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DETERMINATION OF THE TENSILE STRENGTH OF MAGNESIUM PHOSPHATE CEMENTS CONTAINING DIFFERENT METALS USING THE BRAZILIAN TEST

Irene Buj Corral
Technical University of Catalonia
Barcelona
Spain

Josep Torras Grané, Daniel Casellas Padró, Miquel Rovira Boixaderas, Joan de Pablo Ribas
CTM Technological Centre. Technical University of Catalonia
Manresa
Spain

ABSTRACT

Surface treatment processes like electrolytic or electroless plating provide coatings to metallic parts improving some of their properties like corrosion resistance, wear resistance and appearance [1]. Such processes use baths containing high concentration of heavy metals like chromium, nickel, zinc, etc. When exhausted, the bath becomes a hazardous waste which has to be properly managed. An option for the valorization of the waste is manufacturing of magnesium phosphate cement parts that may be cast in order to obtain road walls or as a base for roads [2]. The stabilized waste may also be disposed at a landfill. In order to know the performance of the material, the strength of the specimens is usually determined. Pastes containing different heavy metals (cadmium, copper, chromium, nickel, lead and zinc) were prepared with a metal concentration of 25000 ppm, a water-to-solid ratio(W/S) of 0.3, 0.4, 0.5 (0.4, 0.5 and 0.6 for Cr) and a magnesium oxide content of 50 % in weight of the total solid. They were allowed to solidify and after 10 months of curing. After that, disks were cut and they were subjected to an indirect tensile strength test (Brazilian test or splitting test) [3]. In general, tensile strength decreased with increasing water content as expected. The specimens prepared with a water-to-solid ratio (W/S) of 0.3 showed relatively high tensile strength values.

Keywords: magnesium phosphate cements, tensile strength, Brazilian test.

1. INTRODUCTION

Magnesium phosphate cements show properties of both cement and ceramic materials: they can be obtained at room temperature by mixing the reagents with water (like cements) but they are highly crystalline (like ceramics) [2]. Magnesium phosphate cements may be employed for Stabilitzation / Solidification (S/S) of metal bearing wastes like exhausted baths of electroplating and electroless plating processes. In order to allow the disposal of the stabilized wastes a minimum mechanical strength for the material is required. Although the most employed test is the unconfined compressive strength test, in many cases the specimens may be subjected to tensile strength, for example if the material is employed for manufacturing road walls or as a base for roads. The Brazilian test is often employed for determining the tensile strength of cementitious materials [4]. For brittle materials that show defect flaws with a great variability on the strength results, the Weibull statistics is a useful tool.

2. MATERIALS AND METHODS

Specimens were prepared by mixing magnesium oxide grade PC (70 % purity) provided by the company Magnesitas Navarras, S.A. with potassium dihydrogenphosphate of reagent grade (50:50 % in weight) and a metal nitrate solution containing 25000 ppm of Ni, Cd, Pb, Cu, Zn or Cr at different water-to-solid ratios (W/S = 0.3, 0.4, 0.5 except for Cr with W/S = 0.4, 0.5, 0.6). The metals tested were Ni, Cd, Pb, Cu, Zn and Cr. The pastes were poured into cylindrical moulds of 30 mm diameter and 310 mm length and left for curing inside a plastic bag for 10 months. After the curing time, the cylinders were cut in order to obtain disks of 30 ± 1 mm diameter and 10 ± 1 mm thickness. Then the circular surfaces were polished with glass paper. The specimens were tested at a universal machine INSTRON 5585 (maximum load of 200 kN). The Brazilian test, which is explained at standards ASTM C496 [3] and UNE 83306 [5], consists of compressing a disk diametrically between two plates at a constant speed of 2.5 mm min^{-1} until it breaks. The forces area applied over two opposite generatrices of the disk (figure 1):

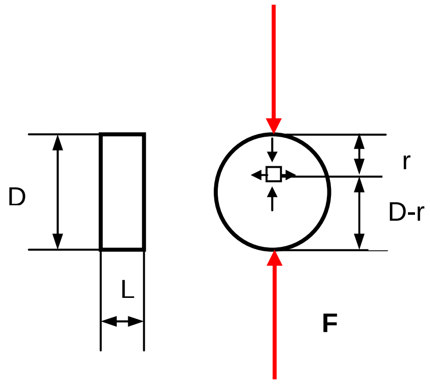

Figure 1. Brazilian test

Along the plane that contains the two opposite generatrices where the force is applied a biaxial strength state is developed with a tensile component orthogonal to that plane, uniformly distributed and of value:

$$\sigma_t = \frac{-2F}{\pi \, D \, L} \tag{1}$$

where σ_t is the tensile strength of the specimen (MPa), F is the force developed by the machine (N), D is the disk diameter (mm), L is the disk length (mm) and r is the minimum distance from a point to the surface of the disk (mm). The equation for tensile strength comes from the elasticity theory assuming that two linear compressive forces are applied at the two ends of the disk, i.e., the charge is distributed along a line without width [6].

3. RESULTS

Five replicates were tested for each paste. A probability function was assigned to each result according to the following equation:

$$P_f = \left(\frac{i - 0.5}{n} \right) \tag{2}$$

Where i is the number of replicate considered (in growing order) and n is the total number of replicates. When representing the ln ln $(1/(1-P_f))$ against ln σ_t a straight line may be obtained by regression whose slope is called the Weibull modulus (m). The obtained results for tensile strength (σ_t), standard deviation (Desvest) and Weibull modulus are shown in table 1:

Table 1. Brazilian Test. Tensile strength (MPa), standard deviation and Weibull modulus m

METAL	W/S	σ_t (MPa)	Desvest	m
Ni	0.3	3.85	1.26	3.24
Ni	0.4	2.28	0.30	8.17
Ni	0.5	0.69	0.19	4.23
Cd	0.3	3.85	1.05	3.44
Cd	0.4	1.27	0.21	5.84
Cd	0.5	0.92	0.26	3.71
Pb	0.3	5.12	0.58	8.88
Pb	0.4	1.94	0.13	15.91
Pb	0.5	1.20	0.15	7.71
Cu	0.3	4.17	0.29	13.67
Cu	0.4	1.46	0.16	9.27
Cu	0.5	1.39	0.16	8.97
Zn	0.3	3.53	0.78	4.63
Zn	0.4	2.61	0.41	6.67
Zn	0.5	0.99	0.07	14.66
Cr	0.4	2.09	1.02	1.44
Cr	0.5	0.99	0.09	10.36
Cr	0.6	0.39	0.08	4.42
No metal	0.3	3.77	0.19	20.55
No metal	0.4	1.87	0.36	5.40
No metal	0.5	2.16	0.24	9.06

The results for tensile strength are presented at figure 2:

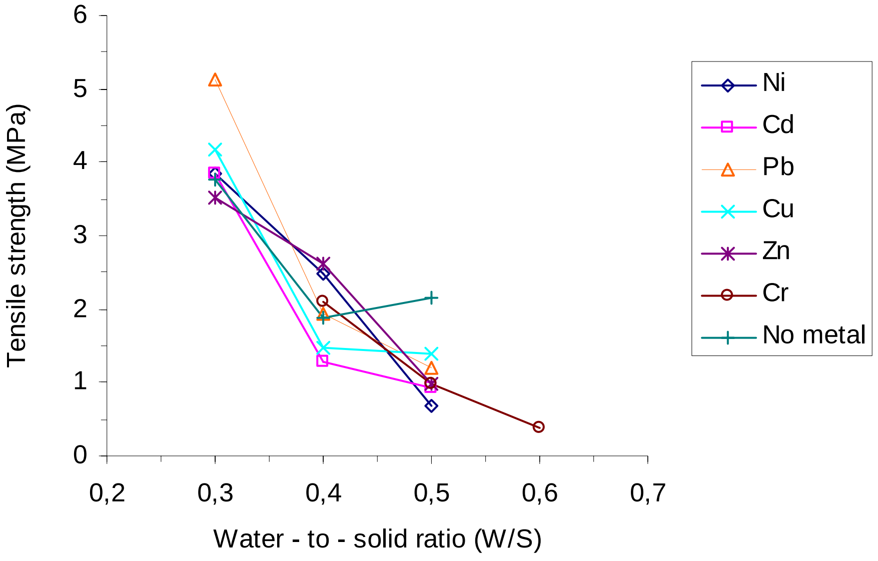

Figure 2. Brazilian test. Tensile strength (MPa) vs. water-to-solid ratio (W/S).

4. CONCLUSIONS

When water – to – solid ratio of 0.3 is employed, the presence of metals improves the resistance of the specimens with respect to the sample containing no metal, except for zinc. For water – to – solid ratio of 0.4 some metals increase and some others decrease the strength of the material compared to the strength of the sample without metal. For water – to - solid ratio of 0.5 all the samples show lower strength than that of the paste without metal. Thus, it is possible to increase the tensile strength of the magnesium phosphate cements by using water – to – solid ratio of 0.3. The low values obtained for the pastes containing zinc are attributed to the granular appearance they show instead of the usual solid appearance of the other pastes.

The paste with water – to – solid ratio of 0.3 and no metal has a modulus of 22 whereas the pastes with the same water amount but containing metals show lower values for modulus. Therefore, the presence of metals increases the variability of the tensile strength. This may be attributed to the heterogeneity of the samples prepared with low water content. On the contrary, for pastes with higher water content the presence of metals increases the modulus thus reducing variability in most cases.

On the other hand, the tensile strength of the paste containing Pb with water – to – solid ratio (W/S) of 0.3 is remarkably high, above 5 MPa. This value is similar to that of Ordinary Portland Cement (OPC). For example, an OPC with a compressive strength of 95 MPa has a splitting tensile strength of 5.5 MPa [7]. This fact confirms the feasibility for reusing the magnesium phosphate cements as building materials, always taking into account that the leaching of the stabilized heavy metal must be low enough to comply with regulations.

5. ACKNOWLEDGEMENTS

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