STUDY OF PERVIOUS CONCRETE PRODUCED WITH SUPPLEMENTARY CEMENTITIOUS MATERIALS

Fernanda dos Santos Gentil[1], Valéria Costa de Oliveira[2], Ieda Fagundes Zanolla[3], Claudio de Souza Kazmierczak[4], Marlova Piva Kulakowski[5], Franciele Rodrigues de Oliveira[6], Kátia Jocasta Ortiz Grings[7], Amanda Ramos Pauletto[8]
[1] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, nandasantos1855@hotmail.com
[2] Universidade do Vale do Rio dos Sinos / Instituto Federal de Ciência e Tecnologia de Rondônia, Rio Grande do Sul, Brasil, valeria.oliveira@ifro.edu.br
[3] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, ieda.zanolla@gmail.com
[4] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, Claudiok@unisinos.br
[5] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, marlovak@unisinos.br
[6] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, fran.civil@gmail.com
[7] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, katiajocasta@gmail.com
[8] Universidade do Vale do Rio dos Sinos, Rio Grande do Sul, Brasil, paulettoamanda@gmail.com

ABSTRACT

The growth of impermeable surfaces in urban regions, caused by fast urbanization, along with basic sanitation issues in developing countries has increased negative impacts in economic, social and environmental areas. Given this scenario, many cities face flooding problems. Studies emphasize that pervious concrete presents itself as an alternative to mitigate problems arising from urban drainage systems overload. This article proposes verifying the influence of adding supplementary cementitious materials such as, silica fume, metakaolin, fly ash, and rice husk ash, on mechanical properties and permeability of pervious concrete. The methodology used in this study was mapping and systemic reviewing literature, Brazilian and international, in order to cooperate for the solidification of knowledge, especifically that comprehending the behavior and applications of pervious concrete produced with supplementary cementitious materials. Results showed that it is possible to produce pervious concretes with supplementary cementitious materials, and use them as permeable pavements to meet the minimum requirements established in technical standards.

Keywords: special concretes, pervious concrete, supplementary cementitious materials, strength, permeability.

INTRODUCTION

Pervious concrete (PC) is a special type of concrete that contains a significant number of large pores, as well as a high-volume fraction. It is a material with almost zero slump; with discontinuous grading; composed of pórtland cement, coarse aggregate, few or no fine aggregate, admixtures, and water [1] .

The American Environmental Protection Agency requires private and public agencies to provide sustainable solutions to problems related to poor management of stormwater runoff. This Agency considers the use of PC as one of the best management practices in its manual of rainwater control technologies [1] . Thus, this technology has been widely used in pavements, known as permeable pavements, mainly in emerging countries such as Germany, The Netherlands and the United States. In the late 1940s, France was the pioneer in the use of permeable paving. Only in the 1970s did Japan, the United States, Sweden, and France itself, studied the use of this structure and applied it on a small scale [2] .

In Brazil, the current technical standard is ABNT NBR 16416 [3], whose basic requirements are permeability coefficient greater than 10^{-3} m/s and compressive strength greater than or equal to 20 MPa, in the case of pervious concrete.

Typical pore sizes found in this material are between 2 and 8 mm, and pores total volume fraction varies from 10 to 35 % [1] . As pervious concrete has a porous microstructure, this material has relatively lower strengths when compared to ordinary concretes.

According to internatonally developed research, compressive strength values found for this technology vary between 2.8 and 28 MPa [4] and permeability values are between 0.00003 and 0.033 m/s [5] . In order to increase the durability of pervious concrete, supplementary cementitious materials (SCM) are used in its composition [1] .The purpose of this review paper is analyzing the influence of SCM incorporation on mechanical properties and permeability of PC.

SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCM)

Cement is one of the most widely used building materials. However, its production ends up releasing a large amount of CO_2 into the atmosphere, consequently affecting global environment. In order to minimize harmful impact on the environment, researchers have investigated the incorporation of supplementary cementitious materials to partially replace cement [6] . Such materials have pozzolanic properties that react with water and calcium hydroxide ($Ca(OH)_2$) producing hydrated calcium silicate (C-S-H), which is similar to that obtained in the cement hydration process [7] .

The use of SCM has contributed to increase concretes strength and durability. Among them, some of the most used are fly ash, metakaolin, rice husk ash, silica fume, and others. Regarding the cementitious materials obtainment, it is known that fly ash is a by-product of burning coal in thermoelectric plants. They are fine, amorphous, and spherical shaped particles. Its chemical properties depend on the type of coal to be used, handling and storage techniques [8] .

Metakaolin is produced from the calcination of high purity clay in a temperature range of 700-850 ºC [7] . Unlike other pozzolans, metakaolin can be produced from rigorous quality control in order to achieve minimum variation in its composition, greater purity and degree of pozzolanic reactivity [9] .

Rice husk ash is a term used to characterize all types of ash produced by burning rice husks, in temperatures ranging between 350-1100 ºC. As a feature, this material is light, bulky and porous [10] . Silica fume is an amorphous material composed of SiO_2. It is an ultra-fine powder formed as a by-product of silicon and ferrosilicon alloys production, and contains spherical shaped particles with an average diameter of 150 nm [8] .

THE USE OF SCM IN PERVIOUS CONCRETES

According to literature review, it can be seen that there is no standardization of the ideal percentages of mineral additions that should be incorporated into permeable concrete mixtures, in order to provide significant results in mechanical properties and permeability.

As a form of investigation, the authors use different amounts of SCM in pervious concrete, as presented in Table 1.

Table 1: SCM's contents and features.

Authors	Type of SCM	SCM features	Content* (%)
[11]	Silica fume	SiO_2 content: 92.45 % Specific surface area: 18.000 m²/kg	6
[12]	Silica fume	-	7 and 10
[13]	Fly ash (Class C)	SiO_2 content: 61.8 % Specific Weight: 2.37 g/cm³	14, 16 and 18
	Silica fume	SiO_2 content: 98.2 % Specific Weight: 1.98 g/cm³	6, 8 and 10
[14]	Rice Husk Ash	SiO_2 content: 86.02 % Specific Weight: 2.1 g/cm³ Specific surface area: 3500 cm²/g	2, 4, 6, 8, 10 and 12
[15]	Fly ash	-	8.2 and 24.7
	Silica fume	-	7.4 and 7.6
[16]	Microsilica	Particle size: 0.4 µm Carbon content: 0.3 %	0.25 (fraction by weight)
	Silica powder	Particle size: 1.7 µm	0.25 (fraction by weight)
[17]	Rice Husk Ash	SiO_2 content: 85.5 – 95.5 % Particle size: < 45 µm Specific Weight: 2.3 g/cm³	10 and 20
[18]	Fly ash	SiO_2 content: 30.86 % Specific Weight: 2.77 g/cm³	20
[6]	Fly ash (Class C)	SiO_2 content: 51.56 % Specific Weight: 2.45 g/cm³ Particle size: < 450 µm	10 and 20
[19]	Fly ash	SiO_2 content: 36.4 % Specific Weight: 2.78 g/cm³	0 – 70
	Nano-silica	SiO_2 content: 92 % Specific Weight: 0.15 g/cm³ Specific surface area: 100±25 m²/g	0 – 3
[20]	Rice Husk Ash	SiO_2 content: 91.33 % Specific surface area: 6.15 m²/g, 6.85 m²/g, 7.74 m²/g and 8.85 m²/g	10
[7]	Fly ash (Class F)	SiO_2 content: 47.5 % Specific Weight: 2.471 g/cm³	0 – 20
	Metakaolin	SiO_2 content: 50.85 % Specific Weight: 2.601 g/cm³	2
[21]	Silica fume	Particle size: 18.62 µm Specific Weight: 2.27 g/cm³	8

* Percentage on cement content

Researchers Yang and Jiang [11] produced pervious concretes with 6 % silica fume. In this study, the size of coarse aggregate, which was between 5-10 mm and 3-5 mm, and the percentage of superplasticizer admixtures were varied through the mixture production. Compressive strength values found were between 13.8 MPa to 57.2 MPa. They found that mixtures with 3-5 mm aggregate size, 6 % silica fume and 0.8 % superplasticizer reached 57.2 MPa compressive strength compared to mixtures that did not use silica fume and admixtures (13.8 MPa). This mixture showed a permeability coefficient of 0.0017 m/s. Thus, authors concluded that the use of smaller aggregates with the presence of silica fume and superplasticizer admixture can contribute to a pervious concrete production with high compressive strength and satisfactory water penetration.

In the studies of Lian and Zhuge [12] coarse aggregate values were set at 4.75-9.5 mm and different water/cement ratios (w/c) were used: 0.28, 0.32 and 0.36. Fine aggregates were not used, silica fume content varied between 7 % to 10 %, and samples with (0.8 %) and without superplasticizer admixture were produced. They found that mixtures which presented 7 % of silica fume and 0.8 % of superplasticizer in their composition obtained higher compressive strength values at 28 days (33.2 MPa) compared to both types of specimens, that is, samples with only 10 % of silica fume (22.0 MPa), and those specimens produced without silica fume and without superplasticizer admixture (17.0 MPa). For those strength values, the following permeability coefficients were found: 0.00398 m/s, 0.00613 m/s and 0.00851 m/s, respectively. In this research, authors mention that the recommended flow rate for pervious concretes is between 0.002 m/s to 0.0054 m/s. In this first study group, they found that silica fume has a significant influence on the compressive strength of pervious concrete.

Considering other analyzes, the same authors kept the size of the coarse aggregates fixed at 4.75-9.5 mm, used different w/c ratios: 0.30, 0.32, 0.34, 0.36 and 0.38, added 18 % sand, 7 % silica fume and 0.8 % superplasticizer admixture in all samples. Mixtures with w/c ratios of 0.30, 0.32 and 0.34 showed higher compressive strength values, greater than 40 MPa, than mixtures with w/c of 0.36 and 0.38, which reached 33 MPa and 23 MPa, respectively. In these analyzes, samples with w/c of 0.38 showed a high permeability coefficient of 0.00842 m/s, and mixtures with w/c of 0.34 presented a 0.00122 m/s permeability, that is, the latter characterizing a value below recommended range. As a result, they concluded that samples with w/c of 0.32 obtained compressive strength (40.5 MPa) and permeability coefficient (0.00242 m/s) results consistent to established goals and recommendations.

The author Costa [21] used silica fume to produce pervious concrete. In her research she used 8 % silica fume with w/c ratios of 0.26 and 0.30. In all samples, a rheology modifying admixture was incorporated. It was found that the incorporation of silica fume in the samples with w/c ratio of 0.30 provided a 1 MPa decrease in the compressive strength value. Samples with w/c of 0.26 and silica fume achieved compressive strength two times higher than mixtures without silica fume. The author believes that this difference is a consequence of the greater admixture content present in mixtures with w/c ratio of 0.26 and silica fume, which caused the paste to precipitate, decreased porosity and increased compressive strength when compared to samples without silica fume. For permeability, mean values of 0.89 cm/s were found for samples with w/c ratio of 0.30 and 0.76 cm/s for mixtures with w/c ratio of 0.26. Specimens with w/c ratio of 0.26 and silica fume achieved a 33 % increase in split tensile strength compared to samples that did not have this SCM in their composition.

In the works of Zhong and Wille [16] high performance pervious concrete was produced with the incorporation of microsilica and silica powder. Each one of these materials was used in a proportion of 0.25 in relation to the cement weight used in the research. They obtained samples that reached compressive strengths above 40 MPa. In this research they mention that compressive strength and permeability parameters are inversely proportional. They find that pervious concrete with compressive strength greater than 50 MPa, and with a permeability coefficient greater than 1 mm/s, meets the goals proposed by the research.

Researchers Kim, Gaddafi and Yoshitake [18] produced pervious concrete with fly ash (20 %). For comparison purpose, they produced control samples, that is, without the presence of SCM in concrete composition. As a result, the control samples obtained 9.4 MPa compressive strength. The incorporation of fly ash in the mixtures represented a 9.6 % reduction in strength. Permeability values were obtained in different ways by subjecting pervious concrete to various levels of load intensity of instantaneous duration (0 %, 50 % and 75 % load). According to the results found, they observed that the greater the load application (75 %) the lower the permeability coefficients.

Fly ash was also used in studies by Um Maguesvari and Sundararajan [6] . The percentages of SCMs used were 10 % and 20 %. Authors varied the content of paste in the mixture (250, 300, 350 and 400 kg/m³). Values between 5.70 and 8.83 MPa were found for compressive strength. Split tensile strength results were found to be between 1.45 and 1.86 MPa. In this work they did not identify, in a relevant way, the influence of the different amounts of SCM in pervious concrete mechanical properties. For permeability, values were in the range of 0.00641–0.0119 m/s. They found that permeability coefficient decreases as paste content increases. Samples with 10 % fly ash showed higher permeability values compared to mixtures with 20 % fly ash.

Both fly ash and silica fume were used to produce pervious concrete in the research led by Sri Ravindrarajah and Kassis [15] . They produced control samples without SCM, samples with 24.75 % fly ash, samples with 7.4% silica fume, and mixtures which combined 8.2 % fly ash and 7.6 % silica fume. They used w/c ratios of 0.30 and 0.32. As a result, compressive strength between 12.8 MPa and 22.5 MPa was obtained. They found that partial replacement of cement by SCM resulted in increases in compressive strength. The lowest strength was found in samples that did not have SCM in their composition. The greatest strength was obtained in pervious concrete mixtures that presented only silica fume. Regarding permeability values, they observed a significant reduction when pervious concretes with SCM were produced. The highest permeability coefficient value (0.00663 m/s) was obtained in samples without SCM, whereas the lowest value (0.00387 m/s) was found for the combined mixtures.

For the production of pervious concrete, the researchers Mohammed et al. [19] incorporated fly ash (0-70 %) and nano-silica (0-3 %) into the mixture composition. In this work, they verified that pervious concrete compressive strength is affected by the compressive strength of cement paste in the hardened state. They believe that pervious concrete will present significant values for this property, if the compressive strength of the cement paste is improved. They observed that the incorporation of nano-silica increased compressive strength, as it modified cement paste microstructure. They point out that nano-silica has the advantage of activating fly ash reaction, thereby reducing the roughness of the voids' internal surface and improving water penetration. They found that the increase in fly ash percentage in the mixture led to a decrease in pervious concretes compressive strength. Regarding permeability, they concluded that the increase in cement percentage replacement by fly ash provided higher values of permeability coefficients.

Other researchers Saboo, Shivhare, Kori and Chandrappa [7] used the supplementary cementitious materials, fly ash (0-20 %) and metakaolin (2 %), in pervious concrete production. They found that the increase in fly ash and metakaolin content allowed the pervious concrete to have lower porosity values. They found that mixtures with an addition of 2 % metakaolin, without any amount of fly ash, showed an increase in density of 6.5 %. As fly ash was added to these samples, they observed a growth trend in the density property. Considering the mixtures that had 2 % metakaolin, the researchers were able to verify that the permeability decreased with the increase in the percentage of fly ash, which may be related to the increase in density and the decrease in porosity.

Permeability reduction was greater in samples that presented 5 to 15 % fly ash in its composition. Another observed point was that the increase in fly ash and in the metakaolin content in the mixtures provided greater results for compressive strength. Thus, the increase in compressive strength was greater among samples that showed between 5 and

15 % fly ash. Through statistical analysis, authors concluded that only the fly ash content significantly influenced the permeability and compressive strength values.

The Hesami, Ahmadi and Nematzadeh [14] produced pervious concrete with rice husk ash (RHA) (2 %, 4 %, 6 %, 8 %, 10 % and 12 %). Coarse aggregate and sand contents were set at fixed values. The amounts of superplasticizer admixture, rice husk ash, and the w/c ratios (0.27, 0.33 and 0.4) were varied. The researchers report that pozzolanic properties of RHA provide improvements to the physical structure of cement, thus contributing to cement paste becoming denser. This SCM reacts with calcium hydroxide in the hydration process and promotes better adhered paste connectivity, thereby reducing transition zone thickness between the coarse aggregate and the cement paste. For this reason, they believe that pervious concrete samples had their mechanical properties improved.

In the first analysis carried out by the researchers in mixtures with only RHA, they concluded that the percentage of 8 % of this material, in pervious concrete, is an ideal content and provided compressive strength of 17 MPa, as percentage values higher than this cause a decrease in this property. The incorporation of 8 % of rice husk ash allowed pervious concrete to reach 29 % higher compressive strength than the control samples, those without SCM in their composition.

These authors Hesami, Ahmadi and Nematzadeh [14] found permeability coefficients in the range of 0.0008-0.0048 m/s. They observed that permeability decreased in the samples that presented the ideal RHA value (8-10%), and increased when they used greater amounts of this SCM. However, they verified the opposite behavior in the compressive strength property.

The Arshad et al. [20] also produced pervious concrete with rice husk ash (RHA). Cement was replaced by 10 % of RHA. Researchers analyzed the influence of the incorporation of this SCM provided through several grinding periods (33 h, 48 h, 63 h and 81 h). They found that the compressive strength of concrete tends to increase as the grinding periods for RHA production increase. The highest compressive strength (18.99 MPa) was found in pervious concrete semples with RHA from the 63-hour grinding period. According to researches raised by [8] , RHA can not fully replace cement in the production of pervious concrete. Levels between 10-12 % of this SCM are considered ideal to obtain a pervious concrete with good mechanical and hydraulic performances.

CONCLUSION

Pervious concrete is influenced by some variables, such as cement content, w/c ratio, types of aggregates, admixtures, compaction and curing process. According to outcomes found in the reviewed studies, it is noted that SCMs have a significant influence on the compressive strength of pervious concretes.

The optimal w/c ratio, as addressed in the studies, is between 0.25 and 0.32. Compressive strength and permeability parameters are inversely proportional. Pervious concrete's compressive strength is affected by the compressive strength of its cement paste in the hardened state

From literature review, it was found that SCMs can be considered as alternatives for improving permeable concrete performance. Among the mineral additions mentioned in this article, which requires further study development, as they provided good characteristics to the permeable concrete are: active silica, rice husk ash and fly ash. It was found that the use of active silica and up to 10 % rice husk ash provided excellent results for mechanical properties, even higher than the values presented in the standards. Regarding the hydraulic property, fly ash showed significant results for the material, that is, within limits established in the standards.

REFERENCES

[1] Mehta PK, Monteiro PJM, “Concreto: microestrutura, propriedades e materiais”, 2º ed. São Paulo, Ibracon, (2014), 594-602.
[2] Virgiliis ALC, “Procedimentos de projeto e execução de pavimentos permeáveis visando retençãoe amortecimento de picos de cheia”, Dissertação (Mestrado), Escola Politécnica, Departamento de Engenharia de Transportes, Universidade de São Paulo, São Paulo, (2009).
[3] NBR 16416, “Pavimentos permeáveis de concreto- Requisitos e procedimentos”, Associação Brasileira de Normas Técnicas, Rio de Janeiro, (2015).
[4] Committee 522, “ACI Report on Pervious Concrete”, American Concrete Institute, (2010).
[5] Yap SP et al, “Characterization of pervious concrete with blended natural aggregate and recycled concrete aggregates”, Journal of Cleaner Production, Vol. 181, (2018), 155-165.
[6] Um Maguesvari M, Sundararajan T, “Influência das cinzas volantes e agregados finos nas características do concreto permeável”, International Journal of Applied Engineering Research, Vol. 12, (2017), 1598-1609.
[7] Saboo N, Shivhare S, Kori KK, Chandrappa AK, “Effect of fly ash and metakaolin on pervious concrete properties”, Construction and Building Materials, Vol. 223, (2019), 322-328.
[8] Ghosh SK, Chaudhury A, Datta R, Bera DK, “A review on performance of pervious concrete using waste materials”, International Journal of Research in Engineering and Technology, Vol. 4, (2015).
[9] Brooks JJ, Megat Johari MA, “Effect of metakaolin on creep and shrinkage of concrete”, Cement & Concrete Composites, Vol. 23, (2001), 495-502
[10] Fernandes IJ, “Desenvolvimento e caracterização de compósitos de cinza de casca de arroz em matriz epóxi”, Dissertação (Mestrado em Engenharia Civil), Programa de Pós-graduação em Engenharia Civil, Universidade do Vale do Rio dos Sinos, São Leopoldo, (2015).
[11] Yang J, Jiang G, “Experimental study on properties of pervious concrete pavement materials”, Cement and Concrete Research, Vol. 33, (2003), 381-386.
[12] Lian C, Zhuge Y, “Optimum mix design of enhance permeable concrete – An experimental investigation”, Construction and Building Materials, Vol. 24, (2010), 2664-2671.
[13] Chen Y, Wang K, Wang X, Zhou W, “Strength, fracture and fatigue of pervious concrete”, Construction and Building Materials, Vol. 42, (2013), 97-104.
[14] Hesami S, Ahmadi S, Nematzadeh M, “Effects of rice husk ash and fiber on mechanical properties of pervious concrete pavement”, Construction and Building Materials, Vol. 53, (2014), 680-691.
[15] Sri Ravindrarajah R, Kassis SJ, “Effect of supplementary cementitious materials on the properties of pervious concrete with fixed porosity”, 23rd Australasian Conference on the Mechanics of Structures and Materials, Byron Bay, Australia, (2014).
[16] Zhong R, Wille K, “Material design and characterization of high performance pervious concrete”, Construction and Building Materials, Vol. 98, (2015), 51-60.
[17] Talsania S, Pitroda J, Vyas CM “Effect of rice husk ash on properties of pervious concrete”, International Journal of Advanced Engineering Research and Studies, Vol. IV, (2015), 296-299.
[18] Kim YJ, Gaddafi A, Yoshitake I, “Permeable concrete mixed with various admixtures”, Materials & Design, Vol. 100, (2016), 110-119.
[19] Mohammed BS et al., “Case studies in construction materials properties of nano-silica modified pervious concrete”, Case Studies in Construction Materials, Vol. 8, (2018), 409-422.
[20] Arshad MF et al., “Effect of nano black rice husk ash on the chemical and physical properties of porous concrete pavement”, Journal of Southwest Jiaotong University, Vol. 53, (2018), doi: 10.3969/j.issn. 0258-2724.2018.015
[21] Costa FBP, “Análise e desenvolvimento de misturas de concreto permeável para aplicação em pavimentação”, Tese (Doutorado em Engenharia), Programa de Pós-graduação em Engenharia Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre, (2019).