Wear Resistance Improvement of Copper Alloys Using a Thermochemically Obtained Zinc-Rich Coating

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Abstract—It has been developed a thermochemical process applied on copper alloys: brass and bronze, using pure zinc powder, obtaining a zinc-rich wear protective coating. The layers obtained by a diffusion process, on brass (alloy C36000) and bronze specimens (alloy SAE 62), were characterized using a scanning electron microscope, EDAX microanalysis, Vickers microhardness, X-Ray diffraction analysis, and sliding wear test. The chemical analysis showed a layer composition of 62% Zn and 38% Cu, on average. The microhardness for thermochemical treated brass was 496HV and 598HV for bronze; thus, a microhardness increase for brass is 468% and 532% for bronze. It was made an X-Ray diffraction analysis, confirming the results obtained with the chemical analysis and crystalline structure for coating. It showed the presence of Cu$_2$Zn$_8$ and Cu$_5$Zn$_6$ phases. The wear tests demonstrated that treated specimens show better wear resistance than non-protected specimens.

Index Terms—Copper Alloys, Thermochemical Treatment, Wear Resistance, Zinc-Rich Coating.

I. INTRODUCTION

Methods used to protect a surface against surface deterioration processes involve the need of a coating that isolates the material against damaging situations. There are metallic coatings that can isolate the metal from the atmosphere, creating a barrier layer, which offers higher corrosion resistance. Zn, like other anodic metals, protects the substrate metal even if there are imperfections in the coatings, a situation that does not occur with the cathodic coatings. There are different methods to obtain a zinc rich coating on a surface: sherardizing [1,2], thermal spray, electrogalvanizing, zinc-rich paints [3], hot-dip galvanizing [4].

Copper base alloys, such as bronzes, have been used for many years in applications where they can work under wear conditions. If this behavior is improved, the service life of such parts can be extended. Brass has limited wear resistance and it is also an alloy of engineering interest. A better behavior against wear is expected to increase applying the thermochemical treatment proposed in this work, extending the useful life of these materials.

The hot-dip galvanizing of steels is a well-known process. There is an essential available content in the literature about properties, phases, and microstructure in these coatings. The presence of Zn-Fe intermetallic compounds in different zones of the coatings has been found, as a product of diffusion processes occurring during hot-dip galvanizing.

The literature about diffusion processes using pure zinc powder on steels, which is commercially known as sherardizing, is fewer. In their research, N. Pistofidis [4-6] et al., studied the diffusion mechanism of Zn in Fe, using sherardizing, as an alternative to the hot-dip galvanizing method. The cementation method, performed at 400 °C, provides uniform coating composed mainly of two layers, achieving corrosion resistance similar to that obtained by the hot immersion method. These zones of the layer are gamma (γ-Fe$_1$(Zn$_4$)) and delta (δ-FeZn$_{10}$), corresponding to those indicated in the Fe-Zn Phase Diagram. It was observed, through thermal analysis techniques, that the process is carried out in three stages when ammonium chloride is used as the activator. In the first stage (carried out at 193.9 °C), which is endothermic, the transformation of α-NH$_4$Cl to β-NH$_4$Cl is carried out, and the NH$_4$Cl decomposes into NH$_3$ and HCl. During the second stage (which is exothermic, developed at 248.6 °C), Zn$^{2+}$ ions are formed - mainly - as a ZnCl$_2$. Finally, in the third stage (which occurs at 264.1 °C), the Zn is deposited by an endothermic reaction on the ferrous substrate through the decomposition of ZnCl$_2$. It is also pointed out that the corrosion resistance found in sherardized samples is similar to that found in hot-dip galvanized parts and that the corrosion mechanism in the case of hot-dip galvanizing is associated with a pitting mechanism, and in the case of sherardizing, with phenomena of stress corrosion.

Natrup and Graf extensively describe the sherardizing process [7], pointing out the appropriate temperature conditions, the preparation procedures for the surfaces to be coated, and the characteristics of the zinc powders to be used. They also describe in detail the phenomena of diffusion that can occur during sherardizing, the presence of the gamma (γ) and delta (δ) phases, and the high hardness that can be reached in these coatings is highlighted; in a first hypothesis, it is attributed to the possible presence of a significant number of defects in the coating. An additional
aspect – to take into account is– [8] – the importance of appropriate heat treatment selection – to sherardized steel parts –, to ensure no impact in mechanical properties; it is also necessary - the study of the effect of - - using- different halides on the growth of sherardized layers [9].

In the ‘40s, Ernest Kirkendall studied the phenomena of diffusion in the Cu-Zn pair, and subsequently, other works [10-14] have confirmed the basic ideas that emerged from that study. The investigations described that Zn diffuses faster in the Cu than the opposite case, by a difference of several orders of magnitude.

Recent works [15-17] have focused on determining Cu and Zn diffusion coefficients. The evaluation of the diffusion mechanisms in grain boundaries in the Cu-Zn system and through grains has been considered one of the most viable routes. X. L. Kong et al. [18] used a powder compacting process to create a Cu-Zn alloy nanocrystalline layer on a copper substrate. Non-lubricated wear tests were carried out, and evaluations were performed using scanning electron microscopy (SEM) and X-Ray diffraction. It was found that by performing the process at 300 °C, the layer exhibited excellent mechanical and tribological properties due to the high microhardness achieved [19-21]. It was found, utilizing X-ray diffraction, that a nanocrystalline ZnO film is - formed, which reduces the coefficient of friction with stable and durable layer properties.

II. MATERIALS AND METHODS

A. Coating fabrication

Two stainless steel AISI 304 containers - were used for the experiment. Each container will lodge six specimens. The containers were covered with zinc powder (99.5% purity) and NH₄Cl as an activator (5 and 10%). Subsequently, the pieces were covered entirely, and another layer was added so that containers were wholly encircled by zinc powder and activator. The diffusion process temperature had a notorious effect on the created coating. the zinc powder – did not melt quickly, so that, each microscopic particle of zinc undoubtedly – melted, but the particles – did not join each other to form a melt of any considerable size; this phenomenon – is attributed to the influence of a thin layer of oxide surrounding each dust particle [5,7].

The experiments in the oven were carried out at a temperature of 400 °C for 8 hours in a Lindberg electrical oven (50/60 Hertz, 240 Volts, 5900 Watts, temperature max. =1500 °C). The specimens designated for wear test were treated in groups of 6 specimens per container. Likewise, were treated specimens with different geometrical forms. The final coating - was observed using a scanning electron microscope (SEM) Phillips XL20.

B. Metallographic analysis

Thermochemically treated specimens were cut crosswise to obtain samples and perform a metallographic analysis using the scanning electron microscope (SEM) Philips XL20 [12]. The specimens were then assembled in bakelite and prepared using silicon carbide sandpaper with different sizes (180, 200, 360, 400 600 and 1000), then polished with alumina (3.0 μm and 0.5 μm). Samples were evaluated in the scanning electron microscope to obtain topography, morphology, and thickness of the coating.

C. Chemical Analysis

Using the EDAX microanalysis – probe (the equipment has the capacity to detect chemical elements, starting from sodium, atomic number 11), - coupled - to the Philips XL 20 SEM, chemical analysis was carried out on the thermochemically-treated specimens in different areas of the coating and the base metal, along a cross line from the end of the protective layer to the original material, which determined the elemental chemical composition (by weight). Measurements are made at kV: 25.00 Tilt:15.00 Take-off:47.56 Tc:20 Detector Type: SUTW-Sapphire Resolution :158.51 Lsec :300

D. Microhardness

Vickers microhardness tests were performed using the Leitz Wetzlar Germany 8068 equipment, on the coating of brass and bronze specimens, with – ten indentations in the base metal. It was used a load of 100 g during 10 s.

E. X-rays analysis

For the X-ray diffraction evaluation, the Bruker D8-Advance Powder Diffractometer was used, using Cu K radiation, graphite monochromator, with the Diffplus B_S software, using Powder Method. Likewise, measurements were done using a Siemens 5000 diffractometer, operating at 35 kV and 25 mA with a crystalline graphite monochromator, using a copper lamp. Samples were scanned at a rate of 2° per minute between 20 and 100°.

F. Sliding Wear test

Adhesive wear tests were performed using the Cygnus II Equipment Model 51 with 2000 rpm, 220V, and 60 Hz, designed for dry or lubricated wear testing and test loads from 0.5 to 5 kg that can be applied in axial form. In this case, loads ranging from 0.1 kg to 0.5 kg were used. The tests were carried out by placing and evaluating 3 pieces simultaneously, according to the configuration of the equipment. Speeds from 180 rpm to 300 rpm were varied in the tests, which gives the distance traveled and is used to determine the wear of it. The contact disc is AISI D2 heat-treated tool steel. The test radius is 0.035 m. To determine the weight of the test pieces, and Ohaus electronic scale balance with a resolution of 0.0001 g was used every 60 s.

III. RESULTS

A. SEM, Thickness and Chemical analysis

Fig. 1 shows a treated and an untreated sample after the pin on disc test. Some aspects are highlighted. There is a change in surface hue, which is associated with the presence of a zinc-rich layer. It is also observed the difference in the surface condition of the worn brass part with evidence of plastic deformation, and the absence of plastic deformation in the treated sample.

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Fig. 1. Brass samples with and without coating. The edge is observed in the upper part of the uncoated specimen, a burr is generated after pinning on disc test, by plastic deformation.

The thickness on the different coating layer for the brass specimens had an average of 80 μm; this can be observed in Fig. 2:

Fig. 2. Coating layer on brass obtained by zinc diffusion, 8 hours at 400 °C.

In the case of bronze, it was observed that the thickness of the coating layer is more significant than the obtained for brass, with an average of 142 μm; this can be observed in Fig. 3. For the case of the white zones, the results of the analysis are very similar, which can be interpreted as evidence of the possible presence (in small quantity) of phase β' of the Cu-Zn system.

Fig. 3. Coating layer on bronze obtained by zinc diffusion, 8 hours at 400 °C.

Fig. 4, 5, 6, and 7 show the chemical composition for the coatings. Tables I, II, III and IV show the semi-quantitative results of the respective EDAX analyzes.

**TABLE I: WEIGHT PERCENTAGE FOR COATING IN BRASS (FIG. 4)**

| Element | Wt % | At % |
|---------|------|------|
| CuK     | 38.13| 38.8 |
| ZnK     | 61.87| 61.2 |

**TABLE II: WEIGHT PERCENTAGE FOR COATING IN BRASS (“WHITE” AREAS) (FIG. 5)**

| Element | Wt % | At % |
|---------|------|------|
| CuK     | 52.1 | 52.81|
| ZnK     | 47.9 | 47.19|

**TABLE III: WEIGHT PERCENTAGE FOR COATING IN BRONZE (FIG. 6)**

| Element | Wt % | At % |
|---------|------|------|
| CuK     |      |      |
| ZnK     |      |      |
CuK | 37.09 | 37.76
ZnK | 62.91 | 62.24

Table IV: Weight percentage for coating in bronze ("white" areas) (Fig. 7).

Element | Wt % | At %
--- | --- | ---
CuK | 50.86 | 51.57
ZnK | 49.14 | 48.43

With all the obtained information, the Activation Energy $Q$ and Diffusion Coefficient $D_0$ were calculated. For brass:

$$Q = 0.00422234 \frac{kJ}{kg \cdot mol}$$

(1)

$$D_0 = 1.70358 \times 10^{-13} \frac{m^2}{s}$$

(2)

In the case of bronze, the Activation Energy $Q$ and Diffusion Coefficient $D_0$ calculated were:

$$Q = 0.576164 \frac{kJ}{kg \cdot mol}$$

(3)

$$D_0 = 6.35177 \times 10^{-13} \frac{m^2}{s}$$

(4)

As can be seen, the coating layer on thermochemical treated bronze (average of 142 µm) is thicker than thermochemical treated brass (average of 80 µm).

**B. Microhardness**

Using a load of 100 g, the Vickers microhardness was measured for each specimen; for the coating on brass an average value of $496 \pm 165$ HV was obtained, in this case the base material had a hardness of $106 \pm 4.4$ HV. It is possible to obtain a linear correlation between the two variables with an $R^2=0.41$. For bronze, the coating microhardness $-\rightarrow$ was around $598 \pm 65$ HV, $-\rightarrow$with a linear relationship - of $R^2=0.69$ and $113 \pm 6.4$ HV for the base metal. Fig. 8a shows the microhardness results for the coating on brass and Fig. 8b on bronze.

The above results clearly indicate the positive effect of the incorporation of the Zinc rich coating on the bronze, since the average microhardness increased 5 times. In addition, the HV measurements also reached higher values at larger distances of penetration, which is in accordance with the data of activation energy calculated for this system. The increment of microhardness is attributed to the formation of the γ phase composition (63%) within the Cu-Zn system. Therefore, the diffusion process induces the enrichment of this phase mainly on brass alloy.

**C. X-rays analysis**

Results obtained by the X-Ray analysis, are presented in Fig. 9 and 10. It is confirmed an existing crystalline structure in the coating. The presence of phases of the Zn-Cu system and of various oxides of Cu and Zn, including the coexistence of the CuO and Cu$_2$O structures were identified.
Fig. 9. Results of X-ray analysis for Zn rich coating obtained by thermochemical treatment on brass, where are shown phases present in the coating, varying the 2-Theta angle from 5 to 120°.

Fig. 10. Results of X-ray analysis for Zn rich coating obtained by thermochemical treatment on bronze. There are shown phases present in the coating, varying the 2-Theta angle from 5 to 120°.

D. Sliding wear test

The results (Fig. 11) show a substantial increase in the wear resistance achieved in the treated specimens compared to those without treatment (higher for bronzes). For bronzes, when velocities of 180 rpm and 0.1 kg load were applied, the weight loss varied between 0.39 and 6.26 times higher in untreated specimens. With the increasing speed at 300 rpm and a load of 0.5 kg, the order of magnitude for weight loss reaches 18.58 times more in untreated specimens compared to untreated bronzes. For brass, at low speeds, weight loss is about 2.75 times higher in untreated specimens, but when tested at 300 rpm and a load of 0.5 kg, the weight loss is 76.6 to 164.4 higher in the untreated parts compared to the treated. The percentage of weight loss for brass after the tests is within 24% for pieces without treatment, and 0.15% for the treated. For bronze, the percentage of weight loss is higher than 8% for the untreated samples compared to 0.45% for those of bronze that were subjected.

IV. Discussion

The coating layer is more prominent in bronze (average of 142 μm) than in brasses (average of 80 μm). The crystalline structure for Cu is fcc (face-centered cubic), for Zn is hcp (hexagonal close-packed), and for Sn is bct (body-centered tetragonal), and the atomic packing factor (APF) for Cu and Zn is 0.74 and for Sn is 0.64. Then, there is more probability of finding free spaces in the crystal structure of bronze (Cu-Sn) than in brass (Cu-Zn) for atoms diffusion. For brass specimens, it was obtained composition on the coating of 38.13% Cu and 61.87% Zn weight percentage. For the bronze case, it was obtained a result of 37% Cu and 63% Zn weight percentage. Thus, the coating layer is uniform and very similar in composition comparing brass and bronze (see Fig. 4 to 7).

Considering the Vickers microhardness analysis for brass and its coating, the increase in microhardness is within 468% (Fig. 8). The results were taken along the coating and base metal, from 20 μm (coating) to 500 μm (base metal). The length of the coating for brass is 80 μm average and the
microhardness decrease after that magnitude. Then, the obtained coating and the increase in microhardness are correlated between them as reported elsewhere [22]. For the bronze case, the increase in microhardness is in the order of 532%. The data were obtained along with the coating and base metal, from 20 μm (coating) to 400 μm (base metal). In the case of bronze specimens, the thickness of the -coating was 142 μm average.

The results of the Vickers microhardness test are in agreement with this asseveration. The hardness in α phase is attributed to the local distortion, and in β phase, to the difference in the type of lattice. Hardness in the γ phase is attributed to the small atomic volume and the loss of symmetry. This loss of symmetry, coupled with the fact that in γ brass, is obtained the maximum amount of distortion, will probably account for the exceptional hardness of γ brass as compared with the hardness of the other alloys in the series. As discussed in [22-31], the complex crystalline structure of this phase is associated with a high defect density that would also contribute to greater coating hardness. Both coated materials show a linear relationship between their microhardness and the distance from the surface, in the case of bronze there is a correlation index of 0.41, for brass a value of 0.69 is obtained. These values provide a clear estimate of the relationship between the model and the response variable (microhardness).

The X-Ray analysis (Fig. 9 and 10), shows a cubic structure of Copper Zinc (Cu₆Zn₃6. JCPDS card No 50-1333) phase with Miller’s index equal to a=b=c=3.69612 Å. The results report the presence of a Cu₂Zn₈ phase structure, (JCPDS 65-6566, cubic system cubic, space group I43m, cell parameter 8.85-8.89 Å). These results agree with literature [22-31], and show the presence of the γ phase of the Zn-Cu system, which is a harder phase.

In the case of bronze, the X-Ray analysis shows – the formation of a cubic structure of Copper Zinc (Cu₆Zn₃6. JCPDS card No 50-1333) with Miller’s index equal to a=b=c=3.69612 Å and a phase Cu₂Zn₈ (JCPDS 65-6566, cubic system cubic, space group I43m, cell parameter 8.85-8.89 Å). It is confirmed - for brass case and according to various references [22-31], the presence of γ phase of the Cu-Zn system. Also, a cubic structure of Copper Oxide in which a=b=c=4.26960 Å is perceived. The identification of phases in corresponding diffractograms pointed out the presence of γ phase in the coating, which confirms data found by the chemical analysis from the microprobe. Additionally, the appearance of a ZnO phase is evidenced according to the ICSID 01-079-0208 reference standard, located at the peak 2θ=31.49° and in a preferential direction (100), which coexists with Cu₆Zn₃6. Cu₂Zn₈ and CuO in the peak 2θ=72.22° with preferential direction (004), this oxide has a hexagonal crystalline structure with space group P63mc. In turn, it is possible to detect CuO according to the ICSID 01-080-0076 reference standard in the peak 2θ=72.22° with Miller index (311), this oxide has a space group number 15 (C2 / c), and structure monoclinic crystalline. Despite the composition, both alloys show the presence of Cu oxides (and ZnO), this feature is associated with the oxophilic behavior of copper atoms that allows higher oxygen adsorption [32].

In the other hand, the wear behavior of brass without a zinc-rich layer shows evidence of plastic deformation, and bronze without zinc-rich layer does not show deformations. A detailed interpretation of the wear mechanisms is beyond the scope of this work. Thus, in a following study, the wear mechanisms and the role, especially of Cu and Zn oxides as suggested by Kong et. al., [19], will be evaluated with the use of microscopic techniques.

It has been confirmed – with SEM/EDAX and X-ray diffraction - the formation of a zinc-rich γ phase, - with high hardness properties. It should be noted that, in sliding wear test, at low speeds with low loading (0.1 and 0.15 kg), the coating did not disappear, only to 500 rpm with 0.5 kg of axial load the coating was removed. The microhardness increment can be related to the improvement of wear resistance (Fig. 11 and 12).

V. CONCLUSIONS

The thermochemical treatment applied on copper alloys in this research, using pure powder zinc (~ during 8 hours - at 400°C), obtained a coating layer of 80 μm average for brass and 142 μm for bronze.

The coating layer is uniform on the entire surface of the specimen, regardless the geometry of this one. The chemical analysis determined a chemical composition on the coating layer of 62 % Zn and 38 % Cu average for both brass and bronze. Using the data obtained in the chemical analysis and the values for Atomic Packing Factor (APF) for Cu (fcc structure with APF=0.74), Zn (hcp structure with APF=0.74) and Sn (bct structure with APF=0.64 approximately), it can be inferred that there is more free space for the atoms for diffusion in bronze than in brass; this is the reason of bigger -coating thickness - in bronze. The X-Ray analysis confirmed the phases, and also determined that exist crystalline structures in the coating: Cu₆Zn₃6, Cu₂Zn₈ phases, and copper oxide in small quantity.

The increase in microhardness for brass is in the order of 468% up to 532%. The composition of the Zn (63% weight) in the coating corresponds to the γ phase of the Cu-Zn phase diagram and confirms - the reason to explain the significant increase in microhardness. This, in turn, confirms the results of the wear tests, which indicate that the weight loss experienced by an untreated brass sample, is much higher than that experienced for the case of thermochemically treated parts. Similar behavior was observed in the case of bronze. It can be concluded that the process developed in this work is a technology that improves the wear resistance of these copper alloys properly and, in this sense, allows them to extend their useful life and increase their possibilities of application.

REFERENCES

[1] F.C. Porter, Corrosion Resistance of Zinc and Zinc Alloys; New York Marcel Dekker, Inc., CRC Press, 1994, p 87-96
[2] P.E. Vasilevich, “Galvanizing, sherarding and other zinc diffusion coatings,” British Corrosion Journal, vol. 11, no. 2, pp. 58, 1976.
[3] A.J. Vázquez and J.J. Damborenea, Ciencia e Ingeniería de la Superficie de los Materiales Metálicos, Textos Universitarios, Consejo Superior de Investigaciones Científicas, 2000, pp. 282-294.
[4] G. Voulihas, N. Pistofidis, D. Chialampatis, and E. Pavlidou, “A
comparative study of the structure and the corrosion behavior of zinc coatings deposited with various methods,” Surf. Coat. Technol., vol. 200, pp. 6594–6600, June 2006.

[5] N. Pistofidis, G. Vourlias, D. Chaliampalias, K. Chrysafis, G. Stergioudis, and E.K. Polychroniadis, “On the mechanism of formation of zinc pack coatings,” J. Alloy. Compd., vol. 407, pp. 221–225, January 2006.

[6] G. Vourlias, N. Pistofidis, D. Chaliampalias, E. Pavlidou, and G. Stergioudis, “On the corrosion mechanism of zinc pack coatings deposited on low carbon steel: results of laboratory tests,” Corrosion Engineering, Science and Technology, vol. 42, no. 2, pp. 152-160, November 2013.

[7] F. Natrup and W. Graf, “Sherardizing: corrosion protection of steels by zinc diffusion coatings,” in Thermochemical Surface Engineering of Steels, Sherart b.v., Helmond, Impreglon Se, Elsevier, 2015, pp. 737-750.

[8] V.M. Konstantinov and L.A. Buloichy, “Some aspects of sherardizing implementation during anti-corrosion protection of heat-treated metal parts,” IOP Conference Series: Materials Science and Engineering, vol. 71, no. 1, pp. 1–4, 2015.

[9] D. Wortelen, R. Frieling, H. Bracht, W. Graf and F. Natrup, “Impact on Zn halide addition on the growth of Zinc-rich layers generated by sherardizing,” Surface and Coatings Technology, vol. 263, pp. 66-77, February 2015.

[10] C. Valdés, “Galvanizado por Difusión de Aleaciones de Cobre y Caracterización de los Revestimientos Obtenidos,” Ph.D. Thesis, Universidad Nacional Autónoma de México, Ciudad de México, México, 2010.

[11] E. Kirkendall, L. Thomassen, and C. Upthegrove, “Rates of Diffusion of Copper and Zinc in Alpha Brass,” AIME Trans. 133, pp. 186-203, 1939.

[12] H. Nakajima, “The Discovery and acceptance of the Kirkendall Effect: The result of a Short Research Career,” Journal of Metals, vol. 49, no. 6, pp. 15-19, June 1997.

[13] C. Sequeira and L. Amaral, “Role of Kirkendall effect in diffusion processes in solids,” Trans. Nonferrous Met. Soc. China, vol. 24, no. 1, pp. 1–11, January 2014.

[14] R.A. McCoy, “Cu-Zn Binary Phase Diagram and Diffusion Couples,” NASA 1992021026, presented at the NASA-LaRC, Cleveland, OH, June 1, 1992.

[15] F.S. Palubinskas, “Diffusion in alpha brass,” Ph.D., Thesis, Iowa State University, United States, 1952.

[16] A. Hoxhaa, H. Oettelt and D. Hegerb, “Calculation of the interdiffusion coefficient in the Cu-Zn diffusion couple,” AIP Conference Proceedings, American Institute of Physics, February 3, 2010.

[17] B. Sivaiha, S.P. “Gupta, Diffusion induced grain boundary migration in the Cu-Zn System,” Materials Characterization, vol. 59, no. 9, pp. 1141-1151, September 2008.

[18] A.K. Pradhan, S.P. Gupta and K. Mondal, “Effect of Zn concentration on diffusion induced grain boundary migration in Cu – Zn system, Transactions of The Indian Institute of Metals,” vol. 62, no. 3, pp. 233-239, August 2009.

[19] X.L. Kong, Y.B. Liu and L.J. Qiao, “Dry sliding tribological behavior of nanocrystalline Cu-Zn surface layer after annealing in air,” Wear, vol. 256, pp. 747–753, April 2004.

[20] F. Hung, T. Lui, L. Chen and J. You, “The Effect of Electrical Current on Tensile Properties and Vibration Characteristics of Sn-9Zn-1Cu Lead Free Solder,” Materials Transactions, The Japan Institute of Metals, vol. 47, no. 12, pp. 2395-2941, December 2006.

[21] J. Song, Y. Shen, Ch. Su, Y. Lai and Y. Chiu, “Strain Rate Dependence on Nanodentation Responses of Interfacial Intermetallic Compounds in Electronic Solder Joints with Cu and Ag substrates,” Mats Trans, Japan Institute of Metals, vol. 50, no. 5, pp. 1231-1234, April 2009.

[22] E.A. Owen and G.D. Preston, “X Ray Analysis of zinc-copper alloys,” presented at the Proceedings of the Physical Society of London, London, 1923.

[23] S. Lunarska, “Kinetics of Diffusion Galvanizing for Brass,” Metal Science and Heat Treatment, vol. 25, pp. 794-797, November 1981.

[24] M. Kowalski and P.J. Spencer, “Thermodynamic Reevaluation of the Cu-Zn System,” Journal of Phase Equilibria, Vol. 14, no. 4, pp. 432-438, August 1993.

[25] W. Giertocha and S. Chen, “Thermodynamic Descriptions of the Cu-Zn System,” Journal of Materials Research, vol. 23, no. 1, pp. 258-268, January 2008.

[26] O. Antonoglou, J. Moustaka, I. Dimosthenis S. Adamakis, I. Sperdouli, A. Pantazaki, M. Moustakas and C. Dendrinou, “NanoBrass CuZn Nanoparticles as Foliar Spray Nonphytotoxic Fungicides,” ACS Appl. Mater. Interfaces, vol. 10, pp. 4450–4461, January 2018.

[27] Y. Sun and Y. Ren, “New preparation method of porous copper powder through vacuum dealloying,” Vacuum, vol. 122, pp. 215-217, December 2015.

[28] D. Chaliampalias, M. Papazoglou, S. Tsipas, E. Pavlidou, S. Skoliandas, G. Stergioudis and G. Vourlias, “Fabrication and examination of oxidation resistance of zinc coated copper and brass components by chemical deposition,” Surface Engineering, vol. 27, no. 3, pp. 362-367, November 2013.

[29] Z. Ke-sheng, X. Sheng-qi and Z. Jing-en, “Effect of temperature on mechanical alloying of Cu-Zn and Cu-Cr system,” Trans. Nonferrous Met. Soc. China, vol. 19, pp. 1206-1214, October 2009.

[30] M. Hacibrahimoglu, M. Bedir and A. Yavuz, “Structural and Corrosion Study of Uncoated and Zn-Cu Coated Magnesium-Based Alloy,” Metals, vol. 6, no. 12, pp. 322, December 2016.

[31] X. Zou, X. Lu and X. Xie, “Electrodeposition of Zn, Cu, and Zn-Cu Alloys from Deep Eutectic Solvents, Ionic Liquids: Progress and Developments,” Ed, Intech Open, Web of Science, 2017, ch. 12, pp. 263-281.

[32] H. Li, K. Shin and G. Henkelman, “Effects of ensembles, ligands and strain on adsorbate binding to alloy surfaces,” The Journal of Chemical Physics , vol. 149, pp. 174705, November 2018.

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1) D.G. Agredo Díaz, A. B. Pingarrón, J. J. Olaya Florez, J. R. Gómez Parra, J. Cervantes Cabello, A. Moncada, A. Covelo Villar, M.A. I Hernández Gallegos. Effect of a Ni-P coating on the corrosion resistance of an additive manufacturing carbon steel immersed in a 0.1 M NaCl solution. Materials Letters 275 (2020) 128159

2) Enhancement of Corrosion Resistance of NiCrFeBSi Coatings obtained by Flame Thermal Spray Process adding an Electroless Nickel Coating Ni-P. A. Barba-Pingarrón, R. Navarro-Valdez, F. Sánchez-de Jesús, A.M. Bolarin-Miró, R. González-Parra, A. Covelo-Villar, M.A. Hernández-Gallegos, C. Domínguez-Ríos. Journal of Surface Engineered Materials and Advanced Technology Vol 7 No 4, p. 86-97. doi: 10.4236/jsat.2017.74008.

3) Caracterización Electroquímica de Recubrimientos Zn-Al sobre fundición nodular grado 2, obtenidos por Proyección Térmica por Flama con alambre”. G. Agredo, R. Valdez, N. Ortiz, A. Barba, J. Olaya, R. González, A. Covelo, M. Hernández. Aceptado para su publicación en la revista Avances: Investigación en Ingeniería, Volumen 17, No 1 (2020) de Colombia. ISSN: 1794-4953 - eISSN: 2619-6581. https://doi.org/10.20414/1794-4953/avances.1.5747
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In this group she is the leader to generate and to characterize superficial treatments of materials to modify their mechanical and electrochemical properties, mainly focused to corrosion protection. She has published different and many works (chapters books, international articles) such as: 1) A. Covelo, S. Rodil, E. O. López-Villegas, C. A. Álvarez, M. Hernández. Evaluation and correlation of electrochemical and mechanical properties of PVA/SA nanofibres. Surface and Interface Analysis (2020). Article accepted in Press.https://doi.org/10.1002/sia.6768. 2) O. Álvarez, A. Barba, A. Rojas, R. González, R. Valdez, A. Covelo, M. Hernández. Applications and contributions of physics to the surface treatment process of materials part H: Other treatments. European Journal of Engineering Research and Science 3,4 (2018) 80 – 86. 3) R. James-Ramírez, A. Covelo, S.E. Rodil, P. Corona-Lira, A.C. Ramírez-Resivich, M. Hernandez. Development and characterization of hydrophobic anodized aluminum layer to act as a long-lasting protective film in corrosion.

Surface Interface Analysis 50 (2018) 1030 -1035. Dra. Covelo has been a member of the Galician association research as well as an active member of the Mexican Society of Mechanical Engineering (SOMIM). Her publications in journals and in international congress have gained different awards. Her PhD thesis received the Cum Laude award from the university.

Miguel A. Hernández was born in Mexico City on November, 1975. He got his PhD in materials engineering at the Chemistry School of the National University of Mexico in 2004 (Mexico City, Mexico) studying the electrochemical and the anti-corrosion properties of waterborne organic coatings applied on steel substrates. His expertise area relies on the electrochemical-corrosion properties of materials mainly metals/alloys.

He accomplished several fellowship jobs during his career. In 2003 he was at the Ecole Polytechnique Federal de Lausanne (EPFL), Switzerland with Prof. D. Landolt. From 2008-2010 and in 2019 he was at the University of Vigo, Spain with Prof. R. Növoa developing sol-gel coatings on aluminium alloys and hydrophobic anodized layers. In 2010 he also stayed with Prof. M. Zheludkevich at the University of Aveiro, Portugal studying localized corrosion measurements on AA2024 alloys. His current job since 2010 is located at the Engineering School of the National University of Mexico, Mexico at the CENISA group. During this time he has published different works in the area of corrosion/metallurgy concerning books chapters and international articles such as:

1) D.G. Agredo_Díaz, A. B. Pinagarón, J. J. Olaya_Florez, R. R. González_Parra, J. Cervantes_Cabello, I. A. Moncaleano, A. Covelo_Villar, M.A. 1 Hernández_Gallegos. Effect of a Ni-P coating on the corrosion resistance of an additive manufacturing carbon steel immersed in a 0.1 M NaCl solution. Materials Letters 275 (2020) 128159. 2) M. Hernández, M.A. Álvarez-Pérez, J. Genesca, K.K. Gómez, A. Covelo. Evaluation of the biocompatibility of a PVA/SA scaffold with a human gingival fibroblast (HGF) by using electrochemical impedance spectroscopy. Bioelectrochemistry 131 (2020) 107386. 3) Sandra Viveros, Camina Menchaca, Miguel A. Hernández, Alba Covelo, Jorge Urschurtu. Recycled ABS Polymer Doped with Outstanding Lanzoprazole as a Corrosion Protection Composite Coating for Mild Steel in Chloride Solution. European Journal of Engineering Research and Science 5,4 (2020) 429 – 435.

Dr. Hernandez has been a member of the NACE corrosion association as well as part of the Electrochemical Society. He has received several awards in international congresses for his contributions of corrosion protection of metallic materials.