepage: http://main.tu-jo.com/ojs/index.php/TJPS/index

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

Raed N. Razooqi[1] , Khalid H. Razej[2] , Ahmed T. Abdulhameed[2] , Saif S. Irhayyim[1]

[1] Department of Mechanical Engineering , College of Engineering , University of Tikrit , Tikrit , Iraq
[2] Department of Physics , College of Education for pure science , University of Tikrit , Tikrit , Iraq

ARTICLE INFO.

Article history:
-Received: 14 / 2 / 2018
-Accepted: 3 / 4 / 2018
-Available online: / / 2018

Keywords: Shape Memory Alloys, Powder Metallurgy, Carbon Nanotubes, Cu-Al-Ni alloys, Physical and Mechanical Properties.

Corresponding Author:

Name: Ahmed T. Abdulhameed
E-mail: ata_life@yahoo.com
Tel:

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 (0,0.5,1.0,1.5,2.0,2.5) % 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 Austanite for the English scientist (William Chandler Austen). The second stage is at low temperatures and is called martinsite 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

ISSN: 1813 – 1662 (Print)
E-ISSN: 2415 – 1726 (On Line)

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 Naonotubes (CNTs) and The Table (1) shows the powders used in the search and their parameters.

Table (1) The powders used in the search

No.	Materials	Density (gm/cm^3)	Purity(%)	Particle Shape	Origin
1	Copper(Cu)	8.94	99.8	Dendritic	England
2	Aluminum (Al)	2.71	99.0	Dendritic	Germany
3	Nickel(Ni)	8.90	99.9	Dendritic	England
4	Carbon Nanontubes (CNTs)	2.10	95.0	Multiwall Tubes	USA

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 (2) volume fraction of materials in alloys.

Samples	Chemical Composites %			
	Cu	Al	Ni	CNTs
A	83.0	13	4	0.0
B	82.5	13	4	0.5
C	82.0	13	4	1.0
D	81.5	13	4	1.5
E	81.0	13	4	2.0
F	80.5	13	4	2.5

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.

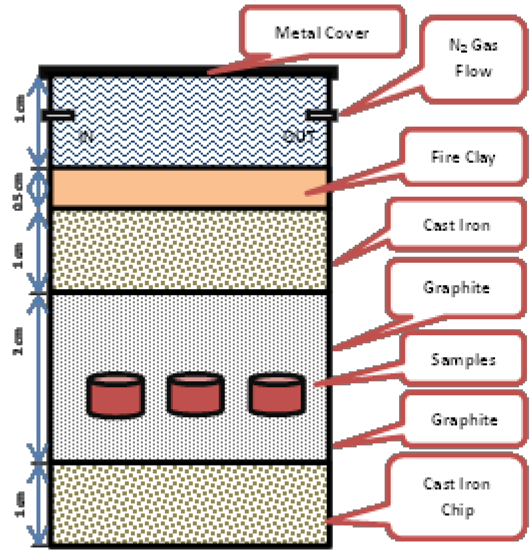

Figure (1) Plan for metal container during sintering process

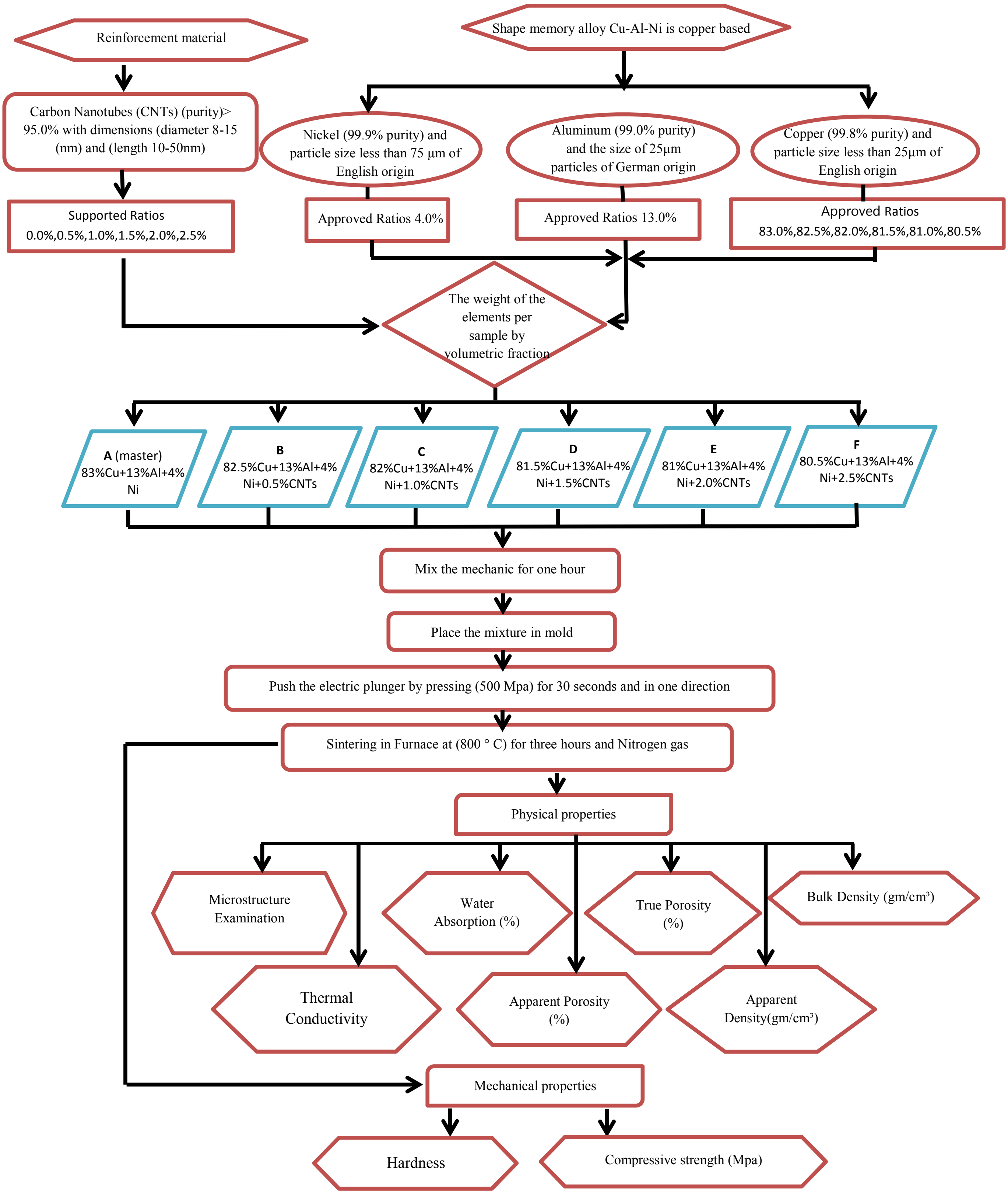
Reinforcement material
Shape memory alloy Cu-Al-Ni is copper based
Carbon Nanotubes (CNTs) (purity)> 95.0% with dimensions (diameter 8-15 (nm) and (length 10-50nm)
Nickel (99.9% purity) and particle size less than 75 µm of English origin
Aluminum (99.0% purity) and the size of 25µm particles of German origin
Copper (99.8% purity) and particle size less than 25µm of English origin
Supported Ratios 0.0%,0.5%,1.0%,1.5%,2.0%,2.5%
Approved Ratios 4.0%
Approved Ratios 13.0%
Approved Ratios 83.0%,82.5%,82.0%,81.5%,81.0%,80.5%
The weight of the elements per sample by volumetric fraction
A (master) 83%Cu+13%Al+4% Ni
B 82.5%Cu+13%Al+4% Ni+0.5%CNTs
C 82%Cu+13%Al+4% Ni+1.0%CNTs
D 81.5%Cu+13%Al+4% Ni+1.5%CNTs
E 81%Cu+13%Al+4% Ni+2.0%CNTs
F 80.5%Cu+13%Al+4% Ni+2.5%CNTs
Mix the mechanic for one hour
Place the mixture in mold
Push the electric plunger by pressing (500 Mpa) for 30 seconds and in one direction
Sintering in Furnace at (800 ° C) for three hours and Nitrogen gas
Physical properties
Microstructure Examination
Water Absorption (%)
True Porosity (%)
Bulk Density (gm/cm³)
Thermal Conductivity
Apparent Porosity (%)
Apparent Density(gm/cm³)
Mechanical properties
Hardness
Compressive strength (Mpa)

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 w□. The sample is weighed and suspended and immersed in distilled water with a sensitive balance and weight is w_i 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]:

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

$$B.D.=\frac{Wd}{Ws-W_i}\times \rho w \quad ...(2)$$

$$A.D=\frac{Wd}{Wd-Wi}\times \rho w \quad ...(3)$$

$$A.P.=\frac{Ws-Wd}{Ws-Wi}\times 100\% \quad ...(4)$$

$$T.P.=\frac{T.D-B.D.}{T.D.}\times 100\% \quad ....(5)$$

$$W.\ A.=\frac{Ws-Wd}{Wd}\times 100\% \quad ...(6)$$

ρw: 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]:-

$$\text{Hardness Vickers(H.V.)}=\frac{2F\ \mathrm{Sin}(\frac{136}{2})}{d^2}\approx 1.854\frac{F}{d^2}......(7)$$

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]: -

$$\sigma=\frac{2F}{\pi hD} \quad ....(8)$$

σ: 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

ISSN: 1813 – 1662 (Print)
E-ISSN: 2415 – 1726 (On Line)

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)

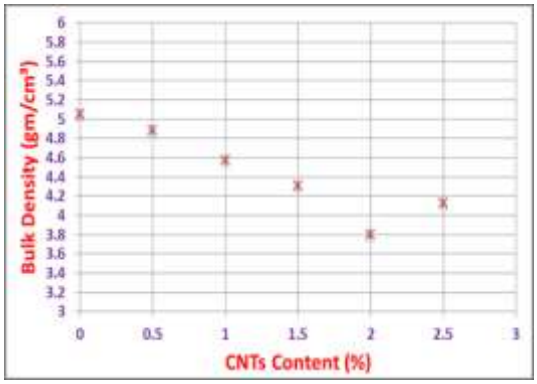

Figure (4) Relationship between volumetric fraction of Carbon Nanotubes and Bulk Density.

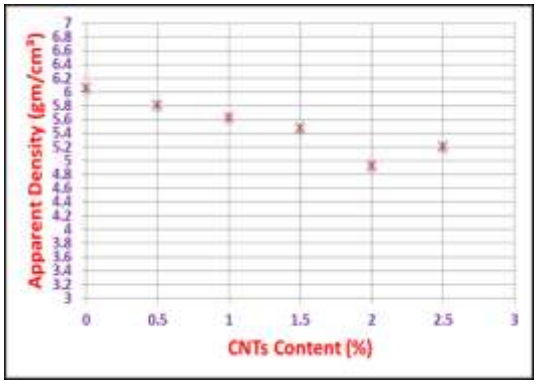

Figure (5) Relationship between volumetric fraction of Carbon Nanotubes and Apparent Density.

Figure (6) shown the x-ray diffraction where the intensity of peaks are change with increase of (CNTs) content for samples (A),(B),(D) and (E).

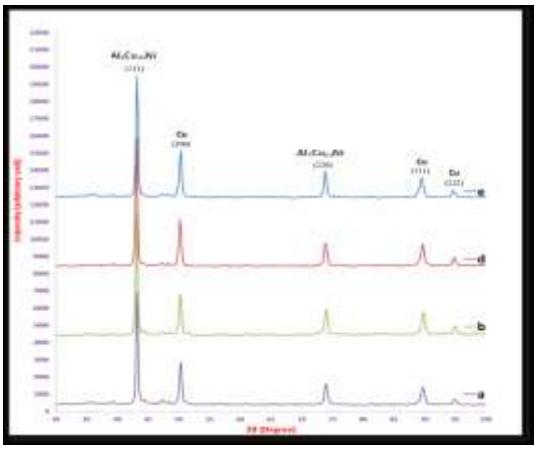

Figure (6) X - ray diffraction samples of shape memory alloy and their compound reinforced carbon nanotubes.

Figures (7) and (8) shows the analysis of component constituents of compounds (E) and (F) respectively and Figure (9) show the Carbon Nanotubes (CNTs) in the composite (F).

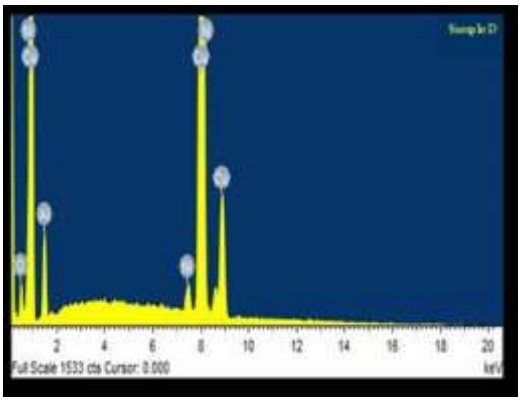

Figure (7) A model for the analysis of Composite (D) system (EDS).

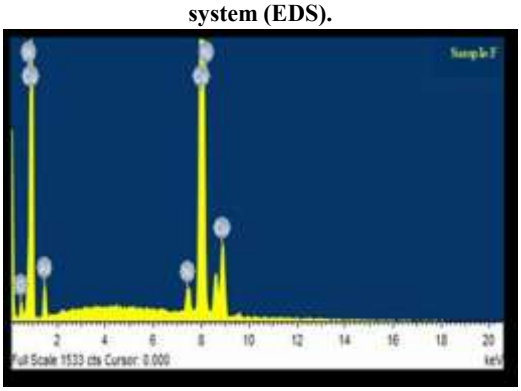

Figure (8) A model for the analysis of Composite (F) system (EDS).

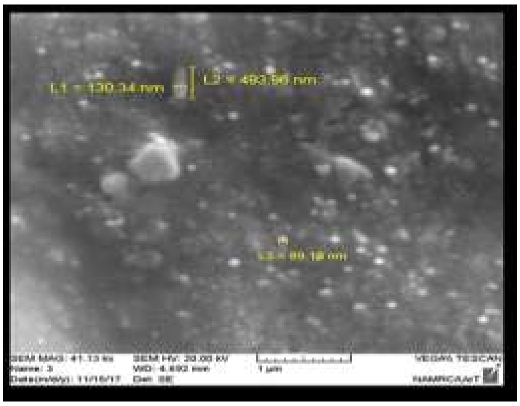

Figure (9) An image of the scanning electron microscopy (SEM) of part of the nanotubes (CNTs) in the Composite (F).

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.

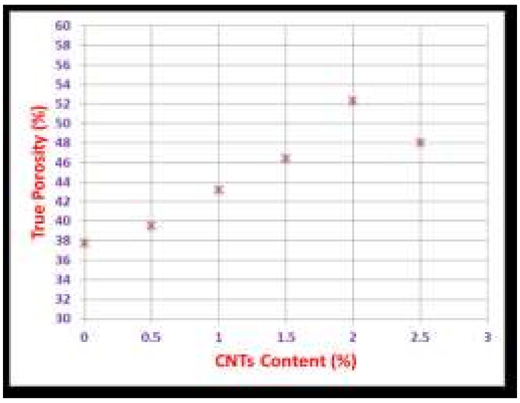

Figure (10) Relationship between volumetric fraction of Carbon Nanotubes and True Porosity.

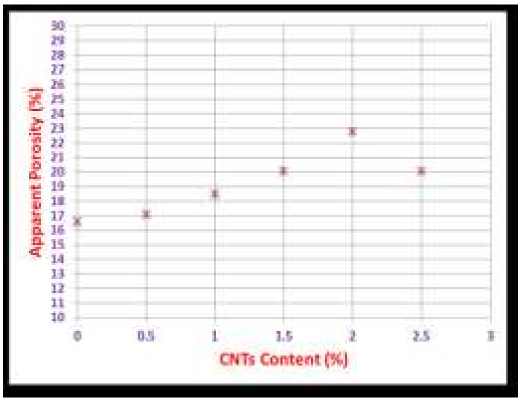

Figure (11) Relationship between volumetric fraction of Carbon Nanotubes and Apparent Porosity.

Figure (12) shows Photographic microscopy of microscopic structure of the surface of the samples surface, an increase in porosity when the content of (CNTs) increases.

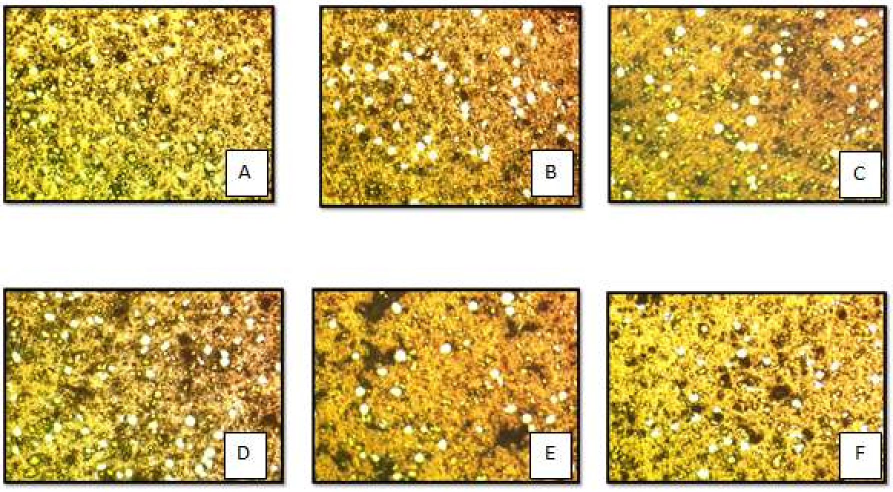

Figure (12) Photographic microscopy of microscopic structure.

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%) .

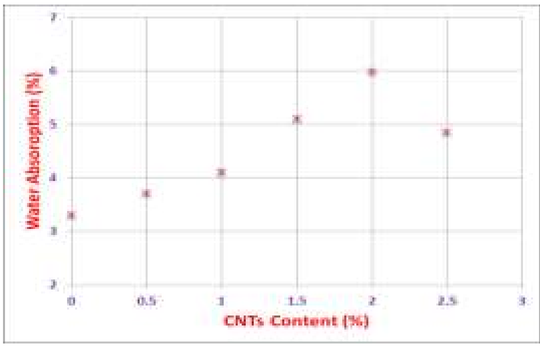

Figure (13) Relationship between volumetric fraction of Carbon Nanotubes and Water Absorption.

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.

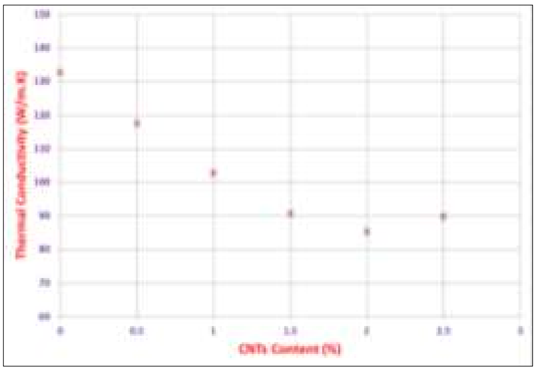

Figure (14) Relationship between volumetric fraction of Carbon Nanotubes and Thermal Conductivity.

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).

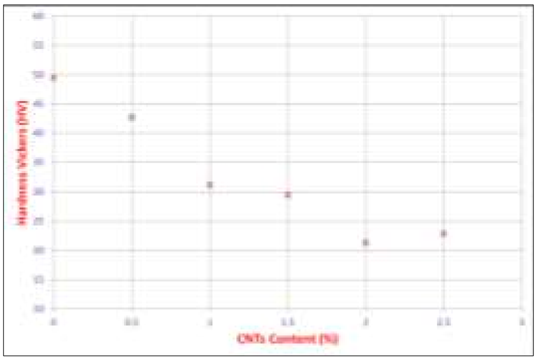

Figure (15) The relationship between volumetric fracture of carbon nanotubes and microscopic vickers hardness.

4-2 Compressive Strength

Figure (16) represents the relationship between compressive strength and CNTs content. The increase in the content of CNTs causes a significant reduction in (Cu-13% Al-4% Ni) for the Compressive Strength. The compressive strength, for example, decreases from (22.39) Mpa to (12.61Mpa) for the content of (CNTs), From (0.0%) to (2.0%) respectively. This behavior is due to the decrease in bulk density and the increase in true porosity, This is agreed with the behavior with [13,14], while at (2.5%) of the carbon nanotubes content it is observed that the density and porosity behavior of the nanotube is in addition to the hardness of the same ratio. This is consistent with [17,18] other ratios of copper alloy reinforced by carbon nanotubes.

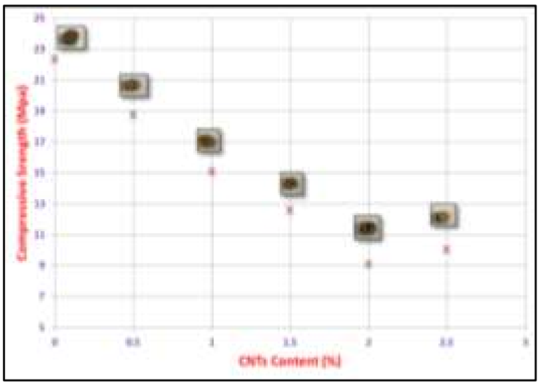

Figure (16) The relationship between the volume fraction of carbon nanotubes and compressive strength.

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

[1] Hodgson, D. E. (1998). Shape Memory Alloys: 5th edition. ASM Handbook Properties and selection Nonferrous Alloy and special Purpose Materials., Vol. 2:897-902.

[2] Man, H.C.; Zhang, S; Cheng, F.T., and Guo, X. (2005). Laser Fabrication of Porous Surface Layer on NiTi Shape Memory Alloy. Materials Science and Engineering A, **404(2005)**:173–178

[3] Lagoudas, D. C. (2008) .Shape Memory Alloys: Modeling and Engineering Applications. Springer Science and Business Media:1-51.

[4] Srinivasan, A. V.; McFarland Michel, D. (2001). Smart Structures – Analysis and Design. Cambridge university press: 26–69.

[5] Pérez - Landazábal, J.I.; Vicente Recarte and Raul Perez B. (2002). Determination of The Next - Nearest Neighbor Order in β Phase in Cu-Al-Ni Shape Memory Alloys. Applied Physics Letters, **81**.

[6] Lojen, G.; Anžel, I.; Kneissl, A.; Križman, A.; Unterweger, E.; Kosec, B. and Bizjak, M. (2005). Microstructure of Rapidly Solidified Cu–Al–Ni Shape Memory Alloy Ribbons. J. Mate Processing Tech, **162–163**: 220–229.

[7] Safaa Sauda, N.; Hamzaha, E.; Abubakara, T. and Raheleh Hosseinian, S. (2013). A Review on Influence of Alloying Elements on The Microstructure and Mechanical Properties of Cu-Al-Ni Shape Memory Alloys. Journal Technology (Sciences & Engineering), **64(1):**51–56.

[8] Eric Layton,V. (2002) .Fabrication and Characterization Of Porous NiTi Shape Memory Alloy by Elevated Pressure Sintering. MS.c thesis, Texas A&M University, USA.

[9] Berger, M. B. (2010) .The Importance and Testing of Density / Porosity / Permeability/Pore Size for Refractories .The Southern African Institute of Mining and Metallurgy, Refractories Conference.

[10] Dutta, G. and Bose, D. (2012). Effect of Sintering Temperature on Density, Porosity and Hardness of a Powder Metallurgy Component. International Journal of Emerging Technology and Advanced Engineering, **2(2012)**.

[11] ASTM C373 – 88 (2006). Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, And Apparent Specific Gravity of Fired White Ware Products. Reapproved.

[12] Jabur, Adnan S. (2013). Effect of Powder Metallurgy Conditions on The Properties of Porous Bronze. Journal of Powder Technology, **23(7):77-83**.

[13] Hamza, M. Sellab (2008) .Study the Effect of Carbon Fiber Volume Fraction and their Orientations on the Thermal Conductivity of the Polymer Composite Materials. Al-Khwarizmi Engineering Journal, **4(1): 80-89.**

[14] Almousawi, Ali I.; Salman, Ali J. and Abdulsada, Abdullah F. (2011). Study Effect of the Fraction Volumetric on The Values of Thermal Conductivity for Composites Micro polyester. journal of Kufa, **4(1).**

[15] Jons´en, P. (2006). Fracture and Stress in Powder Compacts. Ph.D. Thesis, Department of Applied Physics and Mechanical Engineering, Lulea University of Technology, Lulea, Sweden,

[16] Mahdi , F. M.; Razooqi, R. N. and Irhayyim ,S. S. (2013) .Effect of Graphite Content and Milling Time on physical Properties of Copper-Graphite Compsities Prepared By powder Metallurgy Rout .Australian Journal of Basic Applied Science, **7(12)**:245-255.

[17] Matar,M. M. (2010). Preordered and Study Electric, Mechanical, Thermal Properties for Copper-Graphite composites. Ph. D. thesis, college of science, almustansriya university.

[18] Vincent, C.; Silvain, J.F.; Heintz, J.M. and Chandra, N. (2012) .Effect of Porosity on The Thermal Conductivity of Copper Processed by Powder Metallurgy.Journal of Physics and Chemistry of Solids, **7**: 499-504.

[19] Wei, X.; Rui , H.; Jin-shan, L.; Yong-zhen, . and Heng-zhi, F. (2012). Tribological Behavior of CNT - Cu and Graphite - Cu Composites with Electric Current Journal of Nonferrous Met. Soc., **22**: 78 – 84.

[20] Deng, H.; Jianhong, Yi; Xia, C. (2018). Improving The Mechanical Properties of Carbon Nanotube - Reinforced Pure Copper Matrix Composites by Spark Plasma Sintering and Hot Rolling. Materials Letters, **2(10):** 177-18.

[21] Mahdi, F.M.; Razooqi, R.N. and Irhasyyim, S. S. (2017). The Influence of Graphite Content and Milling Time on Hardness, Compressive Strength and Wear Volume of Copper – Graphite Composition Prepared Via Powder Metallurgy. Tikrit Journal of Engineering Sciences, **24(3)**:47-54.

الخواص الفيزيائية والميكانيكية لسبيكة ذاكرة للشكل مقواة بأنابيب الكاربون النانوية

رائد نجيب رزوقي[1] ، خالد حمدي رزيج[2] ، أحمد تركي عبد الحميد[2] ، سيف صباح أرحيم[1]

[1]قسم الميكانيك ، كلية الهندسة ، جامعة تكريت ، تكريت ، العراق

[2]قسم الفيزياء ، كلية التربية للعوم الصرفة ، جامعة تكريت ، تكريت ، العراق

الملخص

حُضرت سبيكة الذاكرة للشكل (Cu - Al – Ni) في بحثنا هذا بتقانة ميتالورجيا المساحيق (PM) وبنسبة مكونـات (Cu – 13% Al- 4% Ni) وضغط كبس (500 Mpa) باتجاه واحد والتلبيد بدرجة حرارة (800°C) ولمدة ثلاث ساعات وبوجود غاز النيتروجين (N_2) وكانت إضافة انابيب الكاربون النانوية (CNTs) بالنسب (0,0.5,1.0,1.5,2.0,2.5)% كنسبة حجمية على حساب نسبة النحاس للحصول على متراكبات متقدمة لما لأنابيب الكاربون النانوية من تأثير متميز على الخواص.

تم تحليل العناصر للسبيكة ومتراكباتها باستخدام منظومة (EDS) الملحقة بالمجهر الإلكتروني الماسح (SEM) ودراسة حيود الأشعة السينية (XRD) لتحديد العناصر والمركبات المتكونة بعد إجراء عملية التلبيد وتصوير البنية المجهرية بكل من المجهر الضوئي (Optical Microscope) و الـ (SEM) .

درست الخصائص الفيزيائية إذ أظهرت النتائج أنَّه بزيادة محتوى أنابيب الكاربون النانوية (CNTs) تنخفض قيم الكثافة الحجمية للسبيكة (Cu-13% Al-4% Ni) ومتراكباتها بنسبة مقدارها (23.5%) لمحتوى أنابيب الكاربون النانوية من (0%) الى (2.0%) وترافقت زيادة المسامية الحقيقية مع زيادة محتوى الـ (CNTs) عند ذات النسب بنسبة مقدارها (27.85%) ويكون الفعلُ معاكسً عند زيادة المحتوى إلى (2.5%) إذ يتطابق السلوك مع قابلية امتصاصية الماء، واما الموصلية الحرارية فان سلوكها يتطابق مع سلوك الكثافة الحجمية والظاهرية ولذات النسب، وانخفضت بعض الخصائص الميكانيكية كالصلادة ومقاومة الانضغاط بزيادة محتوى الـ (CNTs) الى نسبة (2%) بينما حدث تحسن طفيف لتلك الخاصيتين عند النسب المتوافقة.