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# Sintering of Ternary Copper Alloys (Powder Metallurgy) – Electrical and Mechanical Properties Effects

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## 1. Introduction

In order to stay successful in an environment of competing shaping technologies, the manufacturers must also in the future improve every single processing step, which involves in decrease of the compaction press downtime caused by tool-setting interactions or tool readjustments.

The foreword of Paul Beiss (RWTH Aachen) in the book “Modeling of Powder Die Compaction”, edited by Peter R. Brewin, Olivier Coube, Pierre Doremus and James H. Tweed (2008, Springer-Verlag London Limited) shows us that the “*Die compaction of powders that develop green strength on compaction is the absolutely dominating forming technology for powdered materials. Areas of application are structural parts, hardmetal and ceramic indexable inserts, pharmaceutical tablets, electrical contacts, filters, hard magnets, soft magnetic composites, friction materials and many others. In particular, multi cross-sectional net-shape geometries have been gaining importance continuously, because the ability to deliver complex shapes with higher and higher productivity has contributed to competitive advantages over alternative forming techniques. Since the raw material usage is better than 90% in die compaction, even in areas that could be served by competing manufacturing technologies, die compaction of powders is often the most economical solution. The industries applying this technique have seen tremendous innovation especially in shape capability, reproducibility and productivity over the last 15 years that has resulted in high added value, astonishing growth rates and increased employment also in high labor cost countries*”.

To increase the strength, ductility and formability keeping good electric conductivity of these specific copper alloys, there have been used special thermal treatments, as well as variations in the chemical composition. In this work were synthesized ternary copper alloys

with the aim of obtaining a steadily alloys production by sintering (powder metallurgy) in laboratory scale and optimizing the electrical and mechanical properties.

The alloy elements are added to copper to improve its mechanical resistance, ductility and thermal stability, without causing considerable costs on its form, electric and thermal conductivity and its resistance to the corrosion, typical characteristic aspects of pure copper. It is well known that the mechanical resistance in metallic alloys depends on the size, type, form and regular distribution of precipitations, which is also fundamental to obtain an electrical conductivity similar to that of the copper matrix.

Samples of ternary Cu-Ni based alloys (precursors of high purity; powder form; weight %; alloy element: Al; Sn; Cr), initially compressed, sintered and sometimes homogenized were characterized by optical metallography (microstructure), mechanical strength (hardness Vickers), electrical properties (electrical conductivity) and structural characterization (X-rays diffraction) for the study of the influence of sintering (powder metallurgy).

The major contribution of these sintered metallic alloys (compression, homogenization and sintering of metallic powder) is the evolution of their electrical conductivity, mechanical properties (hardness tests) and microstructure changes after appropriate thermal treatments.

In all analyzed samples the conductivity showed a strong dependence of sintering temperature and also of special thermal treatment. Specially, some compositions of Cu-Ni-Cr alloy perform very interesting physical properties, like mechanical resistance of 1000 MPa and an average electrical conductivity of more than 75% IACS.

The copper has different applications in the modern society due to its excellent thermal conductivity, electric properties, resistance to the corrosion, resistance to the fatigue and good mechanical properties. Connectors, contact switches, heaters, valves, piping, pots for absorption of solar energy, radiators for automobiles, current driver, electronic driver, contact sheets, elements of thermostats are common applications. Copper can be used with high purity or with addition of alloy elements (Ni, Sn, Be, Pt, Cr, Nb, Pb, Al) that increase the principal properties.

Products based on copper alloys such as porous material filters, electric friction equipment, contacts and structural parts can be manufactured through the process of powder metallurgy, which have the advantages of making fine grained homogeneous structures, forming complicated shapes with close dimensional tolerances and the ability to produce parts with a superior surface finishing. These advantages reduce or eliminate costly machining processes and allow less scrap loss, compared to other forming methods [1-13].

Diverse types of products based on copper alloys can be manufactured through the process of powder metallurgy: porous, material filters, electric friction equipment, contacts and structural parts [14-18]. The aim of this work is to obtain metallic alloys with high mechanical strength and high electric conductivity after adequate optimization of sintering and thermal treatments (powder metallurgy) followed by structural, microstructural, electrical and mechanical characterization of ternary Cu-Ni based alloys.

The alloy elements are added to copper with the purpose to improve its resistance, ductility and thermal stability, without causing considerable damages on its form, electric and thermal conductivity and resistance to the corrosion, typical characteristic aspects of pure copper. The choice of these current alloys is related to the studies carried through previously in ternary alloys to similar copper nickel base the chosen ones [1-7; 13-16].

The process of making powders, compacting them into useful shapes and then sintering them is costly, but the finished parts have some specific advantages over wrought or cast parts. The main advantages are: the possibility to make fine grained homogenous structures; the ability to form complicated shapes with close dimensional tolerances. Costly machining processes are thus reduced or eliminated and consequently there is less scrap loss compared to other forming methods [13-16].

The mechanical resistance in metallic alloys depends on the size, type, form and a regular distribution of precipitations, which is also fundamental to obtain an electrical conductivity similar to that of the copper matrix. To increase the mechanical resistance, ductility and formability keeping good electric conductivity of these alloys, there have been used special thermal treatments as well as variations in the chemical composition.

The main production of metallic materials is acquired by casting [1-8]. The contribution to the production of metallic parts by powder metallurgy is increased of consistent outline, supported for inestimable advantages. The list of benefits in the industrial processes of sintering is great and, not rare, surprises the coordinators of production of different industries that had not yet tried the technology and attend the explanation of specialists in the area [15-18].

It is therefore most economical to use powder metallurgy for the high volume production of small, intricately shaped, and/or very precise parts such as gears and links. In addition, the process offers the potential to produce a wide variety of alloys with different material properties such as high temperature toughness and hardness.

This work attempts to obtain systematic stages of the sintering and homogenization of the ternary copper nickel alloys utilizing powder metallurgy. Being an alternative process to the conventional processes, the powder metallurgy also allows, in some cases, the structural manufacture of parts and components in economically and more advantageous conditions.

Varied types of products of copper based alloys can be manufactured through the process of powder metallurgy for electric friction, contacts and structural parts. The alloy elements are added to copper with intention to improve the resistance, the ductility and the thermal stability, without causing considerable damages on its shape, electric and thermal conductivity, and also resistance to the corrosion [3-5].

Next to casting, mechanical forming and machining, powder metallurgy (PM) technology is an important method of manufacturing metal parts. Undesirable characteristics of ingot based metals can be greatly reduced, and desired properties of metals, which would normally not alloy easily, can be achieved by combining different metal powders or mixtures of metal and non-metal powders [14-18].

Costly machining processes are thus reduced or eliminated and consequently there is less scrap loss compared to other forming methods. It is therefore most economical to use powder metallurgy for the high volume production of small, intricately shaped, and/or very precise parts such as gears and links. In addition, the process offers the potential to produce a wide variety of alloys with different material properties such as high temperature toughness and hardness [17, 18].

Powder production and mixing is a highly specialized and complex process which produces custom made powder mixes designed to satisfy the needs of a specific application. A good powder mix not only has the ability to produce the required properties of a specific alloy, but also needs to facilitate handling, compacting and sintering.

For instance, the easy flow of powder and its capability to mix evenly with other powders is important for an even powder distribution before pressing, and ensures uniform properties of the finished part. Thinking in the theory for creep of dispersion-strengthened metals developed by Rösler and Arzt [19] to predict the optimum particle size for a given service temperature and to illustrate the need for a high interfacial energy. Resistance to coarsening leads to a requirement for low diffusivity and solubility of particle constituent elements in the matrix.

Based on the needs for a low difference in the coefficients of thermal expansion to minimize thermal-mechanical fatigue damage and low diffusivity and solubility of the constituent elements, several candidate ceramic phases are compared using a weighted property index scheme. The results of this quantitative comparison suggest that  $\text{CeO}_2$ ,  $\text{MgO}$ ,  $\text{CaO}$  and possibly  $\text{Y}_2\text{O}_3$  may be good candidates for the dispersed phase in a copper matrix [18 - 20].

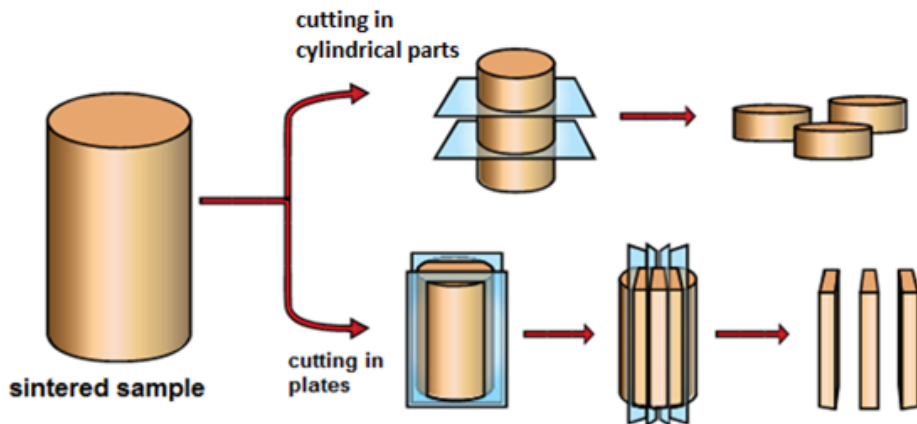
## 2. Experimental conditions

Powder production and mixing is a highly specialized and complex process which produces custom made powder mixes designed to satisfy the needs of a specific application. A good powder mix not only has the ability to produce the required properties of a specific alloy, but also needs to facilitate handling, compacting and sintering. Experimentally, for instance, the easy flow of powder and its capability to mix evenly with other powders is important for an even powder distribution before pressing, and ensures uniform properties of the finished part. In research and failure analysis, metallography is a major tool used to develop new products and improve manufacturing processes. In addition to chemical analysis, quality control also includes physical methods for checking density, dimensional changes, flow rate etc.

As the density of the compacted and sintered part influences its key properties of strength, ductility and hardness, a specific porosity is critical. For process control, metallography is used to check porosity, non-metallic inclusions and cross-contamination.



**Figure 1.** Ternary Cu-Ni alloys distributed in alumina boat for sintering and homogenizing heat treatment in vacuum furnace.



**Figure 2.** Chart for cutting planes of the cylinder samples on ternary Cu-Ni alloys

For the production of components the mixed powders are first compacted under high pressure in a suitable system. At this stage the part has the geometrical features of the finished component, but not its strength and is called the “green” part. The bonding occurs through diffusion between adjacent particles. In order to develop the mechanical and physical properties of the material, metallurgical bonding has to take place through sintering at high temperature in a sintering furnace. The bonding occurs through diffusion between adjacent particles (Fig.1).

Cold mounting of the sintered and homogenization samples was done by optical and hardness studies. The compacts were grinded with 400, 600, 800, 1000 and 1200 SiC papers followed by fine wet wheel polishing (diamond or alumina pastes). Vickers hardness of the polished specimens was measured on a hardness tester (HXD 1000TM – Pantec, load of 100 g).

To avoid oxidation, which would impair the inter-particle bonding, the sintering process is conducted in a protective atmosphere or convenient vacuum. The bonding increases the density, and pressed and sintered powder metal parts generally contain some residual porosity depending of the initial conditions. The as-pressed compacts were conventionally sintered in a vacuum Carbolite furnace that had a stabilized thermal gradient (hot zone) of about 150 mm.

In research and failure analysis, metallography is a major tool used to develop new products and improve manufacturing processes. The procedure for cutting the samples for metallographic and mechanical tests is represented in the scheme in Figure 2.

In addition to chemical analysis, quality control also includes physical methods for checking density, dimensional changes, flow rate etc. Acidic  $\text{FeCl}_3$  was used as the etchant and the microstructures of selected etched samples were observed in an optical microscope. In the case of Cu-Ni-Cr alloys the apparent density of the samples was measured before and after the thermal treatments.

Special samples for electrical conductivity studies were characterized using an Agilent 4338B Milliohmmeter, through resistance measurements, that were performed repeatedly in all samples to avoid eventual errors.

X - rays powder diffraction data of various samples of the three alloys were collected with a conventional diffractometer with fixed monochromator. From samples of the Cu-Ni-Cr alloys the x rays data were collected using synchrotron radiation with a Hubert diffractometer at the beam line XRD2 of the Brazilian Synchrotron LNLS (Campinas, São Paulo State, Brazil), using energies of 8keV and 10keV and counting time of 2 seconds. The structures of the samples were refined by the Rietveld Method using GSAS [23]. The peak profiles were simulated using function number 4 of GSAS.

## 2.1. Cu-Ni-Sn alloys

The as-pressed compacts were conventionally sintered in a vacuum Carbolite furnace that had a hot zone of about 150 mm. At the utilized composition the Cu-Ni-Sn alloys can be consolidated by solid state sintering. The most important conditions are presented in Table 1.

Condition	Premixed		
Compaction pressure	20MPa		
Chemical alloy composition (wt %)	Cu-0.5%Ni-0.5%Sn; Cu-1.0%Ni-0.5%Sn; Cu-1.0%Ni-1.0%Sn; Cu-3.0%Ni-3.0%Sn; Cu-5.0%Ni-5.0%Sn		
Sample dimensions	$\phi = 10.2\text{mm}$ and $h = 14.8\text{mm}$ (cylinder)		
Sample weight	6.5 g		
Sintering temperature and sample conditions	Sintering temperature (K)	Condition for premixed	Vacuum pressure
	823 – 1073	Solid state sintering	$10^{-4}$ mBar
Sintering time	$1.8 \times 10^3$ to $5.4 \times 10^3$ s		
Homogenization time	3.6 to $28.8 \times 10^3$ s		

**Table 1.** Sintering parameters of Cu-Ni-Sn alloys

## 2.2. Cu-Ni-Al alloys

The Cu-Ni-Al alloys can be consolidated by solid state sintering. The most important conditions are presented in Table 2.

Condition	Premixed		
Compaction pressure	20MPa		
Chemical alloy composition (wt %)	Cu-0.5%Ni-0.5%Al; Cu-1.0%Ni-0.5%Al; Cu-1.0%Ni-1.0%Al; Cu-3.0%Ni-3.0%Al; Cu-4.0%Ni-4.0%Al		
Sample dimensions	$\phi = 10.2\text{mm}$ and $h = 14.8\text{mm}$ (cylinder)		
Sample weight	6.5 g		
Sintering temperature and sample conditions	Sintering temperature (K)	Condition for premixed	Vacuum pressure
	823 – 1073	Solid state sintering	$10^{-4}$ mBar
Sintering time (s)	$1.8 \times 10^3$ to $5.4 \times 10^3$		
Homogenization time (s)	3.6 to $28.8 \times 10^3$		

**Table 2.** Sintering parameters of Cu-Ni-Al alloys

## 2.3. Cu-Ni-Cr alloys

High purity powders of copper, nickel and chromium were mixed for a suitable time and then compacted under 20 MPa in a cold uniaxial pressing. Afterwards, the specimens were sintered in temperatures varying from 973 K up to 1073 K in a high vacuum Carbolite furnace that had a hot zone of about 150mm under vacuum. At last, the samples were homo-

genized at 823 K under vacuum, for special times. For process control, metallography was used to check porosity, non-metallic inclusions and cross-contamination. The most important preparation conditions of the samples are presented in Table 3.

Condition		Premixed	
Compaction pressure (MPa)	20		
Chemical alloy composition (wt %)	Cu-0.5%Ni-0.5%Cr; Cu-1.0%Ni-0.5%Cr; Cu-1.0%Ni-1.0%Cr; Cu-1.5%Ni-0.5%Cr		
Sample dimensions (mm)	$\phi = 10.2$ and $h = 12.4$ (cylinder)		
Sample weight (g)	6.4		
Sintering temperature and sample conditions	Sintering temperature (K)	Condition for premixed	Vacuum pressure (mBar)
	823 – 1073	Solid state sintering	$10^{-4}$
Sintering time (s)	$1.2 \times 10^3$ to $5.4 \times 10^3$		
Homogenization time (s)	21.6 to $172.8 \times 10^3$		

**Table 3.** Sintering parameters of Cu-Ni-Cr alloys

### 3. Results and discussion

#### 3.1. Cu-Ni-Sn alloys

The important data with copper-nickel-tin samples is shown in Table 4 concerning mixing, compacting, sintering, homogenizing treatments and also values of hardness and electrical conductivity.

Cu-Ni-Sn Alloys	Sintering		Homogenizing		Mechanical Resistance (MPa)	Electrical Conductivity (% IACS)
	T(K)	t(s)	T(K)	t(s)		
Cu-1.0%Ni-0.5%Sn	823	5400	--	--	(520 ± 9)	(35 ± 4)
Cu-1.0%Ni-0.5%Sn	823	5400	773	21600	(410 ± 8)	(40 ± 4)
Cu-1.0%Ni-1.0%Sn	823	5400	773	32400	(540 ± 9)	(37 ± 4)
Cu-5.0%Ni-5.0%Sn	823	5400	773	21600	(620 ± 9)	(34 ± 4)

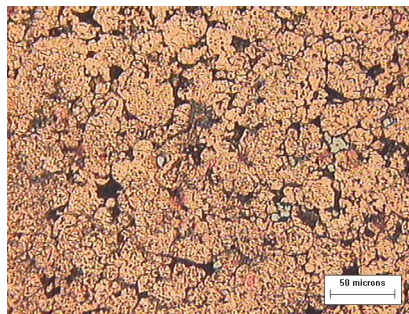
**Table 4.** Mechanical and electrical properties of the copper-nickel-tin alloys obtained by powder metallurgy



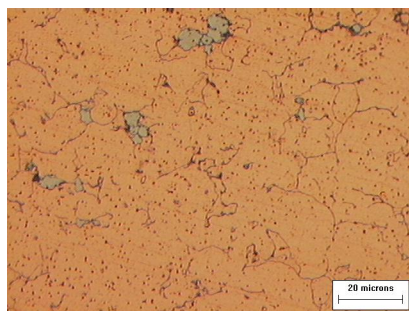
The mechanical resistance in metallic alloys depends on the precipitation distribution to obtain similar electrical conductivity of the copper (matrix). To increase the strength, ductility and formability keeping good electric conductivity of these alloys, there have been used special thermal treatments as well as variations in the chemical composition. At the present time the mechanical strength (620MPa) and electrical conductivity (40%IACS) media values indicate a fine appliance for these alloys utilizing powder metallurgy as a substitute of conventional metallurgy processing.

The Rietveld refinements using x rays powder diffraction data indicate that the utilized amounts of nickel and tin did not distorted the copper matrix structure and the refined profile parameters did not showed any detectable effects in the microstructure.

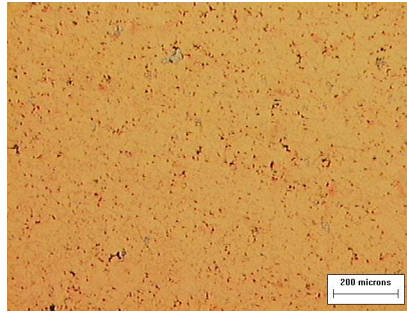
Concerning the microstructural aspects, figures 3 to 5, show optical micrographs of some Cu-Ni-Sn alloys. Fine grains presences but with inadequate porosity and second phases show that a new homogenization treatments will be necessary to overcome this situation and also investigations with scanning and transmission electron microscopy to identify the presence of second phase on these alloys.



**Figure 3.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Sn, cold compact (20MPa) and sintered at 823K for 1200s



**Figure 4.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Sn, cold compact (20MPa) and sintered at 823K for 1200s.



**Figure 5.** Optical micrograph of the ternary alloy Cu-1.0%Ni-1.0%Sn, cold compact (20MPa) and sintered at 823K for 5400s.

### 3.2. Cu-Ni-Al alloys

The Table 5 resumes some data with the copper-nickel-aluminum alloys samples concerning mixing, compacting, sintering, homogenizing treatments and also values of hardness and electrical conductivity obtain the best condition for electrical and mechanical application with powder metallurgy processing.

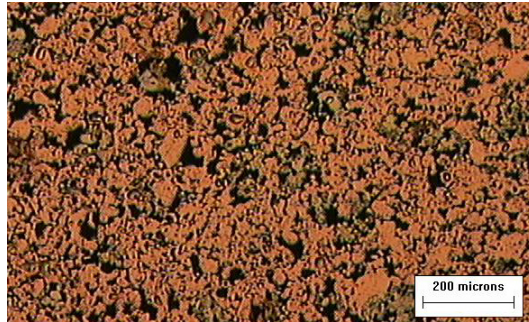
Cu-Ni-Al Alloys	Sintering		Homogenizing		Mechanical Resistance (MPa)	Electrical Conductivity (% IACS)
	T(K)	t(s)	T(K)	t(s)		
Cu-1.0%Ni-0.5%Al	1053	5400	--	--	(420 ± 90)	(30 ± 3)
Cu-1.0%Ni-0.5%Al	1053	5400	773	21600	(280 ± 7)	(35 ± 4)
Cu-1.0%Ni-1.0%Al	1053	5400	--	--	(240 ± 5)	(29 ± 3)
Cu-1.0%Ni-1.0%Al	1053	5400	773	32400	(370 ± 9)	(30 ± 3)
Cu-5.0%Ni-5.0%Al	1053	5400	773	21600	(400 ± 8)	(28 ± 3)

**Table 5.** Some mechanical and electrical properties of the copper-nickel-aluminum alloys obtained by powder metallurgy

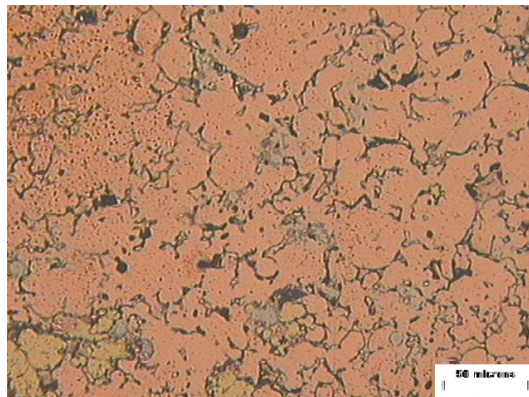
The mechanical resistance in metallic alloys depends on the precipitation distribution to obtain similar electrical conductivity of the copper (matrix). At the present time the mechanical strength (400MPa) and electrical conductivity (35%IACS) values indicate a good application for these alloys utilizing powder metallurgy instead conventional metallurgy.

Concerning the microstructural aspects, figures 6 to 10 show optical micrographs of some Cu-Ni-Al alloys. Fine grained presences but with inadequate porosity and second phases until now show that new homogenization treatments will be necessary to overcome this situation and also investigations with scanning and transmission electron microscopy to identify the presence of second phase on these alloys.

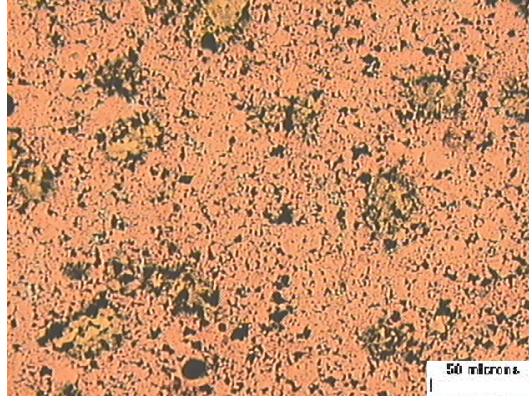
The Rietveld refinements using X rays powder diffraction data indicate that the utilized amounts of nickel and aluminum do not distorted the copper matrix structure significantly. Furthermore, no special broadening of peak profiles was detected, which indicates that crystallite sizes are not affected.



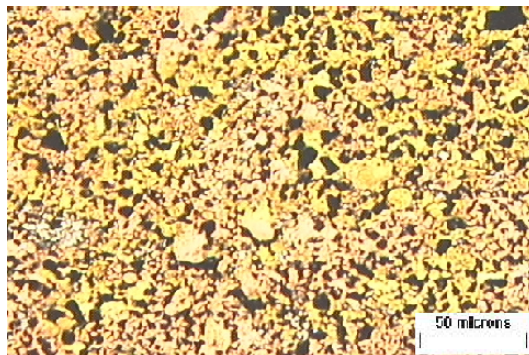
**Figure 6.** Optical micrograph of the ternary alloy Cu-1.0%Ni-1.0%Al, cold compact (20MPa) and sintered at 923K for 1200s



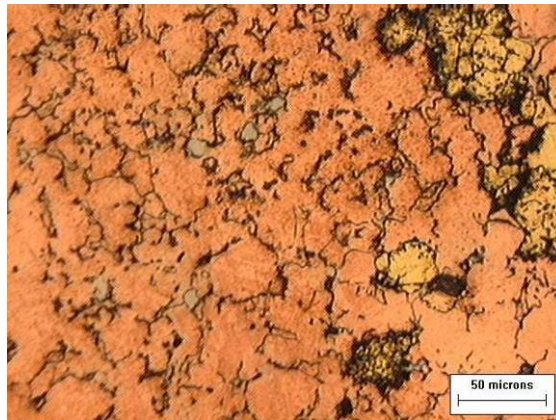
**Figure 7.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Al, cold compact (20MPa) and sintered at 1053K for 5400s.



**Figure 8.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Al, cold compact (20MPa) and sintered at 1053K for 5400s).



**Figure 9.** Optical micrograph of the ternary alloy Cu-5.0%Ni-5.0%Al, cold compact and sintered at 1053K for 5400s and also homogenized at 773K during 21600s.



**Figure 10.** Optical micrograph of the ternary alloy Cu-1.0%Ni-1.0%Al, cold compact and sintered at 1053K for 5400s and also homogenized at 773K during 21600s.

### 3.3. Cu-Ni-Cr alloys

Due to the results for the compositions Cu-1.0%Ni-0.5%Cr and Cu-1.0%Ni-1.0%Cr, special attention was given to these samples. The mechanical strength of 1000MPa and the electrical conductivity of 79%IACS for the Cu-1.0%Ni-0.5%Cr homogenized sample indicate a good application for this alloy, using powder instead conventional metallurgy. This sample also presented an increase in its apparent density of approximately 5% after the thermal treatments. Using the synchrotron X - rays data with energy 8 keV, a Rietveld refinement was performed for only for copper with Fm-3m space group, because the amounts of nickel, chromium and copper oxide were almost insignificant. The discordance factors were  $R_{wp} = 13.96\%$ ,  $R_p = 7.47\%$ ,  $R_{Bragg} = 0.4\%$  and  $\chi^2 = 25.12\%$ . Using the Gaussian broadening formula from GSAS, a crystallite size of approximately 99 nm was calculated for this sample.

For the sample with composition Cu-1.0%Ni-1.0%Cr the increase in apparent density was less than 2% after the thermal treatments. This sample showed also a significant but lower electrical conductivity of  $2.6 \cdot 10^7 \text{ }^{-1} \cdot \text{m}^{-1}$ , i.e. 44.40%IACS. The Rietveld refinement using synchrotron radiation with energy 8 keV was performed until discordance factors of  $R_{wp} = 2.95\%$ ,  $R_p = 2.18\%$ ,  $R_{Bragg} = 10.48\%$  and  $\chi^2 = 2.89\%$ . The amounts of nickel and chromium were not detectable for this sample and a crystallite size of approximately 124 nm was calculated using the Gaussian broadening formula.

Although both values are of the order of 100 nm, the lower size could be due to the more effective homogenization process of the first composition (Cu-1.0%Ni-0.5%Cr), which also exhibit the higher electrical conductivity and mechanical strength. Further thermal treatments shall be applied to continue the study of these alloys and to obtain the best conditions for electrical and mechanical applications using powder metallurgy processing.

The results of mechanical and electrical characterization in dependence of treatment of the samples are resumed in Table 6.

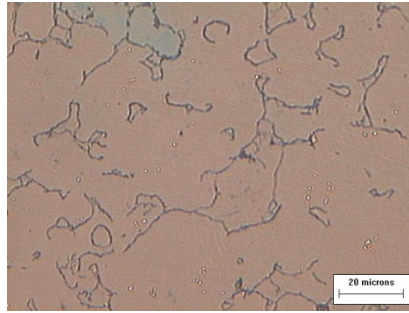
Cu-Ni-Cr Alloys	Sintering		Homogenizing		Mechanical Resistance (MPa)	Electrical Conductivity (% IACS)
	T (K)	t ( $10^3$ s)	T (K)	t ( $10^3$ s)		
Cu-0.5%Ni-0.5%Cr	1053	5.4	773	32.4	(330 ± 5)	(32 ± 3)
Cu-0.5%Ni-0.5%Cr	1073	5.4	--	--	(420 ± 5)	(37 ± 3)
Cu-1.0%Ni-0.5%Cr	1053	5.4	773	21.6	(1000 ± 9)	(79 ± 5)
Cu-1.0%Ni-0.5%Cr	1053	5.4	--	--	(460 ± 5)	(33 ± 3)
Cu-1.0%Ni-0.5%Cr	1073	5.4	--	--	(430 ± 5)	(27 ± 3)
Cu-1.0%Ni-1.0%Cr	1073	5.4	--	--	(370 ± 4)	(37 ± 3)
Cu-1.0%Ni-1.0%Cr	1073	5.4	773	172.8	(400 ± 5)	(44 ± 4)
Cu-1.5%Ni-0.5%Cr	1053	5.4	773	32.4	(370 ± 5)	(35 ± 3)

**Table 6.** Mechanical and electrical properties of the copper-nickel-chromium alloys obtained by powder metallurgy

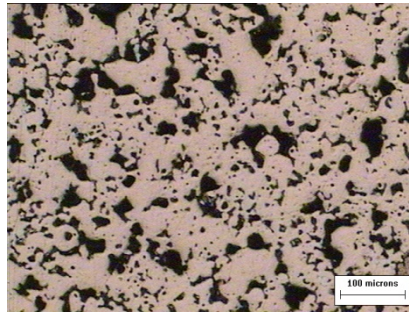
Optical micrographs of some of the samples are presented in Figures 11 to 18 to show their microstructural aspects. Fine grained presences but with inadequate porosity and second phases indicate that further treatments will be necessary to overcome this situation and also investigations with scanning and transmission electron microscopy to identify the presence of second phase on these alloys.



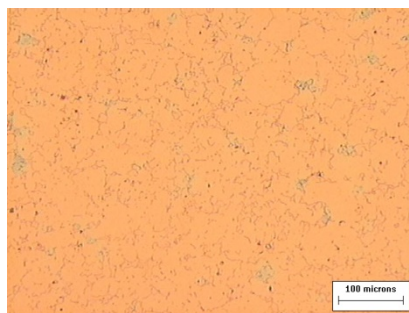
**Figure 11.** Optical micrograph of the ternary alloy Cu-0.5%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1053K for  $5.4 \times 10^3$ s and also homogenized at 773K for  $32.4 \times 10^3$ s.



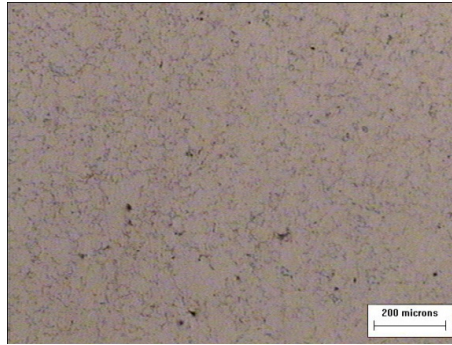
**Figure 12.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1053K for  $5.4 \times 10^3$ s and also homogenized at 773K for  $21.6 \times 10^3$ s.



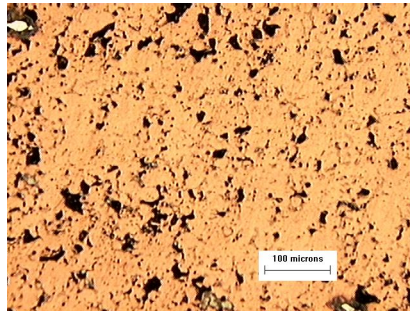
**Figure 13.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1053K for  $5.4 \times 10^3$ s and also homogenized at 773K for  $21.6 \times 10^3$ s.



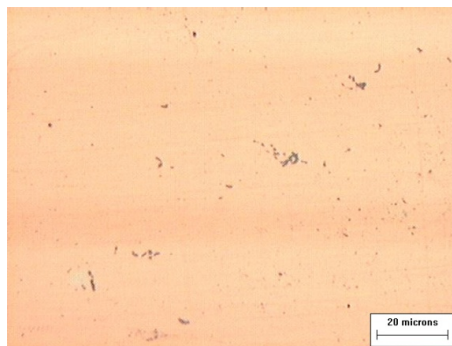
**Figure 14.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1073K for  $5.4 \times 10^3$ s and homogenized at 773K for  $172.8 \times 10^3$ s.



**Figure 15.** Optical micrograph of the ternary alloy Cu-0.5%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1073K for  $5.4 \times 10^3$ s and homogenized at 773K for  $172.8 \times 10^3$ s.

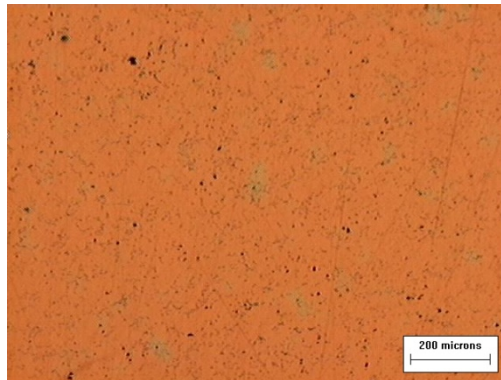


**Figure 16.** Optical micrograph of the ternary alloy Cu-0.5%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1053K for  $5.4 \times 10^3$ s and homogenized at 773K for  $172.8 \times 10^3$ s.



**Figure 17.** Optical micrograph of the ternary alloy Cu-1.0%Ni-0.5%Cr, cold compact (20MPa) and sintered at 1073K for  $5.4 \times 10^3$ s and homogenized at 773K for  $172.8 \times 10^3$ s.





**Figure 18.** Optical micrograph of the ternary alloy Cu-1.0%Ni-1.0%Cr, cold compact (20MPa) and sintered at 1073K for  $5.4 \times 10^3$ s and homogenized at 773K for  $172.8 \times 10^3$ s.

#### 4. Conclusions

The practical powder metallurgy processing steps on the copper-nickel-base alloys corroborate a first-rate mechanical strength and electrical conductivity values (Cu-Ni-Sn: 620MPa, 40% IACS; Cu-Ni-Al: 400MPa, 35% IACS; Cu-Ni-Cr: 1000MPa; 79% IACS) that indicate a good quality application for these alloys utilizing powder metallurgy instead conventional metallurgy processing. Furthermore, the results for these alloys open the possibility to search and make fine grained homogeneous structures with interesting physical properties, also the capacity to produce parts with a superior surface finishing in different dimensions.

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