Effect of Heat Treatment of Cu-Al-Be Shape Memory Alloy on Microstructure, Shape Memory Effect and Hardness

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Abstract

Cu-13Al-0.545Be shape memory alloy are heat treatment at different temperature and time. The microstructure of alloy after heat treatment at 850°C, 650°C and aging at 150°C ,450°C and 550°C for 2, 4 and 6 h study by optical microscope and X-ray diffraction. Bending test is use to show effect of heat treatment on super-elastic and shape memory effect.

Micro hardness test used to show effect of heat treatment on micro hardness .shape memory effect increase at heat treatment 650°C and aging at 150°C, while at 450°C and 550°C will decrease because precipitate formation rate rises with increase in temperature and time. The hardness and precipitates in the alloy increases with increasing ageing duration. Higher ageing temperature avoids the imperfection by moving and filling the empty space thereby hardens the alloy.

Keywords: Alloys; Materials; Thermomechanical; Stabilization

Introduction

Previous investigations on Cu-(11.4-11.8 wt.%)Al shape memory Alloys with the addition of small quantities of beryllium have shown that they exhibit the pseudo-elastic effect at room temperature, due to the martensitic transformation from the b phase to 18R martensite. Shape memory alloys are the metallic group of materials and these materials are used in many application fields as it is capable of recovering its initial shape when exposed to variation of temperature or stress. Understanding of their microstructure and thermal behaviors has brought a major impact on their applications, as in case of aerospace, automotive and robotics components are needed to achieve further improvement in the properties as it require higher transformation temperatures, The thermomechanical properties of Cu-Al-Be alloys have been studied, and their use is highly promising for applications as passive dampers of seismic energy in buildings and in bridges, When these alloys are submitted to heat treatments like a slow cooling from high temperature or an isothermal heating, the formation of precipitates can be produced , and their presence can affect their shape memory properties. Aged Cu-Al-Mn SMAs results in transformation of β'1 martensite to γ'1 martensitic which leads to change in the shape memory characteristics and transformation temperatures. Cu-Al-Mn Alloys aged above 500°C does not show martensitic transformation, because of formation of large quantities of precipitates. Cu-Al-Be alloys show good strain recovery and shape memory effects. Microstructure of as-cast specimens shows austenitic microstructure and after quenching same specimens shows completely lath martensitic microstructure [1-4].

Experimental Work

The alloy Cu-13Al%-0.545Be% was imported from France, Chemical composition analysis of Cu-Al-Be alloy was carried by oxford foundry expert type in central organization for standardization and quality control-Baghdad (Figure 1). Table 1 show chemical composition of Cu-Al-Be alloy.

Homogenization at 800°C for 3 hour in electric box furnace and betatization and quenching from 800°C in salt ice water. Heat treatment at 650°C and aging at 150°C, 450°C and 550°C in electric box France for 2, 4 and 6 hour and quenching in ice water with salt Figure 2 shows electric box furnace.

For microstructure the samples are grinding using different wet paper 120, 320, 500, 1000, 2000 and wishing with water ,polishing with cloth diamond and lubricant using polishing device then samples wishing with water, etching with solution 5 g $FeCl_3$,10 ml HCL and 100 ml H_2O. Theses process is done in samples preparation at metal

Figure 1: Oxford foundry master expert type chemical composition.

Figure 2: Electric resistance box furnace type for aging samples.

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Types of phases in the alloys were determined by optical microscope and using X-ray diffraction device type (shimadzu XRD-6000 X-Ray diffractmeter) (Figure 4).

For Shape memory effect Bending test is use to show effect of heat treatment on superelastic and shape memory effect. Wire specimen of alloy with dimensions 1.2 mm diameter and 50 mm length is used in this bending test (Figure 5).

$$SME=\theta m/180$$

Where,

θe=angle recovered on unloading.

θm=angle recovered on heating.

Microhardness test used to show effect of heat treatment on microhardness. Heat treatment at different temperature, time and quenching media led to effect on microstructure and phases therefore effect on microhardness (Figure 6).

Element	Zn%	Pb%	Fe%	Si%	S%	Sb%	AL%	Be%	Cu%
Wt.%	0.003	0.0134	0.019	0.0242	0.0439	0.112	13	0.545	balance

Table 1: Chemical composition of Cu-Al-Be shape memory alloy.

Figure 3: (a) Electric disk rotary grinding, (b) polishing device (c) optical microscope for microstructure observation.
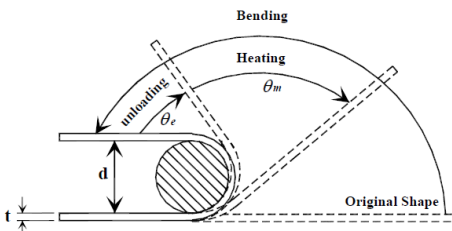

Figure 4: XRD 6000 shimadzu type.

Figure 5: Schematic diagram of bending test for measuring shape memory effect.

Figure 6: Micro Vickers hardness device models TH714 type.

$HV = 1.845P/d^2$

P=applied load, d=length of diagonal.

Result and Discussion

Microstructure

Heat treatment at 850°C at 3 h and quenching in ice water with salt have plate of martensite phase. While microstructure of sample at 650°C at 2 hour was martensite and γ_2 phase, at 4 and 6 h was martensite phase. The martensite transformation is not appreciably effected by 100 h at 220°C or 260°C. Beyond annealing for 200 h at theses temperature, martensite transformation degradation is noticed caused by the precipitation phenomenon. Aging of martensite phase at 450°C will precpitate $(\alpha + \gamma_2)$ phase according to phase diagram of Cu-Al-Be, Increasing aging time led to increase amount of precipitate of γ2 have Cu_9Al_4 (high Aluminum content) and α (low aluminium content). aging at 550°C will precipitate martensiteand γ2 phase, increase aging time led to increase amount of precipitate of γ_2. Figures 7-16 shows martensite phase at different magnifications [5-10].

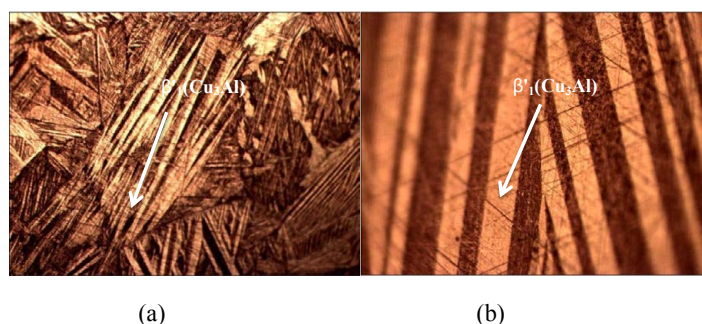(a)   (b)

Figure 7: Plate of martensite phase at different magnifactions by optical microscope. (a) at 10x and (b) at 40x.
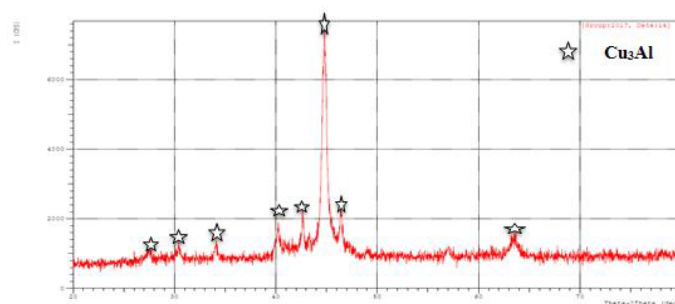

Figure 8: X-ray diffraction of Cu-Al-Be shape memory alloy.

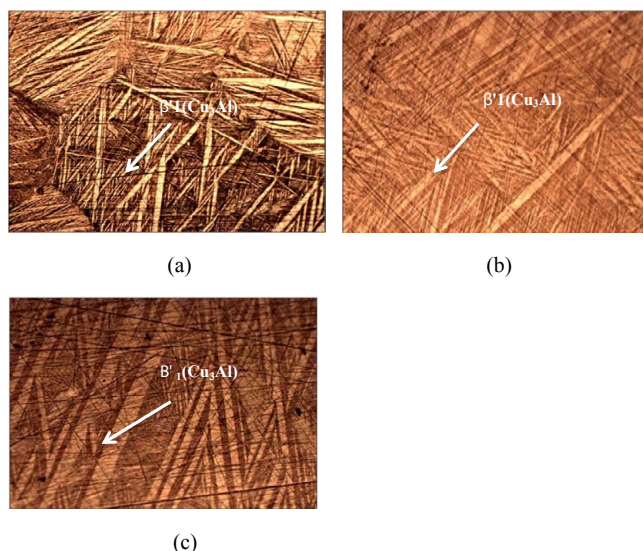(a)   (b)

(c)

Figure 9: Effect of heat treatment on microstructure by optical microscope at magnification (10x). (a) 150°C 2 h salt ice water quenching (b) 150°C 4 h water quenching (c) 150°C 6 h salt ice water quenching.
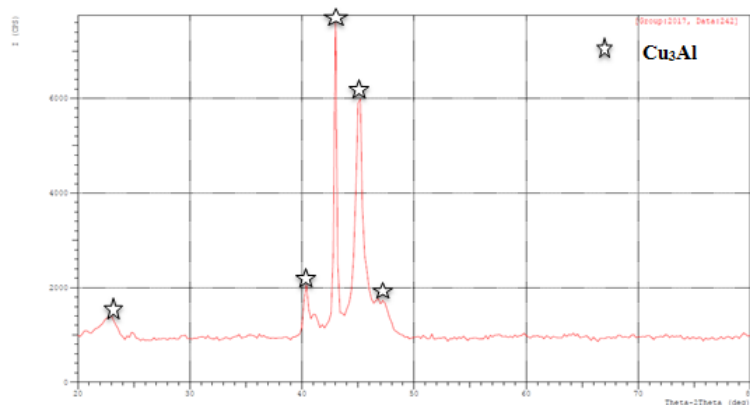
Figure 10: X-ray diffraction of Cu-Al-Be shape memory alloy that heat treatment at 150°C for 6 h and quenching in salt ice water.
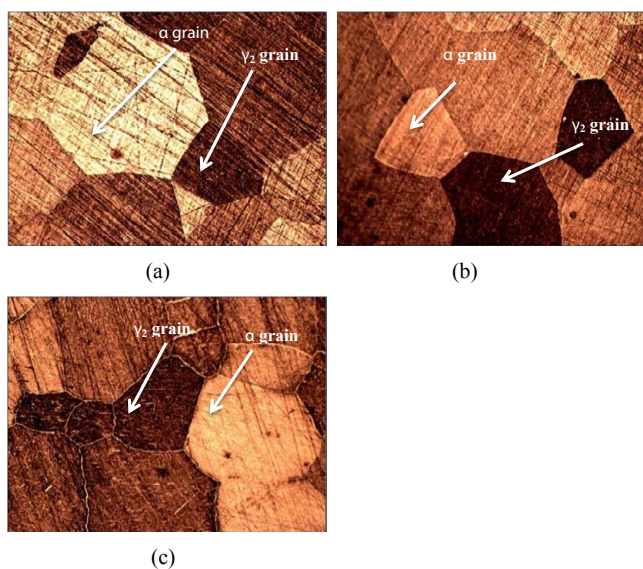

Figure 11: Effect of heat treatment on microstructure by optical microscope at magnifaction (10x). (a) 450°C 2 h water quenching (b) 450°C 4 h water quenching (c) 450°C 6 h water quenching.
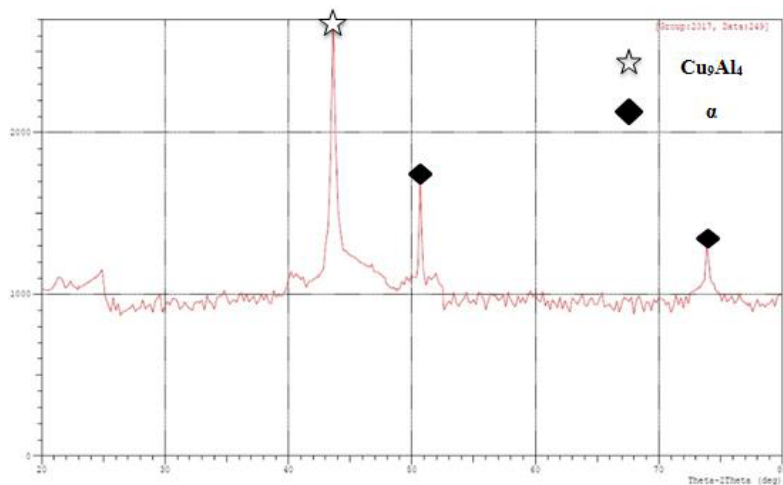

Figure 12: X-ray diffraction of Cu-Al-Be shape memory that heat treatment at 450°C for 6 h and quenching in water.
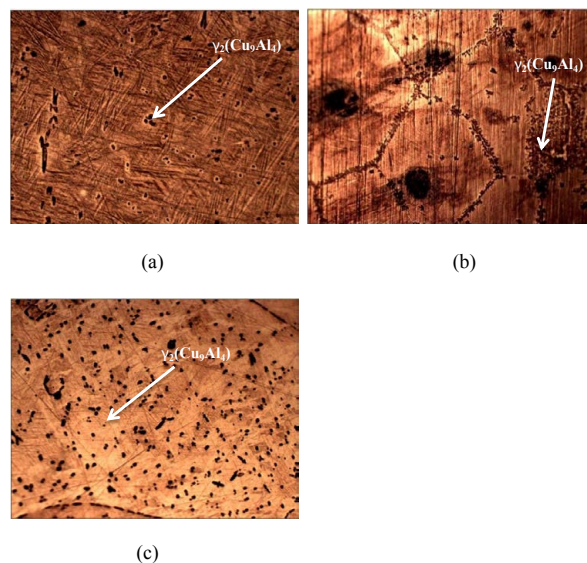
(a)   (b)

(c)

Figure 13: Effect of heat treatment on microstructure by optical microscope at magnifaction (10x). (a) 550°C 2 h salt ice water quenching (d) 550°C 4 h salt ice water quenching (g) 550°C 6 h salt ice water quenching.

Figure 14: X-ray diffraction of Cu-Al-Be shape memory that heat treatment at 550°C for 6 h and quenching in salt ice water.

(a)   (b)

(c)

Figure 15: Effect of heat treatment on microstructure by optical microscope at magnifaction (10x). (a) 650°C 2 h salt ice water quenching (b) 650°C 4 h salt ice water quenching (c) 650°C 6 h salt ice water quenching.
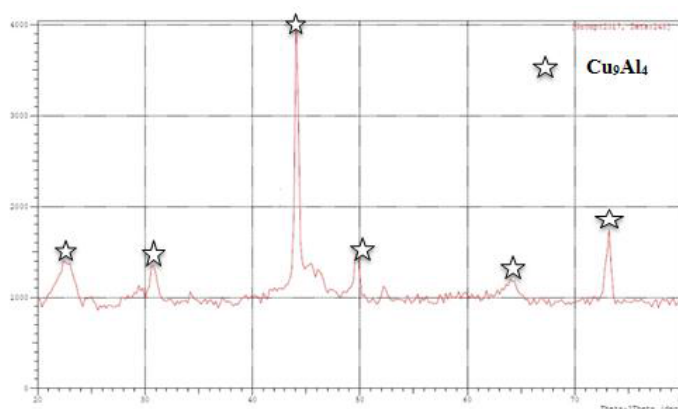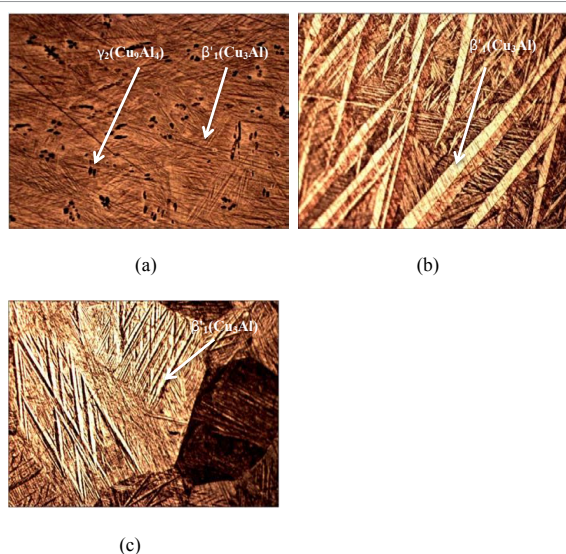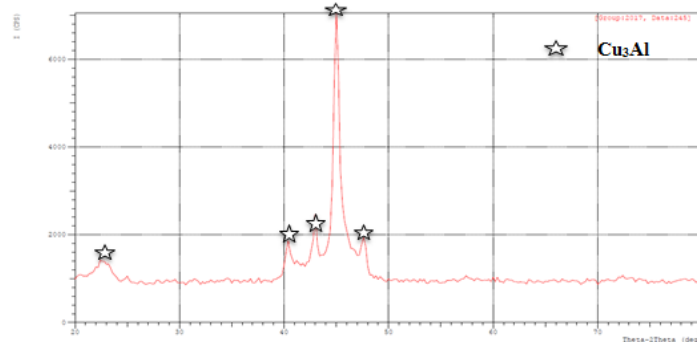
Figure 16: X-ray diffraction of Cu-Al-Be shape memory alloy that heat treatment at 650°C for 6 h and quenching in ice water.

Heat treatment	d (mm)	t (mm)	θe	θm	SME%
Shape memory alloy	18	1.2	145	155	86
150°C 2 h ice water quenching	18	1.2	151	170	94
150°C 3 h ice water quenching	18	1.2	154	174	96
150°C 4 h ice water quenching	18	1.2	154	175	97
450°C 2 h ice water quenching	18	1.2	130	140	77
450°C 3 h ice water quenching	18	1.2	110	130	72
450°C 4 h ice water quenching	18	1.2	100	110	61
550°C 2 h ice water quenching	18	1.2	140	150	83
550°C 3 h ice water quenching	18	1.2	120	135	75
550°C 4 h ice water quenching	18	1.2	110	120	66
650°C 2 h ice water quenching	18	1.2	150	165	91
650°C 3 h ice water quenching	18	1.2	155	170	94
650°C 4 h ice water quenching	18	1.2	165	175	97

Table 2: Effect of heat treatment on shape memory effect.
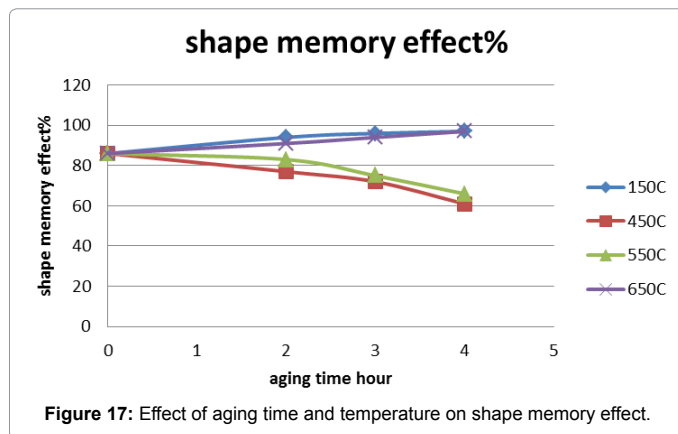
Figure 17: Effect of aging time and temperature on shape memory effect.

Heat treatment	HV
Shape memory alloy as received	178.76
Heat treatment at 150°C 2 h ice water quenching	165.23
Heat treatment at 150°C 4 h ice water quenching	220.06
Heat treatment at 150°C 6 h ice water quenching	226.43
Heat treatment at 450°C 2 h ice water quenching	233.53
Heat treatment at 450°C 4 h ice water quenching	253.16
Heat treatment at 450°C 6 h ice water quenching	257.4
Heat treatment at 550°C 2 h ice water quenching	238.5
Heat treatment at 550°C 4 h ice water quenching	249.1
Heat treatment at 550°C 6 h ice water quenching	313.16
Heat treatment at 650°C 2 h ice water quenching	224.63
Heat treatment at 650°C 4 h ice water quenching	217.76
Heat treatment at 650°C 6 h ice water quenching	216

Table 3: Effect of heat treatment on microhardness.

Shape memory effect

Effect on heat treatment on shape memory effect, shape memory alloy as received have thick plate of martensite phase and when aging at 150°C that can effect on martensite plate by produced small and fine plate of martensite plate, which increase in shape memory effect than thick plate aging at 450°C martensite phase transform into γ_2 and α phase, increase aging time led to increase transform martensite phase to γ_2 and α phase that decrease shape memory effect. Aging at 550°C also led to transform martensite phase into γ_2 phase, increase aging time led to increase transform martensite phase into γ_2 phase that decrease shape memory effect. when heat treatment at 650°C at 2 h produce γ_2 and very fine plate of martensite hamza phase, this very fine plate martensite phase increase in shape memory effect and 3 and 4 hour form fine martensite phase only without γ_2 phase that cause increase shape memory effect [11,12] (Table 2 and Figure 17).

Effect of heat treatment on microhardness

Vickers microhrdness of heat treatment alloy show increases with increasing aging time. The formation of precipitation increased with increase aging time. The imperfection that percent in the alloy will move and fill the empty space at higher temperature which hardens the alloy. Increase aging time at 150°C which led to increase in microhardness because of martensite stabilization by precipitate, change vacancy concentration during aging and change lattice parameters of martensite phase. While increasing aging time at 450°C which led to more decomposed of martensite phase to α and γ_2 phase which led to increase in microhardness aging time at 550°C led to decomposed in to γ_2 phase and when increase aging time that increase γ_2 phase which increase microhardness. Aging 2 h at 650°C that form martensite and γ_2 phase which increase microhardness, while aging
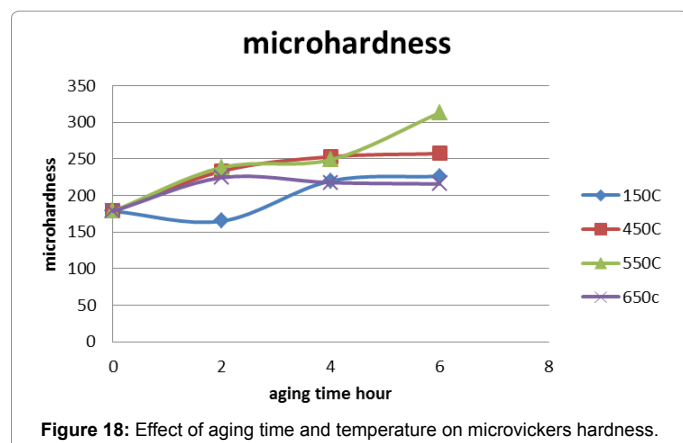
Figure 18: Effect of aging time and temperature on microvickers hardness.

4 and 6 h which form only martensite phase that led to decrease in microhardness (Table 3 and Figure 18) [11,12].

Conclusion

- Cu-Al-Be shape memory alloy have high thermal stability.

- Heat treatment at 650°C and aging at 150°C increase shape memory effect.

- Aging at 450°C and 550°C decrease shape memory effect.

- Heat treatment at 650°C and aging at 150°C, 450°C and 550°C will increase in microhardness.

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