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Structural and electrical properties of copper-nickel-aluminum alloys obtained by conventional powder metallurgy method

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Abstract. This work looked for to search out systematically, in scale of laboratory, copper-nickel-aluminum alloys (Cu-Ni-Al) with conventional powder metallurgy processing, in view of the maintenance of the electric and mechanical properties with the intention of getting electric connectors of high performance or high mechanical damping. After cold uniaxial pressing (1000 kPa), sintering (780°C) and suitable homogenization treatments (500°C for different times) under vacuum (powder metallurgy), the obtained Cu-Ni-Al alloys were characterized by optical microscopy, electrical conductivity, Vickers hardness. X rays powder diffraction data were collected for the sintered samples in order to a structural and microstructural analysis. The comparative analysis is based on the sintered density, hardness, macrostructures and microstructures of the samples.

Introduction

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 followed by structural, microstructural, electrical and mechanical characterization of Cu-y%Ni-x%Al alloys (where x and y are variable values in weight). Diverse types of products based on copper alloys can be manufactured through the process of powder metallurgy: porous material filters, electric friction equipments, contacts and structural parts. The alloy elements are added to copper with purpose to improve the resistance, the ductility and the thermal stability, without causing considerable costs on its form, electric and thermal conductivity and resistance to the corrosion, typical characteristic aspects of pure copper [1-11].

The mechanical resistance in metallic alloys depends on the precipitation distribution to obtain similar electrical conductivity comparing to the copper matrix. To increase the strength, ductility and formability keeping good electric conductivity of these alloys, have been used special thermal treatments as well as variations in the chemical composition. In general, the main production of metallic materials is purchased by casting. The contribution to the production of metallic parts by powder metallurgy is increased of consistent outline, supported for enormous return [12-16].

The first one of the advantages is the cost reduction. This project looked for to acquire steadily, in laboratory scale, copper-nickel-aluminum alloys production by powder metallurgy, concerning the maintenance of the electric and mechanical properties with the purpose of getting electric connectors of high performance or high mechanical damping.

The alloy elements are added to copper 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].

The process of making powders, compressed 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; the ability to produce parts with a superior surface finish. Costly machining processes are thus reduced or eliminated and consequently there is less scrap loss compared to other forming methods [13-16].

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. 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.

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.

Experimental Conditions

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. To avoid oxidation, which would impair the inter-particle bonding, the sintering process is conducted in a protective atmosphere or convenient high vacuum. The bonding increases the density, and pressed and sintered powder metal parts generally contain some residual porosity.

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

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, for example.

Cold mounting of the sintered and homogenization sample was done by optical and hardness studies .The compacts were grinding 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 (load of 100g). Acidic $FeCl_3$ was used as the etchant. The microstructures of selected etched samples were observed in an optical microscope. Special samples for electrical conductivity studies were utilized an Agilent 4338B milliohmmeter and for crystallographic parameter an R-X difractometer [17]. X rays powder diffraction data were collected with a conventional Rigaku MultiFlex diffractometer with a fixed monocromator. The experimental conditions were: 40 kV, 20 mA, $10^o \leq 2\theta \leq 120^o$, $\Delta 2\theta = 0.02^o$, $\lambda_{CuK\alpha}$, divergence slit = 0.5^o, reception slit = 0.3 mm and step time 5 s.

Table 1 - Sintering parameters of Cu-Ni-Al

Condition	Premixed		
Compaction pressure	1000 kPa		
Chemical alloy composition (wt %)	Cu-0.5%Ni-0.5%Al; Cu-1%Ni-0.5%Al; Cu-1%Ni-1%Al; Cu-3%Ni-3%Al; Cu-4%Ni-4%Al		
Sample dimensions	Cylinder diameter ϕ = 10.2mm e h = 14.8mm		
Sample weight	6.5 g		
Sintering temperature and conditions	Sintering temperature (°C)	Condition for premixed	Vacuum pressure
	650 - 800	Solid state sintering	10^{-4} torr
Sintering time (s)	$1.8x10^3$ to $5.4x10^3$		
Homogenization time (s)	3,600 to 28,800		

Results and Discussion

The Table 2 resume some data realized until now with the samples of copper nickel-aluminum alloys concerning mixing, compacting, sintering, homogenizing treatments and also values of hardness and electrical conductivity. The intention is to continue the study of these alloys to obtain the best condition for electrical and mechanical application with powder metallurgy processing.

Table 2 – Some mechanical and electrical properties of the copper-nickel-aluminum alloys obtained by powder metallurgy

Alloys	Sintering		Homogenizing		Mechanical Resistance	Electrical Conductivity
Cu-Ni-Al	T[°C]	T[s]	T[°C]	T[s]	[MPa]	[% IACS]
Cu-1.0%Ni-0.5%Al	780	5400	--	--	420	30
Cu-1%Ni-0.5%Al	780	5400	500	21600	280	35
Cu-1%Ni-1%Al	780	5400	--	--	240	29
Cu-1%Ni-1%Al	780	5400	500	32400	370	30
Cu-5%Ni-5%Al	780	5400	500	21600	400	28

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, have been used special thermal treatments as well as variations in the chemical composition. 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.

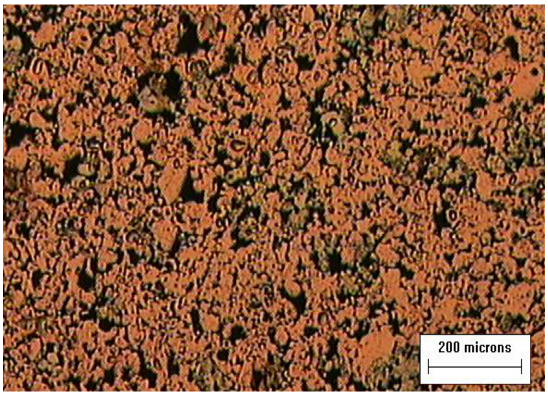

Figure 1 Optical micrograph of the alloy Cu-1%Ni-1%Al, cold compact (250 MPa) and sintered at 650C for 1200s

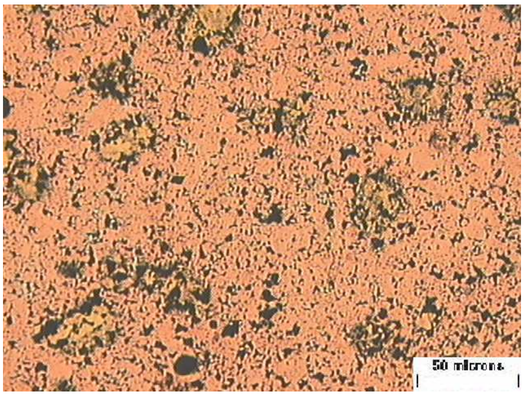

Fig.3- Optical micrograph of the alloy Cu-1%Ni-0.5%Al, cold compact (250 MPa) and sintered at 780^{o}C for 5400s

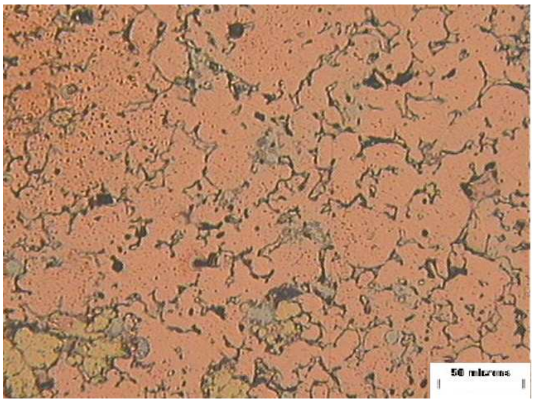

Fig.2- Optical micrograph of the alloy Cu-1%Ni-0.5%Al, cold compact (250MPa) and sintered at 780^{o}C for 5400s.

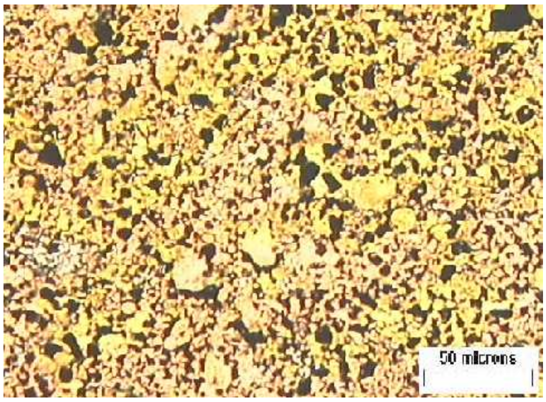

Fig.4- Optical micrograph of the alloy Cu-5.0%Ni-5.0%Al, cold compact and sintered at 780^{o}C for 5400s and also homogenized at 500^{o}C for 21600s.

Concerning the microstructural aspects, figures 1 to 4 show optical micrographs of some Cu-Ni-Al alloys samples. 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 powder diffraction data indicate that the utilized amounts of dopants do not distorted the copper matrix structure significantly. No special broadening of the Bragg peaks was detected, which indicates that crystallite sizes are not affected.

Conclusion

The applied powder metallurgy processing steps on the copper-nickel-aluminum alloys confirm a good mechanical strength (400MPa) and electrical conductivity (35%IACS) values that indicate a good application for these alloys utilizing powder metallurgy instead conventional metallurgy. The possibility to search and make fine grained homogenous structures, the skill to form complicated shapes with close dimensional tolerances and the capacity to produce parts with a superior surface finish with close dimensional tolerances encourage this metallurgical application.

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