Chapter 4
The Design of a Cementitious Material Modified with the Synergistic Addition of Sodium Silicate and Fine Aggregate Sourced from Granite Waste in Order to Obtain a Mortar with Low Capillary Suction

Natalia Szemiot and Łukasz Sadowski

Abstract The aim of the study was to design a cementitious material that is prepared with the synergistic addition of sodium silicate and granite fine aggregate in order to obtain low capillary suction. For this purpose, three different classes of cement mortar (M15, M10, M5), one type of granite fine aggregate and two different proportions of additive in the form of sodium silicate (0.002 kg, 0.005 kg) were analysed. Firstly, the capillary suction of the granite aggregates was analysed and compared with traditional sand. Afterwards, nine cementitious material bars were made, which were then used to examine the capillary suction. It was proved that the M15 cementitious material with the granite fine aggregate and a higher proportion of the additive had the lowest capillary suction. In turn, the M5 cementitious material without the additive had the highest index of capillary suction, which shows that adding sodium silicate to cement mortar can significantly reduce its capillary suction. Finally, the results of this study were compared with the previous authors' studies concerning basalt and quartz fine aggregates. As a result of the research, it was found that the cementitious material with the fine quartz aggregate had a lower rate of capillary suction index than the cementitious material with the fine basalt aggregate.

Keywords Design · Cementitious materials · Capillary suction · Granite fine aggregate · Mortar

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4.1 Introduction

Dampness is one of the main causes of the degradation of civil engineering structures made of brick (e.g. buildings and bridges). In winter, moisture can freeze and lead to the bursting of building materials due to an increase in the volume of water as it becomes solid (Clim et al. 2017; Aval et al. 2022; Yik et al. 2004; Hoła and Czarnecki 2022). The common process of the flow of moisture in the structure of building materials is known as capillary suction (Popek and Wapińska 2009; Pratiwi et al. 2020; Saberian et al. 2017; Karagiannis et al. 2018), which involves the upward transport of water in a porous material by means of capillary forces. These forces depend on the amount of open pores in the material, as well as their diameters (Karoglou et al. 2005; Dondelewski and Januszewski 2008). The smaller the diameter of the capillaries, the higher the level of wall dampness. The height at which capillary suction is noticeable which depends on the structure of the material, primarily its porosity and the system of pores and capillaries (Moropoulou et al. 2001). Figure 4.1 shows the capillary suction of water.

Moisture occurring in building partitions causes the deterioration of their properties, such as e.g. their thermal resistance. In article (Kon and Caner 2022), the authors present the influence of various insulation materials (e.g. hemp wool insulation), and their thicknesses, on the reduction of dampness in walls. They also describe the use of various energy sources for limiting the appearance of dampness in walls. Regardless of the type of used insulation, dampness and mould, to a greater or lesser extent, appeared on the walls.

Cement mortar contains cement, water and aggregate, and therefore when designing cementitious materials, the type of fine aggregate is important (Woźniak

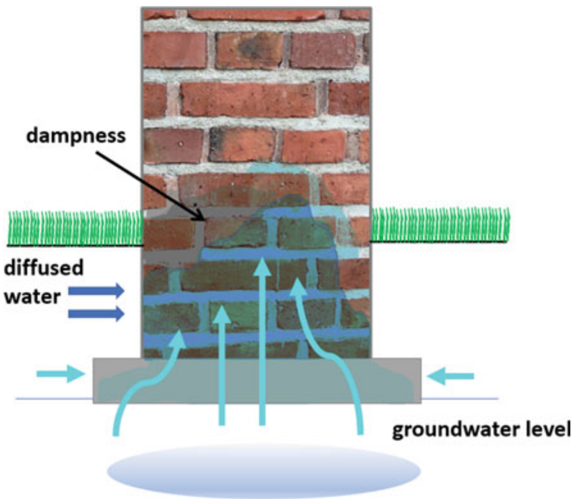

Fig. 4.1 Capillary suction of water as a one of the main reasons of dampness in civil engineering structures made of brick

and Chajec 2022). Approximately 71–78% of the volume of cement mortar is fine aggregates sourced from granite quarry waste. Nowadays, the application of aggregates from industrial wastes is getting more attention (e.g. regarding their use in fine-grained concrete with enhanced durability (Zajceva et al. 2021), or mortars with fine aggregates sourced from crushed glass (Czapik et al. 2020)). In the research presented in this article, granite fine aggregate was used. The results of this study were compared with the authors' previous studies concerning basalt and quartz fine aggregates. Moreover, the used cementitious material was modified with the addition of sodium silicate in various proportions.

The novelty of the article involves the design of a cementitious material that is modified with the addition of sodium silicate and granite fine aggregate in order to obtain a material with low capillary suction. Moreover, the authors conducted research on the reduction of the capillary suction index of cementitious mortars that were prepared with the use of sodium silicate, basalt fine aggregate and quartz fine aggregate.

4.2 Materials and Methods

4.2.1 Granite Fine Aggregate

In the authors' studies, granite fine aggregate with a density of $\rho d = 2.60$ g/cm^3 was used. The grain size of granite fine aggregate ranges from 0.25 to 2.5 mm. It is a natural aggregate that consists of many minerals, such as mica (about 10%), quartz (about 35%) and feldspar (60–65%). Granite is the most common igneous rock and occurs on all the continents in the world (Nedelec and Bouchez 2015). Figure 4.2 represents the particle size distribution of granite fine aggregate.

4.2.2 Cement

Portland cement CEM I 42.5 R was used in the research. Portland cement is a loose and grey material that is made by combining ground cement clinker (95%) with gypsum (max. 5%) (Bogue 1948). The chemical composition of clinker includes: alite; tricalcium silicate (50–65% of the clinker's mass); belite; dicalcium silicate (approx. 20% of the clinker's mass); brownmillerite; a compound of calcium oxide, aluminium oxide and iron (III) oxide (approx. 10% clinker mass); tricalcium aluminate (approx. 10% of the clinker's mass); and other aluminium, calcium and magnesium compounds (Double et al. 1978). CEM I is a Portland cement with no additives and is a pure form of cement. In Portland cement CEM I 42.5 R, there is 0.07% of Cl-, 3.2% of SO_3 and 0.80% of Na_2O. The grain size of Portland cement ranges from 0.02 to 0.14 mm.

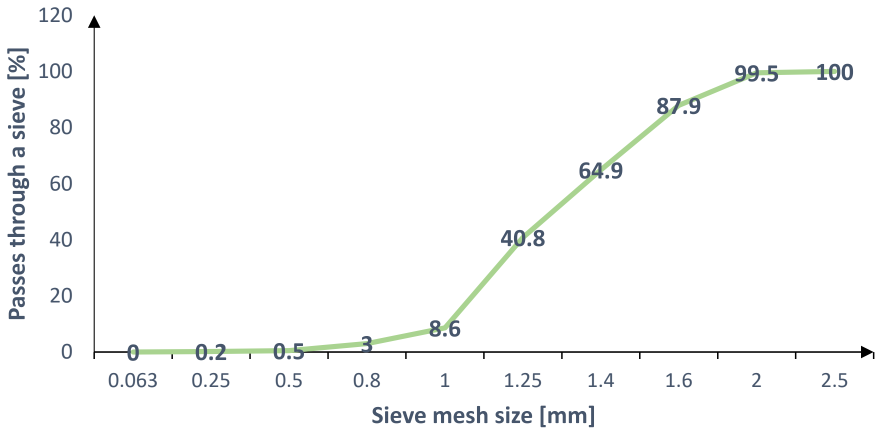

Fig. 4.2 Particle size distribution of granite fine aggregate

4.2.3 Sodium Silicate

Sodium silicate was used in this study as an admixture. The chemical formula of this admixture is Na_2O $nSiO_2$. The content of the pure substance ranges from 18 to 40% ($Na_2O + SiO_2$), and the rest is water. Sodium silicate is a semi-translucent, white or colourless, viscous and odourless liquid, which is easily soluble in water. It is inorganic, non-flammable and has a pH of 11–13 in a temp of 20 °C. The pour point of sodium silicate is 730–870 °C, and its softening point is 550–670 °C. The relative density of this substance ranges from 1.26 to 1.71 g/cm^3, and its tenacity ranges from 20 to 800 mPa/20 °C. The substance is mixed with water in different ratios.

4.2.4 Testing the Capillary Suction of the Granite Fine Aggregate

The research consisted of measuring the height of the capillary suction of the granite fine aggregate. For this purpose, three granite fine aggregate samples were prepared, with each being placed in a 1500 mm long pipe of plexiglass. The dimensions of the pipe and the test stand are shown in Fig. 4.3. The pipe was embedded in a glass container filled with liquid up to 10 mm, and then filled with granite fine aggregate. After a specific time, the index of the capillary suction of the fine aggregate was measured. Figure 4.3 shows the scheme of testing the capillary suction of the granite fine aggregate.

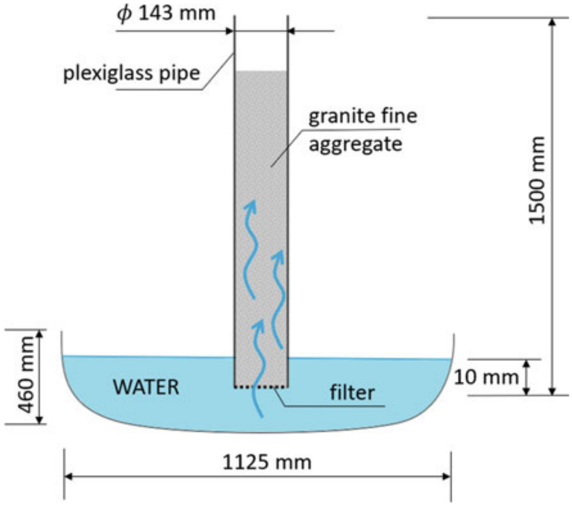

Fig. 4.3 Testing the capillary suction of the fine granite aggregate (own elaboration based on Wysocka et al. 2013)

4.2.5 Testing the Capillary Suction of the Designed Cementitious Material

The research consisted of measuring the height of the capillary suction of the cementitious material. 9 bars of cementitious mortar with dimensions of 40 × 40 × 160 mm were prepared according to standard PN-EN 480-1. Figure 4.4 shows the components of each of the 9 bars of the cementitious mortars. The amounts of the components of the cementitious materials are shown in kilograms. The cementitious material was kept in moulds for 28 days. After this time, the capillary suction tests were performed, with the index of the capillary suction of the cementitious material then being measured.

4.3 Results

4.3.1 The Capillary Suction of the Granite Fine Aggregate

Three samples of granite fine aggregate were used to analyse its capillary suction. Each sample was measured thirteen times. From these 3 samples, the average height of the capillary suction was calculated and is given in the last column of Table 4.1. Table 4.1 presents the results of testing the capillary suction of the granite fine aggregate.

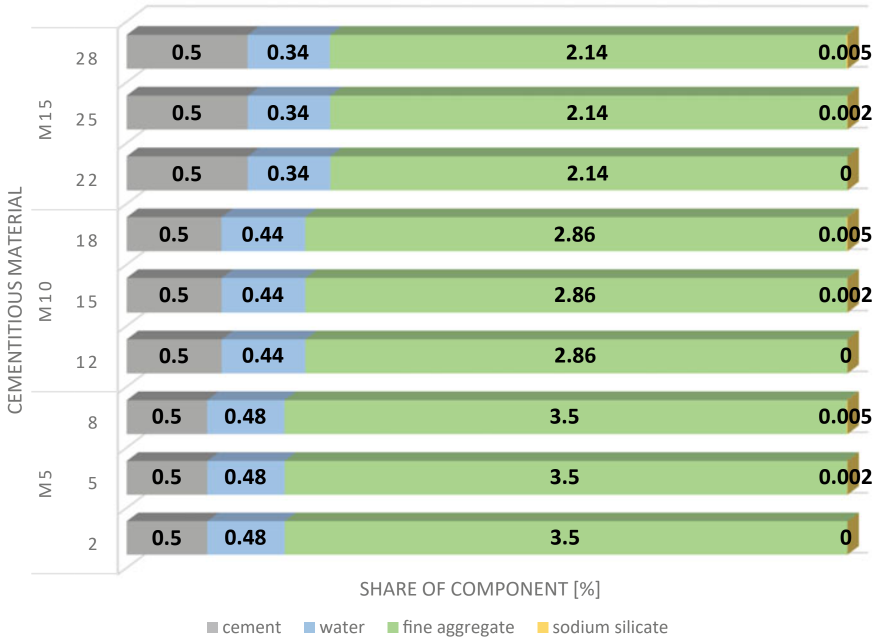

Fig. 4.4 Components of the cementitious mortars

Table 4.1 Tests of the capillary suction of the granite fine aggregate

Granite fine aggregate				
Time (h)	Height (mm)			
	Sample 1	Sample 2	Sample 3	Average
0.12	51	48	50	49.67
0.25	79	76	78	77.67
0.5	101	98	100	99.67
1	136	132	135	134.33
2	178	170	178	175.33
3	195	189	193	192.33
5	220	215	221	218.67
10	235	227	236	232.67
24	249	241	250	246.67
48	261	256	264	260.33
72	275	269	277	273.67
96	280	274	284	279.33
120	291	286	298	291.67

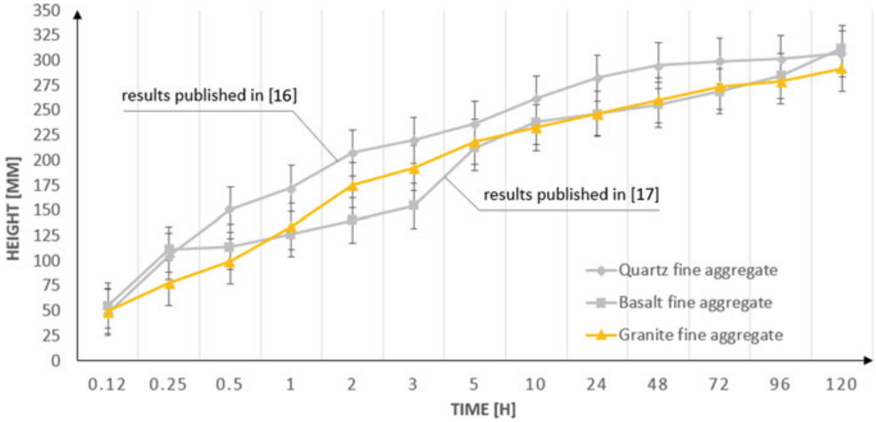

Fig. 4.5 Capillary suction of the granite, quartz and basalt fine aggregates—a comparison

Figure 4.5 presents a comparison of the capillary suction of three different fine aggregates: granite, quartz and basalt. In the first fifteen minutes of the tests, the capillary suction of the basalt and quartz fine aggregate was similar. However, the granite fine aggregate had about a 20% lower capillary suction than the quartz and basalt fine aggregates. From the 15th minute to about the 96th hour of the research, the capillary suction of the granite and quartz fine aggregates was similar, whereas the capillary suction of the basalt fine aggregate was lower when compared to the other fine aggregates. In the last hour of the research, the quartz and basalt fine aggregates had a higher capillary suction than the granite fine aggregate. The granite fine aggregate was about 4.9% more resistant to capillary suction than the quartz fine aggregate, and about 6.6% more resistant to capillary suction than the basalt fine aggregate. The granite fine aggregate had the most favourable result with regards to capillary suction.

4.3.2 *The Capillary Suction of the Prepared Cementitious Materials*

Figure 4.6 shows a comparison of the capillary suction of the M5 cementitious material that was prepared with the addition of sodium silicate and three different fine aggregates: quartz, basalt and granite. A total of six different cementitious material bars was compared (the composition of the cementitious mortar bars is presented in Fig. 4.4). Each cementitious material bar was measured thirteen times.

Figure 4.6a shows the capillary suction of the three M5 cementitious material bars that had a lower amount of sodium silicate. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate and the third bar—the granite fine aggregate. From the beginning of the research to about the 48th hour, the

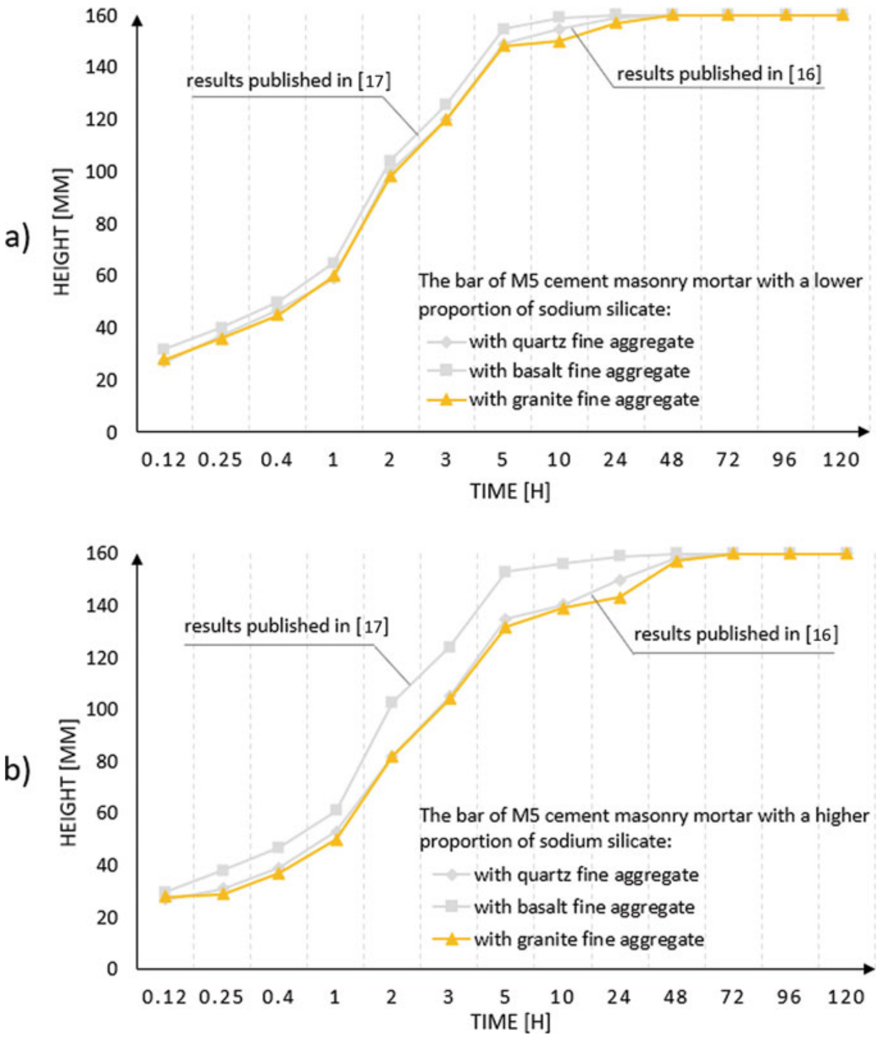

Fig. 4.6 Capillary suction of the M5 cementitious material bars with the granite, quartz and basalt fine aggregates: **a** with a lower proportion of the additive and **b** with a higher proportion of the additive

cementitious material with the granite fine aggregate and the cementitious material with the quartz fine aggregate had similar results. At the same time, the cementitious material with the basalt fine aggregate had about a 6% higher capillary suction than the other bars. After the 48th hour of testing, all the bars achieved the same result.

Figure 4.6b presents the capillary suction of the three M5 cementitious material bars that a higher amount of sodium silicate. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate and the third bar—the granite fine aggregate. As was the case in Fig. 4.6a, from the beginning of the research to about 48 h, the cementitious material with the granite fine aggregate and the cementitious material with the quartz fine aggregate had similar results. At the same time, the cementitious material with the basalt fine aggregate had about a 12.5% higher capillary suction than the other bars. After the 48th hour of testing, all the bars achieved the same result.

Figure 4.7 shows a comparison of the capillary suction of the M10 cementitious material, which was prepared with the addition of sodium silicate and three different fine aggregates: quartz, basalt and granite. A total of six different cementitious material bars were compared (the composition of the cementitious mortar bars is presented in Fig. 4.4). Each cementitious material bar was measured thirteen times.

The capillary suction of the three M5 cementitious material bars that had a lower amount of sodium silicate is presented in Fig. 4.7a. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate, and the third—the granite fine aggregate. The results obtained for the cementitious material with the quartz fine aggregate and the cementitious material with the granite fine aggregate were similar. In turn, the cementitious material with the basalt fine aggregate had about a 6% higher capillary suction index than the other cementitious materials.

Figure 4.7b shows the capillary suction of the three M5 cementitious material bars that had a higher amount of sodium silicate. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate and the third—the granite fine aggregate. The bar of the M10 cementitious material (with the quartz fine aggregate) and the bar of the M10 cementitious material (with the granite fine aggregate) had a lower index of capillary suction when compared to the cementitious material bar with the basalt fine aggregate. However, the M10 cementitious material with a greater amount of the additive had a more favourable result than the M10 cementitious material with a lower amount of sodium silicate, regardless of the type of used fine aggregate. In turn, the bar of the M5 cementitious material had a higher capillary suction than the M10 cementitious material bars. For the production of the M10 cementitious material, less fine aggregate was used than in the case of the M5 cementitious material. The cementitious material with the basalt fine aggregate and a higher proportion of sodium silicate had the least favourable result. The capillary suction rate of the cementitious material with the basalt fine aggregate was 12% higher than the capillary suction rate of the cementitious material with the quartz fine aggregate, and 10% higher than the capillary suction index of the cementitious material with the granite fine aggregate. However, the capillary suction of the M10 cementitious material with the granite fine aggregate and a higher amount of sodium silicate was about 53% lower than the capillary suction of the M10 cementitious material with the granite fine aggregate and a lower amount of the additive.

Figure 4.8 presents a comparison of the capillary suction of the M15 cementitious material that was prepared with the addition of sodium silicate and the three different fine aggregates: quartz, basalt and granite. A total of six different cementitious material bars were compared (the composition of the cementitious mortar bars is presented in Fig. 4.4). Each cementitious material bar was measured thirteen times.

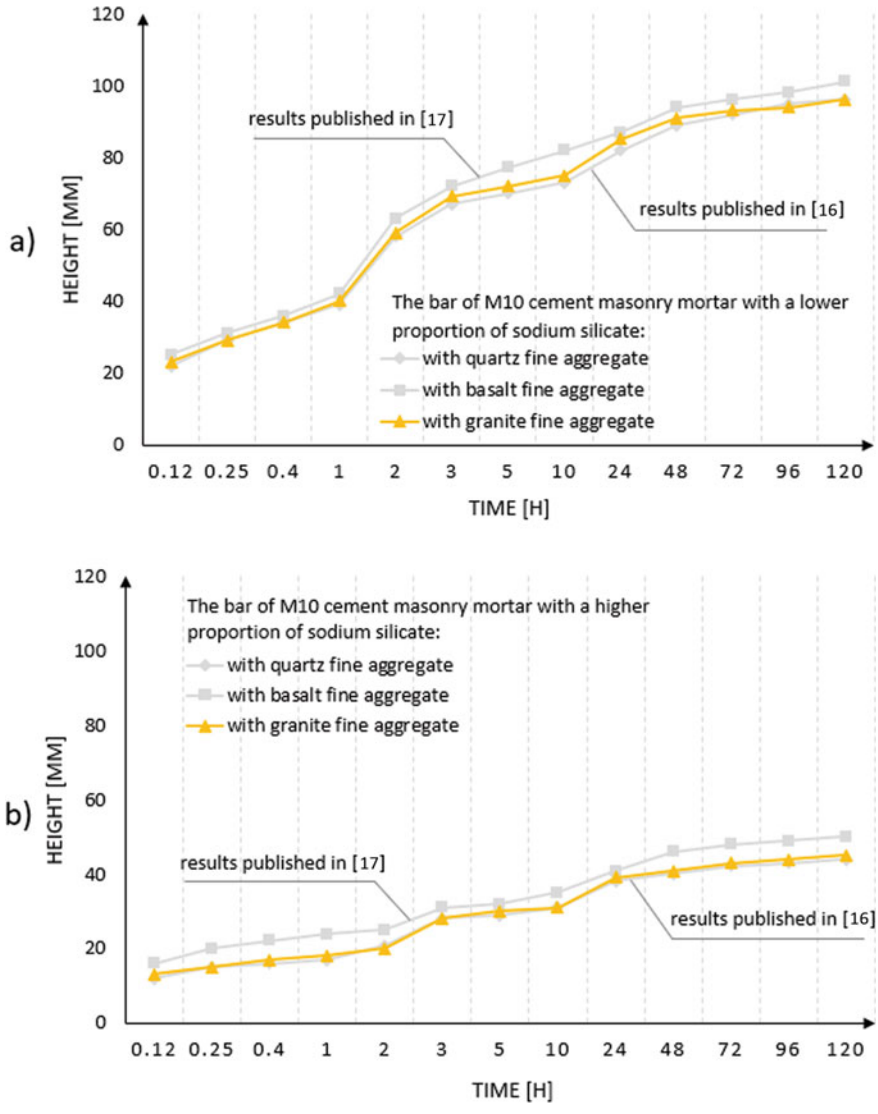

Fig. 4.7 Capillary suction of the M10 cementitious material bars with the granite, quartz and basalt fine aggregates: **a** with a lower proportion of the additive and **b** with a higher proportion of the additive

Figure 4.8a shows the capillary suction of the three M15 cementitious material bars that had a lower amount of sodium silicate. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate and the third—the granite fine aggregate. The result of the capillary suction of the cementitious material with the basalt fine aggregate and a lower amount of sodium silicate was 8% higher than

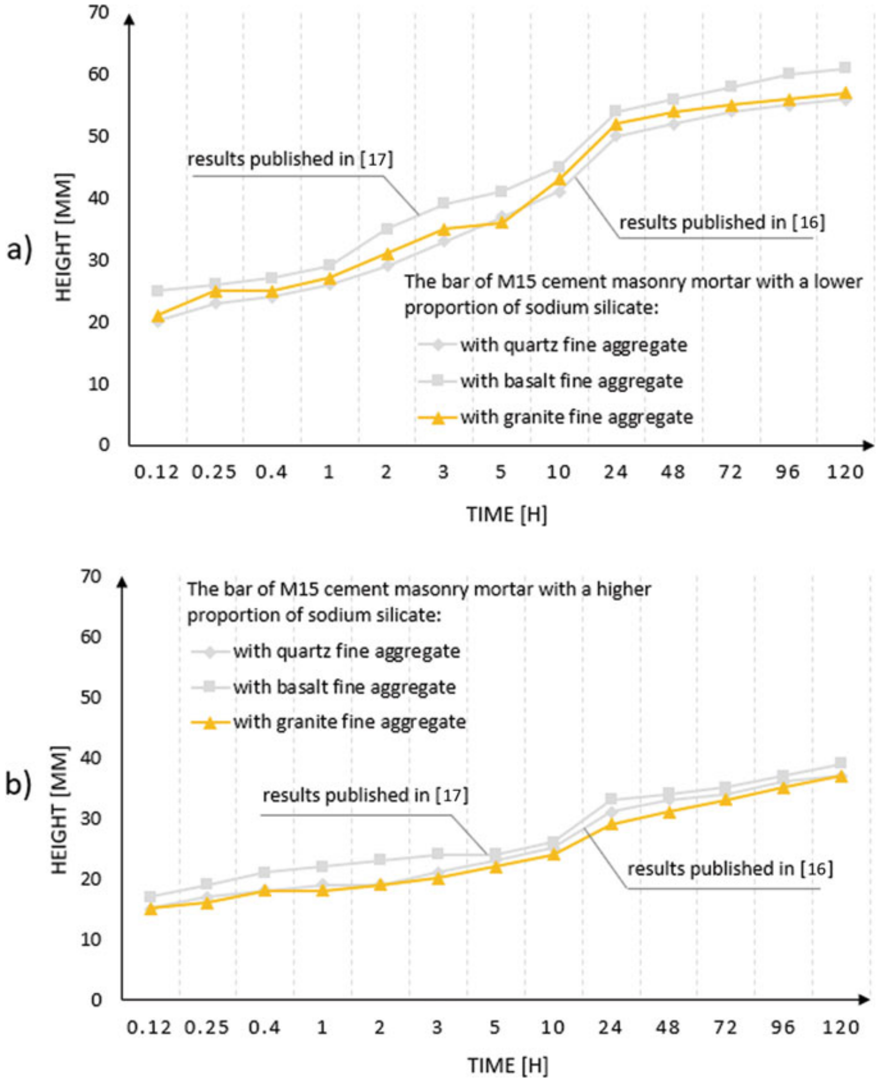

Fig. 4.8 Capillary suction of the M15 cementitious material bars with the granite, quartz and basalt fine aggregates: **a** with a lower proportion of the additive and **b** with a higher proportion of the additive

the capillary suction of the cementitious material with the quartz fine aggregate and a lower amount of sodium silicate and 6.5% higher than the result of the capillary suction of the cementitious material with the granite fine aggregate.

Figure 4.8b shows the capillary suction of the three M15 cementitious material bars that had a higher amount of sodium silicate. The first bar also had the quartz fine aggregate, the second bar—the basalt fine aggregate and the third bar—the granite fine aggregate. In this study, the bar of the M15 cementitious material with the quartz fine aggregate, and the bar of the M15 cementitious material with the granite fine aggregate had the same results (37 mm). However, the M15 cementitious material bar with the basalt fine aggregate had the least favourable result (39 mm). The capillary suction index of the cementitious material with the basalt fine aggregate was 5% higher than the capillary suction index of the cementitious material with the quartz fine aggregate, and the cementitious material with the granite fine aggregate. However, the capillary suction of the M15 cementitious material with the granite fine aggregate and a higher amount of sodium silicate was about 35% lower than the capillary suction of the M15 cementitious material with the granite fine aggregate and a lower amount of sodium silicate.

Figure 4.9a shows a comparison of the capillary suction of the granite, quartz and basalt fine aggregates, the M5 cementitious material with the granite fine aggregate without the additive, the M5 cementitious material with the quartz fine aggregate without the additive and the M5 cementitious material with the basalt fine aggregate without the additive. Figure 4.9b presents a comparison of the capillary suction of the granite, quartz and basalt fine aggregates, the M10 cementitious material with the granite fine aggregate without the additive, the M10 cementitious material with the quartz fine aggregate without the additive and the M10 cementitious material with the basalt fine aggregate without the additive. Figure 4.9c shows a comparison of the capillary suction of the granite, quartz and basalt fine aggregates, the M15 cementitious material with the granite fine aggregate without the additive, the M15 cementitious material with the quartz fine aggregate without the additive and the M15 cementitious material with the basalt fine aggregate without the additive.

The fine aggregates, when compared to the cementitious materials, had less favourable results in terms of their capillary suction.

4.4 Conclusions

In this research, the capillary suction of cementitious materials with sodium silicate (two different proportions: 0.002 and 0.005 kg) and granite fine aggregate was investigated. The research focused on the design of a cementitious material with a low capillary suction. M5, M10 and M15 cementitious materials were used for testing. The obtained results were compared with previous research concerning quartz and basalt fine aggregates. It was observed that the used additive (sodium silicate) had a positive influence on the capillary suction index of the prepared cementitious materials.

The conducted research also showed that:

- The capillary suction of the M5 cementitious material with the granite fine aggregate and a greater amount of sodium silicate was about 77% higher than the capillary suction of the M15 cementitious material with the granite fine aggregate and a greater amount of sodium silicate.

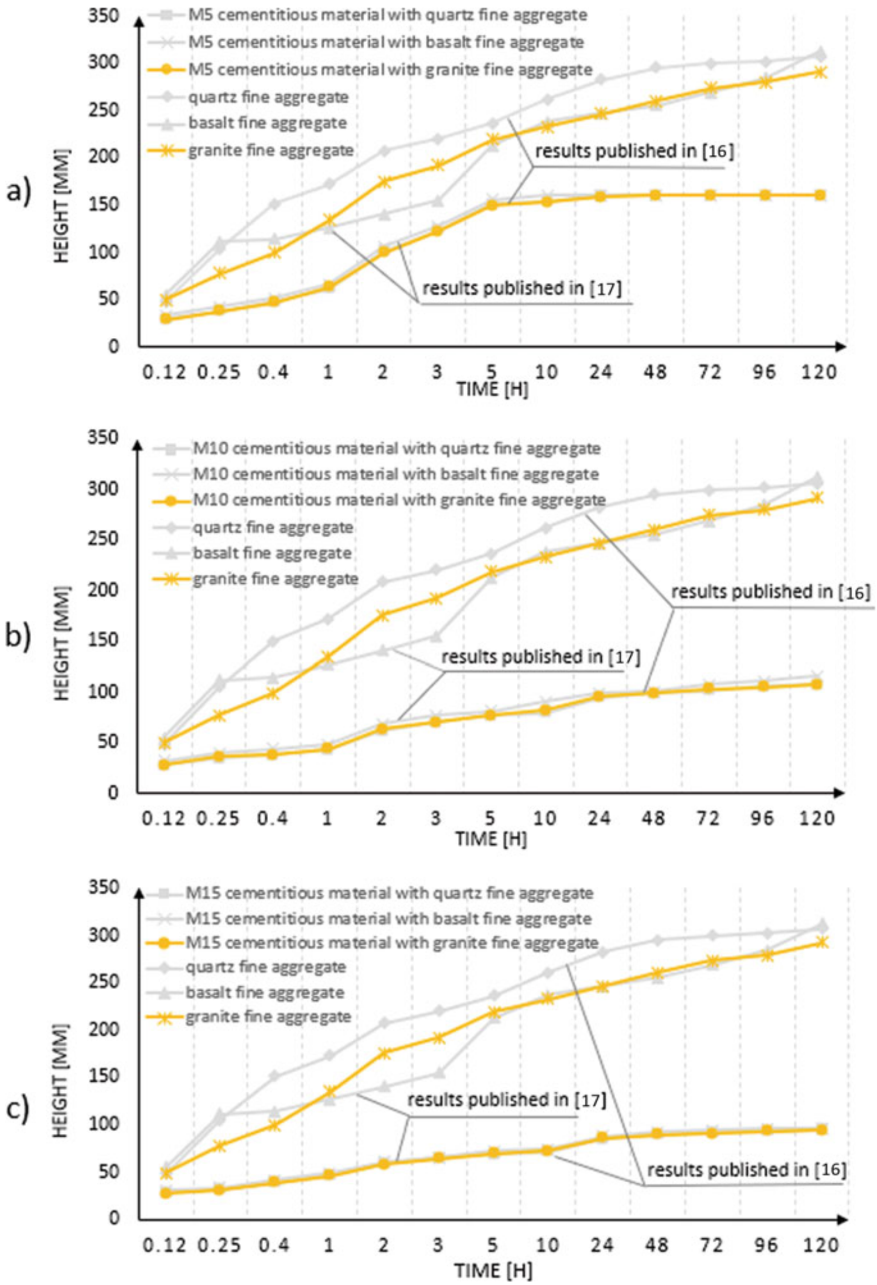

Fig. 4.9 Comparison of the capillary suction of the granite, quartz and basalt fine aggregates with: **a** the M5 cementitious material bar without sodium silicate, **b** the M10 cementitious material bar without sodium silicate and **c** the M 15 cementitious material bar without sodium silicate

- The M15 cementitious material with a greater amount of sodium silicate had the most favourable result. The cementitious material with the quartz fine aggregate and the cementitious material with the granite aggregate obtained the same results with regards to capillary suction. In turn, the M10 cementitious material with the basalt fine aggregate had about a 5% higher capillary suction index when compared to the other two cementitious materials. The least fine aggregate when compared to the M5 and M10 cementitious materials was added to the M15 cementitious material.
- The addition of sodium silicate to the cementitious materials reduced their capillary suction. The M15 cementitious material with the granite fine aggregate had a 60% higher capillary suction index than the M15 cementitious material with the granite fine aggregate and a greater amount of sodium silicate.

To sum up, sodium silicate, the type of fine aggregate and the type of cement mortar had a direct impact on the capillary suction of the cement mortars. Very promising results were obtained for the M15 cementitious materials with a greater amount of sodium silicate. Therefore, this additive, and the type of cement mortar, should be applied in cementitious materials in order to reduce capillary suction. The perspectives for future research include the analysis of the capillary suction of brick walls made using cement mortar with the addition of sodium silicate.

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