Mitigation of aging of glass fiber reinforced cement (GRC) using pozzolan and acrylic resin additions.

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***Abstract*— The present work explores the effectiveness of some types of pozzolanic additives and acrylic resins in improving the properties of the Glass Fiber Reinforced Cement (GRC) to avoid damage of the material due to aging. For this purpose, GRC specimens are manufactured with local materials using the simultaneous projection of fiber and mortar (industrial manufacturing method). The samples are aged using two predictive accelerated ageing techniques: climatic chamber and immersion into hot water. Each sample is subjected to bending tests to verify the effectiveness of the additives with respect to GRC samples aged without additives. Additionally, the samples were analyzed using a micrographic technique to check the structure of the fibers after the accelerated aging process. Pozzolanic additives such as acrylic resins and metakaolin were found to improve the properties of GRC.**

Keywords— Fiberglass Reinforced Concrete (GRC), Accelerated Aging in GRC, Deterioration of GRC Glass Fibers, Pozzolans, Acrylic Resins.

***Resumen*— En el presente trabajo se explora la eficacia de algunos tipos de aditivos puzolánicos y resinas acrílicas en la mejora de las propiedades del GRC para evitar la pérdida de propiedades del material debido al envejecimiento. Para ello se fabrican probetas de GRC utilizando materiales locales mediante la técnica de proyección simultanea de fibras y mortero (método industrial de fabricación), Las muestras son envejecidas mediante dos técnicas de envejecimiento acelerado predictivo: cámara climática e inmersión en agua caliente. Cada tipo de muestra es sometida a ensayos de flexión para comprobar la eficacia de los aditivos respecto a las muestras de GRC envejecidas sin aditivos. Por otra parte, se analizan las muestras usando la técnica de micrografía para verificar la estructura de las fibras luego del proceso de envejecimiento acelerado. Se obtuvo que los aditivos puzolánicos como resinas acrílicas y metacaolín mejoran las propiedades del GRC.**

Keywords—GRC, Envejecimiento acelerado en GRC, Deterioro de Fibras de Vidrio en GRC, Puzolanas, Resinas Acrílicas

I. INTRODUCTION

Glass fiber reinforced cement (GRC) mortars are cement-based materials that have been used in numerous construction applications over the past 50 years (Enfedaque, Gálvez, & Suárez, 2015) [1] . The material is attractive in construction due to its mechanical properties of high compressive strength, high tensile strength, lightness and ductility, which makes it an ideal material and high proliferation in the construction industry. It has been used in the construction of facades, interiors, roofs, pipe protection, arms for aircraft access in airports, lining tunnels and acoustic barriers (Ferreira & Branco, 2007) [2]; (Majumdar & Nurse, 1974) [3]; (Young, 1978) [4].

Different authors (A. Bentur, 2006) [5]; (Fernández, 1996) [6]; (True, 1986) [7]; (Hull, 1987) [8]; (Ferreira, F.A. Branco, 2007) [9] have identified a series of benefits and advantages for which the use of GRC is recommended in certain construction elements. One of the reasons is that there is a greater relationship between strength and weight, since GRC allows the use of small thicknesses that lead to weight reductions of up to 86% compared to concrete panels. This material is ideal for the construction of panels, due to its hardness and coating, in addition to not requiring reinforcements such as steel bars and can be produced in any form with a thickness of only about one centimeter. Among its mechanical properties, it is possible to identify a high resistance to compression, flexion and traction that present almost the same contribution of steel in reinforced concrete.

Another advantage of the GRC is that it is highly resistant to impact, especially at an early age, and can be combined with other core materials to form panel-type elements. For example, it allows the addition of materials such as perlite, vermiculite or fly ash, which together with glass fibers generate fire-resistant products. On the other hand, the GRC facilitates the manufacture of complicated shapes by projection and allows simple cutting or drilling with simple tools allowing incidents to be resolved on site, for reasons not foreseen in the design; for this reason, it is possible to achieve a great diversity of surface finishes, with textures that resemble the finish of other types of materials also used in construction. By using additives, stone materials can be

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imitated, even improving their textures and allowing cladding to replace entire volumes.

Despite its advantages in the use of construction, in numerous investigations (Enfedaque et al. 2015) [1]; (Ferreira & Branco, 2007) [2]; (Genovés, Riestra, Borrachero, Eirás & Payá 2015) [10]; (Borrachero, Eirás & Payá, 2015) [11]; Purnell, Short, Page, Majumdar & Walton, 1990) [12]; they have concluded that the mechanical properties of GRC deteriorate over time, a phenomenon known as aging. There is a loss of ductility and loss of tensile strength (Enfedaque, Cedon, Gálvez, & Sánchez, 2009) [13]; and a degradation of the properties arises due to the chemical attack by alkalis and the growth of cement hydration products, which increase the adherence of the matrix fiber, weakening the material (Proctor, 1981) [14]. Within the advance of research, the reference of the aging produced by natural exposure to the environment of the GRC has been qualified in research carried out by: Enfedaque et al. (2015) [1], Ferreira & Branco, (2007) [2], Genovés, Riestra, Borrachero, Eirás & Payá (2015) [10], Purnell, Short, Page, Majumdar & Walton (1990) [12]. In these investigations an aging has been discovered that produces the fragilization of the material generated by the attack of the alkali of cement to the fiberglass and the growth of products of hydration in the cement on the fibers, which generates the breakage of these (Purnell, 1998) [15].

Due to this problem, glass fibers have been developed with more resistant compositions that prevent deformation and mitigate growth by hydration products, as well as some additives to the matrix that allow for a reduction in aging. One of the most outstanding attempts to solve the problem was presented by Arun Majummdar, who developed a resistant alkali glass fiber called AR, which is composed of zirconia base. With this advance the proscription of the fiber E was motivated, since this material had a high resistance to the chemical attack of the alkalis, making its use suitable for the effort of the cement pastes (Majumdar, A. J. & R. W. Nurse, 1974) [16]. Although the AR fibre showed greater resistance, the material continued to present ageing in the GRC which reduced its tenacity and resistance to the impact of time until presenting very low values, especially for storage in water (Sánchez et al, 1992) [17].

Other later attempts to solve the problem used another type of approach, no longer by improving the fiber, but by improving the matrix, through additions, this line of research is what inspires this study. In experimental tests carried out in Spain, United States & United Kingdom (Sánchez Paradela & Del Aguila A, 2012) [18]. In the field of research they have contributed that the addition of pozzolans, such as silica smoke (SF), Fly Ash (FA), Metacaolín (MK) and treatments with acrylic polymers can mitigate the aging of CRG, however, these experimental programs leave gaps in knowledge, since they do not define any method, the results are diverse and dependent on the proposed experimental programs and the additives and mixtures that vary in proportion.

Taking as a reference the phenomenon of aging of the GRC detected in other countries such as Spain, the United States and the United Kingdom, this research takes advantage of the opportunity represented by the lack of knowledge and little disclosure that the GRC has had in Colombia and seeks to find the components to be added to the GRC that mitigate the deterioration of the mechanical properties in its aging. Although GRC has been used for some years in Colombia and today, it is manufactured and distributed by a single company throughout the country. In this opportunity the materials are taken advantage of at local level, since studies have not been realized that allow to know the pattern of aging in relation to the environment and the form to mitigate this phenomenon -that has been identified at world level- with raw materials of the region. All the research started from the hypothesis -based on the antecedents- that the use of pozzolans and acrylic resins in the matrix of the GRC manufactured with local raw materials reduces the aging produced by the environment.

II. Materials

A. formulation of additions.

In the formulation process it was considered the inclusion of 5 additions and a control sample, with polymers at 1%, 2% and 3%, and pozzolans at 5% and 10% in relation to weight in (KG). It should be noted that AR Cem-Fil 54 was used.

Table 1. Characteristics of the formulations used.

Type of Combination	GRC 1 - Control	GRC 2 - Polymer 1%	GRC 3 - Polymer 2%	GRC 4 - Polymer 3%	GRC 5 - Pozzolana 5%	GRC 6 - Pozzolana 10%
Material	**KG**	**KG**	**KG**	**KG**	**KG**	**KG**
Cement	40,00	40,00	40,00	40,00	38,00	36,00
Metacaolín	0,00	0,00	0,00	0,00	2,00	4,00
Sand Silica	40,00	40,00	40,00	40,00	40,00	40,00
Water	14,00	14,00	14,00	14,00	14,00	14,00
Polymer	0,00	0,40	0,80	1,20	0,00	0,00
Plasticizer	0,40	0,28	0,28	0,24	0,48	0,48
Air	0,00	0,00	0,00	0,00	0,00	0,00
Roving Cem-Fil 54	4,72	4,73	4,75	4,77	4,72	4,72
Theoretical Density	99	99	100	100	99	99

Manufacture of Panels and Preparation of Specimens.

For the preparation of this activity the background was considered, where it is indicated that there are two methods for the development of the investigation, which are: premixing and simultaneous projection for the manufacture of specimens. The latter according to (Enfedaque 2008) [19]. It is the most precise method to recreate the behavior of the GRC installed on site. For the manufacture of GRC panels which must comply with procedures established within the industry standards of fiberglass reinforced mortars, led to the search for a company that would like to be part of this research, the industry offered to collaborate with the study. The first step was to manufacture the plates to cut the specimens.

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The manufacture of the GRC was carried out by means of the simultaneous projection of the cement mortar and the glass fibers. The glass fibers that are introduced in the material are forming coils. One of these coils can be seen in figure 1.



Fig 1. Fabrication of the material: (left) Cem-Fil 54 fiberglass coil; projection of the material (right).

For each formulation, panels of 1,910 x 910 mm were manufactured, with a thickness of 10 mm, which were cut in an industrial way with a circular saw, in order to obtain 60 specimens per formulation, with approximate dimensions of 300 x 50 mm. These dimensions were obtained based on experimental tests carried out by the following authors: Eirás, (2008) [17], (Enfedaque 2008) [19], Enfedaque et al., (2009) [20], (Enfedaque & Sánchez 2010) [13] A diagram of the panels can be seen in figure 2.



Fig. 2. Fabrication of material: (left), demarcation of the specimen cutting material Right.

III. METHODOLOGY

A. *Experimental methodology*

Four-point flexion test: For this test the GRC specimens were used for all the proposed formulations of 300 x 30 mm thick 10 mm, which failed to bending tests in a universal mechanical testing machine Instron Ref. 2820-040 to 4, 28 days (GRC YOUNG) and once completed the cycle of accelerated recreated aging (GRC OLD) following the standard ASTM C947-2009. Figure 3 shows a diagram of the test carried out on the young material.



Fig3. Assembly of bending tests on GRC Young material

The load measurements, provided by the machine's load cell and carriage displacement, measured by a machine's LVDT transducer, are collected in a Data Acquisition System, storing pairs of data every tenth of a second. The results are presented in the form of load-displacement graphs, drawn by the computer plotter.

From the load-displacement records, the proportionality limit (LOP) and the modulus of rupture (MOR) were calculated for each of the test specimens, using the following expression:

$$\sigma = \frac{3}{2}\frac{P.L}{b.c^2} \quad (1)$$

Where: σ sigma is the tension [N/mm2], P the maximum load applied [N], L is the distance between supports [200 mm], b is the width of the specimen and C is the thickness of the specimen [mm].

Subsequently, the beams were subjected to the action of accelerated aging by immersion of hot water and climatic chamber in wetting and drying cycles.

Accelerated aging: The method is based on the hypothesis that the immersion of the material in hot water for short periods of

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time allows predicting the mechanical properties of the material after long periods of exposure to the elements. The ageing of the material was carried out by immersion in hot water tanks at 50ºc. This hypothesis has been tested by comparing tests conducted on accelerated ageing material in the Litherland et al. 1881 [14] research, where equivalence was determined by immersion of hot water in natural and accelerated ageing in the United Kingdom, known as the Arrhenius ratio. See table 2.

Table 2. Accelerated aging equivalence. taken from Enfadaque et al (2010) [20].

1 day de exposition to…	Days of exposition Natural en UK
80 °C	1672
70 °C	693
60 °C	272
50 °C	101

Immersion of specimens in hot water at 50ºC. For the first environment, the specimens submerged in water at 50ºc failed by bending in the Instron Ref. 2820-040 machine for cycles of 5, 8, 10, 20, 30, 40, 50, 70, 80 and 90 days, following the ASTM C1560-2009 standard. Figure 4 shows the immersion of specimens made with hot water immersion equipment in the civil engineering laboratories of Javeriana University, where they had about 180 GRC plates submerged at 50ºc, gradually failing 3 by addition according to the cycles already mentioned.



Figure 4. Immersion of specimens in hot water at 50ºC

Humidification and drying cycles in climatic chamber: For the second environment the aging of the GRC was recreated, humidification and drying cycles with constant temperature. A climatic chamber was used, where 6 cycles are performed in 24 hours in series of 30% to 95% humidity.



Figure 5. Test in cycles of constant temperature of 20ºC and humidity between 30% and 95%.

Figure 5 shows the assembly carried out in the climatic chamber, the cycles were 25, 50, 100 and 200, where at the end of the cycle the test pieces referring to the climatic chamber were extracted and tests were carried out to flexure in 4 points as indicated in the ASTM-C947 Standard (2009).

IV. ANALYSIS AND DISCUSSION OF RESULTS

A.Mechanical behaviour of concrete

The values of the limit load of proportionality and modulus of rupture in the two stages analyzed (rupture and post-cracking) for the modified GRC with addition of fibers are presented in Figures 6. From the results obtained it is possible to conclude: i) The load of the limit of proportionality (LOP) and the modulus of rupture (MOR) of concrete increases significantly due to the presence of the fibers Roving Cem-Fil 54.



Figure 6. Stress-Displacement graph, GRC test aged to 50 cycles.

Performing the analysis of the GRC without aging, it is identified that the additions of pozzolans and acrylic resins show improvements towards flexotracción resistance from the 28 days of manufacture of the GRC. i) The inclusion of pozzolans and polymers in the bonding to the mortar paste contributes to the increase of its flexotracción resistance.

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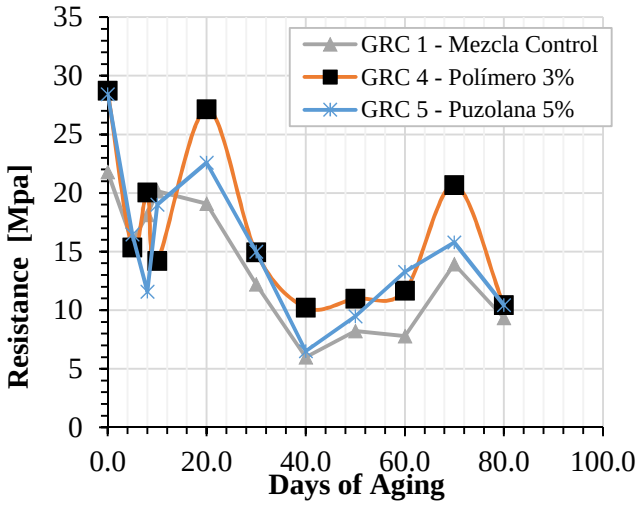


Figure 7. MPa resistance graph of the GRC from 0 to 80 days of accelerated aging in hot water immersion at 50°C, comparison between pozzolana at 5% and polymer at 3%.

The addition of metakaolin in 10% pozzolana does not represent improvements toward flexotracción resistance on the first 28 days of GRC and aged GRC manufacture, while there is a marked improvement for Pozzolana with 5% metakaolin, Figures 8 and 9, from which it can be identified. ii) A higher concentration of metakaolin in relation to the weight within the GRC matrix does not increase its flexotracción resistance, which indicates in pozzolans that the addition content is not proportional to the resistance.

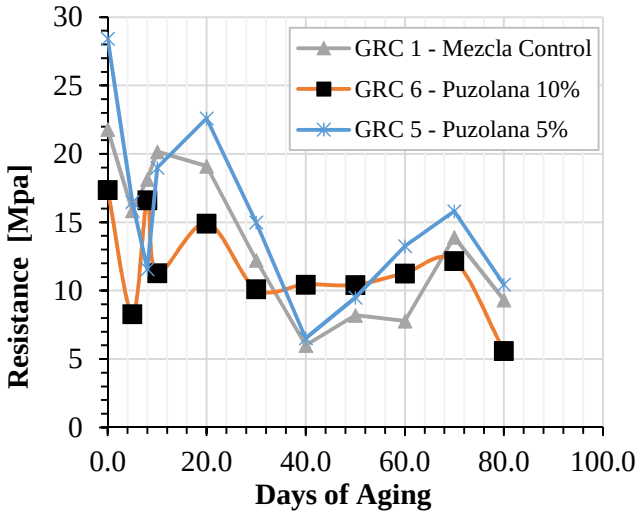


Figure 8. MPa resistance graph of the GRC with metacaolín additions, from 0 to 80 days of accelerated aging in hot water immersion.

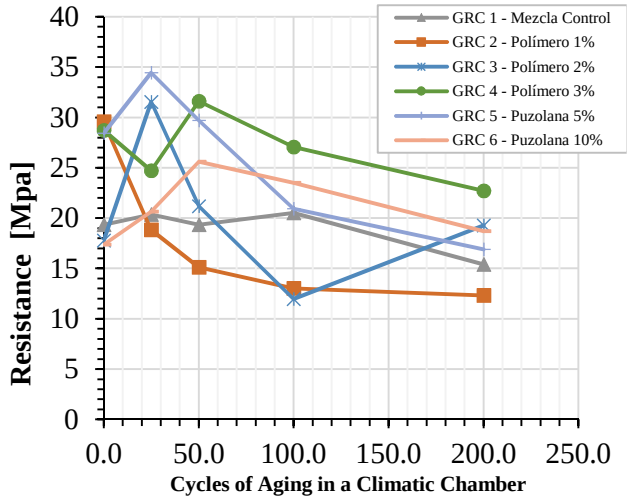


Figure 9. MPa resistance graph of the GRC with the 6 types of mixtures, from 0 to 200 cycles of accelerated aging in a climatic chamber (wetting and drying cycles).

The hot water immersion aging cycle noticeably decreases the mechanical properties of the GRC in comparison to the wetting and drying aging cycles. By comparing Figures 9 and 10, one can conclude that. iii). The two methods used recreate aging in the GRC, being more severe the immersion in hot water.

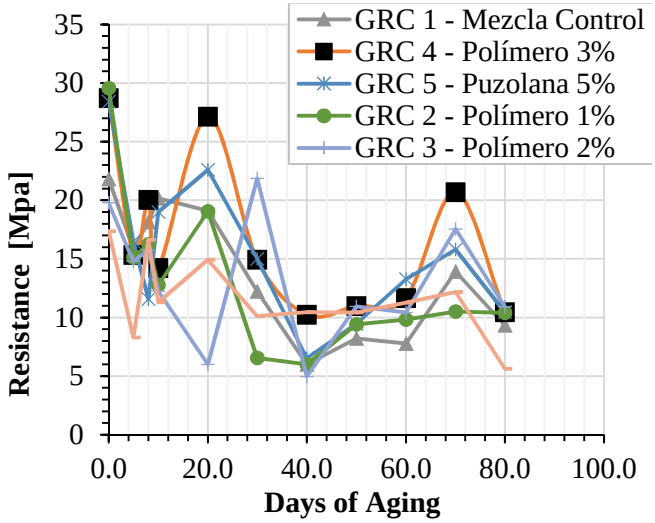


Figure 10. MPa resistance graph of the GRC from 0 to 80 days with the 6 types of mixtures, accelerated ageing in immersion in hot water at 50°C.

The addition of polymers within the GRC matrix increases the strength of the GRC modulus of rupture in accelerated aging environments by 48% for 200 wetting and drying cycles, and 38% in immersion of hot water for immersion in hot water, as shown below in Figures 7 and 11 iv). The addition of 3% polymers in the GRC matrix represents improvements over aging.

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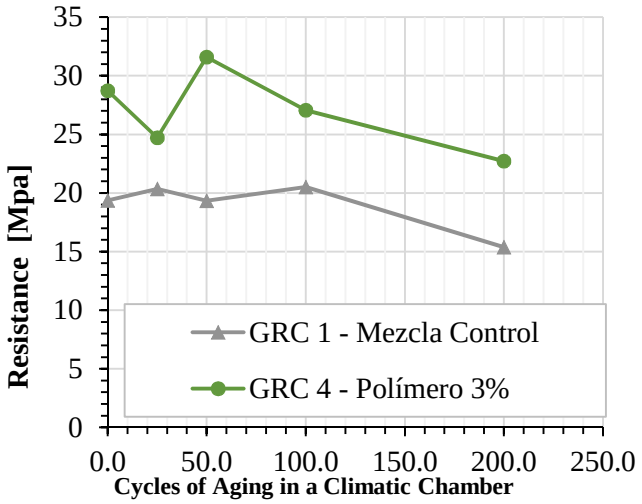


Figure 11. Graphic resistance in MPa of the GRC with 3% Control and Polymer mixture, from 0 to 200 aging cycles

v. CONCLUSIONS

A. The main conclusions of the work are:

- The two methods used recreate aging in the GRC, Immersion in hot water at 50°C and cycles of humidification and drying, the method in climatic chamber not as severe as that of immersion in water, however, if it begins to show a tendency in aging.

-It has been possible to identify the additions that present an improvement in the mechanical behavior to flexotracción of the GRC using accelerated aging, information is provided to the industry to improve the additions of the GRC with the use of polymers with a dosage at 3% according to the formulation in weight used in the industry, it is concluded that the greatest tendency to degradation of the material occurs at 40 days of accelerated aging in hot water at 50 ° C.

- A polymer addition to 3% of the additions proposed for this research is the best resulting addition that improves the properties of GRC samples. Within the results it is possible to appreciate that the flexotracción resistance increases in the order of 20 megapascals in comparison to the control sample without addition.

- The content of polymers in the GRC mixtures has a proportional effect on the resistance of the GRC, while the content of pozzolans (metakaolin) has the opposite effect.

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