Effect of changing silver content on the mechanical properties of Cu-6wt.%Al-Ag for super-plasticity alloy applications

Aqsa Amir[a], Saira Bibi[b], Ahmad Nawaz[c,d], Bilal Islam[c,d], Arshad Ali Khan[c,d*], Saad Anwar[e], Ghulam Asghar[f], Muhammad Ali Ayyaz[g], Fawad Haider[h]

[a]*Institute of Advanced Materials, Bahauddin Zikriya University, Multan 60800, Pakistan.*

[b]*Department of Materials Science & Engineering, Pak-Austria Fachhochschule: Institute of Applied Sciences and Technology, Mang, Haripur 22621, KPK, Pakistan.*

[c]*Department of Mechanical Engineering, University of Engineering & Technology, Peshawar 25120, Pakistan.*

[d]*National Center for Physics, Quaid.i.Azam University Campus, Islamabad, Paksitan.*

[e]*Department of Physics, Bacha Khan University, Charsadda 24420, Pakistan.*

[f]*Department of Physics, University of Poonch, Rawalakot, AJK, Pakistan.*

[g]*Department of Mechanical Engineering, University of Engineering & Technology, Taxila, 47050, Pakistan.*

[h]*Department of Industrial Engineering, University of Engineering & Technology, Peshawar 25120, Pakistan.*

[*]*Corresponding Author: Arshad Ali Khan*

***Abstract*—**Ten grams of button-shaped samples of three different compositions $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$, and $Cu_{80}Al_6Ag_{14}$ were developed by vacuum arc melting technique followed by homogenization in three-zone tube furnaces for 72 hours at 850ºC. Metallography was done to study the microstructure and mechanical properties of these alloys. The microstructures indicate the presence of alpha and beta phases in all three compositions. X-ray diffraction was performed to identify the phases and the crystal structure was found to be FCC (Face centered cubic). The results of mechanical properties indicate that with the increase in the silver content, there is an increase in tensile strength and hardness values and a decrease in ductility.

Keywords— Microstructure; Metallography; Microscopy; X Ray Diffraction; Heat treatment.

I. Introduction

The Ni-Ti based shape memory alloys are mostly used now-a-days but they are expensive. To meet this challenge, a new series of high-temperature copper-based, shape memory alloys have recently been developed which are cheaper and replace the Ni-Ti in mostly modern applications. Among the Cu based shape memory alloys mostly investigated, the Cu-Al-Ni, Cu-Al-Zn, and Cu-Al-Mn alloys have been studied extensively [1-21]. Cu-Al-Ag is the latest Cu based alloy having attractive set of properties. This alloy contains 1-20 wt. % Al, 1-20 wt. % Ag**,** 0-2 wt. % of a minor element (preferably Co) and balance Copper. The martensitic start transformation temperatures of these alloys are above 200 °C and, in some cases; they have good high-temperature stability and may be useful in commercial applications where higher operating temperatures are required. In the Cu-Al-Ag alloy, the transformation temperatures are sensitive to a small variation in the Ag content. The sensitivity increases with the Ag content. According to the Cu–Al equilibrium diagram [22-23], the α-Cu solid solution field limit is between 8.5 and 9.0 wt. % Al below 300°C. The α_2 phase has an ordered FCC structure and exists in equilibrium with α and ϒ below a peritectoid reaction $\alpha+\Upsilon_1 \leftrightarrow \alpha_2$. A silver addition to Cu–Al increases its stress corrosion resistance [24] and modifies the aging characteristics and shape memory effect of the alloys [25], with no ternary intermediate phases being observed [26-27]. Copper-base alloys can be readily hot worked in air. With low aluminum content (<6 wt. %), Cu-Al-Ag alloys can be cold finished with interpass annealing. Alloys with higher aluminum content are not as easily cold workable.

The purpose of this study is to develop Cu-Al-Ag ternary shape memory alloys of varying compositions and to study the effect of silver additions on the mechanical properties of Cu-6 wt. % Al-Ag shape memory alloy.

II. EXPERIMENTAL WORK

Three alloys of varying compositions were prepared by using copper, aluminum, and silver, each of 99.99% purity. Three button shaped alloys each having weight of ten grams were fabricated by vacuum Arc melting unit under inert gas (Argon) atmosphere. Arc melter unit was flushed with high-purity argon many times to ensure the oxidation free melts. Melting was done three times to ensure the homogeneity of the alloying elements. The complete experimental work is explained through a flowchart given in Fig.1

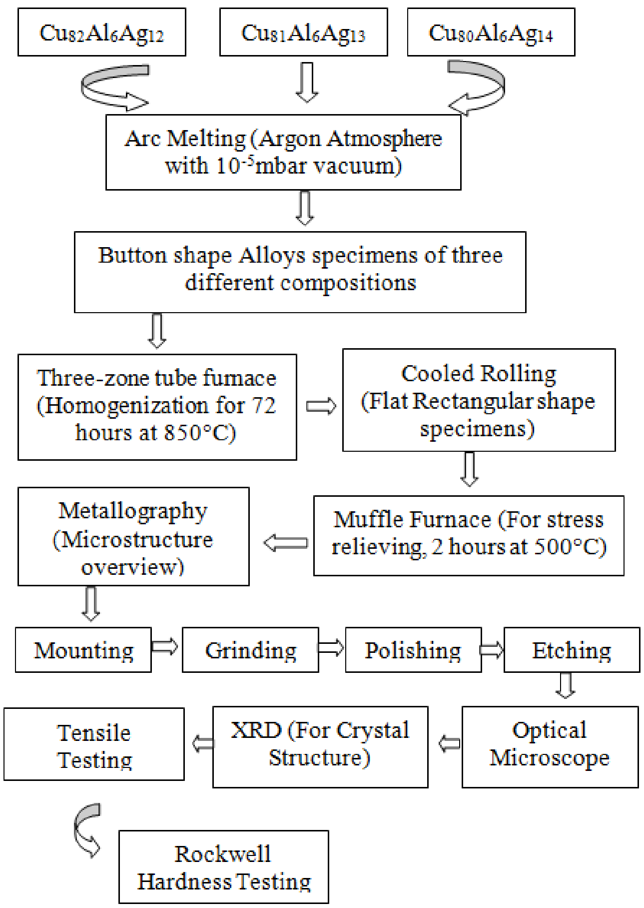

Fig.1. Complete flowchart of activities

The material loss was found to be 1%. All the prepared samples were homogenized for 72 hours at 850°C in the three-zone tube furnace to ensure the mixing of each alloying element completely. Composition of different alloys is given in Table 1.

TABLE 1: Weight Percentages of the Alloys.

Alloys	Cu wt.%	Al wt.%	Ag wt.%
1	82	6	12
2	81	6	13
3	80	6	14

III. RESULTS AND DISCUSSION

A. *Optical Microscopy*

The microstructures of as-cast $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$ and $Cu_{80}Al_6Ag_{14}$ alloys are shown in Fig.2 (a), (b) and (c) respectively at two different magnifications. Microstructures of the said alloys consist of two phases, alpha (α) and beta (β). The alpha phase is visible as a dark phase corresponding to the Cu-based solid solution and the Beta phase is visible as a bright gray phase corresponding to the Ag based solid solution. Aluminum particles are uniformly distributed in the alloy. Segregation of the β phase on grain boundaries is visible. These results are in good agreement with the literature and all the results are comparable with previous research [29].

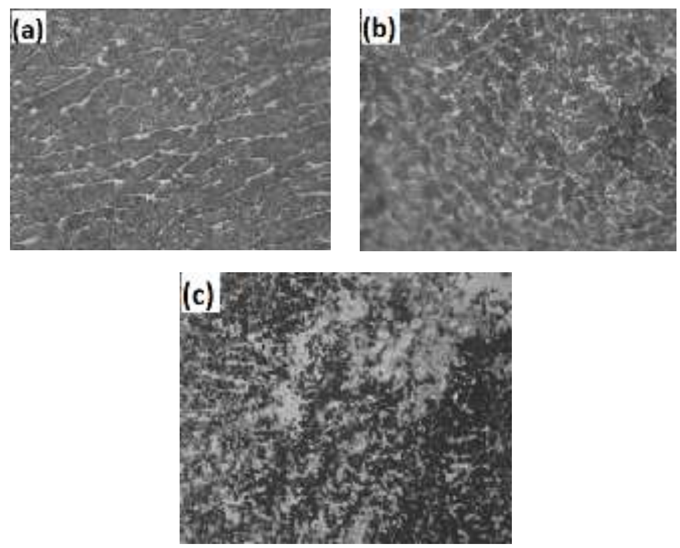

Fig.2. Microstructure of (a) $Cu_{82}Al_6Ag_{12}$ (b) $Cu_{81}Al_6Ag_{13}$ and (c) $Cu_{80}Al_6Ag_{14}$

B. *X-ray Diffraction*

The XRD spectrum is taken in the 2θ range from 15 to 110^{0}C using Bruker D8 advanced X-ray Diffractometer with Cu Kα radiation, showing that the peaks are related to Cu-Al-Ag alloy. The results showed that the crystal structure was in face centered cubic (FCC) structure. Numerous crystalline peaks for the first specimen were observed at 2θ = 43.2483, 50.2378, 73.7664, 89.3368, and 94.5357 degrees along with miller indices values (111), (200), (220), (311), (222). Numerous crystalline peaks for the second specimen were also observed at 2θ = 43.2214, 50.2128, 73.7341, 89.3230, 94.4624 and 115.2499 degrees along with miller indices values (111), (200), (220), (311), (222) and (400). Similarly, for the third specimen numerous crystalline peaks were observed at 2θ = 43.4732, 50.4483, 73.9909, 89.5293, 94.7324, and 115.4453 degrees along with miller indices values (111), (200), (220), (311), (222) and (400). These results were matched with JCPDS card no 04-836. Apart from this, no extra peak of any other metal was observed in the spectrum and the high purity of Cu-Al-Ag was obtained during the development as shown in Fig.3, Fig.4, and Fig.5. The lattice parameters were obtained by using the formula as shown below [29]:

$$\frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2} \quad (1)$$

a = 3.620 Å (Experimental Values)
a = 3.6150 Å (Standard Values)
These are approximately equal to the standard values.

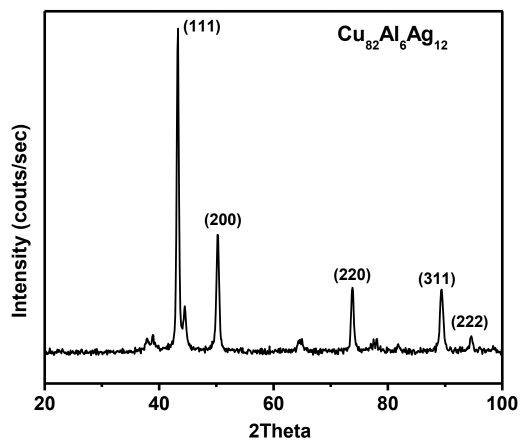

Fig.3. X-ray diffraction pattern of $Cu_{82}Al_6Ag_{12}$

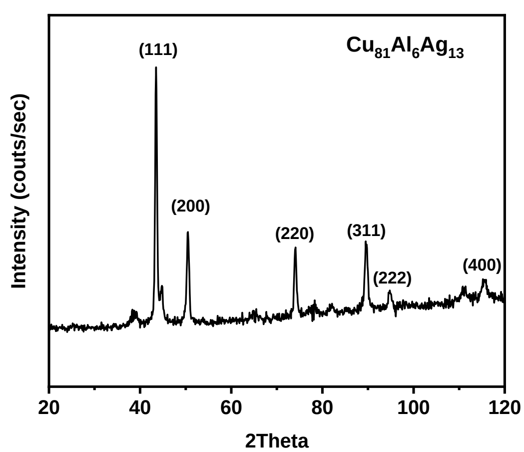

Fig.4. X-ray diffraction pattern of $Cu_{81}Al_6Ag_{13}$

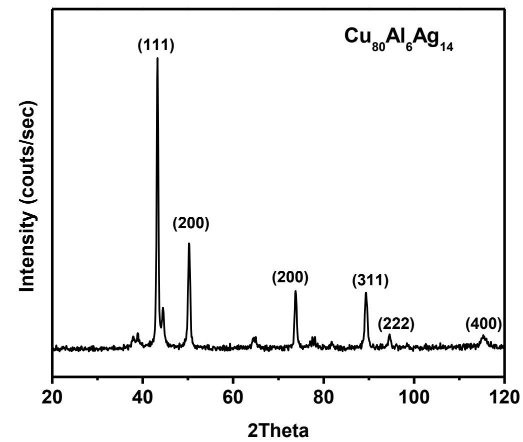

Fig.5. X-ray diffraction pattern of $Cu_{80}Al_6Ag_{14}$

C. *Mechanical properties*

The mechanical properties of developed alloys are listed in Table 2.

TABLE.2. Mechanical properties of the developed Alloys

S. No	Mechanical property	$Cu_{82}Al_6Ag_{12}$	$Cu_{81}Al_6Ag_{13}$	$Cu_{80}Al_6Ag_{14}$
1	Percent elongation	17.3766	17.0078	16.325
2	Young Modulus (GPa)	3.182	4.61375	5.2709
3	Toughness (j/mm^3)	64.175625	47.98725	33.9862
4	Tensile Strength (MPa)	533.125	580.5835	623.6785
5	Hardness	73.11	79.23	83.21

1) *Tensile Strength*

The comparison of tensile strength values of as-cast $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$, and $Cu_{80}Al_6Ag_{14}$ are shown in Fig.6. The trend shows that as the Ag content increases in the alloy, tensile strength increases. As Ag segregates at the grain boundaries, the grain boundaries strength increases and the material shows brittleness.

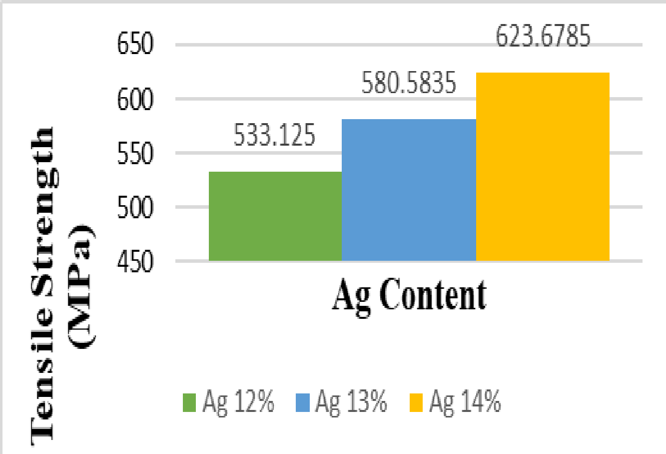

Fig.6. Comparison of Tensile strength in MPa

2) Ductility

The comparison of percent elongation of as-cast alloys $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$, and $Cu_{80}Al_6Ag_{14}$ are shown in the Fig.7. The trend shows that as the ductility decreases gradually with the increase in Ag content. As the tensile strength increases due to the segregation of Ag particles on the grain boundaries the ductility decreases. The material shows brittleness.

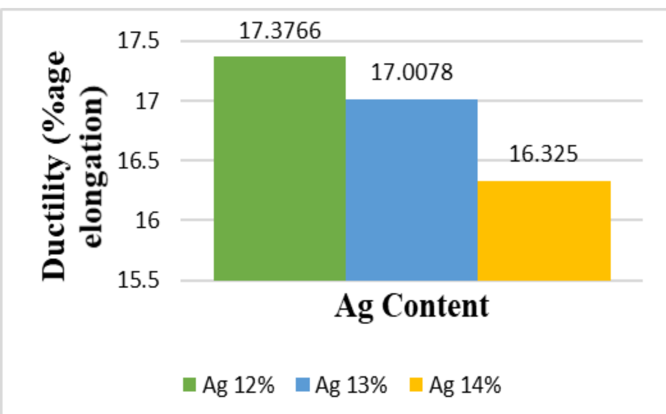

Fig.7. Comparison of Ductility (%age elongation)

3) Hardness Testing

The comparison of hardness values of as-cast alloys $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$, and $Cu_{80}Al_6Ag_{14}$ are shown in Fig.8. The trend shows that as the Ag content increases in the alloy, the hardness also increases. This can also be attributed to the segregation of Ag particles on the grain boundaries.

IV. CONCLUSION

The alloys of the compositions $Cu_{82}Al_6Ag_{12}$, $Cu_{81}Al_6Ag_{13}$ and $Cu_{80}Al_6Ag_{14}$ were successfully developed. The results obtained from optical microscopy examination indicated that the structure of the alloy consisted of an Alpha phase which was a dark phase corresponding to the Cu-based solid solution and the Beta phase was a bright gray phase corresponding to the Ag-based solid solution. Mechanical properties (Young's modulus, Tensile Strength, Hardness, Ductility, and Toughness) were studied and all were found to increase with the increase of Ag content. In contrast, the ductility and toughness were found to be decreased. The results obtained from XRD indicated that the structure of the alloys was found to be FCC.

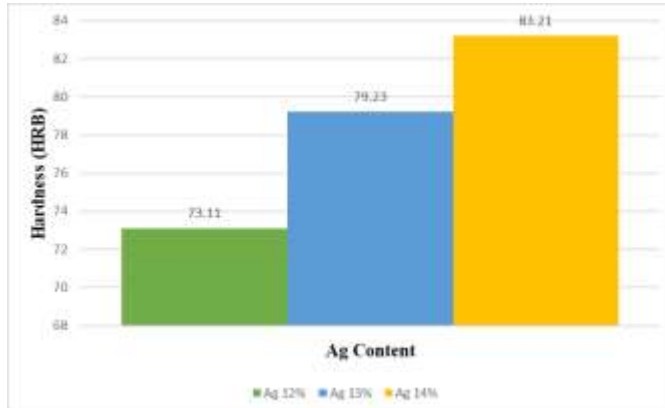

Fig.8. Comparison of Hardness (HRB)

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Corresponding Author: Arshad Ali Khan

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