Effect of Cu-Al Proportions in Smart (Cu-Al-Ni) Alloy for Best Mechanical properties by Using Artificial Intelligent.

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Abstract

In this work study effect two elements (Cu, AL) of alloy (Cu-Al- Ni) on the physical and mechanical properties which is considered one of the smart materials. This alloy has standard weight percentage in [83%Cu-13%Al-4%Ni].Selecting four different weight percentages of elements (Cu-Al) include [78%Cu,18%Al] ,[80%Cu,16%Al][82%Cu,14%Al] and [84%Cu,12%Al]which manufactured by powder metallurgy technique with a constant weight percentage of element Ni in each the percentages. The compacting pressure and sintering temperature are constant in each the fabricated samples. The results of the samples test show the maximum values of shape recovery and micro hardness are83%, 185HVrespectivelywhich appeared in the weight percentage [82%Cu-14%Al-4%Ni] whereas the samples in the weight percentages [78% Cu-18%Al-4%Ni], [80% Cu-16%Al-4%Ni] don't appear any shape recovery because of increasing brittleness and decreasing toughness with increase Al% content which lead into failure in these proportions. IN this research the fuzzy logic model was used to investigate and the predicate of the mechanical properties between the weight percentages of the alloy by using parameters (Cu, Al)

Introduction

Smart memory alloys are unique groups which have ability returning to their original shape under effect heating **[1]**.Smart memory alloy has ability to transform between two phases: austenite phase which occurs in high temperatures is called parent phase and other in low temperatures which is called martensitic phase or solid phase **[2]**.Alloy (Cu-Al-Ni)is one types the shape memory alloys which represent alternative to alloys (Cu-Zn-Al) and (Ni-Ti), the transformation temperature in these alloys are limited in100^{0}C, whereas alloy (Cu-Al-Ni) from Technological point of view near200^{0}C, using powder metallurgy processing can open challenges for the industrial applications which is lead to solve technological problems in these alloys. The martensitic transformation temperature are sensitive to change in concentration that's means difficulty control with high precision the concentration in ternary alloys, that's confirms the composition of alloy is considered important factor in order to determine the martensite transformation temperatures. These unique characteristics of SMA are used in many engineering applications which depended on thermo mechanical properties such as aerospace, medical industries and fire check safety valve, eyes glasses frame.**[3]**.When exact information of mathematical values is not available, the soft computingtechnique is very important to predicate the results,the soft computing technique is different on conventional computing in partial truth approximately uncertained,tolerance of imprecision.One of types soft computing techniques is fuzzy logic system is less complication comparing with other types Artificial intelligent, fuzzy logic is used to investigate and predicate mechanicalproperties which based on input variables.**[4]**

Experimental Procedure

This work includes selection four different weight percentages of elements(Cu-Al)with constant proportion of element Nias shown in **Table1**.Thepowder mixture was put in glass cylindrical container is filled 50% of container volume with adding 1% acetone in order to prevent segregation between alloying elements and then mixed for 6 hr. by using horizontal mixer device as shown in **Fig1**.**[5]**

Fig.1Horizontal barrel mixer.

Table. 1 Samples of each weight percent of alloying elements.

Elements of Powder Metallurgy	Weight Percentage			
	1	2	3	4
Cu (%)	84	82	80	78
Al (%)	12	14	16	18
Ni (%)	4	4	4	4

The powder mixture is compacted by using cylindrical molding which has double action of two sides in order to obtain homogeneity in compacting process. Compacting pressure is 650 Map in all the fabricated samples, with holding time in press device 2min.

Fig .2 Tube furnace with vacuum

The green samples from each percentage are sintered by using electrical tube furnace consist quartz tube which is connecting with vacuum pump system as shown in the **Fig2**.Sintering process is carried out by heating to 500^{0}C for 1 hrthen raising temperature to 850^{0}C for 5hr, than left cooling in furnace. During sintering process, the sintered samples of each weight proportion are exposing to heat treatment to get marten site phase by heating samples to 800^{0}C for 1hr and rapidly quenched in ice water. After quenching process in order to stabilize the martensitic phase, an ageing process is carried out by heating samples to 100^{0}C for 2hr than left cooling in furnace. The samples of each weight percentage are shown in the **Figs 3, 4, 5, and 6**. Porosity and bulk density are measured according to ASTMB328 by Archimedes rule through using sensitive balance which include weighting each sample in dry air then put the samples in container is filled oil for 30 min with using vacuum pressure device, after drying the samples of excessive oil, again weighed in air, then weight the oil impregnated samples in water to calculate porosity and density according to the equations1,2. **[6]**

$$P=[\frac{MB-MA}{(MB-MC+E)\times Do} \times 100]_{(1)}$$

Also Bulk density is calculate by using the Eq (4-3)

$$D=(\frac{MB}{MB-MC+E})\ D_{w(2)}$$

Tests after manufacturing

- Optical Microscopy was used to investigate of homogeneity of particles powder after compacting process and investigate of martensitic phase after heat treatment.
- X-ray diffraction test was applied on fabricated samples which appeared the phases through martensitic transformation.
- Scanning electron Microscope (SEM) which gives more details on micro structure and martensitic layers with pores in each weight percentage.
- Microhardness test by vickers hardness which conducted on samples to investegate of effect the proportions of elements (Cu,Al) on the hardness.
- Shape memory effect test was applied on the samples which have dimensions (11dia * 16mm length) by pressing 4% of its orginal length and heating to

250^{0}C then left in air for cooling.The shape effect was calculated according to the equation below **[7]**

$$\textit{Shape effect}=\frac{L2-L1}{L0-L1}*100\ \% \quad (3)$$

(a) Before grinding and polishing (b) After grinding and polishing

Fig. 3 [Cu-12%Al- 4% Ni]

(a) Before grinding and polishing (b) After grinding and polishing

Fig. 4 [Cu-14%Al- 4% Ni]

(a) Before grinding and polishing (b) After grinding and polishing

Fig. 5 [Cu-16%Al- 4% Ni]

(a) Before grinding and polishing (b) After grinding and polishing

Fig. 6 [Cu-18%Al- 4% Ni]

Fuzzy model development

The Matlab7.1 of Microsoft windows was applied fuzzy logic model as a toolbox to predicate both micro hardness and porosity which is considered as output and Cu, AL, Ni as input variables by using mapping Mamdani system of input and output was used in fuzzy logic as shown in **Fig7.**

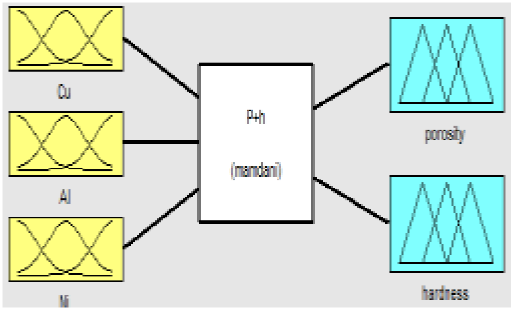


Fig7. Fuzzy inter face system structure.

The linguistic expressions which applied in fuzzy sets were low, medium, high, very high, small, large and very large. The fuzzy set is considered the building stone of fuzzy logic**[7]**.The membership functions which applied in this paper were triangular form which collection of three points forming a triangle and gauss membership as shown in **Fig8,9**

Design of experiments

The most important stage in the designing of an experiment lies in selection of parameters. In this experiment three parameters(Cu, Al, Ni) with three levels in both of Cu, Al and one level in Ni which has a constant value in all different weight percentages of (Cu, Al, Ni)are shown in **Table2**. The fractional factor design which used is a standard L_9experimental array. This array is selected because of its capability to check the interaction among parameters and levels **[8].**

Table 2. Parameters and levels of fuzzy model in this paper

Parameters of Powder Metallurgy	The Experimental Conditions Levels		
	1	2	3
Cu	82	83	84
Al	14	16	18
Ni	4	4	4

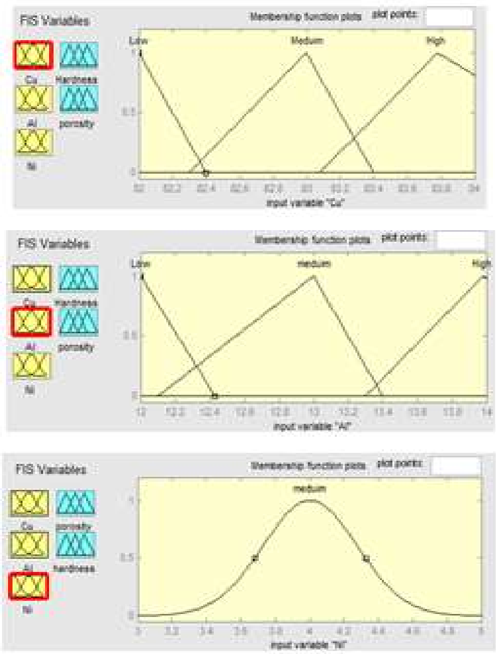


Fig 8. Input parameters and their membership function.

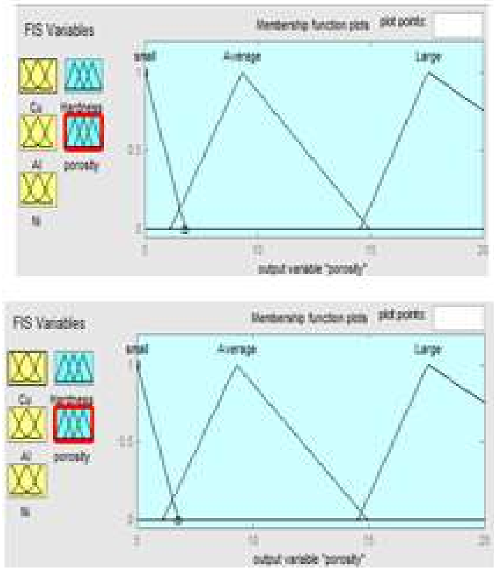


Fig 9. Output parameters and their membership function

The relationship which connect between the input parameters of the powder elements Cu, Al, Ni with output parameters which are micro hardness and porosity referred into construct the fuzzy rules with using the linguistic variables and fuzzy statements of input and output parameters as shown in **Table 3**. The linguistic expressions were used low, medium, and high, as input variables also bad, good, small, average, and large as output variables. After determination the membership functions and using experimental results of weight percentages are referred in **Table2** were trained in fuzzy inference system, the numerical output results of micro hardness and porosity, defuzzification was applied by using centroid of area method or is called center of gravity of area the defuzzification.

Table.3 Fuzzy rules

Rule N	Cu	Al	Ni	Hardness	Porosity
1	Low	Low	Mid	Bad	Small
2	Low	Mid	Mid	Bad	Average
3	Low	High	Mid	Average	Large
4	Mid	Low	Mid	Average	Vlarge
5	Mid	Mid	Mid	V good	large
6	Mid	High	Mid	Average	small
7	High	Low	Mid	Bad	small
8	High	Mid	Mid	Large	large
9	High	High	Mid	Average	Average

Validation of fuzzy models

In order to investigate of application fuzzy logic model, the confirmation experiments of three sets test were conducted and the experimental results with the predicated values of micro hardness and porosity by using fuzzy model in the same conditions were compared, the validation of fuzzy logic model through applying the error percentage, observed the highest error percentages of micro hardness, and porosity is 4.6%, 15%respectively of weight percentages which selected as shown in tables4, 5.

The comparison between the experimental results and predicted values by fuzzy logic of hardness, and porosity are convergent which shown by curves in **figures 10, 11** respectively. This convergence can be indicated to ability fuzzy logic model of predication through range of weight percentages as input parameters.

The predicated values for number of the experiments which lie between the weight percentages (82-84) % Cu and (12-14) % Al are shown in table 7,appeared directly relation of change Cu, AL levels with micro hardness and the clear increasing in porosity with increasing Al % in the alloys,

Table 5.Comparison hardness of Measured and predicated results.

Levels	Parameters of powder metallurgy (%)			Hardness (Actually) (%)	Hardness (Predicated) (%)	Error (%)
	Copper	Aluminum	Nickel			
1	84	12	4	138	142	2.8
2	83	13	4	150	157	4.6
3	82	14	4	185	179	3.2

Table6. Comparison porosity of measured and predicated results.

Levels	Parameters of powder Metallurgy (%)			Porosity (Actually) (%)	Porosity (Predicated) (%)	Error (%)
	Copper	Aluminum	Nickel			
1	84	12	4	12	10.2	15
2	83	13	4	6.3	5.4	8
3	82	14	4	20.9	17.9	14.3

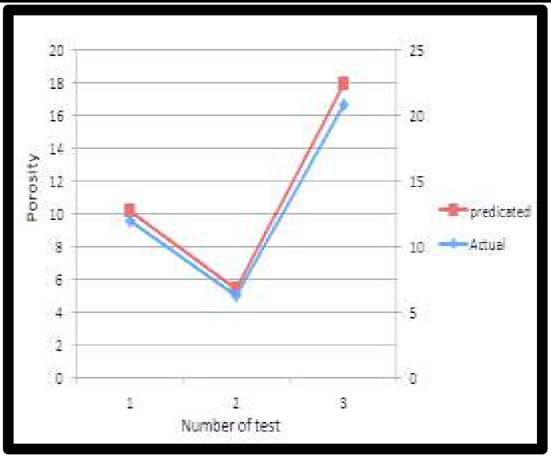


Fig10. Curves of actual and predicated of micro hardness

Table7. Predicated of optimum values of different weight percentages

No of Experiment	Parameters of Powder Elements (%)			Porosity (Predicated) (%)	Hardness (Predicated) HV
	Copper	Aluminum	Nickel		
1	82	14	4	17.9	179
2	82.1	13.9	4	17.8	178
3	82.2	13.8	4	17.7	178
4	82.3	13.7	4	17.5	177
5	82.4	13.6	4	10.5	176
6	82.5	13.5	4	10.4	177
7	82.7	13.3	4	5.7	157
8	82.9	13.1	4	5.5	157
9	83	13	4	5.55	157
10	83.1	12.9	4	5.54	157
11	83.2	12.8	4	5.9	157
12	83.3	12.7	4	5.73	157
13	83.4	12.6	4	5.68	157
14	83.6	12.4	4	8.32	156
15	83.7	12.3	4	9.78	152
16	83.9	12.1	4	10.2	142
17	84	12	4	10.2	142

Results and Discussion

I.**ResultsMicrostructure Examination by**

1). Optical microscopy

Samples after compacting process of each weight percentage are tested by micro structure examination which appeared homogenous distribution particles of the powder mixture and increasing in Al concentration is very clear in each proportion as shown in **Fig12.**

Samples after sintering process which showed the diffusion between particlesof powdersis apparent in crystal structure which confirmed success the sintering process as shown in **Fig13.**

Samples after heat treatment ,the martensitic layers is clear in all weight percentages also pores is very large in weight percentage Cu18%Al4%Ni which showed in black regions as shown in **Fig14.**

2)Scanning electron microscope(SEM)test the images in **Fig15** which is taken by SEM show effect (Cu, Al) content on pores distribution in each weight percentage, observed increasing in pores with increasing Al content in alloys.

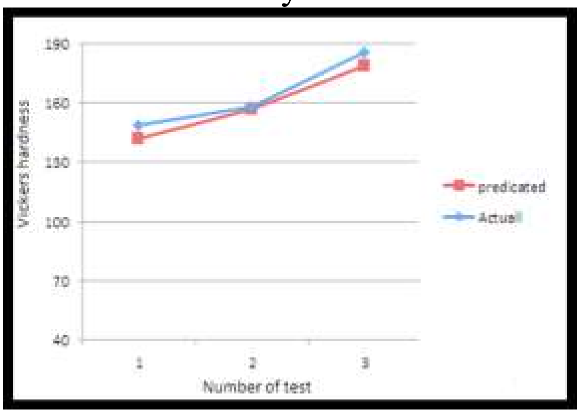


Fig 11. Curves of actual and predicated of porosity

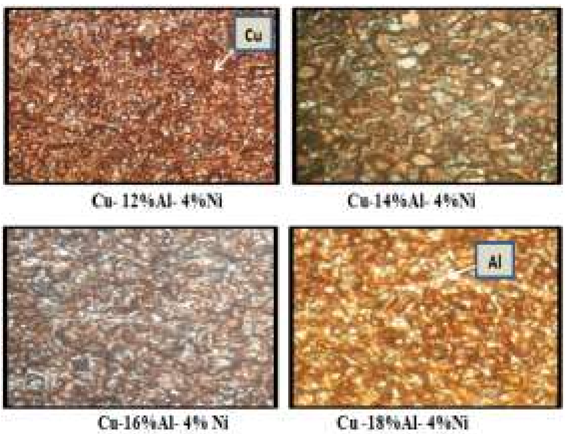


Fig.12 Samples after compacting

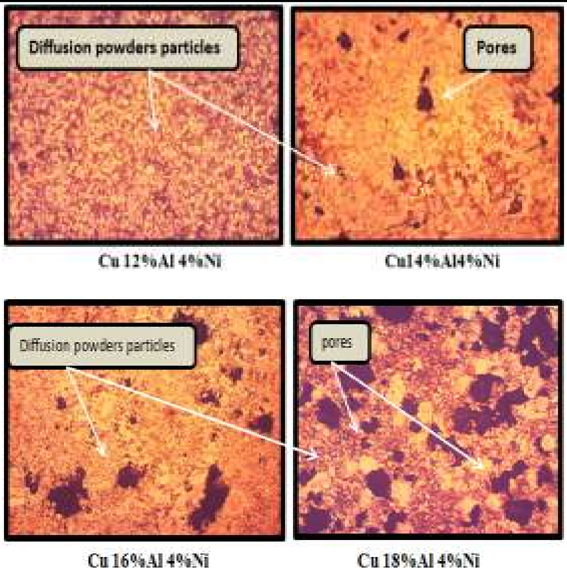


Fig.13 Samples after sintering

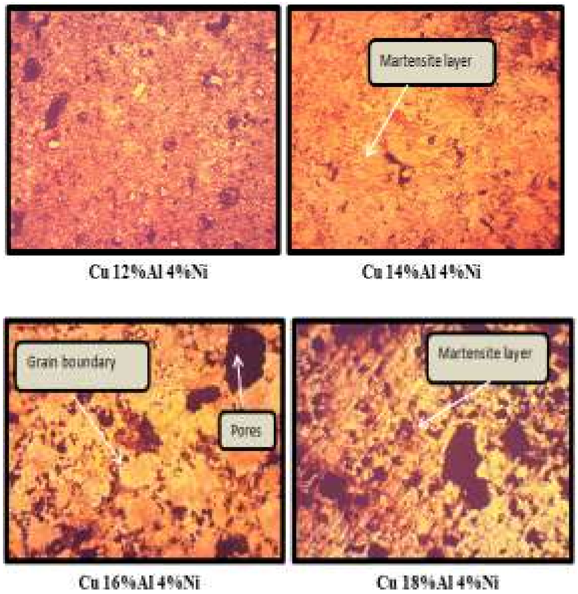


Fig.14 Samples after heat treatment.

II.X-ray diffraction test results.

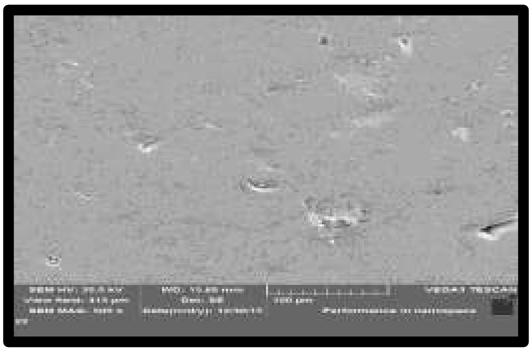
The samples before heat treatment in this test discovered the structure was Al3.8Cu6.1 in each weight percentages which represented austenite phase results of slow cooling in furnace as shown in **Fig16.**The sample after heat treatment; the structure was AlCu3 in all weight percentages**Fig17** which is martensitic phase.

III. Micro hardness test results

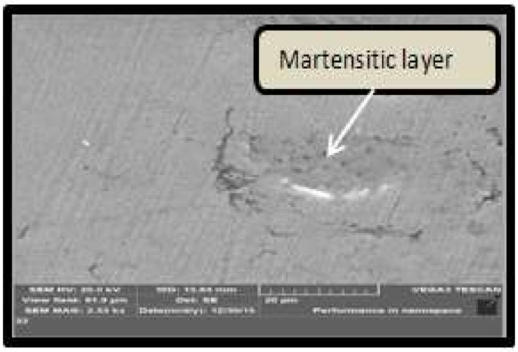
Vickers Micro hardness show the variety in hardness values in each proportion because of effect (Cu-Al) content which appeared the maximum value of micro hardness in the proportion [Cu-14%Al-4%Ni] which reach into 185hvas shown in **Table 8.**Comparing with the standard weight percentage [Cu-13%Al-4%Ni] which has 150 hv as shown in **Table 5** that's lead into the toughness in 13% Al is better of 14% Al.

IV. Shape Memory Effect Test

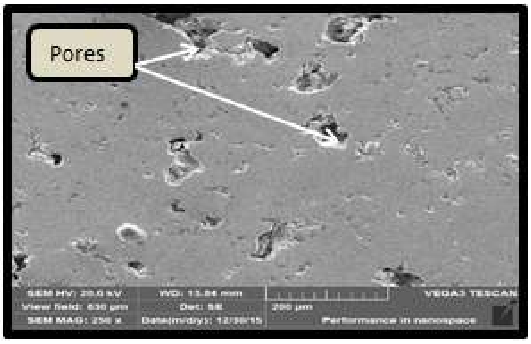
The results of SME are shown in **Table8.**Observed in this test the maximum shape recovery is 83%which appeared in weight percentage[Cu-14%Al-4%Ni] whereas not occur any shape effect in both of proportions [Cu16%Al4%Ni],[Cu18%Al4%Ni]because of increasing in Al% content which lead to high brittleness and lack toughness result failure in these proportions.



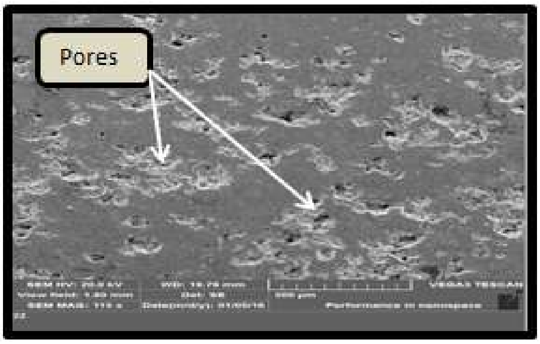
Cu 12%Al 4%Ni



Cu 14%Al 4%Ni

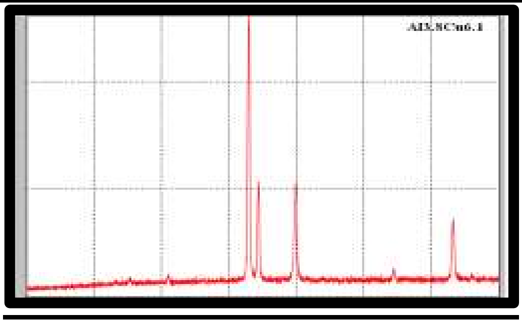


Cu 16%Al 4%Ni

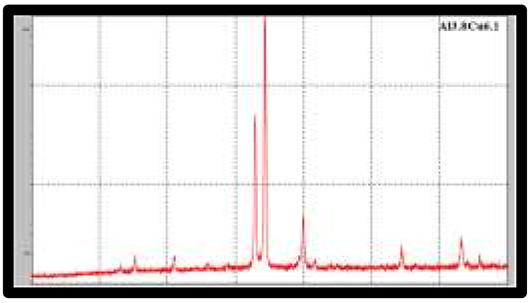


Cu 18%Al 4%Ni

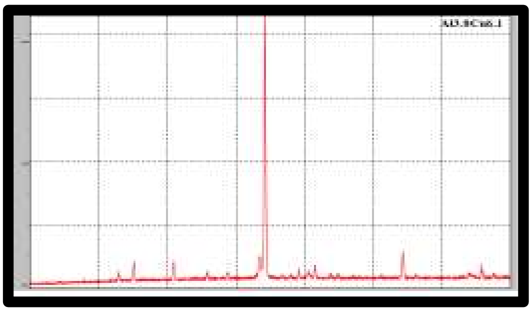
Fig15. SEM Images of each weight percentages.



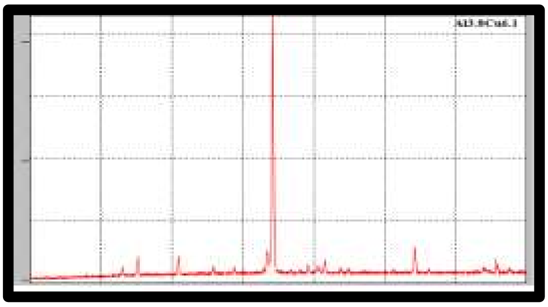
Cu 12%Al 4%Ni



Cu 14%Al 4%Ni

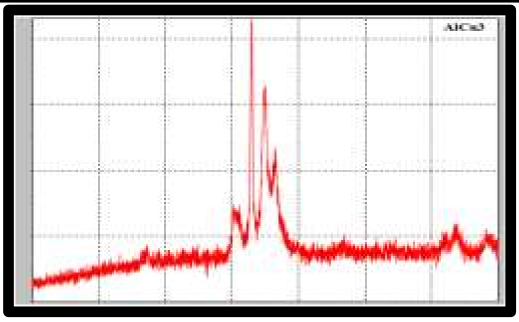


Cu 16%Al 4%Ni

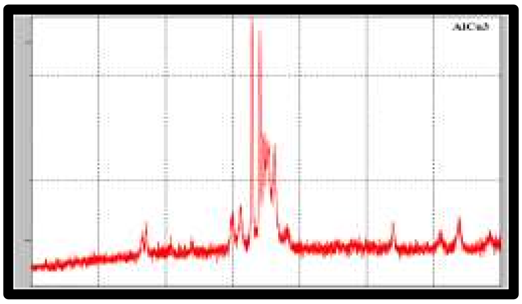


Cu 17%Al 4%Ni

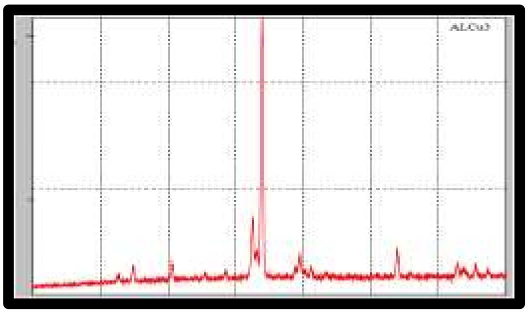
Fig16.Results of X-ray Samples beforeheat treatment.



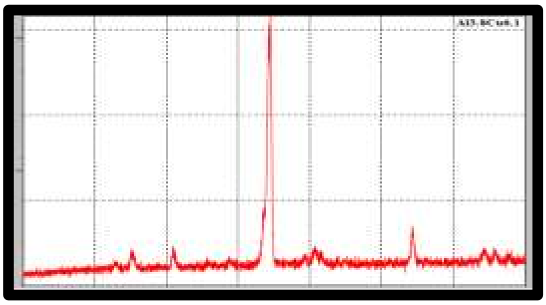
Cu 12%Al 4%Ni



Cu 14%Al 4%Ni



Cu 16%Al 4%Ni



Cu 18%Al 4%Ni

Fig17.Results of X-ray Samples after heat treatment.

Table 8.Results hardness and shape memory effect

Exp	Copper %	Aluminum %	Nickel%	Hardness	Shape Effect
1	84	12	4	138	10%
2	82	14	4	185	83%
3	80	16	4	171	0%
4	78	18	4	178	0%

Conclusions

- Shape memory effect (original length recovery) can be determined within the range (82-84) % Cu and (12-14) % Al, of alloy (Cu,Al,Ni) in according to the experimental tests and the increase in Cu% content out of this range lead to drop the shape recovery in the alloy.
- Raising Al% content out of range (12-14)% in the alloy lead to increase brittleness and decreasing ductility that's interpret the failure in the samples which contain weight percentages [80%Cu,16%Al,4%Ni],[78%Cu,18%Al 4%Ni] through the shape recovery test.
- Increase Al% content out of range (12-14)% lead into increase amount porosity in the alloy which reach into 25.9% in weight percentage [78%Cu-18%Al-4%Ni] although the compacting pressure is constant (650MPa) in all the weight percentages.
- The alloying components of (Cu-Al) have important effect on microstructure can be observed through using optical microscopy, electronic scanning and energy dispersive X-ray test.
- Using fuzzy logic model as intelligent program is very successful to reduce number the experiments in this research and therefore lead to decrease the cost in the work also fuzzy logic has good ability of the predication to get optimum results between different weight percentages.

List of Symbols

symbols	Definition	Units
SME	*Shape Memory Alloy*	
P	*Porosity*	%
D	*Density*	gm/cm^3
D0	*Density in the oil*	gm/cm^3
Dw	*Density in the water*	gm/cm^3
HV	*Hardness Vickers Value*	
M_B	*Mass in air of oil-free specimen*	gm
Mc	*Mass of oil-impregnated in water*	gm
L0	*The original sample length*	*mm*
L1	*Sample length after 0.04 compact*	*mm*
L2	*Restoration length after heating*	*mm*
L9	*The nine experiments that design by fuzzy logic*	

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افضل خواص ميكانيكيه تاثيرنسب النحاس-المنيوم في سبيكه ذكيه (نحاس-المنيوم- نيكل) لحصول على باستخدام الذكاء الاصطناعي.

الاستاذ المساعد الدكتور:احمد عبد الرسول

الماجستير:بسام سلمان درويش

كليه الهندسه/ جامعه بغداد

الهندسه الميكانيكيه

الخلاصه

في هذا البحث ندرس تاثير عنصري (نحاس- المنيوم) من سبيكه (نحاس-المنيوم- نيكل) على الخواص الفيزياويه والميكانيكيه والتي تعتبر واحده من المواد الذكيه وهذه السبيكه تمتلك نسبه وزنيه قياسيه(83٪ نحاس ,13٪ المنيوم,4٪نيكل). بواسطه اختيار اربع نسب وزنيه من عناصر (نحاس-المنيوم) تشمل(78٪نحاس,12٪المنيوم),(80٪نحاس,16٪المنيوم),(82٪نحاس,14٪ المنيوم),(84٪ ٪نحاس,12٪المنيوم)بواسطه استخدام تقنيه مساحيق المعادن مع نسبه وزنيه ثابته من عنصر النيكل في كل النسب, ضغط الكبس ودرجه حراره السنتره تكون ثابته في كل العينات المصنعه . النتائج من اختبار العينات تظهر ان القيمه العظمى من استرجاع الشكل والصلاده تكون 83٪ , 185 بالتتابع وتظهر في النسبه الوزنيه ,(82٪نحاس14٪ المنيوم) في حين فشل العينات في النسب الوزنيه(78٪ نحاس 18٪ المنيوم) و(80٪نحاس 16٪ المنيوم) بسبب زياده محتوى المنيوم في هذا النسب مما يودى الى ارتفاع الهشاشه وقله المتانه. في هذاالبحث نموذج منطق الغموض كان مستخدم لتحقق والتنبه من الخواص الميكانيكيه بين النسب الوزنيه من السبيكه بواسطه العناصر (النحاس,المنيوم).