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CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2022; 32 (1): 0240-0254
DOI: 10.2478/ceer-2022-0014
Original Research Article

SHRINKAGE AND ABSORPTION OF SAND CONCRETE CONTAINING MARBLE WASTE POWDER

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Abstract

In the context of growing scarcity of natural resources, the high demand of aggregates and the difficulties to open new quarries, several studies were carried out to study the possibility of reuse of waste and industrial by-products to replace traditional materials which would run out, replace materials when transport distances increase to reduce construction costs and protect the environment. This experimental study aims to investigate the effect of marble waste used as powder on the shrinkage and absorption of sand concrete in order to reuse it in the production of sand concrete. To achieve this goal, several sand concrete mixtures containing different substitutions rates of marble powder (4, 8 and 12%), and different Water / Cement ratio (0.71, 0.74, 0.77) were produced. Then, the evolution of the shrinkage and absorption values of sand concrete mixtures was studied. The obtained results showed that marble waste powder plays a positive role in reducing of shrinkage and absorption values of sand concrete and lead to the production of eco-friendly sand concrete.

Keywords: sand concrete, marble powder, waste, shrinkage, absorption

1. INTRODUCTION

The use of untapped local materials such as dune sand, recycled aggregates, marble and ceramic wastes in the construction field has become an alternative and

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effective solution to the economic and environmental problems of countries. In this context, the reflection on the research of new concretes (such as self compacting concrete, fiber reinforced concrete, sand concrete) able to solve the economic and technical problems, using abundant and untapped resources was encouraged (Bederina et al. 2005, Jiang et al. 2018). Among these materials, there is the sand concrete (SC) which finds their origin in the years 1850-1875 under the name of agglomerated concrete (Benmalek 1992). Many constructions testify to its existence like the lighthouse of Port Said (Egypt), the Brooklyn Bridge in New York and the metro station of Saint Petersburg (Benmalek 1992). The SC is a concrete that does not contain coarse aggregates or has a proportion of coarse aggregates such that the fine aggregates / coarse aggregates ratio should higher than 1 (Gadri et Guettala 2017). When SC contains coarse aggregates, it is called a filled SC. Several studies investigating the performances of SC were carried out. They showed that SC can compete with ordinary vibrated concrete in many applications such as the repair work of structural elements (Bouziani et al 2012) and pavement construction (Bouziani et al. 2014), and under different forms such as flowing concrete (Benaisssa et al. 2015), fiber-reinforced concrete (Bederina et al 2009, Hadjouja et al. 2014, Belhadj et al. 2016) and light concrete (Benaissa 1992, Djebien et al 2015). SC exhibits specific properties such as Strength, lack of segregation, good surface appearance and small granularity which facilitates its pouring (Cheng et al. 2017).

On the other hand, due to the high water demand during the hydration phase and the water evaporation through the capillary porosity, SC is subject to shrinkage dimensional variations. The shrinkage phenomenon generates significant tensile strength which can lead to cracking. Benaissa (1992) noticed that the kinetics of desiccation shrinkage of SC is extremely fast and the desiccation shrinkage can reach values higher than that of ordinary vibrated concrete by the double. The study carried out by Cheng et al. (2017) showed that 5% of metakaolin can reduce the shrinkage values of SC by 50%, this reduction is attributed to the pozzolanic reaction and the filling effect that the metakaolin plays. Bederina et al. (2012) noted that there is a possibility to reduce the higher values of SC shrinkage by adding wood chips.

On the other hand, the reuse of marble waste coming from a metamorphic rock (with a high calcium carbonate content $CaCO_3$) (Gesoglu et al 2012) in the composition of concrete is studied by several researchers (Rai et al. 2011, Hebhoub et al. 2011, Shirule et al. 2012, Patel et al. 2013, Aliabdo et al 2015). They recommended the use of this type of waste to improve concrete properties, reduce cost, and protect the environment. Hebhoub et al. (2011) studied the possibility of reusing marble waste as aggregates in concrete. They concluded that the mechanical strength and the workability of concrete improve when marble waste rates range from 25 to 75%. Similar trend was found by Djebien et al (2015) which added that the use of marble powder (MP) in SC composition increases the compactness and the cement hydration of SC (Djebien et al. 2018).

Binici et al. (2008) studied the durability of ordinary concretes containing MP. They concluded that MP improves the sulphate ions attack resistance and reduces the depth of chloride ions by 70%. Singh et al. (2019) and Singh et al (2017) noted that 10-15% of MP reduces the absorption values by 15%, increases the mechanical strength values by 15-20% and reduces the cost of concrete production by 9.077%. These improvements are explained by the ability of the MP to penetrate into granular skeleton porosity of the concrete to fill voids and reduce the porosity (Ma et al. 2019). Aruntas (2010) studied the effect of clinker substitution by MP on the chemical and mechanical behavior of cement. The substitution rates were (2.5, 5, 7.5 and 10%). He noted that MP does not affect setting times, improves workability, increases the mechanical strength and reduces the cost of cement production by 10%. He found also that the optimal substitution rate of MP was 10%. For further addition, the compressive strength significantly decreases. This reduction of mechanical strength is due to the reduction of the C_3S and C_2S content in the cement (Corinaldesi et al. 2010, Vardhan et al. 2019). In another study, Nežerka et al. (2018) found that the presence of MP negatively affects the macroscopic performance of cement. Vardhan et al. (2019) used the marble waste as sand in the composition of concrete containing river sand with substitution rates ranging from 10 to 60%. They noted that marble sand increases the mechanical strength of concrete and reduces the penetration of water and chloride ions. The results obtained by Corinaldesi et al (2010) showed that mortars containing MP have good cohesion and higher mechanical strength values with optimal substitution rate of 10%. Hebhoub et al (2014) added that MP reduces the shrinkage values of mortars. Saboya et al. (2007) found that 10-15% MP significantly improves brick mechanical properties. This study aims to investigate the use possibility of MP considered as waste in the composition of SC through the evaluation of their effect on the shrinkage and absorption of SC. In addition to the economic and technical interests, the reuse of this waste in the concrete production field leads to produce a green concrete which meets the sustainable development requirements.

2. MATERIALS

2.1. Materials

According to the European Standards EN-197/1, commercial ordinary Portland cement (OPC) type CEM I 42.5 was used; its chemical, physical and mechanical properties are given in Table 1. The MP comes from the marble quarry of Skikda region (Algeria). Its properties are given in Table2.

Table 1. Properties of OPC

Properties	Value
Initial setting time (min)	76
Final setting time (min)	180
Specific gravity (g/cm^3)	3.125
Blaine fineness (cm^2/g)	3155
Shrinkage for 28 days (µm/m)	792
Compressive strength at 2 days (MPa)	26.91
Compressive strength at 14 days (MPa)	43.56
Compressive strength at 28 days (MPa)	58.45
Flexural strength at 2 days (MPa)	5.08
Flexural strength at 7 days (MPa)	7.22
Flexural strength at 28 days (MPa)	8.81
C_4AF (%)	10.25
C_3A (%)	8.08
C_3S (%)	58.45
C_2S (%)	13.24

Table 2. Properties of MP

Properties	MP
Color	White
Specific gravity (g/cm^3)	2.72
Absorption (%)	0.39
Compressive strength (dry state) (MPa)	9.61
Wear strength (g/cm^2)	1.82
Impact strength (kg/cm^2)	40
Blaine fineness (cm^2/g)	2855
$CaCo_3$ (%)	96.12
CaO (%)	53.85
Al_2O_3 (%)	0.38
Fe_2O_3 (%)	0.22
SiO_2 (%)	1.11
MgO (%)	2.81
Na_2O (%)	0.15
K_2O (%)	0.04
Cl^- (%)	0.02
SO_3 (%)	0.00

River sand (RS) with a nominal particle size of 3 mm was used as fine aggregate. The physical properties and particles size distribution of RS are presented in Table 3 and Figure 1.

Table 3. Properties of RS

Properties	RS
Specific gravity (g/cm^3)	2.597
Sand equivalent (%)	75.89
Fineness modulus	1.92
Fines content (%)	0.48

Fig.1. Particles size distribution of RS

To ensure good workability, Glenuim-26 (polycarboxylic-ether type) was used as superplasticizer (SP) with a specific gravity of 1.08 and PH of 7.

2.2. SC mix design

The composition of SC mixtures was carried out using the Sablocrete method (Sablocrete 1994), it was based on optimizing of the fines volume (Khay et al. 2010). In order to study the effect of MP as partial replacement of sand (4, 8 and 12%) on the shrinkage and absorption of SC, the water/ cement ratio was kept constant for the first test specimens. To assess the effect of water content on the shrinkage and absorption of SC, MP content was kept constant at 8% of sand volume and the water/ cement ratio was varied (0.71, 0.74 and 0.77) for second test specimens. Details of the SC mixtures composition are given in Table 4.

Table 4. SC mixtures composition

SC mixtures	OPC (kg/m^3)	water (l/m^3)	RS (kg/m^3)	MP (kg/m^3)	SP (l/m^3)	W / C	MP/C	Workability (mm)
SC0	400	308	1445,91	0	7.4	0.77	0	120
SC4	400	308	1388,07	60,61	7.4	0.77	0.15	170
SC8	400	308	1330,24	121,22	7.4	0.77	0.30	190
SC12	400	308	1272,37	179,14	7.4	0.77	0.45	210
SC71	400	284	1387.60	126,44	7.4	0.71	0.31	140
SC74	400	296	1358,92	123,83	7.4	0.74	031	160
SC77	400	308	1330,24	121,22	7.4	0.77	0.30	190

2.3. Casting and test methods

To study the shrinkage of SC, 70×70×280 mm specimens were carried out for each mixture to study the variation of the autogenous and drying shrinkage according to NF P 15-433 standard (Figure 02). In the case of the measurement of autogenous shrinkage, the specimens used were sealed with a plastic film to prevent the exchange of moisture with the outside environment.

Fig. 2. Measurement of drying shrinkage

For the water absorption by capillarity test, three 70 ×70×280 mm specimens for each SC mixture were used and the test method was carried out according to NF P 10-502 standard. The water absorption by immersion test was carried out using 100×100 ×100 mm specimens for each SC mixture according to NBN B15-215 standard. All specimens are placed in a room with 20 ± 2 °C and 65 ± 5% relative humidity. Measurements of Shrinkage are carried out until 90 days.

3. RESULTS AND DISCUSSION

3.1. Shrinkage

The results of the autogenous and drying shrinkage are shown in Table 5.

Table 5. Shrinkage of SC mixtures

		Sand concrete mixes						
		SC0	**SC4**	**SC8**	**SC12**	**SC71**	**SC74**	**SC77**
Autogenous shrinkage (µm/m)	07 days	643.75	81.25	106.25	262.5	531.25	275	106.25
	14 days	931.25	300	193.75	387.5	681.25	387.5	193.75
	28 days	1106.25	556.25	600	600	643.75	531.25	600
	90 days	1218.75	700	637.5	643.75	918.75	631.25	637.5
Drying shrinkage (µm/m)	07 days	737.5	750	243.75	306.25	600	500	243.75
	14 days	1462.5	981.25	525	568.75	943.75	918.75	525
	28 days	1506.25	1662.5	1131.25	1012.5	1518.7	1031.25	1131.2
	90 days	1706.25	1756.25	1125	1118.7	1431.2	1050	1125

Figure 3 shows the effect of the MP in autogenous shrinkage of SC. The reference SC (SC0) has higher autogenous shrinkage value than the others SC mixtures. The SC0 reached shrinkage value up to 1200 µm/m at 90 days and 74.10% higher than that of SC4 mixture. It could be shown also that MP used reduced the shrinkage of SC with an optimal value equal to about 8%, which corresponds to a reduction in the autogenous shrinkage value by 91.17%. The reduction of autogenous shrinkage can be attributed to the presence of MP that acts as a catalyst for cement hydration reaction (Ergun 2011, Patel et al. 2013, Aliabdo et al. 2014) and lead to rapid increase of SC tensile strength which has an important role in the resistance against the deformations caused by this type of shrinkage.

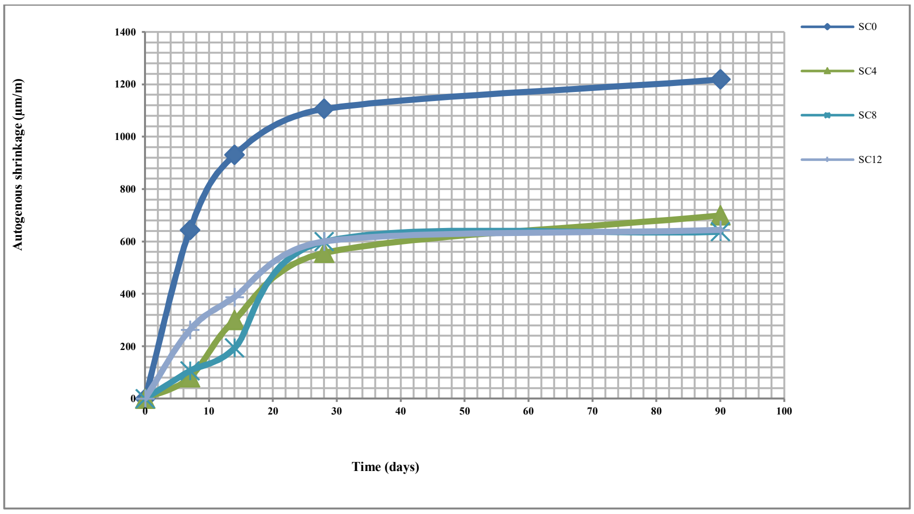

Fig. 3. Effect of MP on autogenous shrinkage of SC

Figure 4 shows that the increase in the water/cement ratio is accompanied by a decrease in autogenous shrinkage of SC. The SC71 mixture reached autogenous shrinkage value of 918.75 µm/m at 90 days, i.e. 44.11% higher than that of SC77 mixture. This trend can be attributed to the decrease of the humidity inside SC when the water/cement ratio decreases. This decrease in the internal moisture of the SC facilitates the transition of the cement matrix from the biphasic state (solid-liquid) to the tri-phasic state (solid-liquid-air), and generates the autogenous shrinkage deformations (De Larrard 1999).

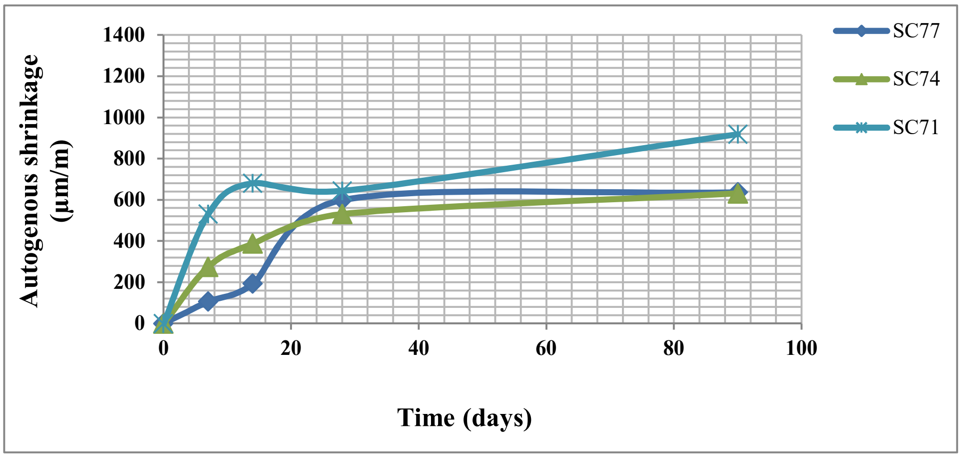

Fig. 4. Effect of water/cement ratio on autogenous shrinkage of SC

As seen in figure 5, it is clear that the addition of MP in the composition of SC reduces drying shrinkage values. This reduction is more pronounced when the substitution rate of RS by PM reach 8%. For example, the drying shrinkage values of SC8 mixture exhibits significant reduction in comparison to that of SC0 mixture. After 90 days, this reduction reaches 51.66%.The reduction of drying shrinkage of SC containing MP can be explained by the filling effect of the MP (Cheng et al. 2017, Jiang et al. 2018) which has capacity to penetrate into the porosity of SC to fill capillary voids and makes the water evaporation through the capillary pores more difficult. This reduction can be also attributed to the promotion of cement hydration and formation of C-S-H which decreases the drying shrinkage values (Topçu et al. 2009).

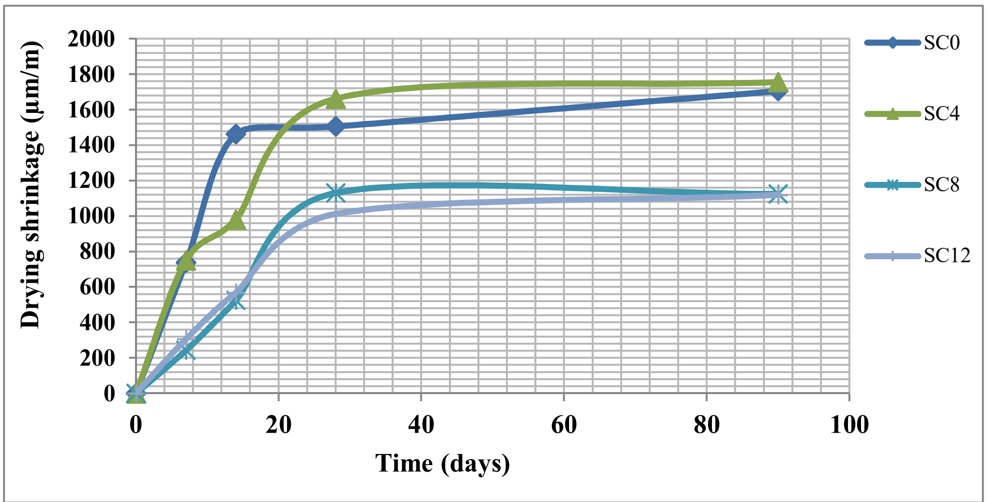

Fig. 5. Effect of MP on drying shrinkage of SC

Like the autogenous shrinkage, the drying shrinkage decreases by increasing of the water / cement ratio of SC (figure 6). At 90 days, the reduction of drying shrinkage of SC77 mixture reached 26.31% in comparison to that of SC71 mixture. This tendency can be explained by a sufficiency of humidity due to the increase in the water/cement ratio.

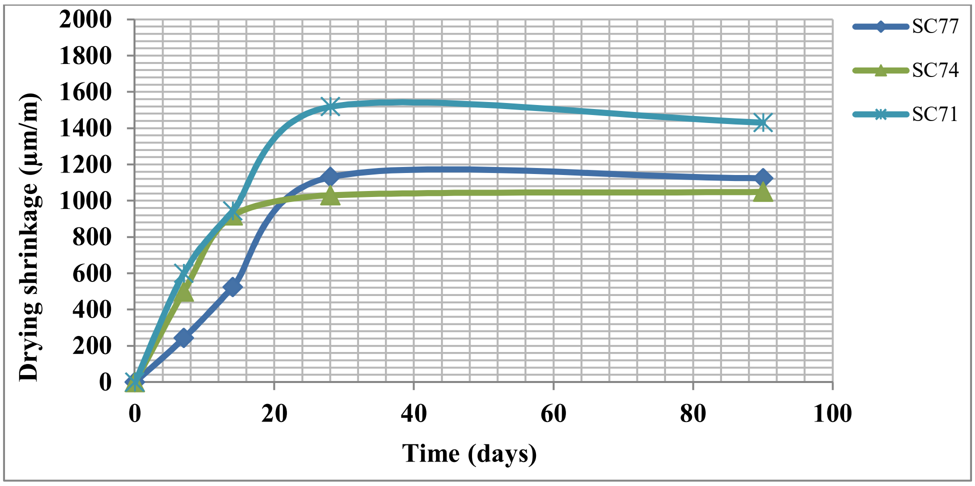

Fig. 6. Effect of water/cement ratio on drying shrinkage of SC

3.2. Absorption

The results of the water absorption are shown in Table 6 and7.

Table 6. Water absorption by capillarity of SC mixtures

	Time (min)	SC mixtures			
		SC0	**SC4**	**SC8**	**SC12**
Water absorption by capillarity (g/mm^2)	10	3.74×10^{-3}	3.40×10^{-3}	3.06×10^{-3}	3.06×10^{-3}
	20	5.30×10^{-3}	4.76×10^{-3}	4.08×10^{-3}	4.08×10^{-3}
	30	5.78×10^{-3}	5.10×10^{-3}	4.40×10^{-3}	5.10×10^{-3}
	40	6.46×10^{-3}	6.12×10^{-3}	5.10×10^{-3}	5.10×10^{-3}
	50	7.14×10^{-3}	7.14×10^{-3}	5.44×10^{-3}	5.78×10^{-3}
	60	7.48×10^{-3}	7.14×10^{-3}	6.12×10^{-3}	6.12×10^{-3}
	70	7.82×10^{-3}	7.82×10^{-3}	6.12×10^{-3}	6.46×10^{-3}
	80	8.50×10^{-3}	7.82×10^{-3}	6.46×10^{-3}	6.80×10^{-3}
	90	8.50×10^{-3}	8.16×10^{-3}	6.46×10^{-3}	7.14×10^{-3}

Table 7. Water absorption by immersion of SC mixtures

SC mixtures	Water absorption by immersion (%)
SC0	19,33
SC4	14,96
SC8	17,18
SC12	16,07

Figure 7 shows that the incorporation of MP in SC mixes reduces the water absorption by capillarity. This reduction is more pronounced when the substitution rate reach 8%. At 90 minutes, the reduction of water absorption of SC8 reached 24% in comparison to that of SC0. It can be seen also that the speed of water absorption by capillarity decrease by increasing of the substitution rate, this trend can be explained by the reduction of porosity and inter-connection of capillary voids by adding of MP.

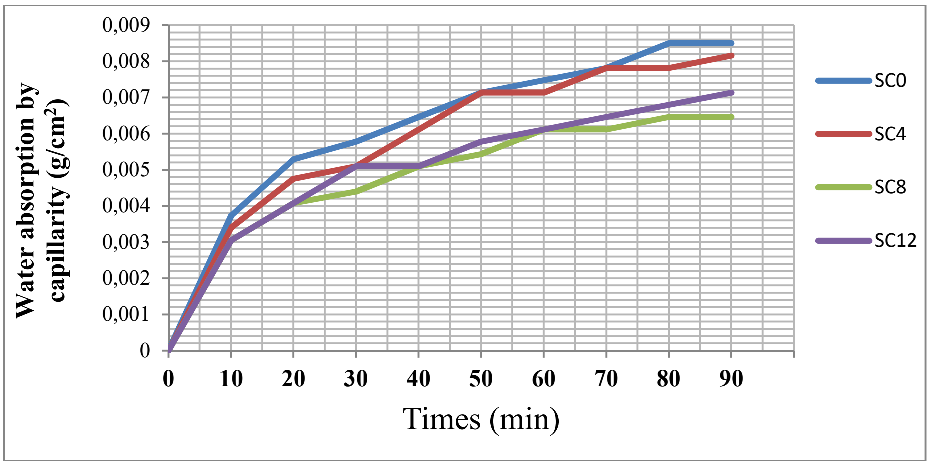

Fig. 7. Water absorption by capillarity of SC mixtures

Figure 8 shows that the incorporation of MP in SC composition has beneficial effect. All sand concrete mixtures containing MP have absorption values lower than that of SC0. For example, 12% of MP reduces the water absorption value by 16.86%. This tendency can be attributed to the improvement of the compactness and the microstructure of SC mixtures by filling effect of MP (Patel et al. 2013, Cheng et al. 2017).

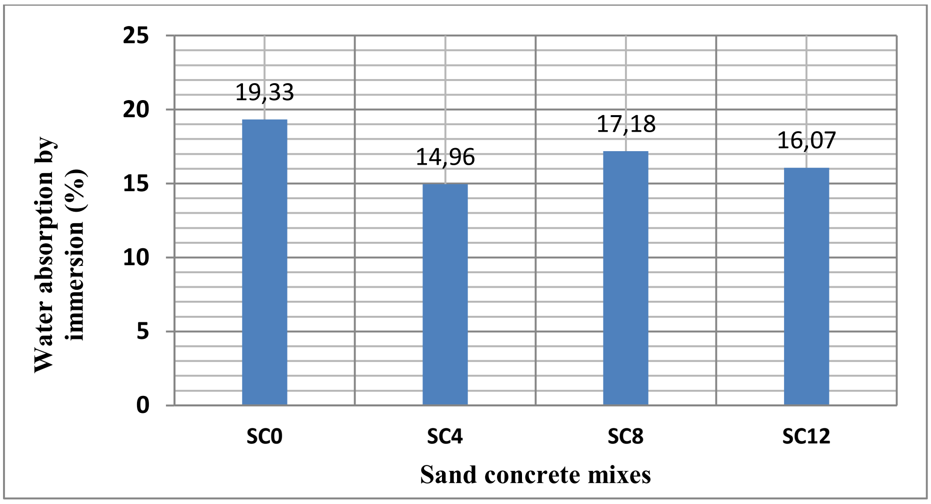

Fig. 8. Water absorption by immersion of SC mixtures

4. CONCLUSIONS

This paper aimed to reuse the marble waste as a powder in the production of SC through the investigation of the effect of MP on shrinkage and absorption of SC. MP was incorporated in SC composition by volumetric substitution of 4, 8 and 12% of fine aggregate. The obtained results allowed us to draw the following conclusions:

- Due to the calcareous nature and filling effect that MP plays, the incorporation of MP in the composition of SC reduces the autogenous and drying shrinkage values of SC.
- The increase in water/cement ratio decreases the SC shrinkage values. This is mainly due to the presence of sufficient moisture in the SC when water/cement increases.
- Water absorption of SC has improved by adding of MP. This trend can be attributed to the filler effect of the MP which led to reduction of absorption rate and amount of water absorbed.
- The optimum substitution rate of RS by MP was about 8%.

REFERENCES

1. Aliabdo, AA, Abd Elmoaty, AEM and Auda, EM 2014. Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials* **50**, 28–41.

2. Aruntas, HY, Gürü, M, Dayi, M and Tekin 2010.Utilization of waste marble dust as an additive in cement production. *Materials and Design* **31**, 4039–4042.
3. Bederina, M, Gotteicha, M, Belhadj, B, Dheily, RM, Khenfer, MM and Queneudec, M 2012. Drying shrinkage studies of wood sand concrete – effect of different wood treatments. *Construction and Building Materials* **36**, 1066–1075.
4. Bederina, M, Laidoudi, B, Goullieux A, Khenfer, MM, Bali, A and Queneudec, M 2009. Effect of the treatment of wood shavings on the physico-mechanical characteristics of wood sand concretes. *Construction and Building Materials* **23**, 1311–1315.
5. Bederina, M, Khenfer, MM, Dheily, RM and Queneudec, M 2005. Reuse of local sand: effect of limestone filler proportion on the rheological and mechanical properties of different sand concrete. *Cement and Concrete Research* **35,** 1172–1179.
6. Belhadj, B, Bederina, M, Makhloufi, M, Dheily, RM, Montrelay, N and Queneudec, M 2016, Contribution to the development of a sand concrete lightened by the addition of barley straws. *Construction and Building Materials* **113**, 513–522.
7. Benaissa, I, Nasser, B, Aggoun, S and Malab, S 2015. Properties of fibred sand concrete sprayed by wet-mix process. *Arabian Journal of Science and Engineering* **40**, 2289–2299.
8. Benaissa, A, 1992. *Déformations différées d'un béton de sable*. Thèse de doctorat, Laboratoire régional des ponts et chaussées.
9. Benmalek, ML, 1992. *Contribution à l'étude des bétons de sables dunaires pour éléments de structures*. Thèse de magister. Université Mentouri de Constantine. Algérie.
10. Binici, H, Shah, T, Aksogan, O and Kaplan, H 2008. Durability of concrete made with granite and marble as recycle aggregates. *Journal of Materials Processing Technology* **208**, 299–308.
11. Bouziani, T, Benmounah, A, Makhloufi, Z, Bédérina, M and T'kint, MQ 2014. Properties of flowable sand concretes reinforced by polypropylene fibers. *Journal of Adhesion Science and Technology* **28** (18), 1823–1834.
12. Bouziani, T, Bédérina, M and Hadjoudja, M 2012. Effect of dune sand on the properties of flowing sand-concrete (FSC). *International Journal of Concrete Structures and Materials* **6** (1), 59–64.
13. Cheng, S, Shui, Z, Sun, T, Yu, R, Zhang, G and Ding, S 2017. Effects of fly ash, blast furnace slag and metakaolin on mechanical properties and durability of coral sand concrete. *Applied Clay Science* **141**, 111–117.

14. Corinaldesi, V, Moriconi, G and Naik, TR 2010. Characterization of marble powder for its use in mortar and concrete. *Construction and Building Materials* **24**,113–117.
15. De larrard, F 1999. *Concrete mixture proportioning, A scientific approach, modern concrete technology*, United Kingdom.
16. Djebien, R, Hebhoub, H, Belachia, M, Berdoudi, S and Kherraf, L 2018. Incorporation of marble waste as sand in formulation of self-compacting concrete. *Structural Engineering and Mechanics* **67(1),** 87-91.
17. Djebien, R, Belachia, M and Hebhoub, H 2015. Effect of marble waste fines on rheological and hardened properties of sand concrete. *Structural Engineering and Mechanics* **53(6),** 1241-1251.
18. Ergun, A 2011. Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and Building Materials* **25(2),** 806-812.
19. Jiang, C, Guo, W, Chen, H, Zhu, Y and Jin, C 2018, Effect of filler type and content on mechanical properties and microstructure of sand concrete made with superfine waste sand. *Construction and Building Materials* **192**, 442–449.
20. Hadjoudja, M, Khenfer, MM, Mesbah, HA and Yahia, A 2014. Statistical models to optimize fiber-reinforced dune sand concrete. *Arabian Journal of Science and Engineering* **39 (4)**, 2721–2731.
21. Hebhoub, H, Belachia, M and Djebien, R 2014. Introduction of sand marble wastes in the composition of mortar. *Structural Engineering and Mechanics* **49(4)**, 491-498.
22. Hebhoub, H, Aoun, H, Belachia, M, Houari, H and Ghorbel, E 2011, Use of waste marble aggregates in concrete. *Construction and Building Materials* **25**, 1167–1171.
23. Gadri, K and Guettala, A 2017. Evaluation of bond strength between sand concrete as new repair material and ordinary concrete substrate (The surface roughness effect). *Construction and Building Materials* **157**, 1133–1144.
24. Gesoglu, M, Güneyisi, E, Kocabag, ME, Bayram, V and Mermerdas, K 2012. Fresh and hardened characteristics of self compacting concretes made with combined use of marble powder, limestone filler, and fly ash. *Construction and Building Materials* **37**, 160-170.
25. Khay, SEE, Neji, J and Loulizi, A 2010. Shrinkage properties of compacted sand concrete used in pavements. *Construction and Building Materials* **24 (9)**, 1790–1795.
26. Ma, B et al. 2019, Utilization of waste marble powder in cement-based materials by incorporating nano silica. *Construction and Building Materials* **211**, 139–149.

27. National Press of School of Bridges and Roads, 1994. *Beton de sable – Caracteristiques et pratiques d'utilisation SABLOCRETE (Sand Concrete – Characteristics and use Practices)*, Presses of bridges, Paris, France.
28. Nežerka, V, Hrbek, V, Prošek, Z, Somr, M, Tesárek, P and Fládr, J 2018. Micromechanical characterization and modeling of cement pastes containing waste marble powder. *Journal of Cleaner Production* **195,** 1081–1091.
29. Patel, N, Raval, A and Pitroda, J 2013. Marble waste: Opportunities for development of low cost concrete. *Global Research Analysis* **2(2),** 94-96.
30. Rai, B, Naushad, HK, Abhishek, K, Rushad, ST and Duggal, SK 2011. Influence of marble powder/granules in concrete mix. *International Journal of Civil and Structural Engineering* **1(4)**, 827-834.
31. Saboya, F, Xavier, GC and Alexandre, J 2007. The use of the powder marble by-product to enhance the properties of brick ceramic. *Construction and Building Materials* **21**, 1950–1960.
32. Shirule, PA, Rahman, A and Gupta, RD 2012. Partial replacement of cement with marble dust powder. *International Journal* of *Advances Engineering. Research Studies* **1**,175–177.
33. Singh, M, Srivastava, A and Bhunia, D 2019. Long term strength and durability parameters of hardened concrete on partially replacing cement by dried waste marble powder slurry. *Construction and Building Materials* **198**, 553–569.
34. Singh, M, Choudhary, Srivastava, KA, Sangwan, KS and Bhunia, D 2017. A study on environmental and economic impacts of using waste marble powder in concrete. *Journal of Building Engineering* **13**, 87–95.
35. Topçu, IB, Bilir, T and Uygunoglu, T 2009. Effect of waste marble dust content as filler on properties of self-compacting concrete. *Construction and Building Materials* **23(5),** 1947–1953.
36. Vardhan, K, Siddique, R and Goyal, S 2019. Strength, permeation and micro-structural characteristics of concrete incorporating waste marble. *Construction and Building Materials* **203**, 45–55.

Editor received the manuscript: 28.10.2021