Original Research Article

Evaluation of Nb-Ni Influence on the Mechanical Behavior in a Cu-Al-Be Shape Memory Alloy

ABSTRACT

Aims: the objective was to investigate the mechanical behavior and grain size of a Cu-11.8%Al-0.58%Be shape memory alloy containing 0.5wt%, 1.0wt% and 1.5wt% of Nb-Ni alloy master.
Study design: The experiment was conducted in a completely randomized design.
Place and Duration of Study: the experiment was carried out at the Laboratory of Rapid Solidification of the Center Technology - CT, Federal University of Paraíba – UFPB, João Pessoa campus, Paraíba, Brazil, between October 2017 and December 2017.
Methodology: The alloys were prepared by induction melting and hot rolled into strips of 1.0 mm thickness at room temperature without protective atmosphere, followed of heat treatments. Subsequently the microscope analysis, differential scanning calorimetry (DSC), tensile test and hardness test were carried out.
Results: The Shape memory alloys produced present phase transformations corresponding to the superelastic effect (SE). Grain size reduced considerably with increases content of Nb-Ni. Additionally the mechanical tensile testing and hardness tests verified that the addition of Nb-Ni increases the stress of the alloy.
Conclusion: The manufactured of Cu-Al-Be alloys by induction melting and hot rolled without protective atmosphere is viable. The microstructure analysis shows the grain refinement in Cu-Al-Be alloys containing 1.0wt% and 1.5wt% of Nb-Ni alloy with considerable reduction in grain size. The reduction in the grain size shows the improvement in the hardness and mechanical tensile properties.

Keywords: Shape Memory Alloys; Cu-Al-Be; Grain Refiners; Nb-Ni; Mechanical Strength.

1. INTRODUCTION

Shape memory Alloys (SMAs) are smart materials which can recover their original shape after large strains (~8%) by heating or removing mechanical load. It occurs because of reversible martensitic transformation (MT). SMA can present Shape Memory Effect (SME) or Pseudoelastic Effect (PE) [1-3].

Several alloys exhibit functional properties associated with phase transformation, but only some alloys such as Ni-Ti and Copper based alloys have been extensively studied. Ni-Ti alloys have exceptional mechanical properties, however they have high cost and difficult to process. On the other hand, copper based SMA have excellent cost-benefit ratio to process, however the industrial application is limited due low plastic property, difficulty for machining, and short fatigue life [4,5].

The main Cu-based SMA are coming from the Cu-Al binary system [6], in which to improve its thermo-mechanical properties is crucial stabilize β-phase at lower temperatures, thus heat treatments and the addition of a third element such as Mn, Ni and Be have been used. Especially the addition of small amounts of Be, for allowing good thermal stability in a broad range of transformation temperatures. [6,7].

Cu–Al–Be SMA present interesting properties such as mechanical damping capability, high mechanical strength and resistance to corrosion [8,9]. This alloy has been considered for several applications such as petroleum industries [10,11] and design of seismic resistant structures, due to damping or internal friction, resulted of significant quantity energy absorbed [12].

The high strain energy absorption capability and consequently the recoverable strain of Cu-Al-Be depends on the grain size, therefore the effect of grain refiners on the mechanical properties, microstructure and phase transformations have been studied in Cu-Al-Be SMA [9,14]. Current research has shown that grain refiners can improve mechanical properties of Cu-Al-Be, Cu-Al-Mn and Cu-Al-Zn SMA by means of yield strength and structural optimize. [15-18].

In this study the microstructure and mechanical properties of Cu-Al-Be shape memory alloy strips manufactured by induction melting and hot rolled are analyzed based on the induced microstructural modifications by grain refiners.

2. MATERIAL AND METHODS

For the present study. three different Cu-Al-Be-Nb-Ni alloys were prepared by induction melting without protective atmosphere. The nominal compositions were Cu-11.8Al-0.58Be-033Nb-0.18Ni. Cu-11.8Al-0.58Be-0.65Nb-0.35Ni and Cu-11.8Al-0.58Be-0.98Nb-0.53Ni (wt.%). called Alloy$_1$. Alloy$_2$. and Alloy$_3$. respectively. Pure metals were used: Cu (99.9%), Al (99.9%), Cu-4%Be master alloy and Nb-35%Ni master alloy (wt%). The Figure 1 resumes the steps of the experimental work performed.

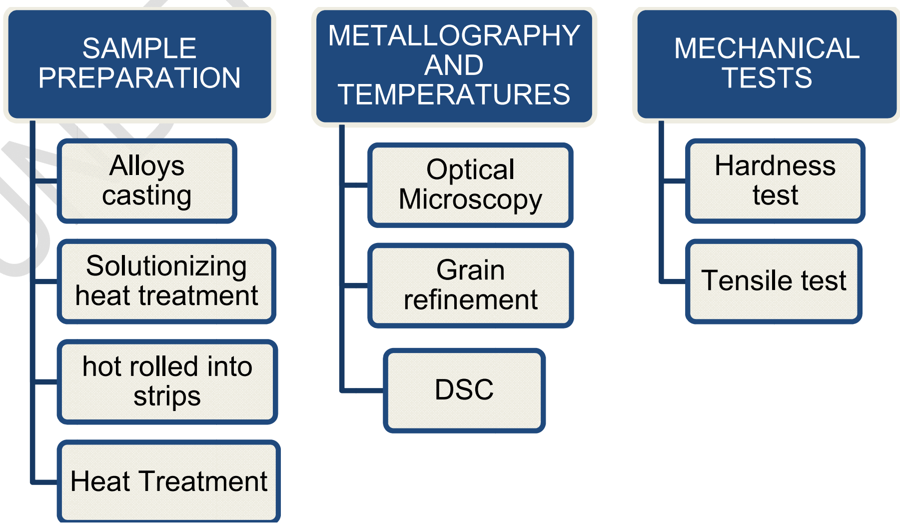

Figure 1 - Workflow diagram.

For each nominal composition was prepared about 0.5kg of the alloy in inductive heating in an 8 KVA high frequency furnace. The alloys were cast in graphite crucible and spills into rectangular steel molds with 22x35x100mm dimensions. Subsequently. the ingots were homogenized at 850 ºC for 12 hours in an electrical resistance furnace. The ingots were hot rolled and cut off into 100x10x1[mm] strips. The ingots were hot rolled into a thickness of 1mm and cut off into 100x10x1mm strips. Later. the strips were heat treated at 850ºC for 1 hours followed of water quenching at 25ºC to obtain the shape memory effect.

Samples used for metallographic examinations were mechanically grinded. polished and chemically etched with ferric chloride ($FeCl_3$). The microstructural characterization was analyzed by microscopy optical. Mean grain sizes were determined by the intercept line method from micrographs obtained of the β phase austenite at room temperature.

The Transformation temperatures (TTs) were determined by differential scanning calorimetry (DSC) using Shimadzu DSC-60 calorimeter machine. DSC measurements were done in argon atmosphere through one heating/cooling cycle from -120ºC to 60 ºC with heating/cooling rates 10ºC.min^{-1}.

The tensile tests were carried out at room temperature (about 25 ºC). with maximum applied strains of 6.0%. using the Shimadzu static-dynamic Servo pulser EHF machine. equipped with 50kN load cell. The hardness tests were carried out with maximum load of 100 kgf gram for 10 sec.

3. RESULTS AND DISCUSSION

3.1. Grain Refinement

The grain size for samples of different compositions acquired by optical microscopy. Figure 2 shows the microstructures of Cu-Al-Be-Nb-Ni SMA.

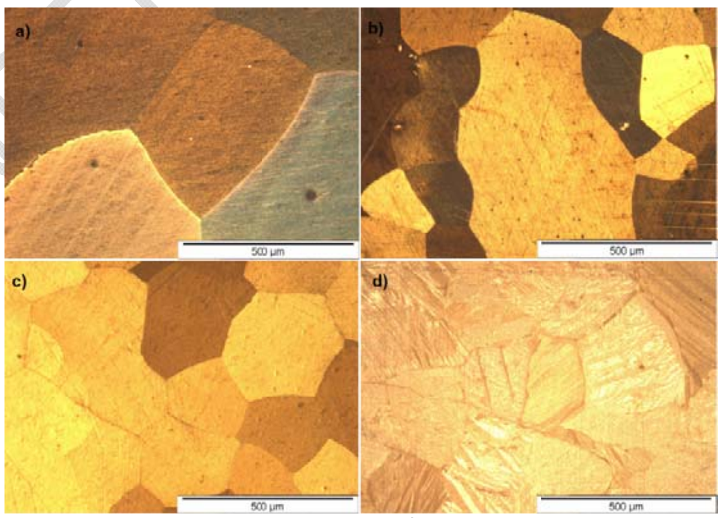

Figure 2 - Optical micrograph illustrating the presence of austenite and martensite in the Cu-Al-Be-Nb-Ni SMA: (a) $Alloy_1$. (b) $Alloy_2$. (c) $Alloy_3$. (d) $Alloy_3$ hot rolled.

The imagens present typical optical micrograph of the austenite phase (Fig. 2a. Fig. 2b. Fig. 2c). The samples preparation process (hot roller process) induced the phase transformation. so, it is possible to visualize the martensite phase in hot rolled samples without heat treatment Figure 2d. Grains in the ingots were roughly equiaxed. with similar size in the longitudinal and transversal faces.

The average grain sizes. determined as the arithmetic mean. are shown in Figure 3 for every alloy. As general behavior. it can be observed that the grain size decreases considerably with the increase of Nb-Ni content. The average grain size is 1200µm. 469µm and 394µm for $Alloy_1$. $Alloy_2$ and $Alloy_3$. respectively. It is worth mentioning that grain refinement of Nb in Cu-Al-Be SMA has also been reported acts such as strengthening mechanism [19-20].

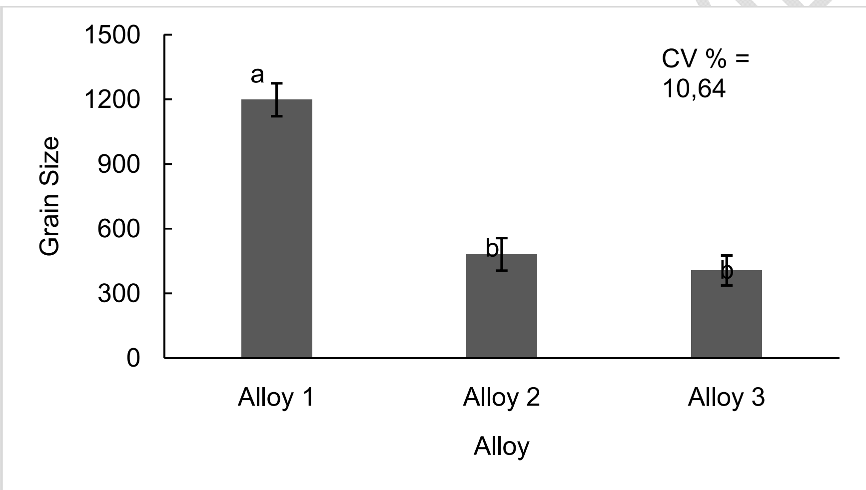

Figure 3 - The average grain sizes.

The grain size refinement is influenced of fine Nb-rich precipitates that form nucleation sites during the solidification. Furthermore. grain growth is inhibited due Nb precipitates appear by the pinning mechanism [21].

3.2. Thermal Characterization

After the microstructural evaluation the samples underwent DSC to determine the critical phase transformation temperatures without applied load. The samples used in this analyze were heat treated in the same way of the SMA strips produced. In Table 1 is listed the average of transformation temperatures for each alloy.

Table 1 - Critical temperatures obtained from DSC for the Cu-Al-Be-Nb-Ni SMA.

Alloy ID	**Temperatures [°C]**			
	M_f	M_s	A_s	A_f
$Alloy_1$	-22.5	19.9	2.2	27.7
$Alloy_2$	-23.7	19.7	5.6	33.5
$Alloy_3$	-27.8	2.9	2.6	15.5

Thermal characterization indicates superelastic behavior at room temperature (about 25ºC, superior to M_s). From Table 1 the austenite temperature intervals span between 2.2ºC to 33.5ºC. Only the values of A_f and M_s temperatures of $Alloy_3$ are different considerably.

Figure 4 shows typical curves resulted from DSC tests for one heating/cooling cycle. In this case, the results are presented only for $Alloy_3$. It was possible to confirm phase transformations throughout the presence of two peaks that characterize the transformations zone.

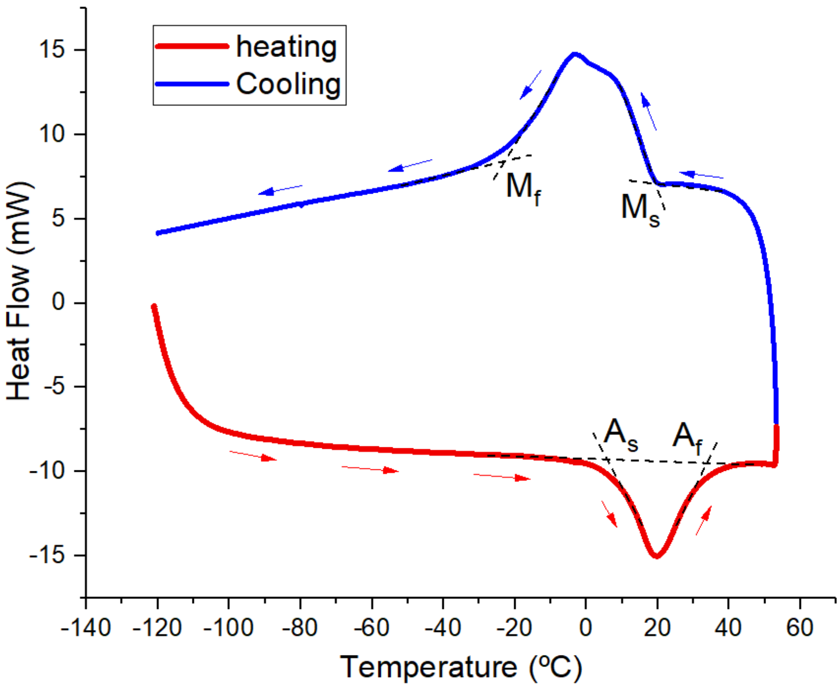

Figure 4 - DSC thermogram for the Cu-Al-Be-Nb-Ni SMA.

3.3. Hardness Test

As previously discussed, the grain size is an important parameter in polycrystalline specimens. It was observed that as the grain size decreases, the Rockwell hardness increases. The variation of Rockwell A hardness of the samples produced is shown in Figure 5. The averages of values were 71 RCA. 72 RCA and 76 RCA for $Alloy_1$. $Alloy_2$ and $Alloy_3$. respectively. This increase of hardness observed with the addition of Nb. It is believed that this increase is due to the Nb-rich precipitates increase the rigidity of the material.

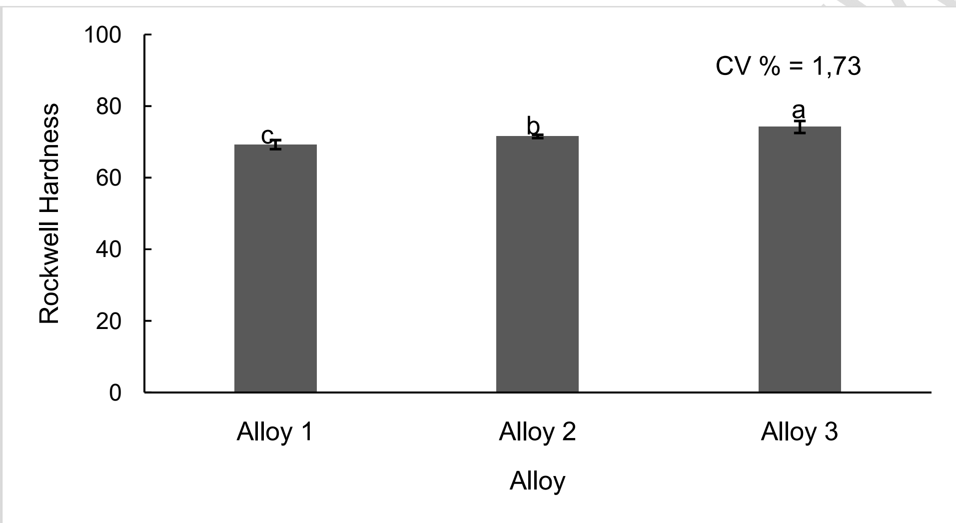

Figure 5 - Rockwell hardness for the Cu-Al-Be-Nb-Ni SMA.

3.4. Tensile Test

The samples were always heated at temperature higher than A_f than and cooling down to the room temperature before tensile tests. Figure 6 shows the typical stress-strain curve. As the grain size decreases, the critical applied stress to start the martensitic transformation increases, following a Hall–Petch relation type in β CuAlBe [22,23]. The maximum strain to the rupture and the rupture stress were 210.7 MPa and 6.01% for $Alloy_1$. 283.2 MPa and 7.1% for$Alloy_2$ and 529.2 MPa and 6.48% for $Alloy_3$.

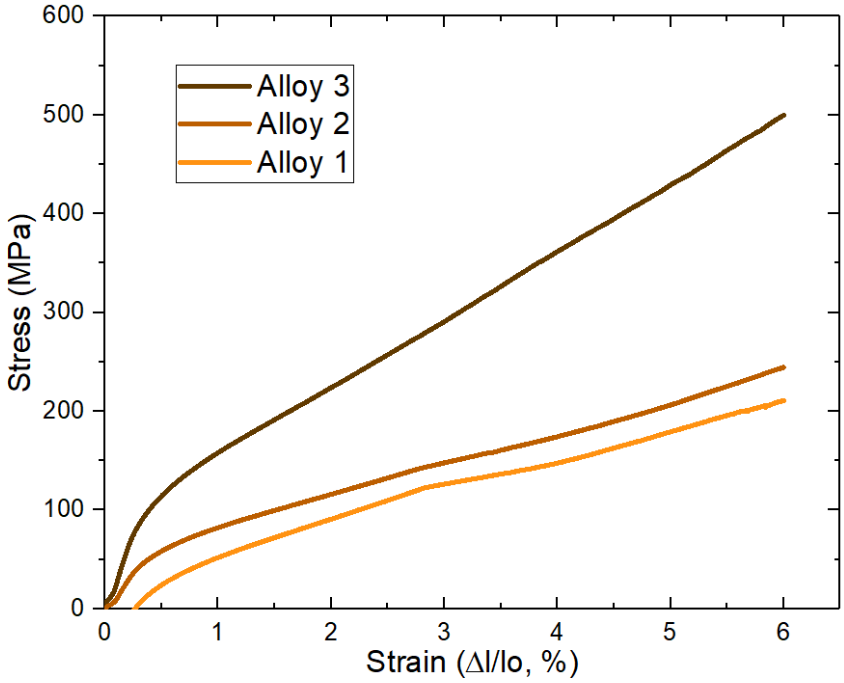

Figure 6 - Typical stress-strain curve to Cu-Al-Be-Nb-Ni alloy T=298K.

The conventional mechanical tensile testing carried out show that the addition of Nb-Ni increases the ultimate strength of the Cu-Al-Be alloy. The austenite elastically deforms in initial linear part followed pseudoelastic slope when starts the typical martensite induced transformation. It was not possible to distinguish the plastic strain of the martensite that should precede the rupture. The average strength values were 144.2MPa. 255.3MPa and 501.9MPa for Alloy1. Alloy2 and Alloy3. respectively in the maximum strain (6%).

4. CONCLUSION

The microstructure analysis shows the grain refinement in the alloy. Grain size reduced considerably with increases content of Nb. Cu-Al-Be-Nb-Ni SMA strips manufactured by hot rolled present fully martensitic microstructure. also, after the heat treatment was identified the austenitic phase. The DSC curves exhibits that the A_f and M_s temperatures decreases considerably in $Alloy_3$.The reduction in the grain size shows the improvement in the hardness. The mechanical tensile testing that was carried out showed that the addition of Nb increases the mechanical resistance of the Cu-Al-Be alloy.

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