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Analysis of Change of Physical Properties of Organic Repair Products due to Fire Exposition

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Abstract. *Organic repair products for concrete can be exposed to accidental incidents, like fire. The increase of temperature produces a modification in some of their properties. In general, these types of repair products have organic fibers to increase their tixotropic properties, but they are more sensible to the high temperature than the Portland cement or aggregates. In order to analyze the behavior of organic repair mortars with temperature three types of repair mortars are studied. These repair products have the organic components composed by acetate fiber of polyvinyl like Vinyl Acetate Acrylate (VAA), Copolymer of Vinyl Acetate Vinyl Versatate (VeoVA) and Acrylic polymers fibres. The repair products are tested increasing the temperature from 1.7ºC /min until 200ºC, 400ºC or 600ºC respectively during 20 minutes. After that, the samples are cooled in four different cooling conditions two of them slow and two others fast, and with and without oxygen. These conditions are used in order to simulate the different conditions that can occur during the cooling after fire. After the testing the visual aspect, the color and brightness and the open porosity is analyzed in each condition of test. In this work the relationship between the temperature of exposition, the cooling conditions and the change in some physical properties are studied.*

Keywords: *Organic Repair Mortar, Fire Resistance Test, Color Change, Open Porosity.*

1 Introduction

The progression of the temperatures in the interior of the fire area is greatly conditioned by a series of very varied parameters, such as the type and density of the fire, the capacity for thermal dispersion of the epidermis, the level and disposition of the ventilation, etc. Kucera, P. (2007). Although it is possible to model or predict the thermal evolution of the gas in the affected area to a greater or lesser degree during the project, and from there and design sufficiently safe structures (with viable criteria for its use). The evaluation of the residual capacity of existing structures affected by a fire usually require a more realistic determination of the distribution of the temperatures in the different elements of the structure, Kodur, V.K.R. and Phan, L. (2007). It must be borne in mind that the real conditions of the fire (strength of the fire, ventilation, etc.) are difficult to determine precisely and a theoretical prediction not contrasted with real data

could give rise to significant deviations in areas relative to the thermal analysis of the structure and hence the mechanical evaluation.

The distribution of the temperatures in the interior of the area affected by the fire is not homogeneous, which is why the determination of the number of testing points, their distribution, etc., so that the results are representative and constitute a sound basis for the structural analysis is a relevant question. However, when samples taken from a real fire are analysed it is not always possible to have the suitable number or disposition samples available.

On the other hand, in order to determine the residual resistant capacity of the elements of the structural concrete affected by the fire, it is important to find out not only the distribution of the temperatures in the elements, but also how the effect on other relevant mechanical properties come about from exposure to fire, such as the steel-concrete adhesion. Within the series of temperatures that are produced in the interior of the section, there is an important significance from the mechanical point of view, as are 500ºC. On the one hand, the average value of the resistance to compression losses of the concrete (with lime aggregate) contemplated at a regulatory level is in the order of 40%, which would correspond approximately to the admissible loss in a residential or administrative building in a strict reinforced position (EN-1992 – Eurocode 2: Design of concrete Structures). It is the basis for one of the most used simplified calculation methods in the verification of concrete structures in the case of fire, which is known as the simplified 500ºC isothermal method, Ashely, E. (2007).

The cement based materials have a low thermal conductivity and an elevated specific heat, which is why ambient temperature constitutes a suitable protection for the reinforcement. However, when it becomes subject to higher temperatures it goes through a series of physical-thermal transformations that bring about a modification in the products of the hydration of the cement. From 300ºC, a loss of water comes about as a result of the decomposition of the CSH gel, which brings about a contraction as a result of this loss, even though it is necessary to exceed 900ºC in order to bring about a complete decomposition. Likewise, a decomposition of the portlandite comes about at between 450 – 550ºC, as does a loss of CO_2 of the carbonates from 600ºC. For its part, the siliceous aggregates also go through a physical-thermal transformation from 573ºC, while the lime experiences a decarbonisation at temperatures greater than 600ºC. Although it is important to indicate the possible changes in the aggregate as an effect of the temperature, it also depends on other factors such as size, porosity permeability, etc. – the less porous the aggregate, the less susceptible it is to the action of the fire, Charreau, G.L., Luna, F. (2000). The decomposition of portlandite in cement based materials can be used as an indicator of progression of temperature inside of the material and situate the isotherm 500 in the material, Menéndez, E., Vega, L. (2012).

The physical-thermal transformations undergone by the concrete as an effect of the temperature are translated into a loss of performance, especially when the material exceeds 600ºC. As the temperature increases, a modification in the creep comes about, which can also be seen as a strong dependency on its resistance and elasticity, Schneider, U. (1976). On the other hand, the conditions of putting out the fire must be taken into account, as the speed of cooling or the contact with the water has a significant influence on the physical-mechanical conditions present in the concrete once the fire is extinguished, Nassil, A. (2006). Specifically, the physical-thermal transformations that the components of the concrete go through serve to characterise it after it has been subject to the fire Colombo, M. and Felicetti, R. (2007). In this case, X-ray diffraction, thermal analysis and scanning electron microscopy techniques have

been used with the aim of analysing the behaviour of the concrete exposed to a real fire. Some of these instrumental techniques, such as thermal analysis, are usually used to study the behaviour of certain materials when exposed to the action of fire and high temperatures. As a rule, the fundamental objective of these analyses is to look at the possible improvements that could come about through the use of certain materials that could substitute or complement others, Zhong, H., Wei, P., Jiang, P. and Wang, G. (2006).

Polymer-modified mortar (PCM) contains synthetic resins and/or combustible polymers such as rubber. Hence, the combustibility of PCM is strongly affected by the type and amount of combustible polymer, S. Akihama, *et.al* (1973). The combustible properties of several types of PCMs at high temperatures can be tested using JIS A 1321 (a testing method for incombustibility of internal finish material and procedure of buildings), Y. Oham, S. Suzuki and H. Ozawa (1980). The influence of a polymer admixture on the fire resistance of PCC and analysis of peeling and explosion of PCMs by fire tests are carried out Chandra, S., Berntsson, L., and Anderberg, Y. (1980). On the other hand, the incombustibility of polymer-modified mortars is strongly affected by the polymer type rather than the polymer-cement ratio or polymer content. Some authors have been performed tests about heat release of PCMs Ohama, Y., Shirai, A., and Imamoto, K. (2011).

In the present work, studies of different polymer-modified mortars have been done. The repair mortars have exposed at 200ºC, 400ºC and 600ºC during 20 minutes and are cooling quickly or slowly. The visual aspect, open porosity and colorimetry is analysed in the different samples tested to take conclusions on their behaviour at different temperatures.

2 Raw Materials

Repair mortars were made from three products that were previously selected. Repair mortars, suppliers, characteristics, visual appearance, as well as the organic components that make up the fibers (main components), are shown below in Table 1.

Table 1. Information of repair mortars.

Product	Codification	Type of polymer	Visual Aspect
PLANITOP HDM MAXI	PHM	Acrylic polymer	
MAPEGROUT EASY FLOW GF	MEF	Copolymer of Vinyl Acetate Vinyl Versatate (VeoVA)	
MASTER EMACO S 5400	S5400	Vinyl Acetate Acrylate (VAA)	

3 Manufacturing, Curing Process of Repair Mortars and Test Procedure

Repair mortars were manufactured following the procedure described in the manufacturer's instructions, the mixture is kneaded, poured into the molds and the specimens are cured at 20° C and 60% humidity. Next, in Figure 1, the general appearance of the cured specimens is shown. Samples were tested at temperatures of 200 ° C, 400 ° C and 600 ° C. The exposure time as well as the thermal gradient of the test is shown in Figure 2 below. Four samples of each product

were tested, two in the presence of oxygen and another two in the absence of oxygen respectively. The cooling conditions are shown below:

- Slow cooling: Condition that allows the sample to cool inside the oven until it reaches room temperature (20ºC).
- Fast cooling: Condition that consists of suddenly removing the sample from the oven, so that it loses temperature quickly, while the sample is reserved in a desiccator.

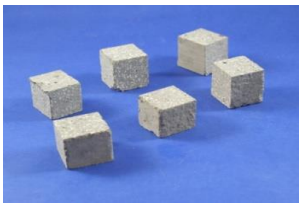

Figure 1. Visual Aspect of the repair mortar.

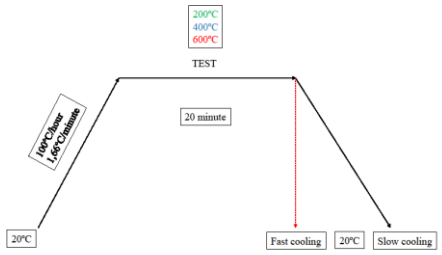

Figure 2. Heating curve proposed for the test.

4 Porosity Accessible to Water

The porosity of the mortars that have been made with the repair products is determined. For this, the porosity of samples that have not been subjected to heat treatment (reference) is determined, and the porosity of the samples subjected to the fire resistance test is determined. Procedure that allows to study the behavior of the porosity as the test conditions change.

The methodology described in the UNE EN 1936 standard is used to determine the porosity accessible to water. Next, Table 1 shows the test conditions that the samples are subjected to.

Table 2. Test conditions.

Temperatures	**200ºC**	**400ºC**	**600ºC**
Test conditions	Slow cooling without O_2 **(SC)**		
	Slow cooling with O_2 **(SCO)**		
	Fast cooling without O_2 **(FC)**		
	Fast cooling with O_2 **(FCO)**		

4.1 Porosity of Mortars as a Function of the Product Used

Next, Figures 3 shows the porosity values obtained from this test are plotted. Some dispersion in the porosity values is observed for each of the mortars tested. Porosity increases as the test temperature increases; the apparent increasing of cracking in mortars can causes this effect.

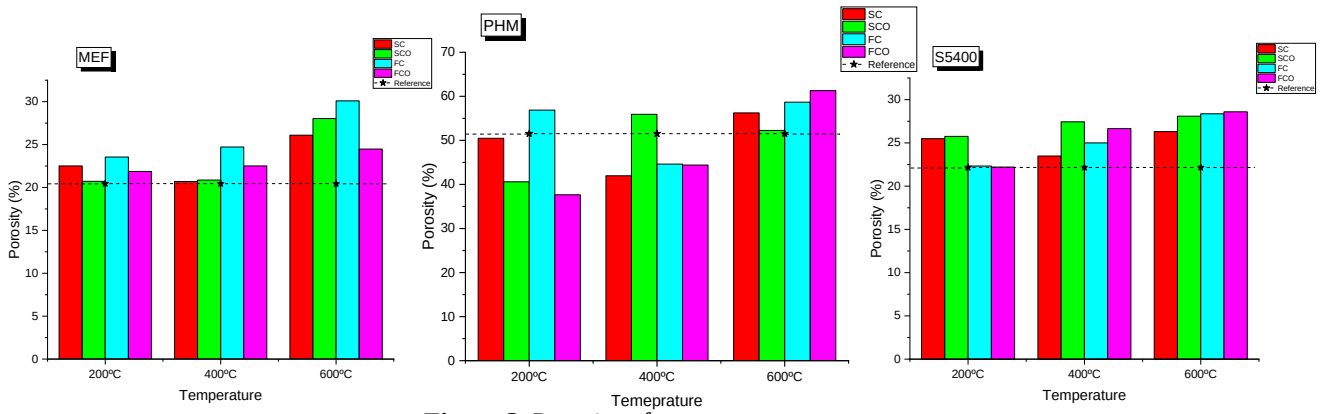

Figure 3. Porosity of mortars.

4.2 Porosity Variation as Function of the Test Temperature

In order to study the behavior of the products tested, at each test temperature, the variation of the porosity as a function of the study temperature is shown below (Figures 4).

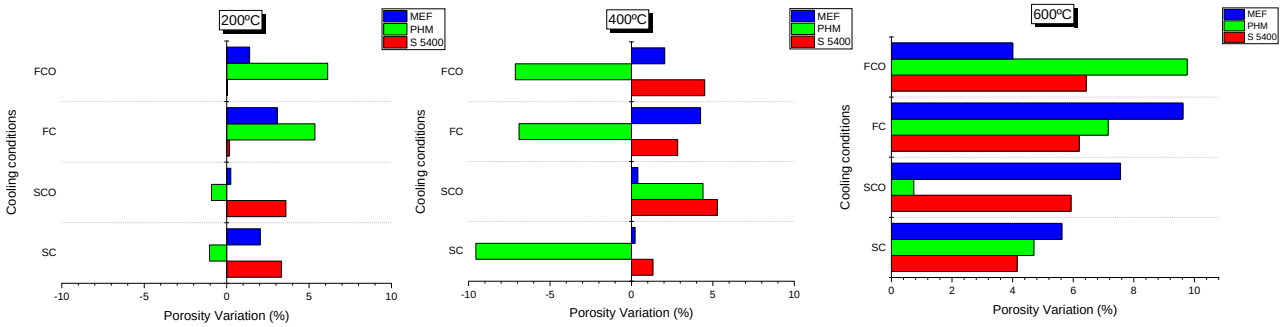

Figure 4. Porosity variation of mortars tested at **2**00, 400 and 600 ºC.

In general, an increase in porosity is observed as the test temperature increases. Samples subjected to 600°C contain fibers composed of polymers that decompose at temperatures above 500°C, forming gases such as methane, carbon dioxide and carbon monoxide among others. These gases increase the pressure inside the mortar, causing tensions in the areas where the pressure is higher, this effect can cause cracking, increasing the porosity of the mortar.

On the other hand, a decrease in the porosity in the PHM mortar is observed, at 400°C, caused by the fusion and diffusion of the fibers through the pores, filling the air pores, an effect that would explain this behavior.

4.3 Porosity Variation as Function of the Cooling Conditions

The increment of the porosity is shown depending on the test condition, it should be noted that the values shown below are values that reflect the increase in porosity with respect to the reference porosity values for each mortar tested. In any case, the most favorable scenario (least increase in porosity) is in which the mortar tested is cooled slowly. Although between the two scenarios in which it cools slowly, the one performed without oxygen shows less increase in porosity.

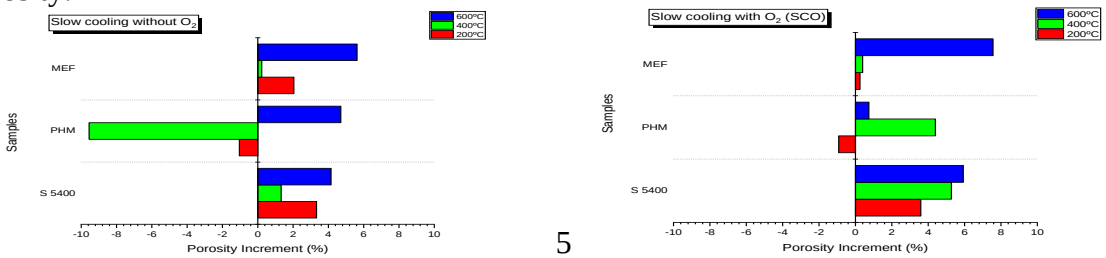

Figure 5. Porosity increment of mortars that were cooled slowly with and without O_2.

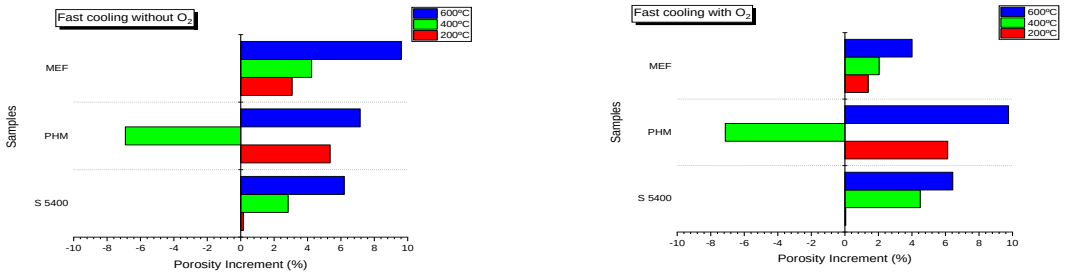

Figure 6. Porosity increment of mortars that were cooled suddenly with and without O_2.

5 Colorimetry

Colorimetric techniques are based on the measurement of radiation absorption in the visible area by colored substances. All systems that quantify color from three variables have colorimetric aspects: Luminance, Length and Purity.

With this technique, the color behavior of the mortars tested is studied, the color is measured in the mortars that have not been subjected to the test conditions, and then the color is measured in those mortars that have been analyzed in the test conditions shown in Table 3.

Table 3. Test conditions.

Temperature	**200ºC**	**400ºC**	**600ºC**
Test conditions	Slow cooling without O_2 **(SC)**		
	Slow cooling with O_2 **(SCO)**		
	Fast cooling without O_2 **(FC)**		
	Fast cooling with O_2 **(FCO)**		

5.2 Colorimetric Variation as Function of Test Temperature

Next, a data processing is carried out. The color variation of the tested products is determined, compared with the color tones of the reference (product without heat treatment).

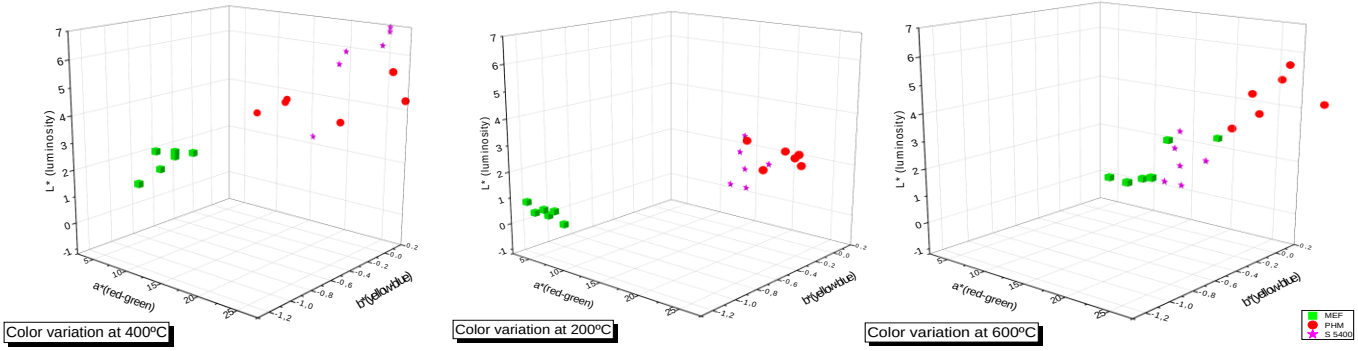

Figure 7. Color variation of the mortars tested at 200, 400 and 600°C.

At 200ºC and 400ºC, it is observed that the MEF product does not show variation around the

reference colorimetric values. As for the temperature of 600 ° C, the color variation of the products tested show a linear trend around the blue color when the brightness increases.

6 Conclusions

The following conclusions are obtained from the tests performed:

- The repair mortar that has the lowest porosity is MEF; on the other hand, the product that has the highest porosity is the PHM.
- In temperatures, at 200ºC and at 400ºC a good behavior is observed in the materials tested, while at 600ºC the behavior is very unfavorable in all cases, because at 600ºC, the increase in porosity is significant and it can cause reduction of mechanical strength. On the other hand, the PHM mortar is the one that shows the highest porosity, but it is the only one in which the porosity decreases when tested at temperatures between 200ºC-400ºC. This behavior may be caused by the composition of the fibers. The melting temperature of fibers is in the range 200° C - 400°C, causing diffusion of the fibers through the pores of the cementitious paste, filling capillary pores, and decreasing the porosity.
  In general, a linearity is observed between the increase in temperature and the decrease in brightness, approaching darker tones as the test temperature increases.

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