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Mechanism of a vegetable waste composite with polymer-modified cement (VWCPMC)

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Abstract

In search for improved construction materials and techniques, two main factors must be taken into account: ecological impact and production costs. The incorporation of recycled materials originating from renewable sources into cementitious cores is a feasible alternative that has gained ground in civil construction. This study investigated the matrix of a vegetable waste composite with polymer-modified cement. Several mixtures composed of Slag-Modified Portland cement, treated vegetable residue, wood from the *Pinus caribaea* species, latex type polymer, styrene–butadiene rubber (SBR) and an adequate water ratio for the mixtures were studied. The composite was characterized based on mortar tests carried out according to ABNT norms to determine its mechanical behavior, workability and water absorption by capillarity. Some of the essential properties of mortars, such as workability, mechanical strength and durability were substantially altered by the addition of polymers when compared to mortars without this addition. The effect of reduced capillary pores resulting from the action of the polymer contributed to decrease in the permeability of the material, preventing the penetration of aggressive agents due to the phenomenon of water transport. The composite containing vegetable residues and SBR-modified core presented the best mechanical behavior, and an increase of the polymer content resulted in greater water retention in the fresh mixture and a significant reduction in porosity.

Keywords: Cementitious materials; Vegetable waste; Polymers; Water absorption; Porosity; Permeability

1. Introduction

The use of composites based on vegetable residues deriving from reforested tree species opens up a vast field of study, production and application in civil engineering. The application of these elements is interesting, among other aspects, from the standpoint of recycled residues from the wood industry, since these are easily available and renewable low-cost raw materials. The viability of the use of vegetable residues in cement paste depends on the appropriate chemical treatment for each species. Usually, in the wood extracts these residues are incompatible with Portland cement, particularly the soluble sugar components, inhibiting its adhesiveness and hardening [1]. This incompatibility can also be attributed to the amount of alkalis and dissolved wood extracts, which interfere in the cement hydration process and, hence, in the formation of the essential products that contribute to the strength of the composite [2]. Vegetable residue-based cementitious composites are highly porous and this porosity is a very important parameter, constituting the link between particle size distribution and the properties of the materials [3]. Among other characteristics, polymers have the property of dispersing their particles among other smaller ones. This particle

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distribution increases the composite strength by the filler effect that it produces, filling the empty spaces in the structure of the material [4]. The durability of conventional composites, the pathologies deriving from their dosage, the lack of knowledge about the characteristics of the materials employed, and the use of inadequate materials, are factors relevant to their performance and service life, demonstrating certain limitations associated with their diverse properties. The introduction of polymers into Portland cement composites allows for their use in a variety of applications in the form of constructive elements, owing to the properties conferred on them [5], which substantially alter their workability and mechanical strength. These properties are also affected by other factors, such as the types of polymers used, the cement–polymer ratio, the water–cement ratio, and the curing conditions [6]. This study investigated the behavior of a cementitious composite based on vegetable residues, *Pinus caribaea*, as a function of the variation of the SBR (styrene–butadiene rubber) polymer content, determining its physical–mechanical properties through fresh stage tests for mortars: consistency, mass density and content of incorporated air, water retention and, in the hardened stage: mechanical resistance, apparent mass density, capillary absorption, permeability and porosity.

2. Materials and methods

2.1. Materials

The vegetable residues used to prepare the composite originated from a renewable source, and the material was sieved through a # 4, 8 mm mesh sieve. After this separation, the vegetable material, *Pinus caribaea*, was chemically treated. This treatment consisted of minimizing the incompatibility between the cement and the vegetable residue using an alkaline solution $Ca(OH)_2$ bath, resulting in an improvement of the composite physical–mechanical performance. Owing to its hygroscopic characteristics, a previous analysis was made to determine the water content of this vegetable residue, thus minimizing the possibility of significant errors in the results. An infrared IRP-150 drier was used for this purpose, since it speeds up the testing procedure. The vegetable residue was then obtained after the separation, granulometric classification (NBR 7217), determination of the water content and chemical treatments of the raw material. The binder used was Slag-Modified Portland cement (ASTM C 595), characterized according to the Brazilian standards EB 2138/NBR 11578. The emulsive type polymer added to the composite is a petroleum by-product: styrene–butadiene rubber (SBR), specified as shown in Table 1.

Table 1
Properties of SBR (styrene–butadiene rubber)

Particle diameter (μm)	Viscosity (cp/20 °C)	pH	Solid density (%)	Specific gravity (g/cm^3)
0.2	100–300	6–7	49–51	1.00–1.03

2.2. Composite mixture proportions

The compositions used were determined based on earlier tests, analyzing the consistency of the composite and setting the W/B (water/binder) ratio. The ratio by mass was 1:0.69:1.52 (cement, vegetable residue and water), the reference trace, based on which the value of the SBR content was varied by 1%, 3%, 5%, and 7%, emulsified in the mixing water of the mixture. These variations produced five distinct compositions. The mixture was prepared using a mechanical mixer, into which were placed the initial dry materials (vegetable residue and cement), followed by the polymer and water emulsion. For the hardened stage tests, the samples were formed in 5 cm diameter, 10 cm high cylindrical molds and manually compacted in four layers with 25 blows each. After moulding, the samples were left in a air-conditioned environment (laboratory) for 48 h, after which they were removed from the molds and left in the lab until the date of the tests.

2.3. Flesh stage tests

The composite was characterized according to the fresh stage tests, for which it was determined that, initially, all the compositions follow the consistency index of the Flow Table Test (NBR 13276). This was followed by water retention tests (NBR 13277), and content of incorporated air and mass density (NBR 13278). The dosage of the composite components is an important factor for workability evaluation. The fresh stage tests permitted us to evaluate the methodology of preparation, optimizing the handling time of the mixture and facilitating the moulding of the sample.

2.4. Hardened stage tests

For the compressive strength tests (NBR 7215 and NBR 13279) and tensile strength (Brazilian Test—NBR 7222), the results were evaluated at the ages of 7, 14 and 28 days with three repetitions for each composition. For the remaining tests in the hardened state were carried out at 28 days to measure apparent mass (NBR 13280), water absorption by capillarity (NBR 9779), gas expansion porosity and permeability (based on Darcy's Law). Water absorption by capillarity [7],

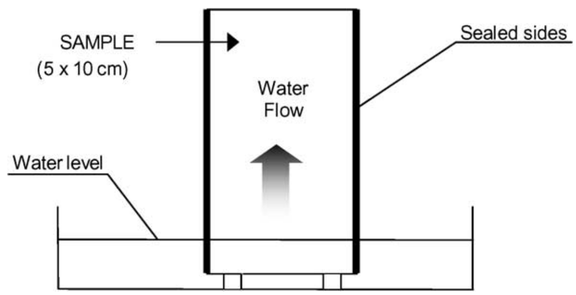

Fig. 1. Diagram of the VWCPMC capillary absorption testing device.

based on the NBR 9779 standard, was characterized by the penetration of water through the lower surface of the sample for 24 h in an atmosphere air-conditioned to approximately 23 °C. The preparation of the specimens, after moulding, consisted of oven drying at 100 °C until the mass became constant, ensuring an absorption flow in a single direction, as shown in Fig. 1.

2.5. The nitrogen gas expansion porosimeter—Boyle's law

The particle size distribution of cement influences the properties of fresh and hardened cement paste [8]. A porosimeter is a volume-measuring instrument that can be used to determine a sample grain or pore volume. Nitrogen is used as the test gas because its small molecules penetrate the tiny capillaries sometimes associated with residue composites, while the low mass of nitrogen atoms renders it highly diffusive [9]. The samples used in the gas expansion porosity tests in the porosimeter were prepared from the mortar specimens, machined down to a diameter of 1 in. diameter and a height of 2 in., which were the measures adapted to the molds used in the testing equipment. Thus, the same characteristics were maintained as those of the samples molded for the hardened stage tests.

2.6. Gas Permeameter operating instructions

The permeameter is an instrument designed to determine this property of fluid transmissibility. The specific permeability of a core may be experimentally determined by subjecting a prepared sample to an elevated gas pressure and measuring the volume flow rate of the gas [10]. Similarly to the porosity test, nitrogen gas is also used in the permeability test. Owing to the same properties described earlier, it is interesting to observe that the samples to be tested are the same ones used in the previous test. The results of the permeability test depend, essentially, on the capillary pore system and distribution in the sample, as well as on the water absorption by capillarity tests.

3. Results and discussion

Among the changes that occurred with the addition of PVA-type polymers to the conventional mortar and concrete in the fresh stage were the effective increase of the incorporated air content and of apparent fluidity [11]. Fig. 2 shows the variation in the values of the consistency rate produced by the addition of SBR, and confirms this tendency, displaying a significant increase in the composite fluidity with the use of increasing amounts of SBR in comparison to that of the reference. The best performance was observed with the addition in mass of 5% of SBR, which produced a 23% increase in the composite fluidity in comparison to that of the reference. Based on Fig. 3, which shows the variation in the values of water retention by the addition of SBR, it was found that there was a significant increase of the composite water retention properties with the addition of SBR in comparison to the reference, reaching a maximum mass value of 97.10%, which corresponds to the addition of 7% mass of SBR. This parameter demonstrates that the water retention capacity of VWCPMC is in agreement with the increased fluidity of the mixture and the easy moulding of the samples, the reasons for this can be explained in terms of the hydrophilic colloidal properties of the polymer latexes themselves and the

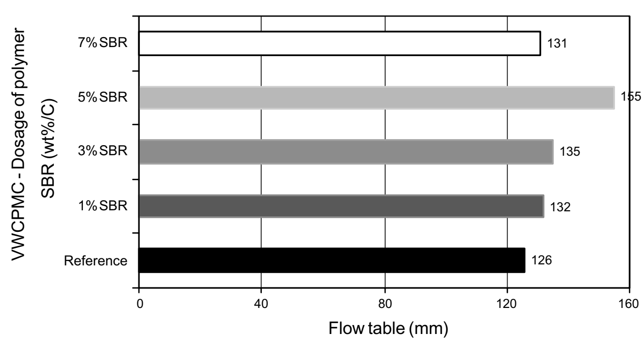

Fig. 2. Index of consistency versus the SBR content for the VWCPMC composite.

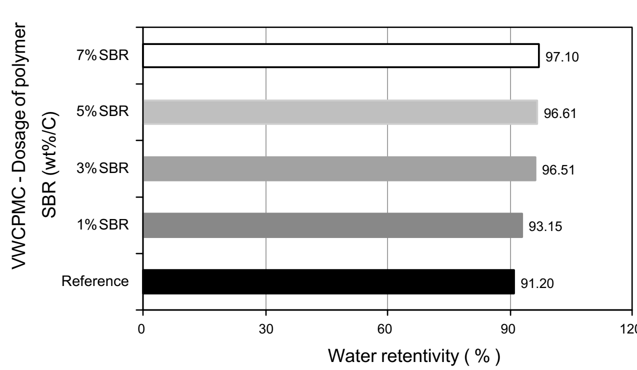

Fig. 3. Variation of water retention as a function of the SBR content for the VWCPMC composite.

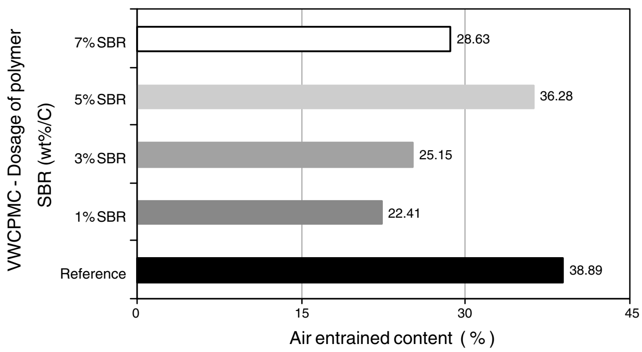

Fig. 4. Variation of the air incorporated as a function of the SBR content of the VWCPMC composite.

inhibited water evaporation due to the filling and sealing effects of impermeable polymer films formed [6]. Fig. 4, which shows the variation in the values of air incorporated by the addition of SBR, reveals a significant initial reduction in the content of air incorporated by the addition of SBR in comparison to the reference, followed by a gradual increase of this parameter, reaching a maximum value corresponding to an addition in mass of up to 5% of the polymer content. An analysis of Fig. 5, which illustrates the variation of compressive strength values by the addition of SBR, reveals that, up to 21 days of age, there was an initial increase in the compressive strength of this composite in comparison to that of the reference composite. However, from that age on, it was found that, for the 1% and 3% SBR contents, the values at 28 days were lower than those of the reference. On the other hand, using greater SBR contents resulted in a significant increase in compressive strength at 28 days, with an increase of approximately 46% above the value of the reference obtained for a content of 5% SBR. Fig. 6, which shows the variation in the values of tensile strength by the addition of SBR, revealed a significant increase in the tensile strength of the composite modified with more than 1% of SBR polymer in comparison to the reference composite. A 7% mass content gave rise to an increase of approximately 35% at 28 days. The use of SBR produced a considerable increase

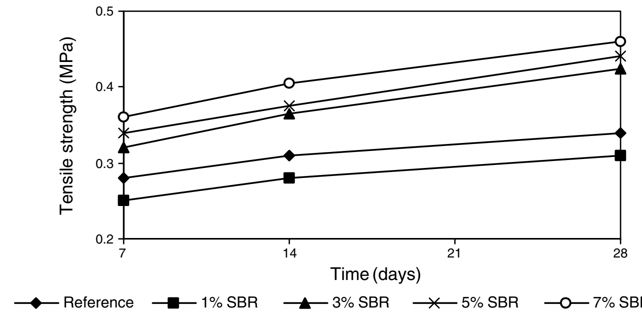

Fig. 6. Tensile strength versus time for the VWCPMC composite.

of the composite's tensile strength, it appears that the microcracks in latex-modified mortar and concrete under stress are bridged by the polymer films or membranes formed, which prevent crack propagation, and that simultaneously a strong cement hydrate-aggregate bond is developed [6]. Water absorption by capillarity depends, essentially, on the individual absorption capacity of the composite components and on the system and distribution of capillary pores and does not, necessarily, define the manner by which water is transported through the composite. Fig. 7 illustrates the variation of water absorption by capillarity as a function of the square root of time. Results clearly shows that the composite with a 5% addition of SBR was the one that absorbed the least amount of water in relation to its weight after 24 h of testing, remaining close to the result obtained for the reference composite. This may be attributed to the fact that the modified composite contained fewer interconnected pores. Fig. 8 shows the variation in the composite porosity as a function of the increase in polymer content, revealing a reduction in porosity with increased amounts of SBR. Analogous to the absorption test, the composition containing 5% added SBR presented the best result in comparison to the other compositions studied, indicating an ideal index in relation to the other SBR contents tested, and was therefore adopted as the mix proportion for the vegeta-

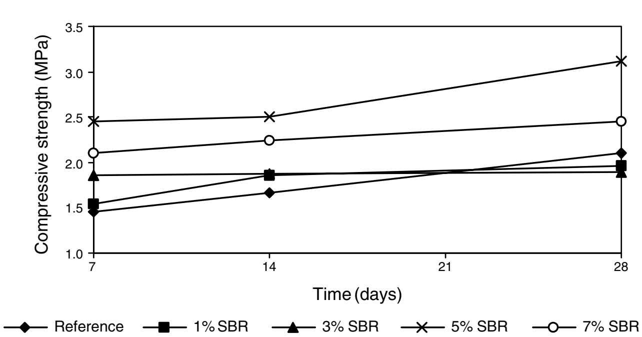

Fig. 5. Compressive strength versus time for the VWCPMC composite.

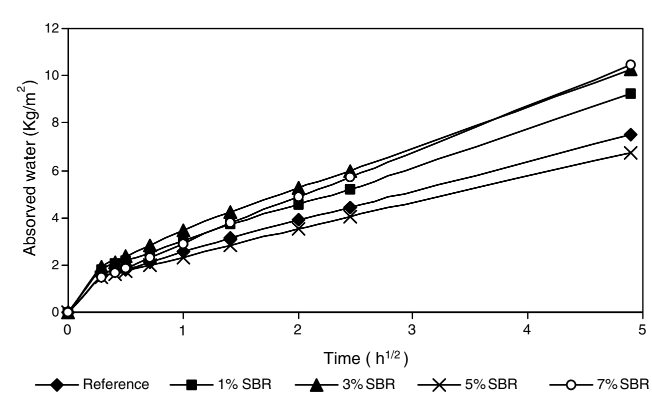

Fig. 7. Water absorption by capillarity versus square root of time for the VWCPMC composite.

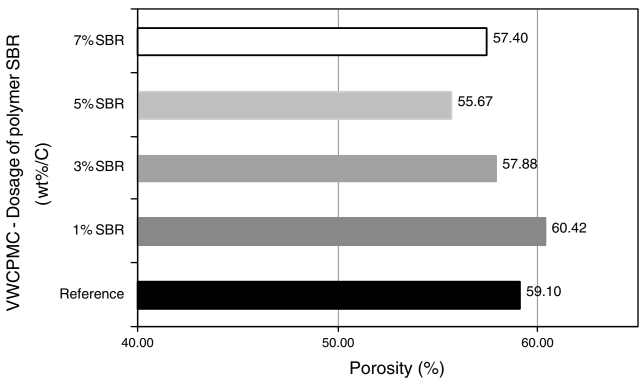

Fig. 8. Variation of porosity of the VWCPMC composite.

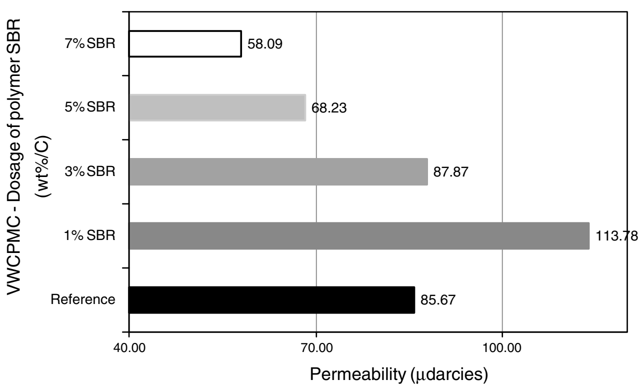

Fig. 9. Variation of permeability of the VWCPMC composite.

ble residue of the mixture. Fig. 9 presents the variation of permeability of the composite as a function of the increase in polymer content. It can be observed that permeability decreased with SBR contents of 5% and 7% in the composite. The addition of the polymer, in this case, led to a significant change in the transportation system of the material, due to the filler effect.

4. Conclusion

The application in civil construction of cementitious composites based on vegetable residues with cement paste modified with styrene–butadiene rubber (SBR) appears to be feasible, considering the results obtained from the analysis of its properties. From this standpoint, this study contributes toward the program of vegetable residue recycling and pollution reduction, since this material is biodegradable. The addition of polymer to the cementitious paste improved the physical–mechanical properties of the composite in both the fresh and hardened stages in comparison to the properties of the reference, and was efficient starting from the addition of 3%, while the best performance corresponded to the addition in mass of 5% of SBR, which represented a significant value. The polymeric emulsion was found to be a determining factor of the composite porosity and permeability reduction.

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