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Investigate the Effect of Titanium Addition on the Microstructure, Sliding Wear Resistance and Shape Memory Effect of Cu-Al-Ni SMA Prepared via. Powder Metallurgy

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Abstract: The effect of various amounts (0.4, 0.7, 1 and 1.5% wt.) of Titanium additions on the dry sliding wear, shape memory effect, hardness and microstructure of Cu-11.9% Al-4.5% Ni SMA were investigated by wear instrument, vickers hardness instrument, SEM and XRD. It was found that the properties of the alloy were highly sensitive to the composition variation. It was observed from SEM image that the alloy without the addition lead to form platelet like martensite phase (• •) while with addition of Titanium lead to form needle like martensite phase (• •). It is shown that the wear rate of Cu-11.9% Al-4.5% Ni increases with increasing time and when added (1% wt.) Ti, the wear rate then decreases with increasing time. This is mean that the addition of titanium increase the wear resistance of the alloy. It was noticed that the hardness of Cu-11.9% Al-4.5% Ni SMA is 118 g/μm^2 and when added (0.4, 0.7, 1, 1.5% wt.) of Ti , the hardness increasing to (132.4, 149, 153.1, 162.3 g/μm^2), respectively with Ti addition. It was found that the best SME founded when added 1.5% wt. Ti. This improved that the alloy containing Titanium element has better properties compared with alloy without Titanium.

Key words: Cu-Al-Ni alloy, powder metallurgy, sliding wear, SMA, microstructure, Titanium

INTRODUCTION

In most industrial applications Cu based alloys outfit more economical alternative to NiTi alloys especially in thermo mechanical actuation mechanisms (Otsuka and Ren, 1999). The term " Shape Memory Alloys (SMA) is applied to that group of metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure" (Hodgson, 1988). Many research were presented to improve the Properties of this alloy. Ali and Al Tai (2010) have studied the the effect of iron addition on the dry sliding wear and corrosion behavior of Cu Al Ni shape memory alloy. The effect of Fe additions as (0.4, 0.8 and 1.2 wt.%) on the sliding wear and corrosion behavior of base alloy has, also, been studied. It is clear that Cu Al Ni shape memory alloy in martensitic state has more wear resistance than in austenitic structure. Furthermore when the iron content increases, wear rate increase too. Saud *et al.* (2017) study "The effect of Ta additions on the microstructure, damping, corrosion resistance and shape memory behavior of prealloyed Cu-Al-Ni shape memory alloys". The prealloyed Cu-Al-Ni SMAs with the addition of 2.0 wt.% Ta exhibited the highest shape recovery ratio in the first cycle (i.e., 100% recovery) and when the number of cycles is increased this ratio tends to decrease. Aseel (2013) studied the microstructure, corrosion and dry sliding wear of Cu-Al-Ni shape memory alloy. In this study Cu-11% Al-4% Ni based alloy has been prepared using powder metallurgy technique. The alloying elements such as Cr and Ag with (0.3, 0.6 and 0.9 wt.%) have been added to the base alloy. It was found that the wear resistance of Cu-Al-Ni SMA alloy increases with the increase in alloying elements and weight loss increases with increasing of normal load.

Purpose: The purpose of this study was to investigate the dry sliding wear, shape memory effect , hardness and September 7, 2018 micro structure of Cu-11.9% Al-4.5% Ni SMA with different contents of Ti additions (0.4, 0.7, 1 and 1.5 wt.%). Study the influence of Ti element addition. In (0.4, 0.7, 1, 1.5% wt.) on the dry sliding wear of Cu-11.9% Al-4.5% Ni SMA prepared by powder metallurgy not been reported elsewhere.

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Table 1: Elemental powders specifications and alloys composition

Properties	Cu	Al	Ni	Ti
Particle size (μm)	14	15	27	30
Purity (%)	99.95	99.92	99.95	99.94
Composition (wt.%)	83.6	11.9	4.5	---
	83.2	11.9	4.5	0.4
	82.9	11.9	4.5	0.7
	82.6	11.9	4.5	1.0
	82.1	11.9	4.5	1.5

MATERIALS AND METHODS

Experimental procedure

Sample preparation: The samples are produced by powder metallurgy technique using an elemental powders Cu, Al, Ni, Ti. Table 1 show the particle size, purity and composition of the powders. The elemental powders are mixed using planetary ball mill for about 6 h with mixing ratio 1:5 by weight and rotation speed 350 rpm, 0.5 cc ethyl alcohol are used to reduce the temperature initiated from mixing which lead to oxidation of powder. Then, the mixed powder are compacted by hydraulic press with 750 MPa using cylindrical stainless steel die with 10 mm as diameter. After that the green samples were inserted in vacuum furnace for about 120 min at 550°C and continue the sintering at 850°C for about 100 min with heating rate 10°C/min. The sintered specimens were heated at 900°C for 60 min and then quenched directly in iced water, followed by heating the sample up to 200°C for 30 min in order to age intermetallic compound ($•_2$) and to stabilize the martensite phase. The samples used in the tests were all in aged state.

Preparation of specimens for microstructure observation: The specimens in the aged condition has been wet grinding using 800, 1000, 1200, 1500, 2000, 2500, 3000 grit silicon carbide papers using grinding wheel machine and then polishing by using polishing paper and diamond with 1-3 μm particle size. These samples are then cleaned with distilled water and dried with hot air after that the samples are then etched with etching solution is (2.5 g $FeCl_3$. $6H_2O$+48 mL CH_3OH+10 mL HCl) ferric chloride acid/methanol/hydrochloric acid ,etching time is 10 sec and then use for SEM observation.

Material characterization: Sample with dimensions (d = 10 mm, t = 5 mm) was used for X-ray diffraction characteristics using XRD type mini flex2. X-ray generator with CuK• radiation at 30.0 mA and 40.0 kv is used, the instrument was held at scan speed (2°/min) angles 2• range between 30-90° with step 0.02°/sec.

Mechanical tests

Dry sliding wear: Dry sliding wear has been studied by using vertical pin on sample surface using (950 rpm) and fixed sliding distance (6.3 cm) with (10 N) load. The pin is made of grey cast iron with hardness 55 HRC. The specimen weight is measured before wear test using 0.0001 accuracy electrical balance. After wear time (5, 10, 15, 20 and 25 min) the sample weight is measured again and weight loss during sliding wear has been determined. The test method have been covered according to ASTM-G99-04.

Vickers micro-hardness: This test has been done by using HV-1000 with load 500g and holding time 20 sec and X200 as magnification. Four readings has been taken for each sample and then taking the average. The readings has been taken directly from the instrument screen.

Shape memory effect test: Shape memory effect can be determined form the brinell impression by using brinell macrohardness test with load 31.25 KP and holding time 10 sec .The heat treatment temperature used is 275°C this temperature was estimated from DSC test result. The diameter of the ball impression before and after the heat treatment has been determined using light optical microscope with X100 as magnification then the shape memory effect can be calculated from the equation below (Ariapour, 1998):

$$\text{Shape memory effect (SEM\%)} = \frac{d_b - d_a}{d_b} \times 100$$

Where:

d_b = Diameter of impression in μm before heat treatment
d_a = Diameter of impression in μm after heat treatment

RESULTS AND DISCUSSION

Microstructure and X-ray diffraction for phase analysis of Cu-Al-Ni smas after and before Ti addition: Scanning electron microscope observation has been used in order to explain the effect of Ti addition on the microstructure of the alloy. After sintering process the microstructure has only • and $•_2$ (Cu_9Al_4) phases and after direct quench process the microstructure involve full martensite structure and there is no precipitation of $•_2$ in the microstructure. Figure 1 shows SEM images of Cu-11.9% Al-4.5Ni SMA microstructures after aging with and without (1.5%wt.) titanium addition. It was found that the microstructures obtained from SEM were all in martensitic structure at 25°C. In case of the alloy without Ti addition as shown in Fig. 1a, the microstructure of the alloy included • phase, coarse platelet like martensite (••) and precipitates of ($•_2$) intermetallic compound as fine particles on the martensite phase. The precipitates from ($•_2$) phase looks like white and grey particles with

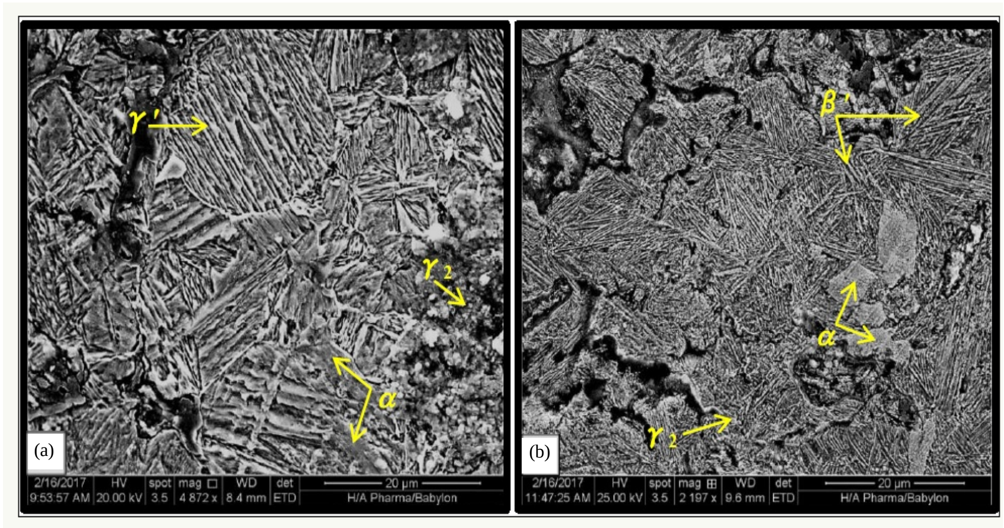

Fig. 1: a) SEM microstructure image of Cu-Al-Ni SMA and b) SEM microstructure image of Cu-Al-Ni-1.5% Ti SMA

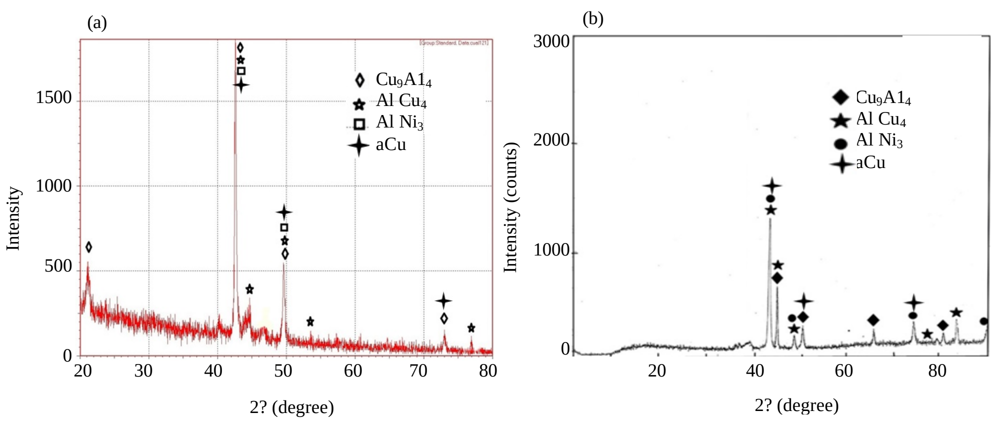

Fig. 2: The XRD test results of; a) Cu-Al-Ni SMA and b) Cu-Al-Ni-1.5% Ti SMA

rounded or irregular shapes and distribute randomly. The precipitates (•$_2$) were spherical with 10-20 nm size and homogenously distributed in martensite plates (Elef, 2004). The presence of these phases have been proved by XRD test as shown in Fig. 2. In case of the alloy containing (1.5%wt.) Ti as shown in Fig. 1b, it was found that the titanium addition affect the martensitic transformation and this will lead to form needle like martensite shape (••). The needlelike martensite (••) has very high thermo-elastic behavior which can be refer to their controlled growth in the self-accommodating groups (Saud *et al*., 2015). These platelet like and needle like martensite phases created and grew up in different orientations. "The growthoperation of the martensite phase include the accommodation of the topical stress field, therefore, it request forming other groups (Sari, 2010).

Figure 2 shows the XRD results of the Cu-Al-Ni SMA with and without (1.5% wt.) Ti addition. In both cases it was found that the phases exist was • phase, martensitic structure AlCu4, intermetallic compound Cu_9Al_4 and $AlNi_3$. It was found that during aging heat treatment there is intermetallic compound with titanium alloying element as $(C_u, Al)_2$ (Kadhum, 2008). The addition of Titanium create a kind of precipitates known as X-phase which are related to the $Ni_3(Al, Ti)$, $Ni_{0.35}Al_{0.3}Ti_{0.35}$ and $Ti_{3.3}Al$ compounds (Saud *et al*., 2015). In both cases $AlNi_3$ is formed during aging heat treatment which is an equilibrium phase of B_2 type structure.

Dry sliding wear results: The relationship between weight loss (mg) during wear test and the time (min) has been presented in Fig. 3. It was found that weight loss increases with increasing time as conduct of conventional structural alloys. However, the weight loss of all increases

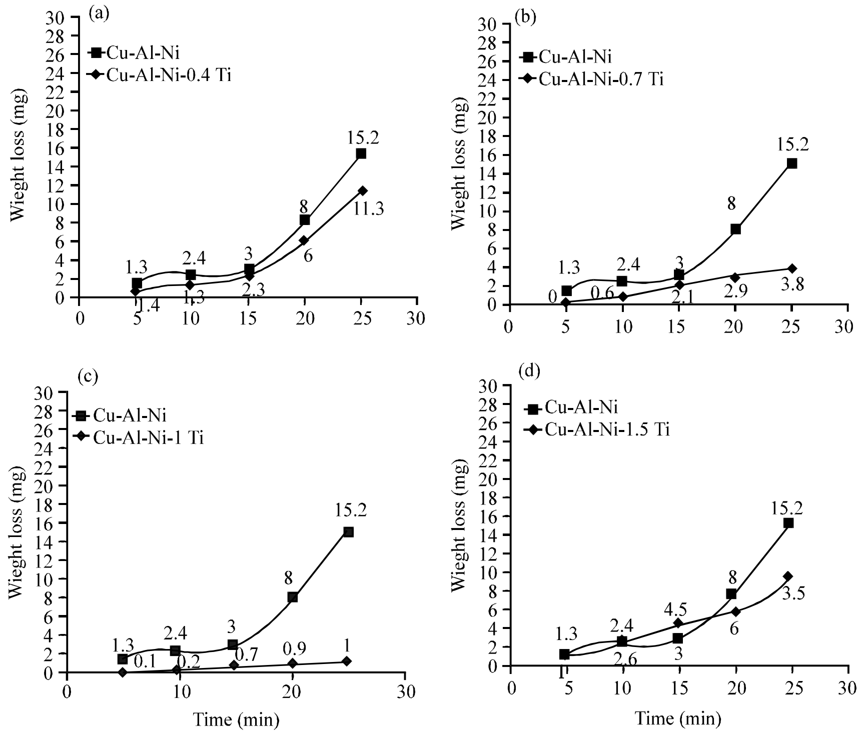

Fig. 3: The relationship between weight loss and time for: a) 0.4% wt. Ti; b) 0.7% wt. Ti; c) 1% wt. Ti and d) 1.5% wt. Ti

with increasing the time and this is certainly because more time of friction tend to remove more material from the surface.

This increases in the weight loss has been attributed to increase in plastic deformation for the materials in the surface (Aseel, 2013). The sample that include martensitic structure has high wear resistance than that contain austenitic structure because the martensite has superelastic behavior, so that, it distort elastically under loading which gives the sample more resistance to mass loss as a result to friction and sliding effect (Abid Ali and Al Tai, 2010). From Fig. 3c it is shown that the weight loss of Cu-11.9% Al-4.5% Ni increases with increasing time and this will lead toincreasing the wear rate of the alloy.

While in the addition of (1%wt.) Ti, the weight loss become smaller with increasing time and this means that the wear rate decreases with increasing time. The best addition amount was (1% wt.) Ti which gives the lowest wear rate with increasing wear time compared with other addition amounts. The high wear resistance accomplished when titanium added is due to grains refinement and the grains refinement is associated with the inhibiting effects of grain growth of Ti element in solid solution (Sampath, 2005). The effect of other addition amounts of Ti on the weight loss is shown in Fig. 3a, b, d.

Vickers microhardness test results: Vickers microhardness values as a function of weight percentage of Ti addition have been shown in Fig. 4. It was noticed that the hardness of Cu-11.9% Al-4.5% Ni SMA is 118 g/μm^2 and when added (0.4, 0.7, 1, 1.5% wt.) of Ti the hardness increasing to (132.4, 149, 153.1, 162.3 g/μm^2) respectively with Ti addition. The best addition amount is 1.5%wt. Ti and this is attributed to the grains refinement which was associated with the inhibiting effects of grain growth by Ti element in solid solution (Lee and Wayman, 1986). Also, the increase in the hardness with increasing Ti addition maybe lead to increase the amount of intermetallic precipitates (•$_2$) which is act as obstacles prevent the dislocation movement.

Shape memory effect results: The Shape Memory Effect (SME%) of Cu-11.9% Al-4.5% Ni SMA after and before the titanium addition has been determined. It was found that the best SME was when added 1.5% wt. Ti . The SME increase with increasing the addition of Ti. The results were shown in the Table 2.

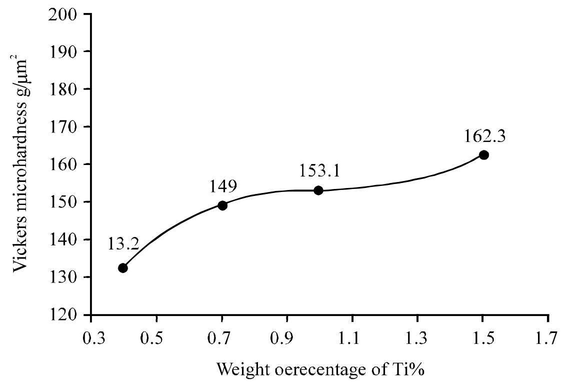

Fig.4: The relationship between the vickers microhardness and weight percentage of Ti addition

Table 2: The influence of Titanium on shape memory effect of Cu-11.9% Al-4.5% Ni SMA

Alloy composition	d_b (µm)	d_a (µm)	SME (%)
Cu-Al-Ni	616.06	594	3.571
Cu-A1-Ni-0.4% Ti	529.16	506	4.347
Cu-A1-Ni-0.7% Ti	523.09	485	7.265
Cu-A1-Ni- l% Ti	637.00	577	9.419
Cu-A1-Ni- l.5% Ti	538.00	485	9.851

CONCLUSION

It was concluded that the alloy without the addition of Titanium lead to form platelet like martensite phase (••) while with addition of Titanium lead to form needle like martensite phase (••). The wear rate of Cu-11.9% Al-4.5% Ni increases with increasing time and when added (1%wt.) of Titanium, the wear rate decreases with increasing time. The best addition amount of Titanium was 1.5% wt. which give hardness equal to 162.3 g/µm^2 compared with the hardness of base alloy which was 118 g/µm^2. It was found that the best SME was 9.851% when added 1.5% wt. of Titanium.

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