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Influence of the cure procedure on the properties of Polymer-Modified Cement Mortars (PMCM)

Influencia del procedimiento de cura en las propiedades de los morteros de cemento modificados con polímeros (PMCM)

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Abstract

To study the influence of the curing procedure polymer-modified cement mortars (PMCM) were realized in two stages. In stage 1, PMCM with different percentages of PVA (5, 10, and 15%) were produced considering two times of PVA addition in the mix (3 and 6 minutes) evaluating the fresh and the hardened state. Stage 2, focuses on analyses of different cure procedures: dry, wet, and two types of intermittent cure (dry/wet and wet/dry) by compressive, tensile strength, water absorption, and dynamic modulus of elasticity. In stage 1, the mixtures produced with 10 and 15% of PVA were selected for their results. Regarding the time of addition of the PVA to the mix, the results obtained do not show significant differences when the samples were produced with the two times. Then the addition time of 3 minutes is considered optimal, for manufacturing efficiency. In stage 2, the results show that the cure influences the performance of the PMCM, wherein the M1 cure showed the best results in the mechanical properties (justified by the correct hydration of the cement). In general, the incorporation of polymer reduced the absorption of water and the dynamic modulus of elasticity, thus contributing to producing more durable materials.
Keywords: PMCM, mortar; polymer; latex; mechanical properties; curing procedure.

Resumen

Para estudiar la influencia del procedimiento de curado en morteros de cemento modificados con polímeros (PMCM) se realizaron dos etapas. En la etapa 1 se produjeron PMCM con diferentes porcentajes de PVA (5, 10 y 15%) considerando dos tiempos de adición de PVA en la mezcla (3 y 6 minutos) evaluando el estado fresco y endurecido. La etapa 2 se centra en el análisis de diferentes procedimientos de curado: seco, húmedo y dos tipos de curado intermitente (seco/húmedo y húmedo/seco) por compresión, resistencia a la tracción, absorción de agua y módulo dinámico de elasticidad. En la etapa 1 se seleccionaron por sus resultados las mezclas elaboradas con 10 y 15% de PVA. En cuanto al tiempo de adición del PVA a la mezcla, los resultados obtenidos no muestran diferencias significativas cuando las muestras se elaboran con los dos tiempos. Entonces, el tiempo de 3 minutos se considera óptimo, para la eficiencia de fabricación. En la etapa 2, los resultados muestran que el curado influye en el desempeño del PMCM, donde el curado M1 mostró los mejores resultados en las propiedades mecánicas (justificado por la correcta hidratación del cemento). En general, la incorporación de polímero redujo la absorción de agua y el módulo dinámico de elasticidad, contribuyendo así a producir materiales más duraderos.

Palabras clave: PMCM, mortero; polímero; látex; propiedades mecánicas; procedimiento de curado.

1. Introduction

Mortars are cementitious materials with properties such as adhesion, adherence, strength, and plasticity that facilitate their application for coating and settling of different materials, brickwork among them. Mortars are basically formed by Portland cement, fine aggregate (sand), and water, considering also the possibility of incorporating chemical additives or mineral additions to optimize both fresh and harden state properties (Mehta and Monteiro, 2006); (Ohama, 1995); (Ramachandran, 1984).

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Commonly, the most incorporated modifiers in both brick masonry and finishing mortars are polymers. Their main function is to increase the workability and adherence of the material to and can be used to improve abrasive wear resistance and durability in aggressive environments (acids) (Almeida and Sichieri, 2006); (Barluenga and Hernández-Olivares, 2004); (Mansur et al., 2009); (Ohama, 1995); (Sumathy et al., 1997); (Susilorini et al., 2014); (Torgal and Jalali, 2010); (Winnefeld et al., 2012). Latex or polyvinyl alcohol (PVA), synthetic elastomer, styrene-butadiene rubber (SBR), epoxy resins, and vinyl acetates are the main polymers added into mortars (Beersaerts et al., 2021); (Pascal et al., 2004); (Sumathy et al., 1997), but the PVA is the most widely used in PMCM for its stabilizer and modifier characteristics (584.3R-03, 2003); (ASTM, 2008); (Ohama, 1995). . With the addition, the mix results in polymer-modified cement mortars (PMCM), which are understood as special mixtures that seek to improve the fresh properties (plasticity) of the material in response to new engineering demands.

PVA can have a viscosity in the range of 20 to 26 mPa.s, a variable solids content of up to 98% (which can vary depending on the manufacturer), pH values generally above 7.0 (alkaline), and particle size varying from 80 to 150 mm (584.3R-03, 2003); (Zhang et al., 2021). This polymer helps to increase the consistency of mortars, decreases permeability and shrinkage, increases the cohesion of mortars, and helps reduce cracking (ASTM, 2008); (Ohama, 1995); (Sumathy et al., 1997); (Zhang et al., 2021). As each PVA has different solid contents, some more concentrated than others, there is no single consensus on the optimal content that must be added to the mortar to enhance its properties.

As a cementitious material, the advantages of the PMCM are achieved with adequate procedure of curing (Pascal et al., 2004). In that sense, ACI 548.3R-03 (584.3R-03, 2003) standard recommends an initial wet cure (24 to 48 h) to prevent cracking, followed by a dry cure with a relative humidity of 50%, which is considered surface drying (584.3R-03, 2003). On the other hand, ASTM C1439-08a (ASTM, 2008) recommends that immediately after unmolding, the specimens need to be wrapped in polyethylene and stored at a controlled temperature of 23 ° C for approximately 24 hours. Then, the samples need to be uncovered and stored in a place with humidity and controlled temperature (23 °C and 50% relative humidity, respectively). Some authors have used curing immersed in water (Łukowski and Dominika, 2020), and curing with variations in relative humidity (with the specimens wrapped in plastic to avoid rapid evapotranspiration of the water)(Beersaerts et al., 2021) . Based on that, no consensus allows defining the curing procedures to enhance the performance of the PMCM.

On the other hand, the time of addition of the polymer in the mix is not clear. Standards do not specify the exact moment the polymer must be incorporated. This is stated by (Zhang et al. 2021) who emphasize that there is no standard method for fabricating PMCM (Zhang et al., 2021). In that regard, (Ribeiro, 2012) worked with two times of addition (3 and 6 min after the beginning of the mixing process) (Ribeiro, 2012). The results showed that the longer the time of addition is, the higher content of air is incorporated in the mix, increasing workability and improving its physical and mechanical properties. Therefore, the time of addition of the polymer to the mixture is an important variable considering that the hydration process of the cement is complex and the reaction of the addition of the polymers to the mixture is not controllable (Zhang et al., 2021).

Taking into account the above, this study aims to analyze the mechanical properties of mortars modified with polymers (PMCM), evaluating the influence of the polymer content, the polymer time of addition, and, mainly, the effect of the wet curing on the properties studied. For this, the experiment was divided into two stages. First, mortar mixtures with different percentages of PVA (0, 5, 10, and 15%, respectively) were produced considering two times of polymer addition in the mixture (3 and 6 minutes). The fresh properties (consistency index and unit weight) and the compressive and tensile strengths are obtained and analyzed. Through the first conclusions, in the second stage, more samples were produced considering the optimal PVA content and optimal addition time, and these were cured with four different methods: dry cure, wet cure, and two types of mixed cure (dry/wet and wet/dry respectively). Finally, the samples were studied, and based on the mechanical properties, the optimal curing procedure was suggested.

2. Methodology

2.1. Materials

Type II Portland cement (CP II F 32, Brazilian denomination) with limestone filler addition was used to produce the mortars. This cement was chosen due to the benefits in permeability, density, and workability provided (Benachour et al., 2008); (Galobardes et al., 2014), (Galobardes et al., 2015). Tap water was used for mixing the samples, meeting the requirements described in the standard NBR 15900:2009 (Brazilian Standard) (ABNT, 2009).

The fine aggregate used to produce the mortars was quartz sand with a continuous granulometry, a fineness modulus (FM) equal to 2.60, and its maximum characteristic dimension equal to 2.38 mm. These characteristics (FM, granulometry, and Dmáx) meet the Brazilian standard NBR NM 248: 2003 (ANBT, 2003) requirements to produce mortars and concrete. (Table 1) shows the results of the sand characterization tests. The density, filler content, water absorption, and bulk density were estimated according to the requirements of Brazilian standards NBR NM 52: 2009 (Associação Brasileira De Normas Técnicas (ABNT, 2009), NBR NM 45: 2006 (ABNT, 2006), NBR NM 46: 2003 (ABNT, 2003), and NBR NM 30: 2001 (ABNT, 2001), respectively. The obtained results meet the standard requirements to produce mortars and concrete (NBR 7211, 2019).

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Table 1. *Main characteristics of the sand used*

Property	*Value*
Density (g/cm3)	*2.60*
Filler Content (%)	*2.50*
Water Absorption (%)	*0.55*
Bulk Density (g/cm3)	*1.64*

Besides that, the polymer used in this study is polyvinyl acetate (PVA) copolymer emulsion, as it is the most commercial in the region where the study was carried out and one of the most used in the literature (Barluenga and Hernández-Olivares, 2004); (Pascal et al., 2012); (Zhang et al., 2021). (Table 2) shows the chemical characteristics of this material given by the manufacturer. Notice that, the properties are within the ranges studied in the literature for this type of polymer, with only the percentage of solids being a little lower than expected (70%) (584.3R-03, 2003); (Almeida and Sichieri, 2006); (ASTM, 2008); (Ohama, 1995); (Pascal et al., 2012).

Table 2. *Properties of the polymer (PVA) used*

Property	*Value*
Density (kg/dm3)	*1.05*
pH	*7.0*
Content of solids (%)	*50*

2.2. Methods

The analysis was performed in two stages, according to the flowchart (Figure 1). In Stage 1 the content of PVA was evaluated, such as the time of polymer addition. By the test results of consistency index, compressive and tensile strength, the content of PVA, and time of addition were selected for stage two. In which the curing condition was analyzed, looking for the best performance of the PMCM.

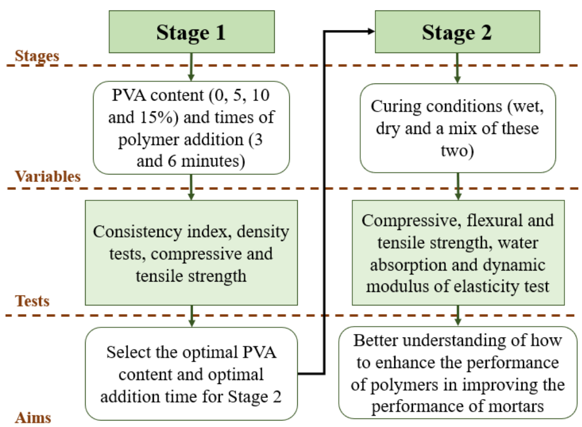

Figure 1. *Experimental flowchart*

In the two stages, mixes were fabricated with a cement content equal to 570 kg/m³ considering a cement/aggregate ratio of 1:3 and water to cement ratio (w/c) of 0.5, being that the PVA water content was discounted from the total water added to the mix. This mix proportion aimed to obtain a consistency index of 240±10 mm (NBR 13276, 2016).

The mixing process was performed in a mixer with 5 liters of volume. Firstly, the cement and sand were added to a mixer and they were mixed for 1 minute at a low speed. Subsequently, the water has been partially added to the mixer and the content was mixed for 2 and 5 minutes for addition time equal to 3 and 6 minutes, respectively (at a speed of 145 rpm).

Finally, the remaining water was added to mix with the PVA, and the contents were mixed for another 5 minutes. As indicated by the NBR 5738 (2015) (Brazilian standard) (NBR 5738, 2015), the mix time for the reference samples was 5 minutes, while these times were 8 and 11 minutes for the samples prepared with polymer addition times of 3 and 6 minutes, respectively. Immediately after mixing, the tests in a fresh state were performed.

2.2.1 Stage 1

To study the influence of the polymer content on the mortar properties, four percentages by cement weight were considered: 0, 5, 10, and 15%, named as M0, M5, M10 and M15, respectively. The mix with 0% PVA (M0) was considered as the reference mortar.

These contents were considered according to the literature review (Ferreira, 2001) and the manufacturer's recommendations (Illampas et al., 2021a); (Priyadharshini and Ramakrishna, 2018); (Wang et al., 2020); (Zhang et al., 2021).

(Table 3) shows de mix proportions used in this research. It is worth remembering that two polymer incorporation times were analyzed during the production of mixes: 3 and 6 min (from the beginning of the mixing process).

***Table 3**. Mix proportions (for a volume of 5.89 liters of mortar)*

Mortars	Cement (kg)	Sand (kg)	Water (l)	PVA (%)
M0	3.36	10.07	1.40	0
M5			1.26	5
M10			1.12	10
M15			0.98	15

2.2.1.1 Consistency index and specific mass tests

The consistency index test was performed following the recommendations of the NBR 13276 (Brazilian standard) (NBR 13276, 2016). A flow table and a metal ruler were used to verify the opening diameter of each mix. On the other hand, the specific mass of mixes was estimated considering the requirements of the Brazilian standard NBR 13278 (ABNT, 1995). For this a metal mold was filled with 3 layers of mortar and each layer compacted with 20 blows, at the end, the surface was shaved, and the mass verified. For both tests, three measurements were made (n=3).

After that, the samples were molded for analysis in the hardened state. For that, samples of ϕ50mmx100mm (diameter and height) were produced and compacted according to the requirements of the Brazilian standard NBR 5738 (2015) (NBR 5738, 2015). After molding, in this stage, the specimens remained inside the molds for 24 hours and then they were sent to wet cure (immersed in water) for further analysis of compressive and tensile strength.

2.2.1.2 Compressive and tensile strength tests

The compressive and tensile strength were evaluated at 28 days of cure. For both tests, five cylindrical samples (ϕ50x100mm) were used (n=5). A universal testing machine (Emic ® PC200) was used to evaluate the compressive and tensile strengths considering the requirements of the Brazilian standards NBR 5739/2007 (ABNT, 2007) and NBR 7222 (ABNT, 2010), respectively. After these tests, the polymer content and the time for its addition were selected for stage 2.

2.2.2 Stage 2

In stage 2, the same mix proportion described in 2.1.1 was used with the selected polymer content and time for the polymer addition of stage 1. To determine how the procedure of curing influenced the performance of the PMCM, four curing conditions were evaluated: wet curing (W), dry curing (D), and two intermittent curing types (M1 and M2).

The wet curing (W) was carried out following the requirements of the standard NBR 5738 (2015) (NBR 5738, 2015), in which the samples were immersed in water until the test age. The dry curing (D) was carried out by keeping the samples in direct contact with the air (exposed to the environment) until the test age. On the other hand, in the first type of intermittent curing (M1), a cyclical process was carried out where the samples were in wet curing for 7 days followed by another 7 days in dry curing. This cycle was repeated until the samples were tested. Finally, the second type of intermittent curing (M2) consisted of 7 days in dry curing followed by another 7 days in wet curing in a cyclical process. Notice that M0 mixes were prepared only with the wet curing method as indicated by NBR 5738 (2015) (NBR 5738, 2015).

It is important to mention that after molding, the samples remained in the mentioned curing procedures until the test ages and were analyzed by water absorption, the dynamic modulus of elasticity, and the compressive and tensile strengths.

2.2.2.1 Water Absorption

A water absorption test was carried out to determine the percentage of relative water absorption (WA) as a measure of comparison between the samples. The test was carried out based on the Brazilian standard NBR 9778 (NBR 9778, 2005) with three cylindrical samples (ϕ50x100mm) for each cure condition (n=3).

The samples were cured for 28 days and after that, they were oven-dried (105°C) for 72 hours and left to cool in a desiccator for 24 ± 0.5 h. Then, the mass was recorded (md) and the lengths of the sample were measured. Next, the samples were immersed in water for 72 ± 8 h. Then, the samples were removed from the water, the surfaces were dried to remove any surface water the saturated mass was recorded (ms). Lastly, the relative water absorption was calculated as shown in (Equation 1).

$$WA = \frac{m_s - m_d}{m_d} \times 100\% \qquad (1)$$

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2.4.3. Dynamic modulus of elasticity

The dynamic modulus of elasticity was performed considering the requirements of the Brazilian standard NBR 15630 (2009)(NBR 15630, 2009). (Figure 2) presents the ultrasonic equipment used to determine this property. Three cylindrical samples (ϕ50mmx100 mm) were tested for each mix at an age of 28 days.

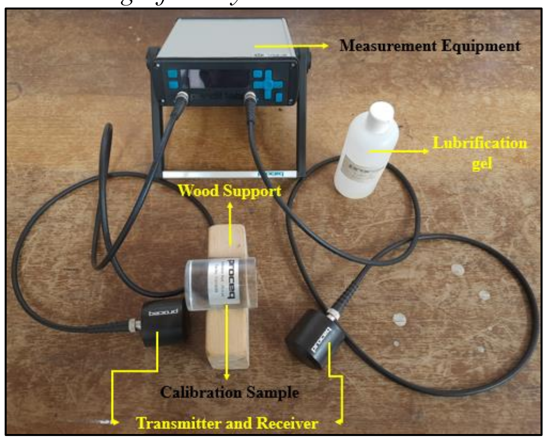


Figure 2. *Ultrasound Equipment*

(Equation 2) is used to estimate the modulus. This depends on the density of the mix (γ) in kg/m3, the speed with which the ultrasonic wave travels the length (100 mm) of the specimen (V) in m/s and Poisson's ratio (ν). Note that the latter was considered equal to 0.2 as indicated by the literature (Silva and Campiteli, 2008) and the density was estimated according to the requirements established in NBR 15630 (2009)(NBR 15630, 2009).

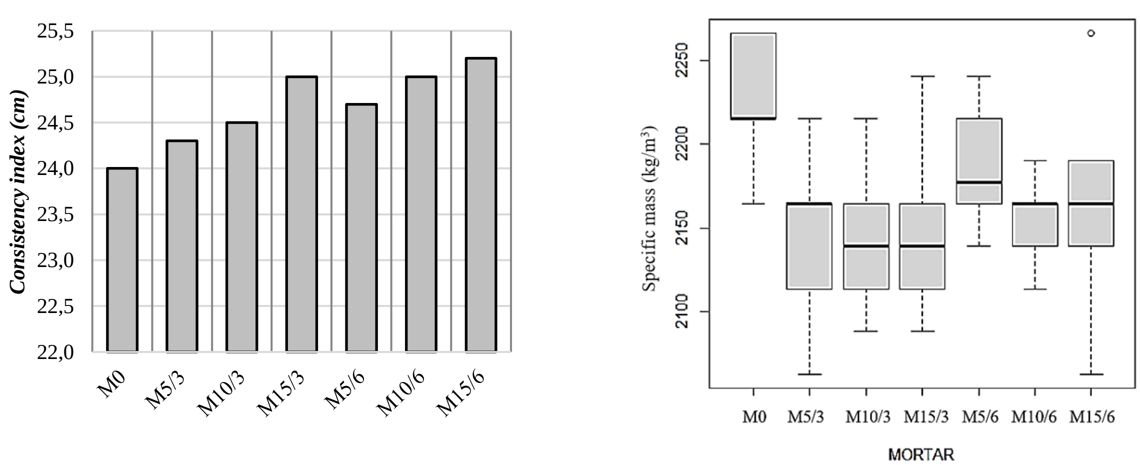
$$E_d = \gamma V^2 \frac{(1+\nu)(1-2\nu)}{1-\nu} \tag{2}$$

3. Results and Analysis

This section is divided into two stages. First, the percentage of PVA and its addition time in the mix are analyzed to obtain the optimal values. In this first stage, tests are carried out on mixes produced with 0, 5, 10, and 15% PVA, with addition times of 3 and 6 minutes. All the specimens of this phase were cured with the wet method. Next, with the optimal values of polymer and time of addition in the mixture, more tests are carried out to study the optimal type of curing procedure (Stage 2). For this, the four methods previously described were used.

3.1 Optimal PVA content and addition time

(Figure 3) presents the results of the fresh state properties for samples produced with 0, 5, 10, and 15% of PVA, with both addition times, 3 and 6 minutes. The properties analyzed are the consistency index and the unit weight (fresh state).



a) b)

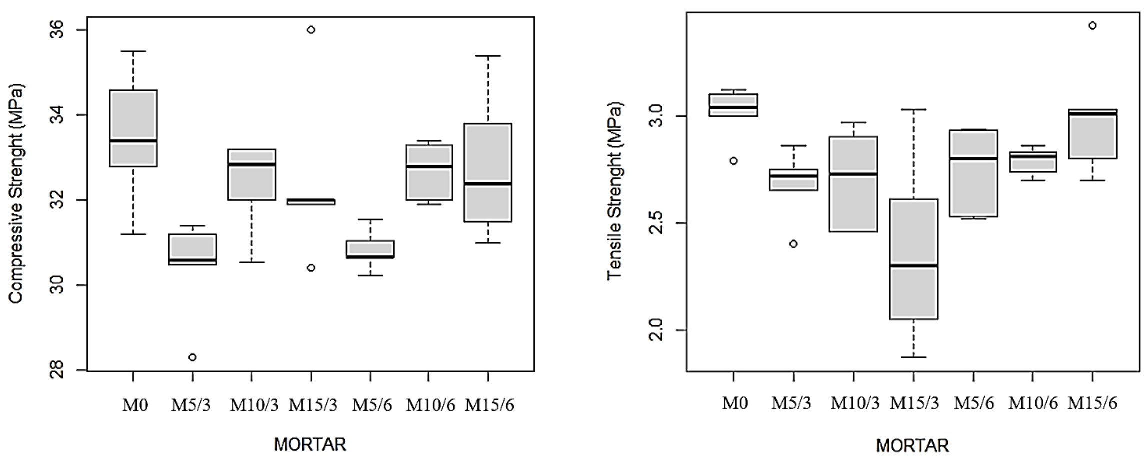
Figure 3*. Fresh state results (stage 1): a) Consistency index and b) Specific mass (n=10)*

The average value of the consistency index was equal to 24.0 cm for the reference mortar (M0), on the other hand, all PMCM presented higher values of consistency index, in agreement with what was found in the literature where the addition of polymer improves the workability of the mortar (Zhang et al., 2021).

Considering the reference (M0), an increase equal to 1.23, 2.04, and 4.00% were observed for samples produced with 5, 10, and 15% of PVA, respectively, from the added time of 3 minutes, while an increase of 2.83, 4.00, 4.76% were obtained for samples produced with 6 minutes. These results corroborate the ones found by (Ribeiro, 2012), in which the longer the time of addition is, the higher content of air is incorporated in the mix.

On the contrary, for the same reason, the specific mass decreases. The average decrease is 3.32 and 1.59% for samples produced with addition times of 3 and 6 minutes, respectively. Also, the difference between the reference value and the others is not significant. It should be noted that the low deviation presented by the results, <5.0% on average, already observed in the literature (Giustozzi, 2016); (Ma and Li, 2013), On average, the incorporation of polymer resulted in a lower specific mass in the fresh state for the mortars studied, in agreement with what was found in the literature, where the incorporation of the polymer increases the air incorporated, decreasing the density (Aattache et al., 2013); (Barluenga and Hernández-Olivares, 2004); (Illampas et al., 2021b); (Medeiros et al., 2009); (Peng et al., 2020); (Zhang et al., 2021).

On the other hand, Figure 4 presents the results of the properties in the hardened state of the samples of stage 1. The properties analyzed are the compressive and tensile strength at the age of 28 days.



a) b)

***Figure 4**. Hardened state results (stage 1): Compressive a) and Tensile Strength b) (n=5)*

The results obtained with M0 were on average 33.50 MPa and 3.01 MPa for compressive and tensile strength, respectively. These values are following the standards that establish the conditions of use of mortars (Navarini Kurz et al., 2018). The addition of polymer reduces the strength, both compressive and tensile, of the material at the evaluated ages (7 - 28 days). It is important to note that the higher the polymer content, the lower the decrease in strength. This decrease can be explained due to the type of cure that was carried out (wet cure) which did not allow the correct polymerization process of the material, agreeing with what was observed in the literature where sometimes the addition of polymer gradually decreased the compressive strength (Aattache et al., 2013); (Barluenga and Hernández-Olivares, 2004); (Illampas et al., 2021b); (Medeiros et al., 2009); (Peng et al., 2020); (Zhang et al., 2021). Furthermore, the addition of polymers to this material leads to a decrease in its unit weight see (Figure 3b), implying a decrease in strength as has already been observed in the literature (Ramli and Akhavan Tabassi, 2012). Notice that the decrease in strength and density was due to the incorporation of air from the polymer when it is added to the mixture (Zhang et al., 2021).

In short, considering the results in the hardened state and obviating the results in the fresh state, which present non-significant differences, it is observed that the mixtures produced with 10 and 15% of polymer present the highest results, regardless of the addition time used. In view of noticing small variations in the ages evaluated in Stage 2, longer ages will be evaluated. Therefore, these quantities are considered optimal ones and are used in the following stages. Regarding the time of addition of the polymer to the mixture, the results obtained do not show significant differences when the samples are produced with 3 and 6 minutes. Since the addition of polymer increases the total production time by 60.00 and 120% compared to the M0 time (5 minutes), the addition time equal to 3 minutes is considered optimal, for manufacturing efficiency.

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3.2. Stage 2: Optimal curing procedure

(Figure 5) presents the compressive strength results of samples produced with 0, 10, and 15% PVA, with an addition time of 3 and the four different types of cure: wet (W), dry (D), intermittent 1 (M1), and intermittent 2 (M2). In this second phase, for each of the samples, the average strength obtained for the ages of 7, 28, 56, and 91 days was presented to analyze short and long ages, considering that in the first ages the polymer can inhibit the development of strength of the material (Illampas et al., 2021b); (Zhang et al., 2021). Notice that the results obtained are compared with the reference mix (M0) which was prepared with wet curing as defined by the standard NBR 5738 (2015) (NBR 5738, 2015).

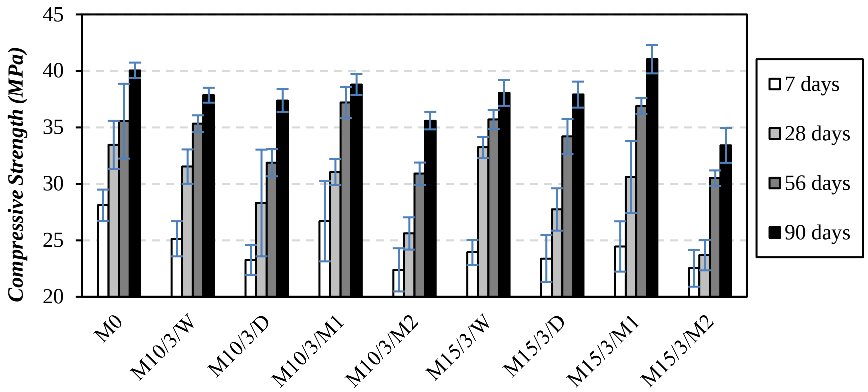

Figure 5 *- Evolution of compressive strength in time considering curing method (n=4)*

The obtained results follow the same tendency observed in (Figure 4a) The addition of PVA in the mixes decreases their compressive strength independently of the content of PVA and the curing procedure used. Samples cured with the method M1 present the highest results among the mixes produced with PVA, independently of the content of PVA used. The lowest results are obtained with mixes cured with M2 and dry procedures. In that regard, the average reduction in strength is equal to -5.35, -13.45, -4.23, and -13.06% for mixes cured with W, D, M1, and M2 procedures, respectively. These results show the importance of wet curing is essential during the firsts moments after demolding to obtain higher strength in short and long ages as indicated by (Zhang et al., 2021). This shows that cement hydration is more important than early age polymerization to assure an efficient formation of the polymer-cement co-matrix, coinciding with what was found by (Peng et al., 2020) who verified that the presence of polymers can alter the hydration products and their microstructure, sometimes limiting the development of such products due to the obstruction of polymer particles. The tensile strength test results obtained for the mixes at 28 days of age are presented in (Figure 6).

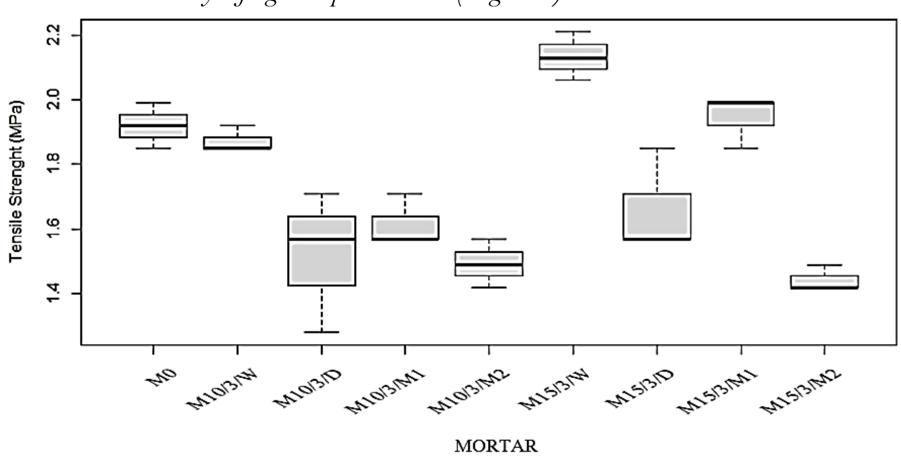

Figure 6*. Tensile strength Stage 2 (n=3)*

As shown in (Figure 6) M15/3/W presented the best results since its tensile strength is even higher than M0. On the other hand, M15/3/M2 presents the lowest results. Considering the PMCM mixes produced, on average, the highest results are obtained by mixes produced with 15% PVA (1.80 MPa) since these present 9.50% greater tensile strength than mixes produced with 10% PVA. These results follow the same trend as the ones indicated by (Sivakumar et al., 2009). These results diverge from those found in phase 1, mainly due to the effects of strength inhibition as a consequence of the procedure of cure used. Additionally, these results agree with that found in the literature where the tensile strength is improved by the addition of polymer under suitable curing procedures (Medeiros et al., 2009); (Zhang et al., 2021).

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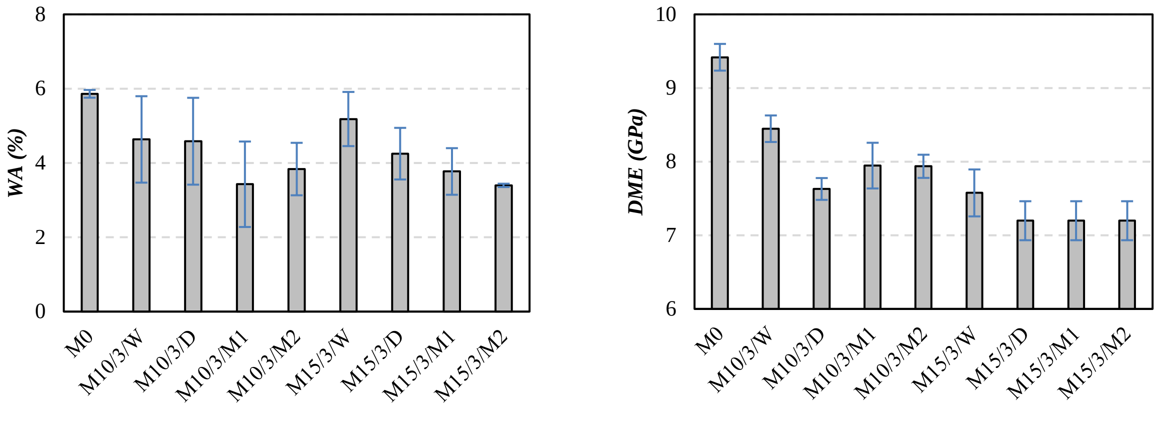
Contemplating the curing procedure, the worst results are the ones obtained with the drying cure followed by the M2 cure, independently of the content of PVA used. The average results obtained with wet, dry, M1, and M2 procedures are equal to 2.00, 1.59, 1.78, and 1.47 MPa, respectively. This tendency was already observed in the literature and it is in accordance with the importance of hydration at the beginning of the curing process (Aattache et al., 2013); (Ma and Li, 2013); (Zhang et al., 2021).

Finally, (Figure 7) presents the results obtained for water absorption and dynamic modulus of elasticity tests. These tests were carried out at the age of 28 days.



a) *b)*

***Figure 7.** Water absorption (WA) a) and dynamic modulus of elasticity (DME) b) results*

Regarding the results obtained performing the water absorption test (WA), the addition of PVA reduces in average 30% the values obtained with the reference M0. This tendency was already observed in the literature (Ohama, 1995); (Ribeiro, 2012); (Zhao et al., 2011). Considering the procedure of curing, samples cured with wet, dry, M1, and M2 procedures present average reductions of WA equal to 16.25, 24.64, 38.59, and 38.29%, respectively. Hence, the curing type that reduces the most water absorption is M1 favoriting the hydration of cement and guaranteeing the formation of a polymeric film. These results indicate that PMCM mixes may lead to an increment of durability.

On the other hand, considering the results obtained carrying on the dynamic modulus of elasticity tests (DME), the results obtained here converge with what (Ramli and Tabassi, 2012) point out in their research. A decrease in the value of the DME is observed when polymers are added to the cementitious mix, and the greater is the addition of polymer, the DME stronger decreases. In this study, the decrease of DME is equal on average to 15.16 and 22.57% for mixes produced with 10 and 15% of PVA, respectively, confirming the tendency found in the literature review (Barluenga and Hernández-Olivares, 2004); (Illampas et al., 2021b); (Ma and Li, 2013); (Ramli and Akhavan Tabassi, 2012). These results state that the higher the addition of PVA is, the more difficult the mortar will stand deformations. Regarding the procedure of curing, samples cured with wet, dry, M1, and M2 procedures present average reductions of DME equal to 14.93, 21.28, 19.59, and 19.65%, respectively. The lowest reductions are achieved by samples cured with the wet procedure. On the contrary, samples cured with M1 procedure present high reductions of DME. Then, M1 is a curing process that allows higher mechanical performance than the others but decreases the ability of the mixes to stand deformations.

4. Conclusions

The effects of the procedure of curing on the performance of PMCM were evaluated by checking the properties in fresh and hardened conditions of the material. In this sense, the results showed that there is a direct influence of the type of cure in the enhancement of the PMCM's mechanical properties (considering the study conditions, mix proportions and polymer used). Apart from that, following conclusions were obtained in the development of this investigation:

- *The addition of polymer (PVA) to the mixes improves the consistency of the material (workability), and decreases the unit weight due to a higher incorporation of air in the mixture.*

- *The time used to add the polymer in the mix does not present direct interference in terms of the material mechanical behavior. Hence, adding the polymer at 3 or 6 minutes from the beginning of the mix has no effect on the performance of the final product. This study shows the addition time equal to 3 minutes as optimal, since it reduces the production process and enhances therefore manufacturing efficiency.*

- *The addition of the polymer decreases the mechanical properties of the PCMC in ages lower than 28 days. In that sense, the highest is the percentage of polymer added, the greater decrease in the mechanical properties is observed., and the higher*

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percentage of polymer lowers the material's strength. Furthermore, percentages of polymer equal to 10 and 15% have the potential to directly interfere in both fresh and hardened properties, according to the study conditions.

- *The procedures of curing used in the PMCM had a considerable influence on their mechanical behavior. M1 presented the best results in the majority of the tests, indicating that when modifying the mortar with polymer it is important to carry out the curing process in a cyclic manner, since the cement can be efficiently hydrate. Besides it allows the formation of the polymeric film allowing a better hydration of the cement and achieving an effective polymer-cement co-matrix.*

- *Wet curing does not allow the development of the polymerization process, as it inhibits the real effect of the polymer and impairs the quality of the material. This justifies the reduction of strength due to the inhibited hydrated cement products.*

- *For advanced ages (> 90 days), the intermittent curing M1 proves to be the best alternative for increasing the compressive strength, when compared to the other procedures of curing. These mixes show mechanical benefits at more advanced ages. Moreover, the combination of incurring polymer and the M1 curing highly reduce both water absorption and dynamic modulus of elasticity.*

- *The PMCM subjected to intermittent curing (M1 and M2) presented the lowest absorption rates, independently of the content of polymer used. This shows that the hydration of the cement and the formation of the polymeric film, caused by the cyclic curing, resulted in a greater filling or isolation of the pores.*

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