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A Study of Mechanical Properties and Conductivity Capability of CU-9NI-3SN ALLOY

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Abstract

Nickel copper (Cu-Ni) alloys are called the coppery alloys with a major metal element-Ni and implemented some other metals, in which the Cu-Ni alloy is supplemented with Sn has high electrical conductivity and low cost. In this study, the results of physico-mechanical properties and microstructure of the Cu-9Ni-3Sn alloy, which contains 86.3% Cu, 9.94% Ni, 3.43% Sn, 0.13% Fe, and 0.25% of other elements, after steeling, annealing, aging or plastic deformation are used for the purpose of measuring physico-mechanical, electrical conductivity, dry friction coefficient and corrosion resistance. In addition, the results of the paper also show that, thanks to Spinodal decomposition, the microstructure conversion into small, smooth structure and the conversion process into 2 phases such as α + γ is presented. The result of this paper contributes to the creation of a new alloy system for the production of electrical contacts that require well the standard.

Keywords*:* Cu-9Ni-3Sn alloy, physicomechanical, high strength, high electrical conductivity

INTRODUCTION

High durability - elastic alloys play an important part in the fabrication of electrical equipment and in machine building; with the development of information technology, telecommunications technology, the application of Cu-Ni-Sn alloy systems in electrical and electronic equipment is ever-increasing. On boards or connectors of common electrical equipment such as electronic computers, cell phones etc, these contacts are usually made of high strength-elastic copper [1]. The requirement such as small shape, high accuracy, high mechanical strength and elasticity, heat, abrasion and corrosion resistance in the environment to ensure the current and electrical signal stability for long time is always mentioned. Design trends of minimizing the size of parts but still ensure the ability of the device working will contribute significantly in the development of the science and the production. The inventions in this field are applied in the information technology that is changing our everyday lives.

Highly durable-coppery alloys are used in common electrical equipment such as Cartridge copper (Cu30Zn), Phosphorus copper (C51000, Cu5Sn0.2P), Beryllium copper (C17200; Cu2Be), Spinodal copper (C72700; Cu9Ni6Sn, C729000; Cu15Ni8Sn). In among of above coppery alloys, the two copper alloys such as beryllium and Spinodal copper with heat treatment give the maximum of the strength and the elasticity, the after-heat treatment hardness is up to 40HRC, the strength is up to 1300-1400Mpa, and the elastic limitation is up to 1200Mpa. Beryllium copper is an alloy of valuable properties suitable for high-up applications in electrical equipment. Because of high cost in production and difficulty in manufacturing technology, the toxic properties of beryllium, so beryllium is limited to use in the world. In Vietnam, beryllium copper is now fully imported, hence the need of finding a copper alloys with similar features, lower cost, fabrication ability in domestic is an urgent issue.

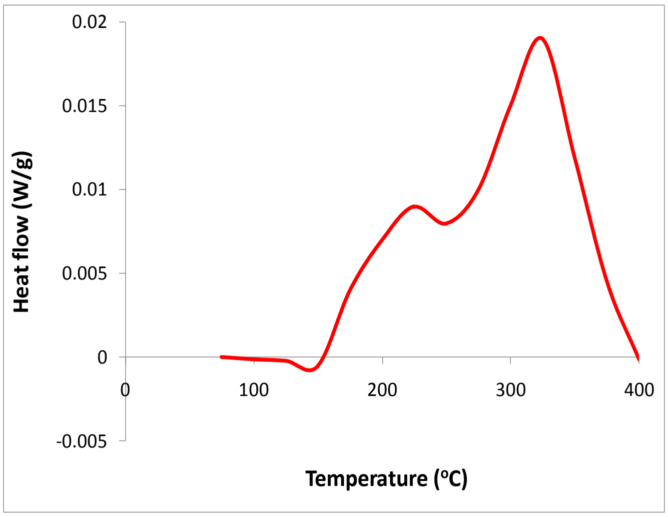

Figure 1. The change of Vicker hardness (HV) depending on the annealing temperatures [2]

Many researchers showed that, the alloys based on Cu-Ni-Sn with the diagram of the ternary phase are significantly used in many fields such as electronic-electricity industry, automotive industry, and aerospace industry due to Cu-Ni-Sn alloys show the combination between the ability of hardness, high electrical conductivity [3], and the resistance of corrosion. Barburaj. E.G et al. [4], Liu. L et al. [5], Zhao. J.C et al. [6][7]

and Singh. J.B.B et al. [8] showed that, the mechanical properties of these Cu-Ni-Sn alloys undergone a significant improvement as aging at 200ºC to 450ºC. This result might be ascribed either to the Spinodal disintegration/decomposition of the alloy with two gradation such as Stannum reach and lean, or to the (CuzNi1-z)3Sn phase grown. Dianez. M.J et al. [9] presented that, DSC (Differential Scanning Calorimetry) allows differencing the regions of the annealing temperature for the Spinodal decomposition and the phase segregation with alloys contained Cu, 10 wt% of Ni and 5.5 wt% of Sn. Figure 1 showed that the effect of the annealing temperature on microstructure and strength of this alloy, the Vicker hardness (HV) values such as HV = 127 at 150ºC, HV = 128 at 250ºC, HV = 303 at 400ºC was improved due to this alloy was aging by Spinodal decomposition. Thus, the heating treatment could be also considered as a suitable method to improve the hardness odd alloys [10].

Morever, Yu. H et al. [11] concluded that Cu content played an important part in the formation of alloy microstructure based on Cu, Ni and Sn, the stabilities of (Cu,Ni)6Sn5 systems and (Cu,Ni)3Sn4 systems depended on dramatically temperature. Vuorinen. V et al. [12] also studied about the influence of liquid Sn to Cu-Ni alloy with changed Cu-content and the results were similar to Yu. H et al. [11] . The other side, Wang et al. [13] used the isothermal section aiming at explaining the (Cu,Ni)6Sn5 formation.

About production of high strength and electrical conductivity for coppery alloys might base on the technique of electrode position [14] or dynamic plastic deformation [15]. Increasing the deformation rate and decreasing the temperature in the plastic deformation process could be the cause for creating out the nano-grained copper with 610 MPa of the tensile yield strength and 95% of the electrical conductivity. However, although some alloys such as Cu-Zn alloys [16], Cu-Al alloys had high mechanical properties but low electrical conductivity [16]. Besides, alloys of Cu and Zr were studied by Naokuni. M et al. [13] based on Cu0.5, Cu1, Cu2 at changed content of Zr, the results were given as 16-83% of electrical conductivity and 690-2234 MPa of tensile yield strength. Above studies show that, alloys based on copper atom always exhibit the high specific properties about mechanical one and electrical conductivity. The requirements should be identified with the alloys for producing and fabricating of the electrical contacts as:

- Good durability and elasticity
- Small resistance and good conductivity
- Corrosion resistance
- Small contact friction coefficient
- High melting and vaporization temperature
- Good machining ability
- Low manufacturing cost

The coppery alloys that may satisfy the above requirements are given in Table 1.

Table 1. Physico-mechanical properties of coppery alloys

Alloys	**Primary alloy atom/Metal**	**Tensile strength (Mpa)**	**Yield strength (Mpa)**	**Rockwell Hardness, HRB**	**Electrical conductivity, IACS at 20ºC (%)**
C17200	Be/Cu	420-1400	140-1220	B45 –85	Min, 17
C17000	Be/Cu	400-1300	140-1050	B60 –100	Min, 22
C17410	Be/Cu	750-900	650-870	B95 –102	Min, 45
C17510	Be/Cu	770-980	700-840	B95 –102	Min, 45
C77000	Cu-Ni (55-18)	415-1000	585-780	B52 –99	Min, 5.7
C72500	Cu-Ni-Sn (9-2)	420-780	540-720	B72 –110	Min, 11
Cu-Ni-Sn (15-8)	15% Ni, 8% Sn	-	610-880	B68 –102	Min, 7.2
Cu-Ni-Sn (21-5)	21% Ni, 5% Sn	-	610-1030	B62 –106	Min, 8
Cu-Ni-Sn (9-6)	9% Ni, 6% Sn				

In this study, along with mentioned and studied coppery alloys the authors focus on the properties of Cu-9Ni-6Sn alloys for the manufacture of electrical contact devices with high strength and high electrical conductivity. The microstructure of Cu-9Ni-6Sn alloys after casting, steeling, rolling are shown and compared. Moreover, hardness, durability, fatigue strength, corrosion resistance, electrical conductivity of Cu-9Ni-6Sn are determined by experiment.

MATERIALS AND METHOD

The Cu-9Ni-3Sn of copper alloy is used for scope experiment in this study. The chemical properties of the Cu-9Ni-3Sn alloy after casting is given Table 2.

Table 2. The chemical component of Cu-9Ni-3Sn alloy after casting

Components	Cu	Ni	Sn	Fe	Others
Mass rate	86.3	9.94	3.43	0.13	0.2

After casting, this alloy is heat-treatment following Figure 2.

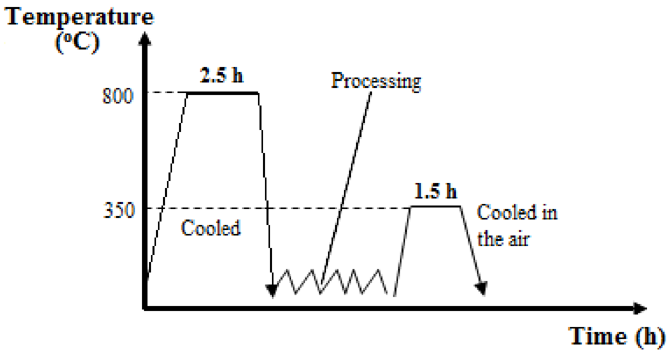

Figure 2. The diagram of heat-treatment for the Cu-9Ni-3Sn alloy

Processing steps include hot rolling to the suitable size, then cold rolling with selected deformation level to the requested thickness. After that, the Cu-9Ni-3Sn alloy is analyzed about microstructure and hardness. In addition, the Cu-9Ni-3Sn alloy is also determined the physico-mechanical properties such as durability, elastic strength, electrical conductivity, corrosion resistance in seawater.

RESULTS AND DISCUSSION

A. Alloys microstructure

Microstructure of Cu-9Ni-3Sn after casting is shown in Figure 3.

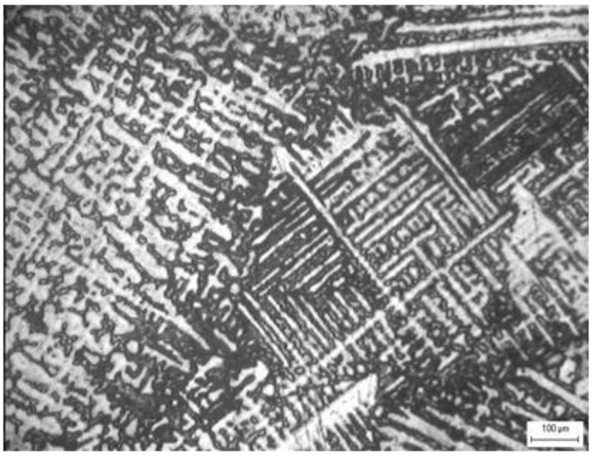

Figure 3. Microstructure of Cu-9Ni-3Sn after casting, x50

It can be seen from Figure 3 that, the Cu-9Ni-3Sn microstructure after casting is heavily separation and microseparation by the crystallization of Ni and Sn during freezing because of the varying of the freezing temperatures. The microstructure of dendrite and large size are formed, the dendrite are created due to the uneven distribution of Ni and Sn during crystallization.

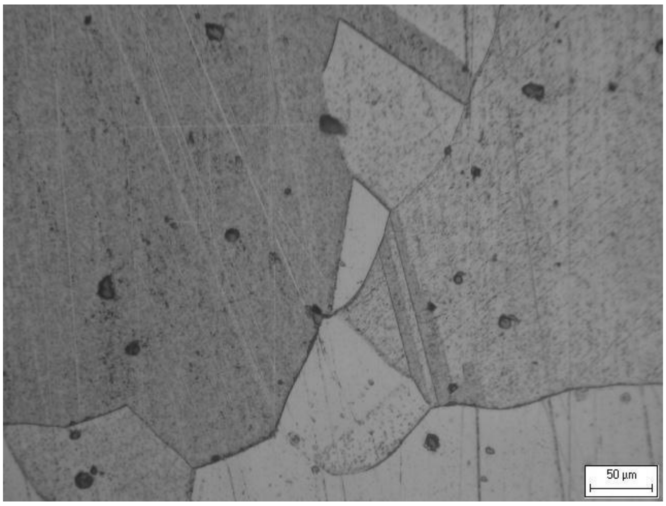

Figure 4. Microstructure of Cu-9Ni-3Sn after annealing, x200

Figure 4 shows that, the sample after annealing for 2.5 h at 800^0C shows the complete removal of the dendrite separation phenomena. Single-phase microstructure is the result of a uniform diffusion process. The microstructure of Cu-9Ni-3Sn after cool-rolling with 40% of deformation level, and being aged or without aging are shown in Figure 5 and Figure 6, respectively.

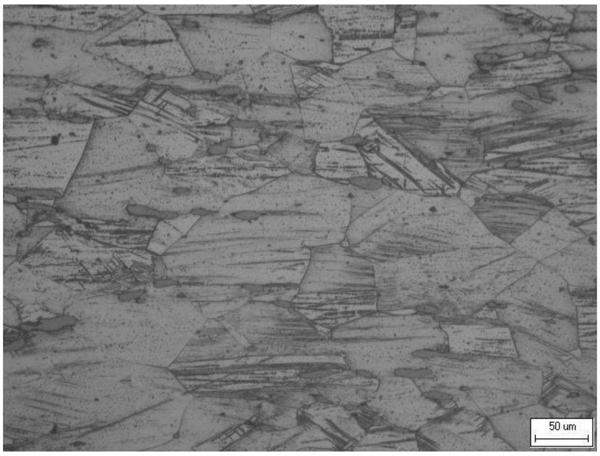

Figure 5. Microstructure of Cu-9Ni-3Sn after cool-rolling with 40% of deformation level, x200

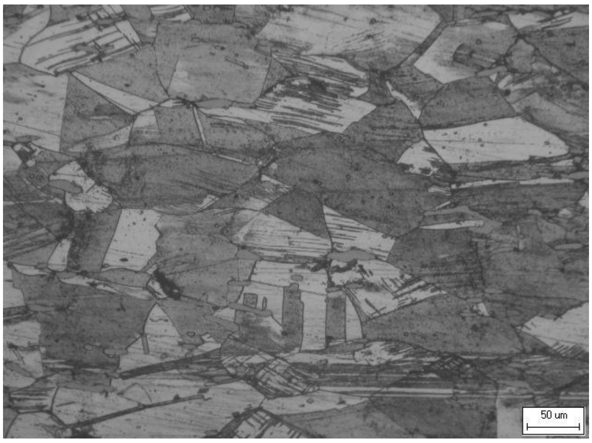

Figure 6. Microstructure of Cu-9Ni-3Sn after steeling, cool-rolling with 40% of deformation level, aging for 2h at 350ºC, x200

Figure 5 and Figure 6 show that, the microstructure of Cu-9Ni-3Sn is transformed following the rolling direction and the appearance of the residual stress in rolling process will reduce the physic-mechanical properties of alloy. However, the residual stress may be eliminated by annealing. Microstructure of Cu-9Ni-3Sn after annealing is still a single-phase one, and aging temperature higher than recrystallization temperatures helps to re-transform the microstructure. Aging causes the Spinodal decomposition to increase the hardness and the electrical conductivity of the alloy.

B. Hardness

The determination of Cu-9Ni-3Sn sample hardness is based on Brinell methods (HB) and shown in Figure 7. The measurement sign created by Brinell method is a spherical ball with D = 10mm of diameter and an impact force (F) is 500kg. This impact force (F) is used to depress the above spherical ball on the surface of the metal. The impact force (F) must meet the following requirements: Slow and controlled impact force (F); 10-30 seconds of time for impact force (F) aiming at overcoming the elastic deformation process. Assuming that, the diameter of the crater is d, HB is calculated by as:

$$HB = \frac{4F}{\pi D(D-\sqrt{D^2-d^2})} \quad (1)$$

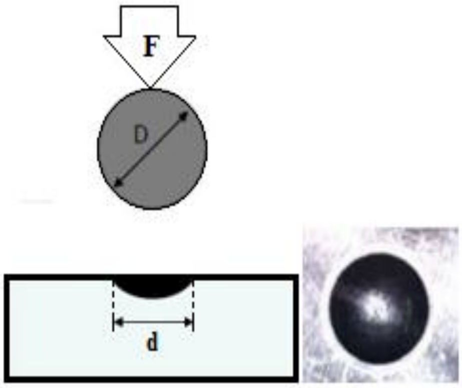

Figure 7. Determination method of Brinell hardness

The experimental result of the Cu-9Ni-3Sn sample hardness after casting is 110 HB and after steeling is 100 HB. Moreover, in this study, the Cu-9Ni-3Sn sample is heated at 350ºC with different times to determine the dependence of the Cu-9Ni-3Sn sample hardness on time and temperature. This dependence is plotted in Figure 8.

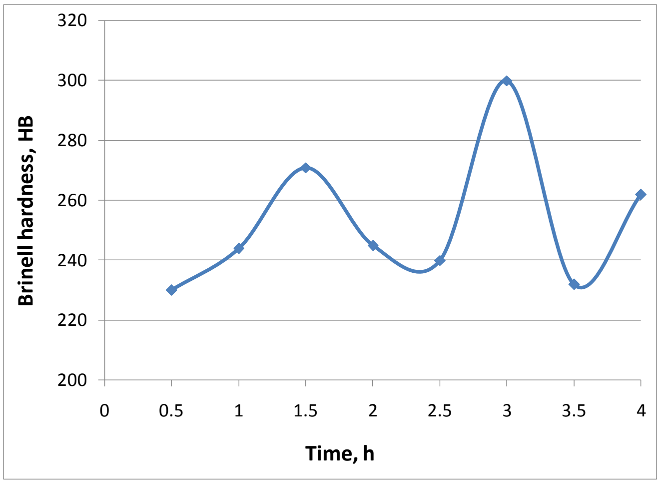

Figure 8. The dependence of Brinell hardness for Cu-9Ni-3Sn on time

Figure 8 shows that, after aging at different time, Cu-9Ni-3Sn alloy hardness tends to vary unevenly. Hardness reaches the maximum value when the aging time is 3 hours. This can be explained by the changing of the alloy microstructure. Initially, the spinodal decomposition occurs and results in increasing the durability and hardness of this alloy. Over time, the Spinodal microstructure conversion from small, smooth structure into big structure, then the conversion process into 2

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phases such as α + γ is considered. Based on the combination betwwen the temperature and aging time, It can be seen that, with 350°C of aging temperatura, the 1.5 hour of aging time is the most suitable for not only high hardness but also uniform single-phase microstructure.

C. Strength and elastic limit

The tensile strength and elastic limit of a plate sample is measured according to Vietnamese Standard 197-85 and is applied to two Cu-9Ni-3Sn samples. Two Cu-9Ni-3Sn samples are also fabricated by steeling at 800°C, cool-rolled by 40% to 0.35 mm of thickness, heat-treated by aging at 350°C but 1h and 1.5 h of time, respectively. The diagram and sample size for carrying out measuring the strength and elastic limit is shown in Figure 9.

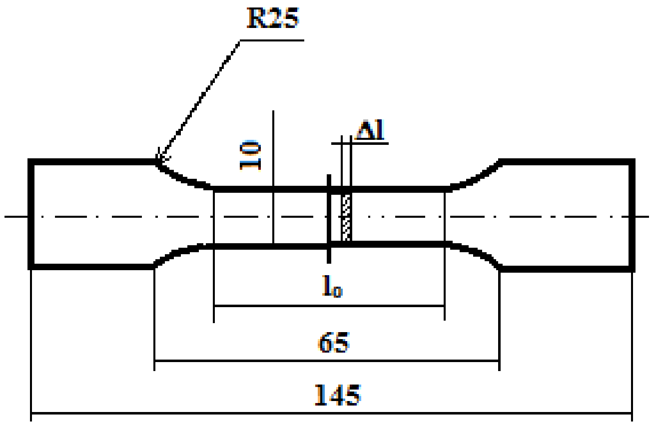
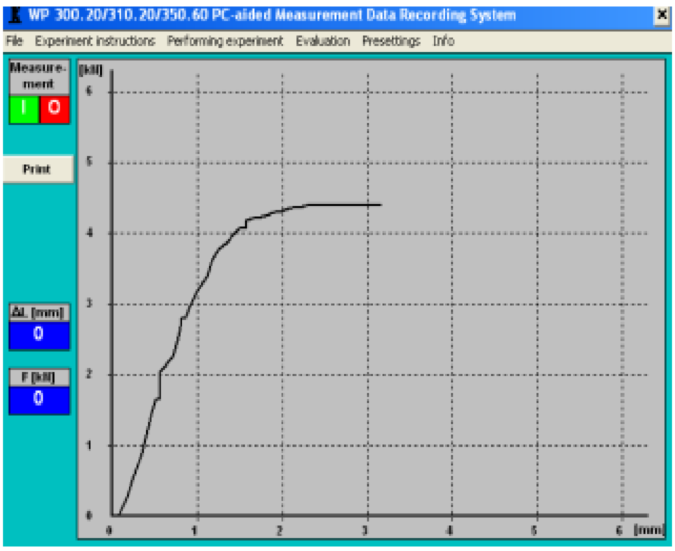
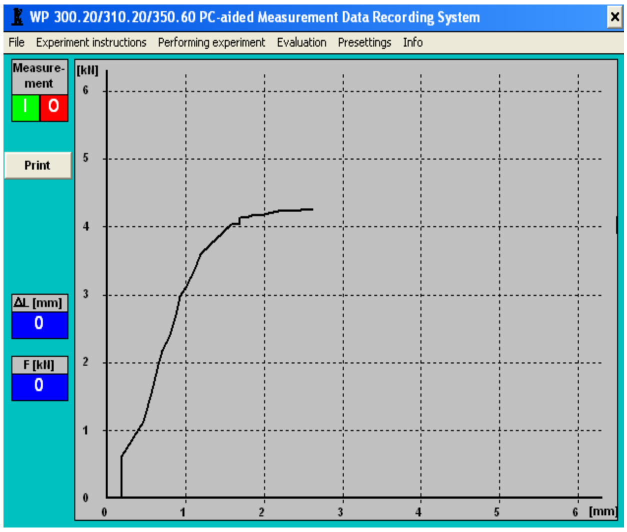


Figure 9. A plate sample for strength and elastic limit measurement

The result about the relationship between Δl and impact force (F) is plotted in Figure 10.



(a)



(b)

Figure 10. Δl as a function of impact force (F)

(a): The Cu-9Ni-3Sn samples are also fabricated by steeling at 800°C, cool-rolled by 40% to 0.35 mm of thickness, heat-treated by aging at 350°C and 1h
(b): The Cu-9Ni-3Sn samples are also fabricated by steeling at 800°C, cool-rolled by 40% to 0.35 mm of thickness, heat-treated by aging at 350°C and 1.5h

Figure 10a shows that, the strength and elastic limit is 1282 MPa and 1166 MPa, respectively as the maximum of impact force (F) is 4.4 kN. Figure 10a shows that, the strength and elastic limit is 1224 MPa and 1137 MPa, respectively as the maximum of impact force (F) is 4.2 kN.

D. Electrical conductivity

In order to measure the electrical conductivity, used sample is wire shape, rectangular section. Selected samples are the same as the size such as length, width, thickness and cross-sectional area but different from the processing mẹhanism and heat-treatment. The sample parameters are given in Table 3.

Table 3. The parameters of the Cu-9Ni-3Sn samples

Sample	Treatment mechanism	Length l, m	Width a, m	Thickness b, m	Cross-sectional area S, m^2
1	After rooling-cool, steeling.	0.40	$1.9x10^{-3}$	$0.8x10^{-3}$	$1.52x10^{-6}$
2	After rooling-cool, annealing-full, aging at 350^0C within 1.5h.	0.40	$1.9x10^{-3}$	$0.8x10^{-3}$	$1.52x10^{-6}$
3	After rooling-cool, annealing-full, aging at 350^0C within 1h.	0.40	$1.9x10^{-3}$	$0.8x10^{-3}$	$1.52x10^{-6}$

Resistance measurement result and calculation of conductivity value is according to the formula:

$$\rho = \frac{R.A}{l} \quad (2)$$

Where:

ρ - Electrical conductivity, S

R- Resistance, Ω

l - Length measurement sample, m

A- Cross-sectional area, m^2

Switch to siemen conductivity, S: S=1/ρ

Switch to% IACS conductivity: 100% IACS = $58x10^6$S

The calculation results are shown in Table 4

Table 4. The electrical conductivity of Cu-9Ni-3Sn samples

Sample	Resistance (R), Ω	Electrical conductivity (ρ), Ω.m	Switch to siemen conductivity (S), 1/m	%IACS
1	0.075	$0.285 x10^{-6}$	$3.508 x10^6$	6.05
2	0.054	$0.2052 x10^{-6}$	$4.873 x10^6$	8.40
3	0.055	$0.2090 x10^{-6}$	$4.784 x10^6$	8.24

The Cu-9Ni-3Sn alloy conductivity measurements are in harmony with the electrical conductivity values of other styudies in the world. Electrical conductivity values also show that after-aged alloys have higher electrical conductivity than that of annealed and steeled alloys. That proves that the aging causes the microstructural change and reduces electrical conductivity.

E. Dry friction coefficient

Measurement of alloy dry-friction coefficient after casting, steeling, aging at 12N of load in an hour is carried out, the results are shown in Table 5.

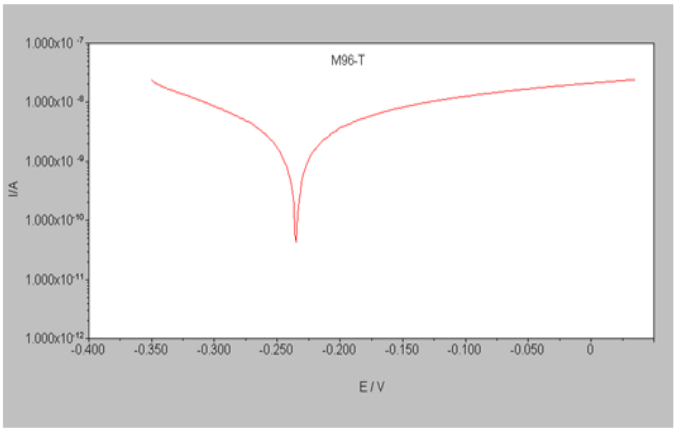
Table 5. The measurement results of dry-friction coefficient

Heat-treatment	**Casting**	**Steeling**	**Aging**
Dry-friction coefficient	0.464	0.473	0.400

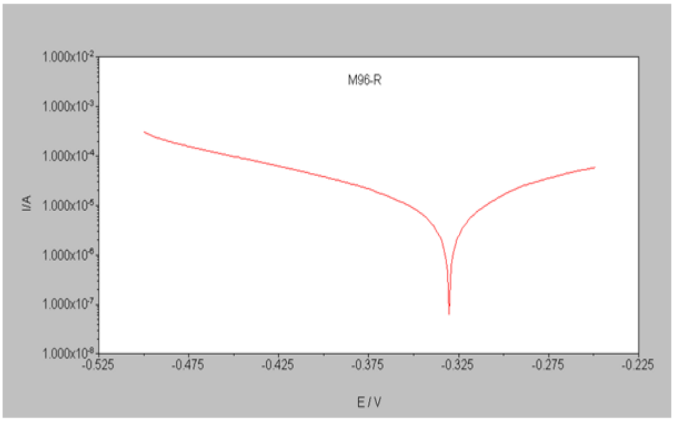
The results show that before and after heat-treatment, the abrasion rate is not changed but the dry-friction coefficient after the aging process is reduced. This can be explained by the fact that there has been a transformation in material microstructure resulting in the reduction of the dry-friction coefficient.

F. Corrosion rate

Two samples of Cu-9Ni-3Sn alloy with the same size is steeled and aged, respectively. Then, they are used to determine the corrosion speed and rate in the seawater environment. The resuilt with $1cm^2$ of cross-sectional area is shown by Figure 11 and given in Table 6.



(a)



(b)

Figure 11. The polarization curves of the Cu-9Ni-3Sn sample after steeling (a) and aging (b)

Table 6. The corrosion rate of the Cu-9Ni-3Sn sample in seawater at 25^0C

Sample	**Results**			
	$I_{corrotion}$ (A/cm^2)	**$I_{corrotion}$ (A/cm^2)**	**R_p (Ω)**	**Corrosion rate (mm/year)**
M96-T	$3.242x10^{-7}$	$3.242x10^{-7}$	$1.491x10^3$	$1.498x10^{-3}$
M96-R	$1.542x10^{-6}$	$1.542x10^{-6}$	$8.717x10^2$	$7.121x10^{-3}$

It can be seen from Table 6 that, the corrosion rate of the Cu-9Ni-3Sn sample is low in the seawater, the corrosion rate is lower than 0.01mm/year. However, the corrosion rate of a phase-uniformly-steeled sample is lower than that of aged sample. This can be explained that, after a phase-uniform-steeling, there is no change in electrodes of the alloy microstructure. Thus, the Cu-9Ni-3Sn alloy may satisfy fully the standards and the requirements of alloys about the electrical conductivity, durability, corrosion resistance, friction coefficient, but low price. This study has proved strength mechanism of Cu9Ni3Sn alloy by Spinodal decomposition. The experimental values of the Cu-9Ni-3Sn alloy properties show that this alloy is fully used for electrical contact fabrication with working temperature up to 300^0C.

CONCLUSIONS

Based on the experimental study results about the Cu-9Ni-3Sn alloy system, main physicomechanical properties may be shown as:

The Cu-Ni-Sn alloy is increase the strength by heat-treatment mechanism. The Cu-Ni-Sn alloy properties such as strength, elastic limit may be adjusted though the heat-treatment combined mechanical process.

After taking out the heat-treatment such as steeling at 800ºC, cool-rolled by 40% to 0.35 mm of thickness, heat-treated by aging at 350ºC and 1.5h in order to occur the Spinodal mechanism, the strength of Cu-9Ni-3Sn alloy is up to 1200MPa, elastic limit is increased to 1100MPa, hardness gets 300HB, electrical conductivity is about 8,4%IACS. Thus, it is certainly that the Cu-9Ni-3Sn alloy may be used to fabricate the electrical contacts with the requirements of high strength, high elastic limit, high corrosive resistance and abrasion resistant, operating in high temperature environment. However, as using this Cu-9Ni-3Sn alloy, it is treated in order to get a uniform phase and using the Spinodal mechanism is to increase the strength.

In next research, using the modern equipment such as TEM; EBSD to prove the alloy structure is a Spinodal structure will be carried out. Development of some other alloy of Cu9Ni3Sn with higher durability, higher electrical conductivity will be considered. Besides, the application of alloy Cu9Ni3Sn with high durability in the shipbuilding industry or mining industry will be mentioned

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