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Improvement of metallic joint electrical conductivity using a novel conductive paste produced from recycled residues

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Resumo

A transmissão de eletricidade na indústria usualmente implica altas correntes transportadas por grandes distâncias e, em alguns casos, como em fábricas de alumínio, o uso de altas correntes é essencial no processo de redução. As conexões entre os cabos de transmissão e os fornos elétricos são feitas com barramentos, que podem ser de apenas um tipo de metal, ou de dois diferentes tipos. Nesse processo de transmissão, a principal maneira de aumentar o desempenho do circuito é através da melhoria da condutividade na interface das juntas elétricas. Devido às necessidades de redução de custos e de simplificação dos procedimentos de manutenção, as interfaces nas juntas são apenas escovadas e pastas contutoras são pressionadas entre os metais em contato. O material mais comumente usado é uma pasta condutora de grafite de alto custo, a qual não é produzida por nenhuma companhia brasileira. Esse artigo apresenta uma pasta condutora inovadora, facilmente elaborada a partir de resíduos industriais e com baixo custo de produção, ao mesmo tempo apresentando melhor desempenho que a pasta de grafite.

Palavras-chave: pasta condutora, reciclagem de metais, barramentos.

Abstract

In industry, the transmission of electricity usually requires high currents transported for very long distances, and in some cases, such as in aluminum plants, the use of high currents is essential for the reduction process. The connections between the electrical furnaces and the transmission cables are made with busbars, which can be comprised of either one or two different types of metal. In this transmission process, the main method to upgrade electrical circuit performance is by improving conductivity at the joint interface. Due to the need to reduce cost and simplify maintenance procedures, the interfaces at the joints are simply brushed, and conductive pastes are pressed between the contacting metals. The material most commonly used is a high-cost graphite paste, which is not produced by any Brazilian company. This paper presents a novel conductive paste, easily elaborated from industrial residues, involving low-cost production, yet presenting better results than those obtained with the graphite paste.

Keywords: *conductive paste, metals recycling, busbars.*

1. Introduction

The production of metals using electricity usually involves very high values of electrical currents and relatively low voltages. Under these conditions, any increment in the resistance value of the circuit provokes considerable power loss. The joints along the circuit are low-conductivity positions, and the use of highly conductive pastes between the faces of the joints is unavoidable. [1-4]

Despite the use of conductive pastes, the joints always increase the total resistance of the circuit. The quality of the surfaces in the interface plays an important role in the efficiency of these joints. However, the production of high grade polishing is too costly and time consuming for the process, and the contacting surfaces are simply brushed, creating irregularities which reduce the contact surface of the joints. The use of pastes in the joints is also intended to help prevent oxidation of the interfaces, a problem that usually leads to a premature replacement of the parts. The graphite paste does not present a conductivity as high as that of the metals in the joint, but, when compressed in the interfaces, it fills the empty cavities created by brushing and, as it is a better conductor than air, improves the conductivity while protecting the surface against oxidation.[5-9]

The purpose of this study is to present a conductive paste that acts more efficiently in the improvement of the electrical conductivity of high-current electrical joints. This conductive paste, as it will be called here, was produced from particles of metallurgical residues embbeded in a pasty medium; therefore, recycling is one of the steps for its production. Besides being environmentally friendly, the conductive paste proved to perform better than the graphite paste used in the industry.

2. Experimental

Recovered metallurgical residues with a high concentration of iron micro-spheres, varying in size from 48# to 325#, were used as raw material for the production of the conductive paste. The micro-spheres were milled, to clean their surfaces of oxidized layers, and subsequently sieved, to separate the fraction between 100 and 200#, which would be used in the paste.

After the milling and the sieving steps, the micro-spheres were attacked in a solution of sulfuric acid, with mechanical agitation, followed by a bath in a saturated copper sulphate solution ($CuSO_4$), with mechanical and ultra-sonic agitation. After coating with copper, the spheres were dried and mixed with regular grease, forming the conductive paste.

The performance of the joints was tested, measuring the resistance of the joints under three different conditions: 1) brushed surfaces without any paste between them were pressed together; 2) brushed surfaces covered with the graphite paste were pressed together; and 3) brushed surfaces covered with the recycled conductive paste were pressed together. In all cases, the joints were pressed to simulate the compression pressures applied in electrometallurgical companies. Three types of joints were tested under various pressures: the copper/copper joint, the aluminum/aluminum joint and, finally, the copper/iron joint.

Table 1 shows the dimensions of the metal bars used in the joints, and figure 1 shows the experimental set-up of the joints in the press that measured resistivity vs. pressure.

3. Results and discussion

Figures 2, 3 and 4 show joint resistance as a function of pressure, for the Cu/Cu, the Al/Al and the Cu/Fe joints, respectively. They also compare joint resistance with simply brushed surfaces, to the resistance of joints brushed and filled with either graphite or conductive paste.

The Cu/Cu joints showed the lowest resistance, not only due to copper's naturally low resistance, but also due to its mechanical and chemical properties, as will be seen below.

An increase in pressure is always followed by a decrease in resistance, as expected, because it increases the surface of contact in the joint interface, increasing the cross section for the current flow. Resistance reaches a minimum value for very high pressures when it no longer depends on the material between the inner surfaces of the joint. This is because at such pressures practically all the voids are eliminated, together with air or any paste. However, these pressures are way above practical limits in industry.

The decrease in resistance with pressure is more pronounced in the Cu/Cu joint, followed by the Cu/Fe joint and the Al/Al joint. This is because of the

Table 1 - Dimensions of the metal bars in the joints (see figure 1).

Material	L	b	h	ϕ	x	y	Surface
Copper	7,5 cm	2,5 cm	1,0 cm	1,0 cm	0,75 cm	4,0 cm	Brushing
Iron	7,5 cm	2,5 cm	1,0 cm	1,0 cm	0,75 cm	4,0 cm	Brushing
Aluminium	7,5 cm	3,8 cm	0,8 cm	1,0 cm	0,75 cm	5,0 cm	Brushing

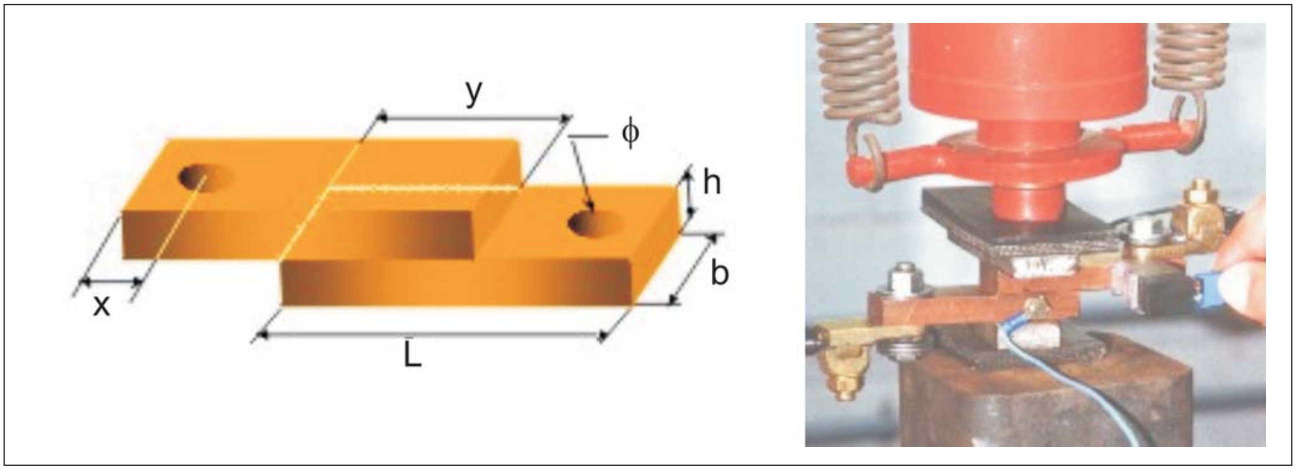

Figure 1 - Experimental set-up of the joints in the press that measured resistivity vs. pressure.

lower yield limit of copper, which allows an easier plastic flow of the metal to fill in the voids at the joint. The aluminum joint, despite the relatively low yield limit of the material, presents the drawback of the presence of a high-resistance passivation layer, which can be broken, but not taken off the joint.

In all cases, the use of the conductive paste showed the best results, with the smaller values for the resistance of the joints. In the case of the Al/Al joint, the graphite paste could not be used, because it had an insulating effect in the joint.

These results can be explained by the fact that, besides filling the voids between the contact surfaces of the joints, the conductive paste plays yet two other important roles. First, the small iron/copper spheres in the conductive paste, under the pressure at the joints, break the oxide layers formed right after brushing, decreasing their detrimental effects. This is even more pronounced in the Al/Al joint, where the graphite paste is not capable of causing the rupture of the alumina passivation layer, a job easily accomplished by the conductive paste. At the same time, the copper layer of the spheres in the conductive paste get in contact with each other, forming a highly conductive network that electrically connects the inner surfaces of the joints, increasing their conductivities and, as a result, improving their performances.

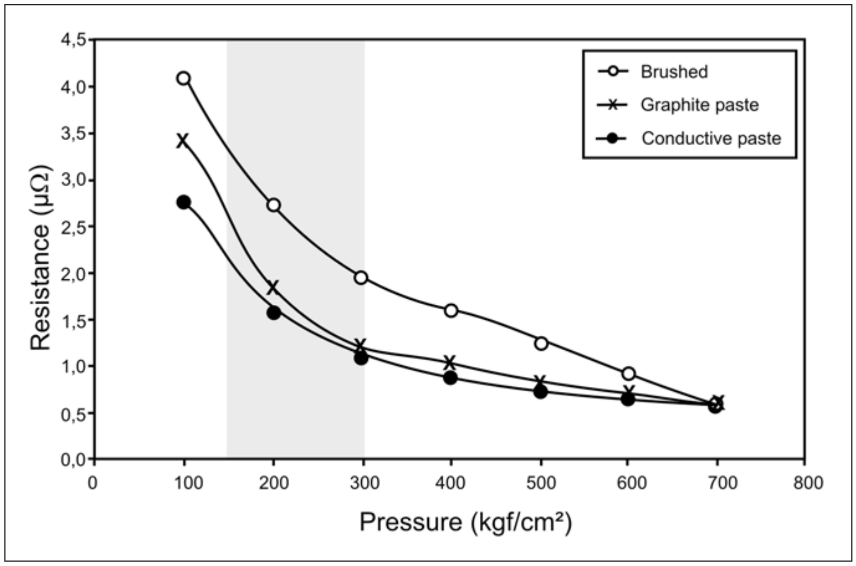

Figure 2 - Resistance of the Cu/Cu joint as a function of pressure, for the joints with simply brushed surfaces, and for the joints brushed and filled with either graphite paste or conductive paste. Dark area represents the usual range of pressures at the joint in industry.

4. Conclusions

- The Cu/Cu joints show lower resistances than either the Al/Al joints or the Cu/Fe joints.
- An increase in pressure is always followed by a decrease in the resistance of high current electrical joints.
- Decrease in resistance with pressure is more pronounced in the Cu/Cu joint than in the Al/Al and Cu/Fe ones.
- The resistance reaches a minimum value for very high pressures, independent of the use of paste, however, these pressures are way above practical limits in industry.
- The use of the conductive paste showed the best results, with smaller values for joint resistance.
- The small iron/copper spheres in the conductive paste, under pressure at the joints, break the oxide layers formed right after brushing, decreasing their detrimental affects.

- In the Al/Al joint, where the graphite paste is not capable of causing the rupture of the alumina passivation layer, the conductive paste easily accomplishes the job.
- Under pressure, the copper layer of the spheres in the conductive paste get in contact with each other, forming a highly conductive network that electrically connects the inner surfaces of the joints, increasing their conductivities and, as a result, improving their performances, when compared to the simply brushed surfaces and to the brushed surfaces with graphite paste.

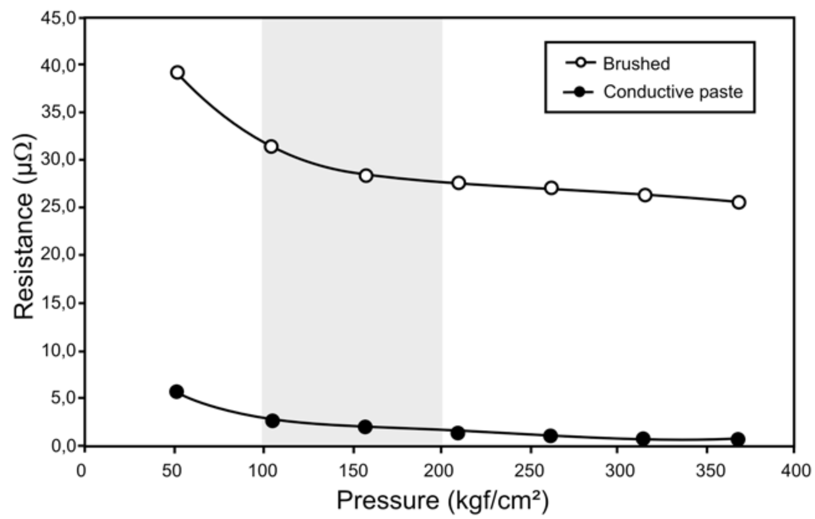

Figure 3 - Resistance of the Al/Al joint as a function of pressure, for the joints with simply brushed surfaces, and for the joints brushed and filled with graphite paste and the conductive paste. Dark area represents the usual range of pressures at the joint in industry.

5. Acknowledgements

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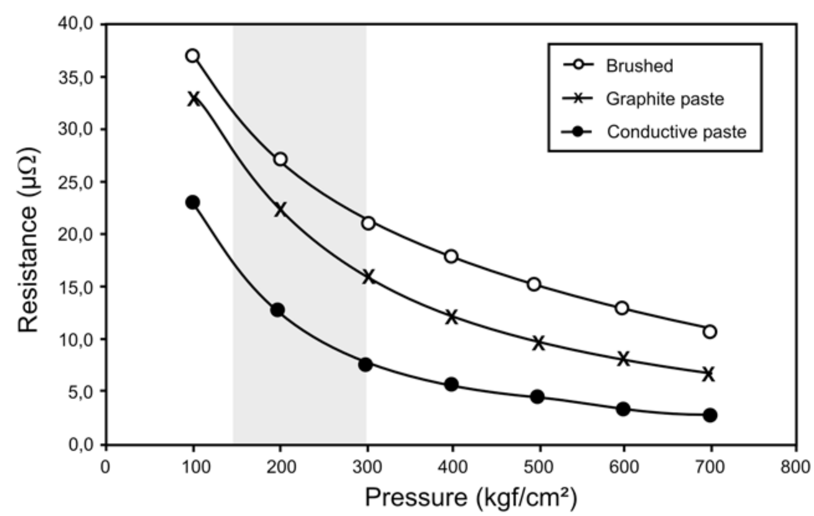

Figure 4 - Resistance of the Cu/Fe joint as a function of pressure, for the joints with simply brushed surfaces, and for the joints brushed and filled with either graphite or conductive paste. Dark area represents the usual range of pressures at the joint in industry.

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