The Effect of Thermo-Mechanical Treatment on Mechanical Properties & Microstructure for (Cu-Al-Ni)Shape Memory Alloy

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ABSTRACT

This paper aims to study the effect of thermo mechanical treatment in different temperatures of (260 ,280& 300) ◦C on the microstructure and mechanical properties of Cu-14wt%Al-4.5wt%Ni shape memory alloy which prepared by casting method in induction furnace under argon atmosphere. Then thermo –mechanical treatment was performed upon the alloy by applying stress of 190MPa with heating upto 260◦C,280◦C,300◦C, then cooled to room temperature performingstrain recovery measurement. Many tests and inspections such as optical and SEM examinations , DSC Measurement ,XRD inspection , compression and Vickers hardness tests were investigated. The results showed that there is an increase in the transformation temperatures, shape memory limits at 300◦C .It was found that hardness increases and Young modulus decreases Also It was found that the thermo-mechanical treatment at 260 ◦C gave better properties , 2%in recovery strain , increase hardness due to the formation of martensitic phase and austenite phase in structure.

Keywords: Cu-base shape memory alloys, mechanical properties, shape memory effect

INTRODUCTION

Over the last decade the SMA had been studied in extensive manner due to the need for it in technology ,in particularfield the Cu-ternary shape memory alloys because it is a good substitute for Ni-Ti SMA especially in the non-medical applications for example the field of coupling and fasteners[1]. Designing the SMA applications is more over the years the SMA actuators are 25 more times than electrical actuators in work density[2]. The Cu-based SMA are more on demand particularly in non-medical application for economic reasons because of the high transformation temperatures (-100 to 170 ◦C) , good recovery strength (3%-6%) and low producing cost compared with NiTi alloys render theirusage for many applications impractical, especially for high temperature usage. Therefore, Cu–Al–Ni SMAs are the most preferred option as successful alternatives to NiTi due to their high transformation temperatures (-200 to 300 ◦C), low producing cost, and high thermal stability However, the brittleness [3], low strength, large elastic anisotropy, and large grain size hinder its practical applications. ,although the brittleness can hold a problem in machining but that can be solved in EDM or wire cutting .Thermo-mechanical treatment is one of the solutions of that problem .it is one of ways to obtaingrainrefining up to 5 μm also improving fracture strain upto 10%[3] ,**Gama *etal.***[4] studied the effect of thermo-mechanical treatment by hot rolling and it is effect on mechanical properties.**Hornbogen**[5]studied the thermo-mechanical treatment effect on fatigue characterization for many SMA including Cu-Al-Ni.**AksuCanbay*etal.* [6]**studied the effect of heat treatment on thermo –mechanical propertiesof Cu -Al-Ni SMA. **Dagdelen*etal.***.[7]studied

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the thermal treatments on Cu-based SMA. **Gastien*etal.*** [8]studied the isothermal treatments, **Ibarra etal**.[9]studied thermo-mechanical characterization for Cu-Based SMAforCu-based alloy manufactured by powder metallurgy.The aim of this paper is to study the effect of thermo-mechanical treatment on Cu-Al-Ni SMA which manufactured by vacuum induction furnace casting by applying uniaxial compression load on the alloy in three different temperature above 200 ◦C.

Experimental Work

A Pure Cu(99.99%)wires ,Al(99.99% purity) foils and Ni(99.99%) powder particle size of (294-1726 nm) were melt in vacuum inductionfurnaceunderargonatmosphere at 1200 ◦C and then the melt waspoured into a cylindrical alloy steel die of 1.4 cm in diameter. Homogenization was carried out at 900 ◦C for 30 min and then quenched in Iced brine solution ,wire cutting were used to cut the ingot into two specimens groupsthe first2.8 cm height for a ASTM E-9compression test specimen and the second group is 0.5cmheightfor optical microscopy SEM ,HV, DSCand XRD .and chemical compositions was performed at the special institute of Engineering Industries as cast and homogenized as shown **in Table (1).**XRD was performed by using Shmidzoo 3000 XRD- EDXinstrument,Cu- Target Cu(α)(λ=1.45 A◦). Then the specimens were thermo-mechanically treated at three different temperatures (260,280,300)◦C.It was done by applying uniaxial load with heating on the specimen held in 34 type alloy steel die connected with a heating unit by four poles and probe connected with the specimen to measure temperature as shown in **Figure (1).** A loading was preformed until at stress of σ=195 MPaat designated temperature then unloading results were recorded and stored in a PC file can be exported to MICROSOFT EXCEL.DSC test was performed in Materials Engineering Department in UOT by SATRAN Labsys 300deviceat range (700-(-170)◦Cwith range (25◦C - 250 ◦C) in both directions exothermicandendothermic.Also Vickers Micro hardness testwas performed by taking three readings andaverage value is used in Vickers hardness equation. The instrument model Larray 600was used for loading and unloading compression loads on the alloy.For microstructure examination the specimens were ground and polished andetched in solution which consists of ($FeCl_3.6H_2O$+HCl+Methnol) for 4 min and then examination was performedusingKrussopticalmicroscopeThenSEM-EDS Images were done by using TESCAN easy probe SEMin Production Engineering and Metallurgy Department at UOT.

Elementwt%	Alwt%	Niwt%	Nbwt%	Cuwt%
Percentage ASM	>13.44	4.5	___	Rem
Percentage SIEI	>13.44	4.4	0.134	Rem

Table(1) Chemical composition of the base SMA

Figure (1).The thermo-mechanical treatment system

Results and Discussion

XRD Results

Figure(2)shows the XRD patternanalysis for the base alloy SMA (Cu-14%Al-4.5%Ni) after casting andhomogenization. It was observedthatthe formation of phases as seen in **Table (2)**which indicates the form of the both martensitic and austenite phase .

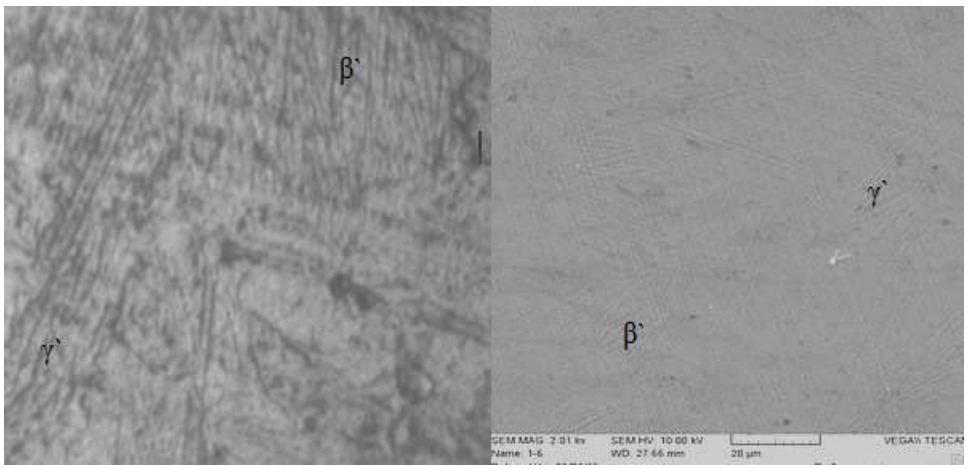
Figure (2).XRD for SMA (Cu-14Al-4.5%Ni)

Table (2) .XRD phases for the SMA

Phase	2θ(deg.)	d_m A°	d° A°	I/I◦
$AlCu_3$	44.8084	1.998	2.021	100%
$Al_{19}Cu_{23}Ni$	46.6098	1.947	1.9307	80%
$Al_7Cu_{23}Ni$	42.7377	2.0881	2.114	65%

Microstructure Examination

As for the microstructure as seen in **Figure (3)** the martensite phase is in two forms a needle shape (β `) and ( γ`) stack shape form in pairs or two pairsas was seen by **Gama***etal* [3] shown in **Figure (4) .** The SEM Image for the base alloy in which the martensitic phase β is found intensively than (γ`) phase with appearance of less austenite phase (β) as shown in **Figure (5).** It was seen that the austenite phase (β) in fine grain size is increasing in growth with more (γ`) martensite phase than (β`) martensite phase in more ,while in **Figure(6)**the austenite phase is increasing with fine grain size also the stack of martensite less in size with more (γ`) martensite phase than (β`) fine needle shape martensite phase. This isdue to thermo-mechanical treatment which reduced the martensite and increased the austenite. Since (β`) is thermally induced phase and the (γ`) martensite phase is self accommodated.



A B

Figure (3) (A).Optical Image at 200x &(B) SEM Image of SM

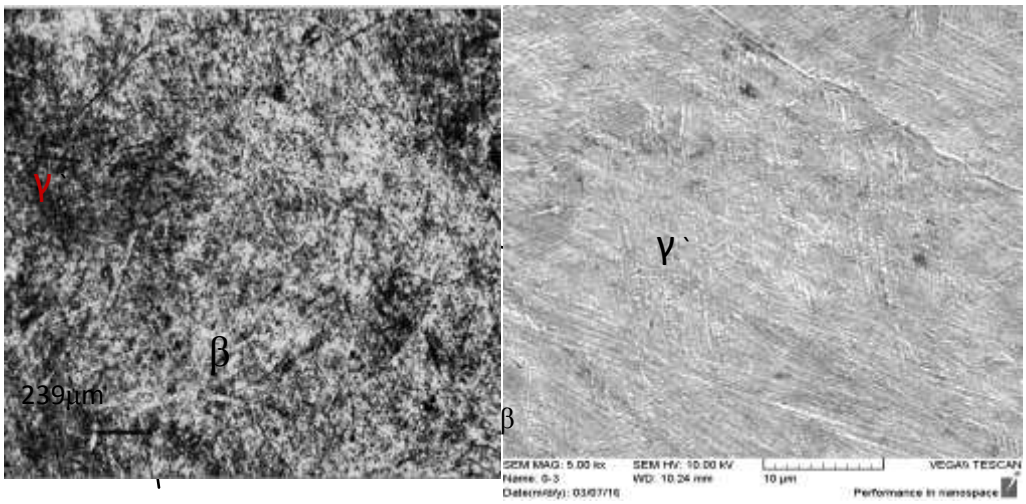


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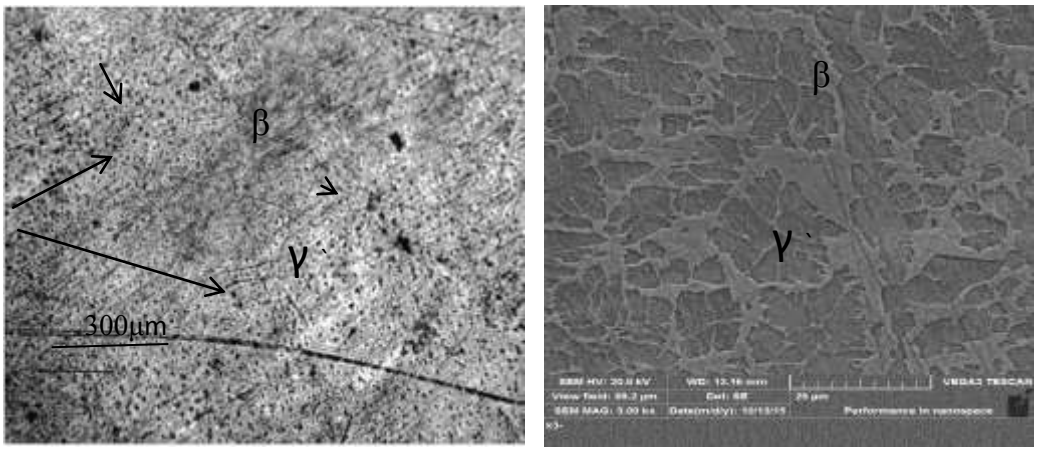
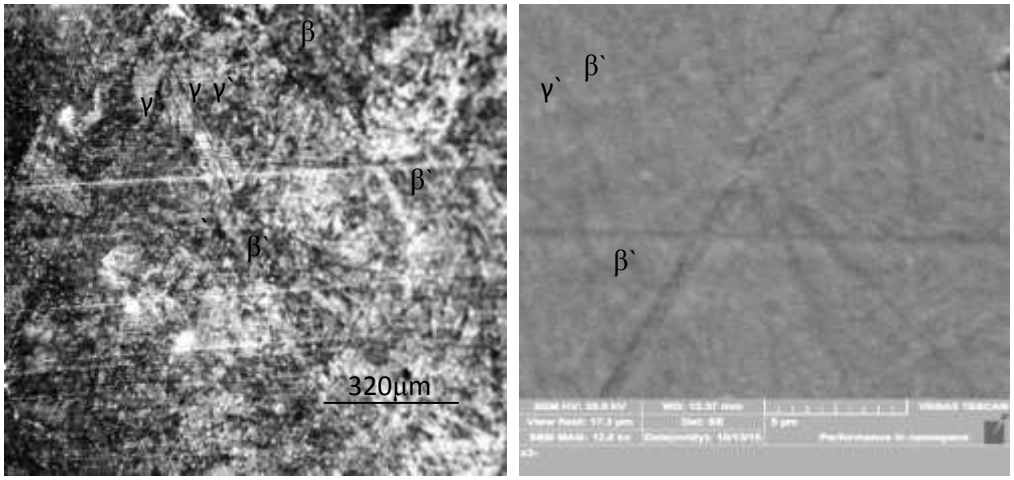
Figure (4).(A) Microstructure at 200x&(B) SEM SMA TMT at 260 ◦C



A B

Figure(5). (A) Optical imageat 200x &(B) SEM Image of SMA TMT at 280 ◦C



A B

Figure (6). (A) microstructure at 200x and (B) SEM Image of SMA TMT at 300 ◦C

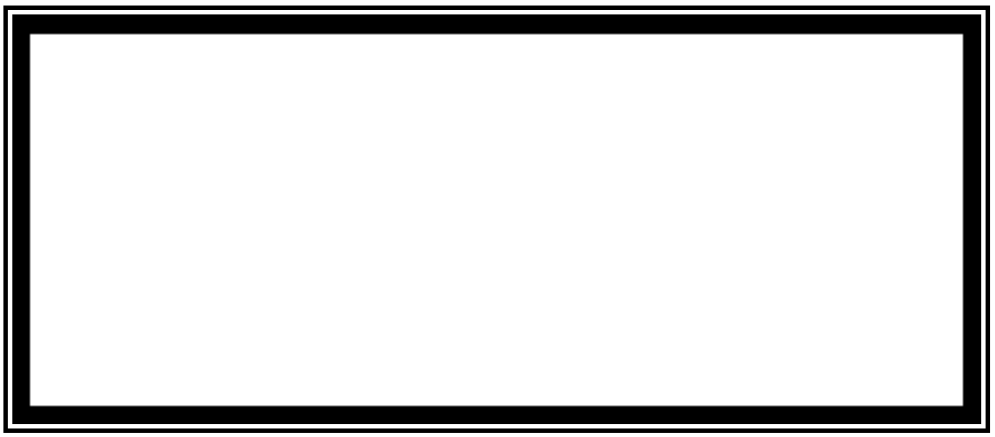
DSC Results

The DSC results for SMA before and after TMT are shown in **Table (3).**It was observed that at TMT 260 ◦C there is a slight change in A_f& M_f that is caused by the small transformation in the martensite phase and the grain size was less finer and a few austenite phase at TMT 280 ◦C.There is a shifting in A_f&$M_f$beyond the limit (100-170) ˚C that is caused by the bigger transformation in the martensite phase and the grain size was less finer and a more austenite phase formation with an increase in equilibrium temperature TMT at 300◦C . It was showed that there is a shifting in exothermic direction (Heating) and shifting in $M_f$beyond the limit 100˚C .This is caused by the bigger transformation in the martensite phase and the fine grain size was shorter finer and a more austenite phase formation with very high increase in equilibrium temperature.In**Figure (7)** the hysteresis of (A_s-M_f) = 30 ◦C and the spread of (A_s-A_f)= 34 ◦C of the SMA within known range. It was shown from the**Figure(8)** there is an increase in the hysteresis remained within limit butraise in spread above limit

lloy	A_s◦C	A_f◦C	M_s◦C	M_f ◦C	T˚	H	S
SMA	129	165	133	100	149	29	34
SMA TMT at 260	125	179	150	97	174	28	54

Table(3). DSC results for SMA before and after TMT

◦C							
SMA TMT at 280 ◦C	134	204	146	95	182	39	70
SMA TMT at 300 ◦C	233	255	135	88	277	145	22



Figure(7). DSC thermogram for SMA before TMT

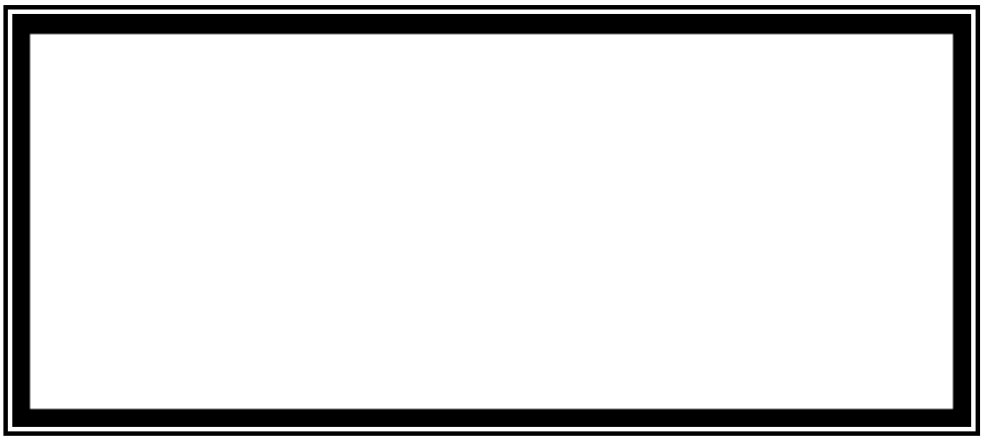


Figure (8). DSC Thermogram of SMA after TMT at 260 ◦C .

In DSC test the range of the alloy has exceeded the known domain (100-170)◦C [3] as shown in **Figure (9**). This is due to the effect TMT which shows sharp peak and increase is spread but hysteresis remained in the same range due to the phase transformation with comparison with TMT 280◦Cand also the spread was less in which lead to less energy a exothermic but more in endothermic reaction . This is because of the increase of austenite phase but with less martensite and the martensite still the effective phase than austenite because of the small distribution of austenite through matrix .

Figure (9). DSC thermogram of SMA after TMT at 280 ◦C .

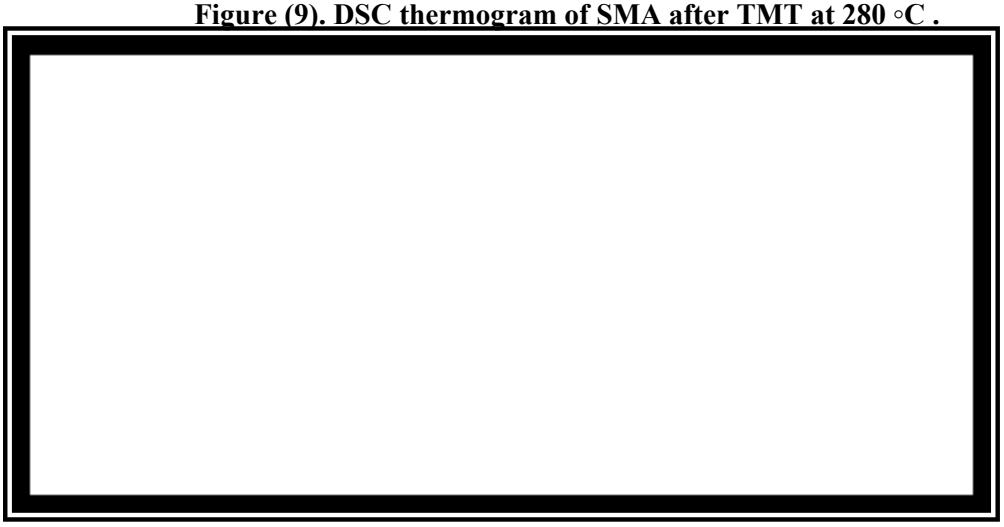


Figure (10). DSC thermogram for SMA after TMT at 300 ◦C

In **Figure (10)**it was seen that from the DSC test the range of the alloy has exceededthe known domain (100-170)◦C [8] as shown in F**igure (6).** This is due to the effect TMT , it shows sharp peak and increasesthespread but hysteresis remained in the same range due to the phase transformation with comparison with TMT 280 ºC and also the spread was less in which lead to less energy a exothermic but more in endothermic reaction . This is because of the increase in austenite phase on the martensite phase with rising temperature of TMT ,These results are similar to **Abbass*etal*[10]** in DSC tests. In which it shows a shift in transformation temperatures and raise in equilibrium temperature .

Thermo-Mechanical Properties

Table (4) indicates the mechanical properties for base SMA before and after thermo-mechanical treatments at different temperatures and by applying stress of 190MPa. It was shown that themechanical properties change according to working temperature and there is a notable increasein hardness with an increase in young modulus (E_M) of martensite and decrease in young modulus (E_A) of austenite with increasing of TMT.While the recovery strain decreases in case of TMT at 260 ºC and increases for TMT at 280 ºC and 300 ºC as compared to the base SMA without TMT .

Table(4). Mechanical properties for base alloy SMA before and after TMT

Temperature ◦C	HV Kg/ mm2	Recovery Strain %	E_M MPa	E_A MPa

Base SMA	371	2.7	39.249	8.855
260	374	2	47.3	6.423
280	398	5.5	47.917	3.184
300	377	6.57	39.942	3.718

Figure (11) shows the stress-strain curves for base alloy SMA after therm-mechanical treatment at (260, 280, 300) ºC at applied stress of σ = 195 MPa , comparing with base alloy before and after TMT. It was noticed that there is a decrease in recovery strain at 260◦C but an increase within the limit with rising temperature to a big limit below the standard 3%. From these curves or charts we use slope function in EXCEL to calculate the young modulus for martensite and austenite transformation as **Lagudas [11]** suggested that the young modulus(E_M)for martensite is increased above the limit as shown in **Table (4)**and also (E_A) decreases for austenite transformation. This is due to the increase of martensite phase and for the fine structure in the γ` but in case of TMT at 300◦C austenite phase is found more effective and increased ,this is due to martensite formation,These results are similar to **Abbass*etal*[10]** in DSC tests. In which it shows a shift in transformation temperatures and raise in equilibrium temperature .

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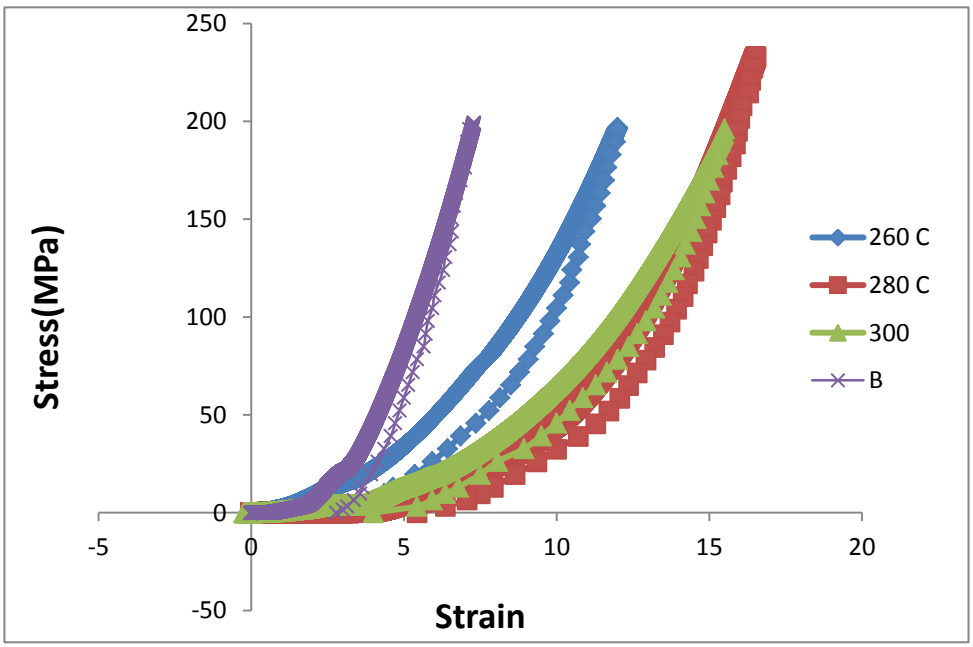

Figure(11). Stress-strain curves of SMA and thermo-mechanical treated SMA

CONCLUSIONS

1. It was found that the shape memory effect improved with increasing thermo-mechanical treatment (TMT)temperature of shape memory alloy (Cu-14Al-4.5%Ni).
2. The recovery strain% decreases below normal range in case of TMT at (260 ◦C)
3. The recovery strain% increases within range when TMT temperature was at (280 ◦C-300 ◦C)
4. It was shown that the young modulus of martensite (EM)increased with TMT temperature rising while the young modulus of austenite (EA) decreased with TMT temperature rising.
5. It was found the hardness increases with rising temperature of TMT .

6. It was found that martensite matrix of SMA and also martensite phase have two types or shapes stacked plate (γ `) phase and fine needles shape (β `) phase and the matrix was more finer grains in structure .
7. The austenite phase increases in growth with the (TMT) temperature rising on the expense of needle shape martensite (β `)
8. The best results for SMA were thermo-mechanical treatment at 260 ◦C

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