Visual Abstract

Assessment of fluidity retention, mechanical strength and cost production of blended cement self-compacting concrete using the concept of a performance index

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ABSTRACT. Construction industry consumes a large amount of natural resources and energy and produces high amount of CO_2 emissions and waste materials. For more sustainable construction industry, various waste materials are used as natural aggregates substitution or as cement replacement materials. In this paper, marble powder (MP) is used as a substitution to ordinary Portland cement (OPC) and its effects on some fresh and hardened properties of self-compacting concrete (SCC) are investigated. The tests at the fresh state were slump flow, L-box and sieve segregation. To assess the fluidity retention, slump flow loss was measured after 30, 60 and 90 minutes. At hardened state, two tests were realized: compressive strength and static segregation. The results indicate that adding MP improved the fresh properties but decreased the compressive strength of SCC. Adding MP allows to maintain the fluidity of SCC until 90 minutes. Production cost can be reduced by using MP. The performance approach showed that a substitution level of MP of 20% is adequate to produce an eco-efficient SCC with high fluidity and acceptable strength.

KEYWORDS. Self-compacting concrete; Marble powder; Fluidity retention; strength; Cost; Performance index.

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INTRODUCTION

Self-compacting concretes (SCC) are very fluid that can flow and fill all the spaces in the formwork under their gravity, without the need for compaction or vibration, and give homogeneous concretes which are resistant to segregation and bleeding. This type of concrete is suitable for the construction of structures that are heavily reinforced or with complicated shapes. SCC can only be prepared with superplasticizer, large amounts of ordinary Portland cement (OPC) and supplementary cementitious materials (SCM). Building demolition, industrial and agricultural processes generate annually a high quantity of wastes as shown in Tab. 1 in which only a low percentage is recycled [1-5]. The utilization of these wastes has become a priority for its economic and ecological benefits. SCC is one of the most eco-friendly types of special concrete because waste materials have always been used as SCM, fine and coarse aggregates [6-14]. According to Tennich et al. [15], incorporation of waste from marbles and tiles factories as partial replacement of OPC, which are freely and cheaply available in the composition of SCC, allows producing environment friendly concretes. The reuse of industrial by-products and wastes as SCM for manufacturing eco-cements is a good way to ensure the ecosystem and the biological components of the environment and human health, which contributes to sustainable development [16]. Moreover, adding SCM such as natural pozzolana and slag to concrete resulted in low hydration heat, higher compressive strength at later ages, lower porosity, improved durability, lower cost and lower environmental impact due to reduced CO_2 emissions [17-25]. Singh et al. [26] reported that using 10% and 15% of marble powder (MP) as partial replacement of cement increased the compressive and split tensile strengths in the range of 15-20%. Alyamac et al. [27] successfully prepared an eco-SCC by incorporating 60% of MP as partial replacement of cement. Ashish [28] showed that the introduction of MP with 15% by partial replacement of sand offered to concrete superior resistance to carbonation. Guneyisi et al. [29] have shown that the introduction of MP by partial replacement of OPC into self-compacting mortars leads to an increase in the flow time and setting times, while it reduced the compressive strength and the ultrasonic pulse velocity. Toubal et al. [30] showed that incorporating MP in cement paste with various replacement rates of 5, 10 and 15% leads to a reduction of the apparent density and compressive strength and an increase of the porosity at age of 3, 7, 28 and 65 days. The authors concluded that acceptable results could be obtained by using 5% of MP. The use of MP in ordinary pastes, mortars and concretes has been widely investigated. However, few studies investigated the effect of MP as partial substitution of OPC on the properties of SCC especially on fluidity retention and static segregation. This work aims firstly to investigate the effects of MP as a substitute of OPC on some properties of SCC such as fluidity retention, compressive strength, and production cost. The performance of each SCC mixture was also assessed by using a performance index by taking into consideration several performance criteria. This approach allows the selection of a suitable replacement rate that corresponds to the researched SCC performance. In this research work, MP was incorporated at substitution levels of 5, 10, 15 and 20%, keeping the other ingredients and proportions constant. SCC mixtures were tested at a fresh state to evaluate the filling, passing ability and the risk to segregation. At hardened state, compressive strength and static segregation were evaluated at the ages of 7 and 28 days. A performance approach index was used to find the optimal substitution levels corresponding to the targeted SCC performances at fresh and hardened states.

Waste type	Quantity (Mt)	Country	Reference
Glass	3.45	Egypt	[1]
Slag	0.5	Algeria	[2]
Marble	0.34	Turkey	[3]
Rice husk	120	China, India, Indonesia and Bangladesh	[4]
Plastic	1.8	Australia	[5]

Table 1: Statistics for some waste types.

Experimental procedure

Materials

OPC (CEMI, 42.5) that complies with the European Standard EN 197-1 was used in all SCC mixtures. The MP is a by-product of marble stone sawing, shaping, and lustration. The chemical composition and physical properties of cement and MP are presented in Tab. 2.

Laser particle distribution analysis was used to determine the particle size distribution of cement and MP (Fig. 1). The results indicated that MP is finer than the cement. Tab. 2 gives the diameter of particles that correspond to 10%, 50% and 90% of passing. The results showed that more than 50% of MP material has particles less than 6.5 μm, and about 50% of cement particles are smaller than 12.35 μm. Fig. 2 shows the results of the scanning electron microscopy (SEM) analysis of cement and MP. This test allows to identify the particles shape of the tested material and confirmed the results for particle size distribution presented in Fig. 1. The particles of MP are finer and appear to have less angular shape compared to the cement particles.

The mineralogical analysis of MP which is presented in Fig. 3 indicates that MP is mainly composed of calcite with some traces of quartz and dolomite.

Chemical composition (%)		Cement	MP
SiO_2		20.14	0.42
CaO		63.47	56.01
MgO		2.12	0.12
Al_2O_3		3.71	0.13
Fe_2O_3		4.74	0.06
SO_3		2.67	0.01
K_2O		0.47	0.01
T_iO_2		0.21	0.01
Na_2O		0.69	0.43
P_2O_5		0.06	0.03
Loss ignition		1.72	42.78
Physical properties			
Specific gravity		3.1	2.7
Fineness characteristics	Fineness (m^2/kg)	330	360
	d_{10} (µm)	1.19	1.36
	d_{50} (µm)	12.35	6.50
	d_{90} (µm)	40.53	21.09

Table 2: Chemical composition and physical properties of cement and MP.

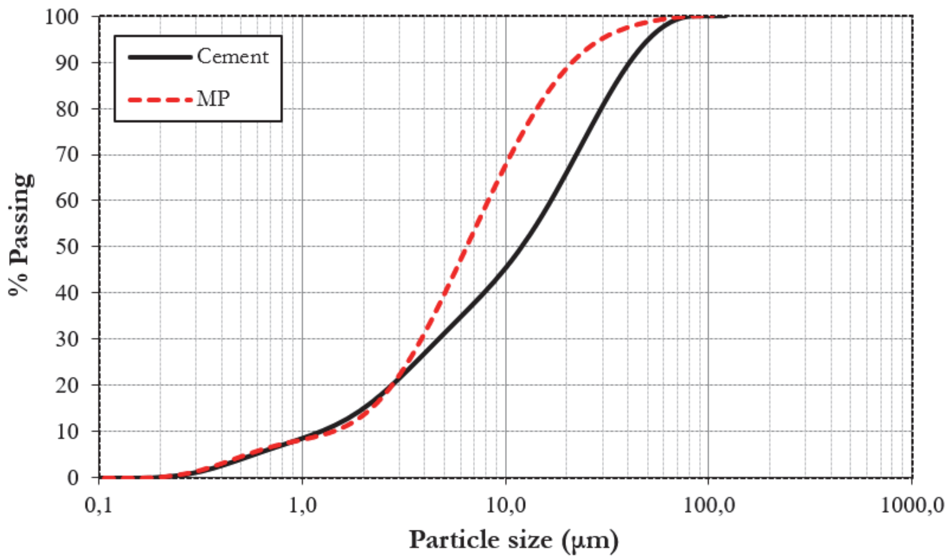
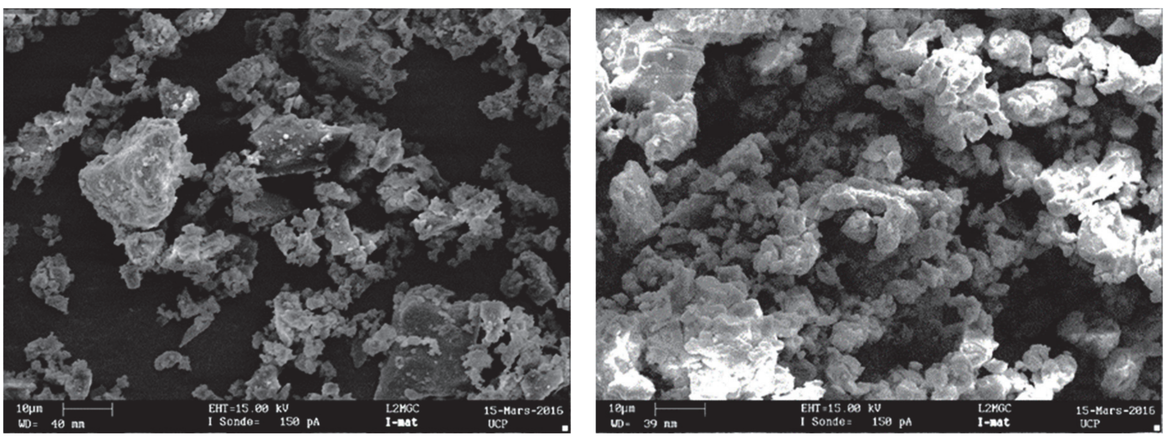


Figure 1: Particle size distribution of cement and MP.



(a) (b)

Figure 2: SEM analysis of (a) cement and (b) MP.

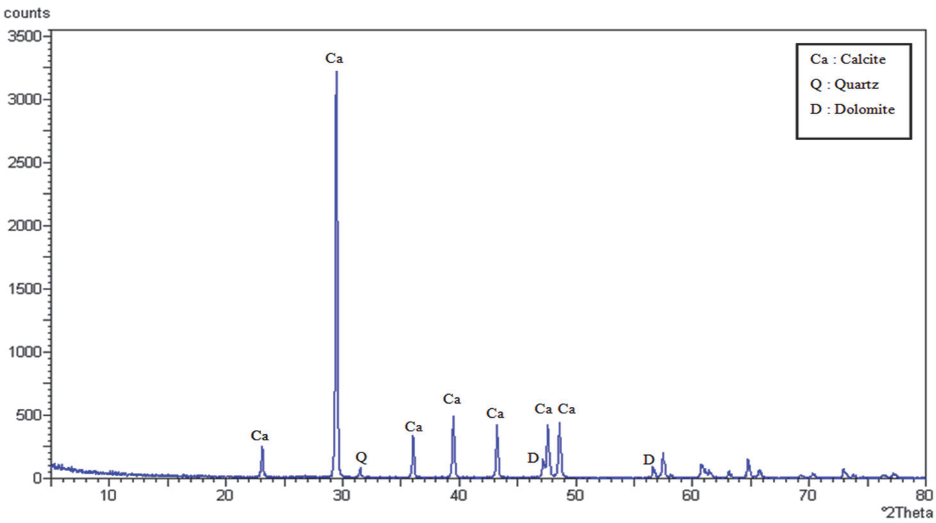


Figure 3: XRD analysis of MP.

A polycarboxylate-based superplasticizer was used as a chemical admixture, it has a density and pH of 1070 kg/m^3 and 8, respectively. Natural river sand was used as fine aggregate. Two classes of coarse aggregate were used. The physical properties of aggregates were meseaured according to European Standared EN 1097-6 [31] and are given in Tab. 3. Fig. 4 presented the particle size distribution of aggeregates.

Properties	Fine aggregate	Coarse aggregate	
	0/5	3/8	8/15
Absorption coefficient (%)	0.59	1.56	2.26
Density (kg/m^3)	2600	2610	2540
Water content (%)	0.03	0.17	0.13

Table 3: Physical properties of aggregates.

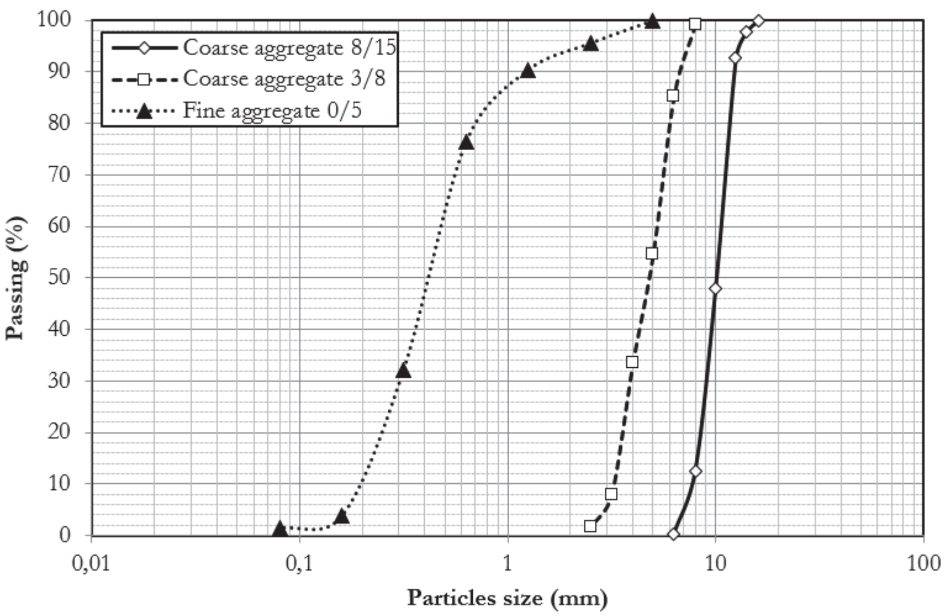


Figure 4: Particle size distribution of aggregates.

Mixture proportions

To study the effect of MP on some fresh and hardened properties and production cost of SCC, five mixtures were prepared. The control mix included only OPC as a binder, whereas in the other mixtures cement was partially substituted with MP at ratios of 5, 10, 15 and 20%. The proportions of all SCC mixtures are shown in Tab. 4.

Constituents		Mix ID				
		0MP	5MP	10MP	15MP	20MP
Cement (kg/m³)		470	448	426	404	382
Marble powder	(%)	0	5	10	15	20
	(kg/m³)	0	22	44	66	88
Sand 0/5 (kg/m³)				882.9		
Coarse aggregate (kg/m³)	8/15			553		
	3/8			277		
Water (kg/m³)				188		
Superplasticizer (kg/m³)				4.23		
Water/binder				0.4		
Superplasticizer/binder				0.9		

Table 4: Mix proportions of SCC mixtures.

Testing procedures

Slump flow, L-box and sieve segregation tests were carried out to characterize the filling and passing ability and the resistance to segregation of fresh SCC according to EFNARC requirements [32]. The fluidity retention was evaluated by measuring slump flow loss after 30, 60 and 90 minutes. This test allows to estimate the practical duration for using each SCC mixture, while the trend to segregation can be qualitatively assessed.

Compressive strength and segregation static tests were carried out according to EN 12390-3 and AASHTO PP58 [33-34], respectively. Prismatic (7×7×28 cm) and cylindrical (16×32 cm) specimens were cast from each SCC mixture. After demolding, the specimens were cured in water at controlled conditions (T=20±2°C and HR>=95%). The average compressive strength test results of six prismatic specimens at the age of 7 and 28 days were determined, while three cylindrical specimens were used to visually assess the static segregation.

Fresh properties		Mix ID						Min	Max
		0MP	5MP	10MP	15MP	20MP			
Slump flow (cm)	0 min	70.5	71.1	72.7	73	73.5	Acceptance criteria of SCC suggested by EFNARC [32]	65	80
	30 min	69.3	70	71.1	71.5	72.2			
	60 min	67	68.5	69	69.4	70.3			
	90 min	63	66	67	67.3	68.5			
T50 flow time (s)		2.53	1.75	1.61	1.52	1.32		2	5
L-box blocking ratio (%)		0.77	0.81	0.82	0.81	0.81		0.8	1
L-box flow time (s)	T20	0.76	0.61	0.5	0.47	0.39		-	-
	T40	1.71	1.53	1.48	1.43	1.38		-	-
Segregation ratio (%)		5.1	6.3	6.2	11.2	13.5		5	15

T50 : is the time required for the SCC slump flow to reach a circle with 50 cm diameter [32].
T20 and T40: are the times required for the SCC to reach points 20 cm (T20) and 40 cm (T40) down the horizontal portion of the L-box [32].

Table 5: Fresh properties of SCC mixtures.

RESULTS AND DISCUSSION

Slump flow

The results of the fresh properties of SCC mixtures are presented in Tab. 5. Fig. 5 depicted the variation of slump flow and T50 flow time as a function of the amount of MP. The slump flow is a good indicator of the ability of SCC to flow under its weight in an unconfined formwork. Fig. 4 showed that all the SCC mixes had good flowability, with slump flow values ranging from 70 to 74 cm. It can be seen that all the fresh SCC mixtures had slump flow diameter generally conforming EFNARC (65 to 80 cm) [32]. It has been noted an increase in slump flow with increasing MP content, which means that mixtures prepared with MP presented better fluidity and deformability, compared to the reference mixture. This result may be attributed to the shape of the MP particles, which is less angular than that of the cement and hence increasing the flow of SCC with MP. On the other hand, the density of MP, which is lower compared to that of cement, increases the volume of paste and reduces the frictions between coarse and fine aggregates [35]. Furthermore, the substitution of cement by MP decreased the amount of water consumed by hydration reactions, which results in the additional free water that increases deformability. Similar findings were stated by Uysal and Yilmaz [36]. However, Guneyisi et al. [29] have reported contradictory results, in which they observed a decrease in the fluidity of the SCC with the addition of MP. It should be noted that it is possible to reduce the need for superplasticizer and water for SCC made with MP to obtain a similar fluidity to control SCC, this reduces the production cost, and on the other hand decreases the water/cement ratio which improves the compressive strength and durability. Fig. 5 presents also the T50 flow time for SCC mixtures. The results indicate that T50 flow time decreases as the amount of MP increases, this means that SCC with MP is more fluid and less viscous. It should be noticed that all SCC mixtures do not meet the flow time values suggested by EFNARC [32], except for reference SCC, but the visual control of fresh SCC revealed that there was no problem of segregation or bleeding (Fig. 6).

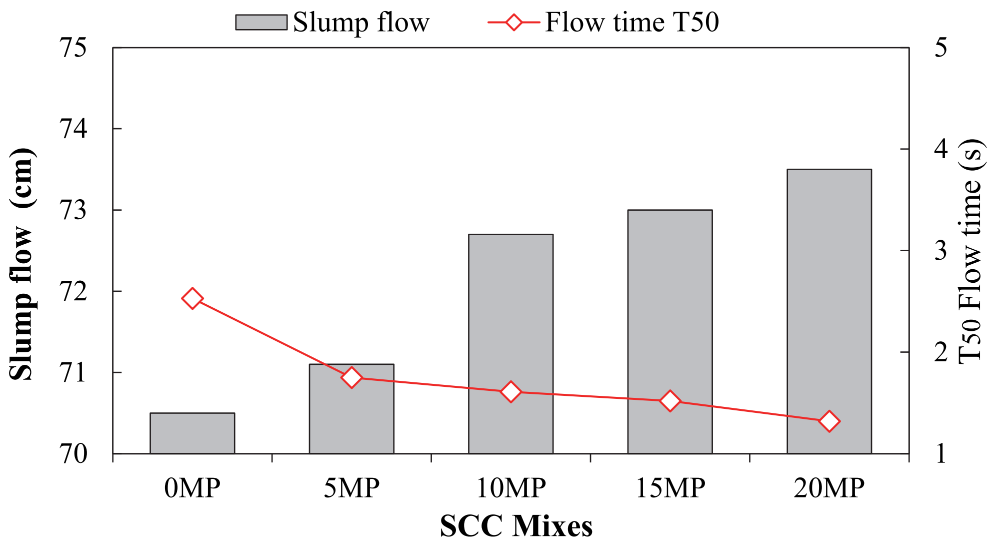


Figure 5: Slump flow and T50 flow time of SCC mixtures vs MP content.

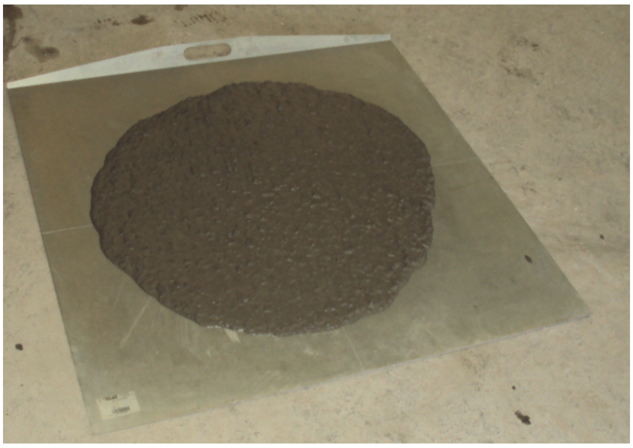


Figure 6: SCC mixture without segregation or bleeding.

Fluidity retention

The effect of MP on the slump flow loss of SCC mixtures over time is plotted in Fig. 7. It can be observed that there was a decrease in slump flow diameter with increasing time. The 0MP, 5MP, 10MP, 15MP, and 20MP mixtures have slump flow values of 71, 71, 73, 73 and 74 cm immediately after being mixed, and after 90 minutes these same mixtures experienced slump flow values of 63, 66, 67, 67.3, and 68.5 cm, respectively. It can be seen that the reference SCC lost its fluidity after 90 minutes with a slump flow value inferior to 65 cm, while the other mixtures maintained their fluidity even after 90 minutes with slump flow values superior to 65 cm.

Adding MP improved and maintained the fluidity of SCC mixtures, this means that SCC can be used for more than 90 minutes after initial mixing or transported for long distances without losing the self-compacting property. These results may be explained by the substitution of cement by MP, which decreased the amount of water evaporated and consumed by hydration reactions, thus offered additional free water in the mixture.

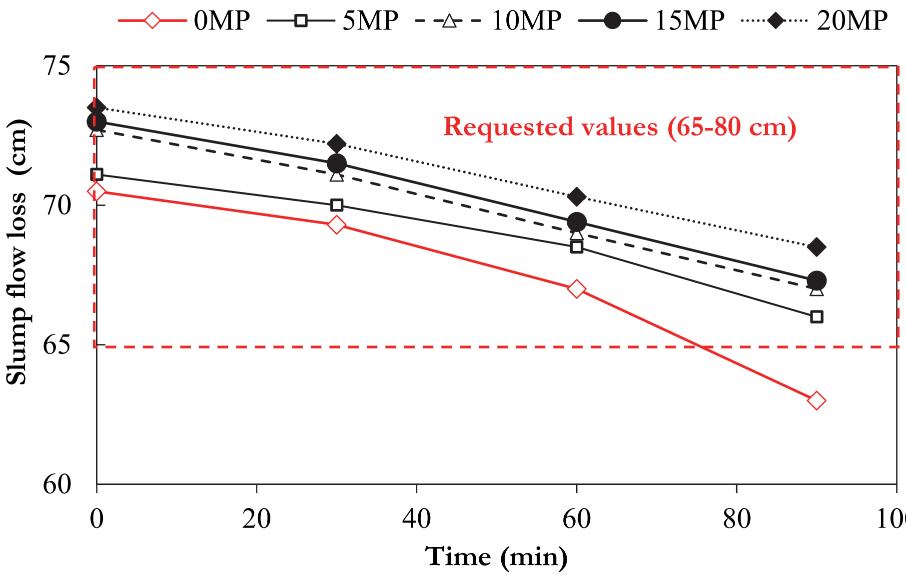


Figure 7: Slump flow loss of SCC mixtures vs MP content.

Blocking ratio

The variation of blocking ratio of SCC mixtures made with different amounts of MP is presented in Fig. 8. EFNARC committee suggests that 0.8 and 1 for lower and upper limits of blocking ratio, respectively, are acceptable for designing appropriate SCC mixtures. The blocking ratio values ranged between 0.77 and 0.82. The results indicated that mixtures containing MP had a blocking ratio higher than 0.8, whereas the blocking ratio of the reference mixture was less than 0.8. This means that SCC mixtures made with MP have great mobility in a confined area. Topçu et al. [37] found similar results.

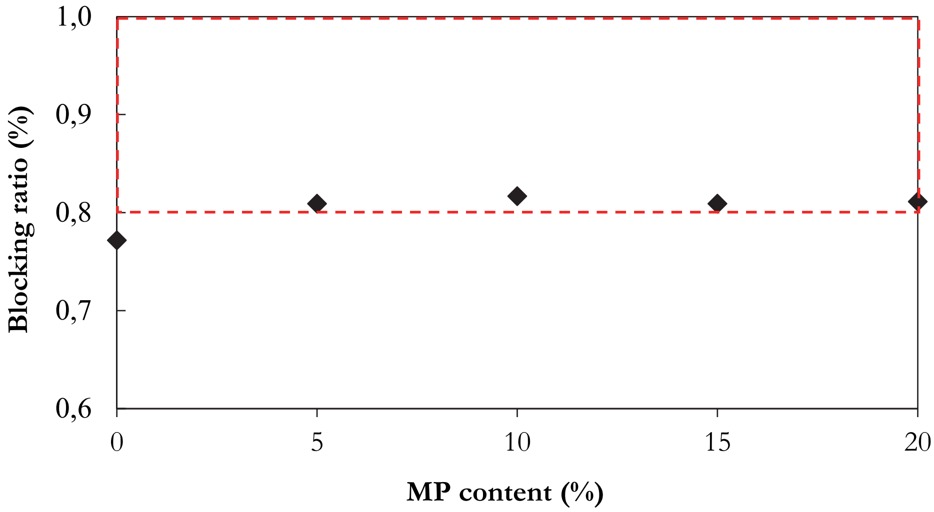


Figure 8: Blocking ratio of L-box of SCC mixtures vs MP content.

Fig. 9 shows the evolution of T20 and T40 flow times in L-box as a percentage of MP. It can be seen from this figure that the replacement of cement by MP reduced the flow times (T20 and T40) due to an increase in the fluidity of these mixtures, this decrease is of the same as the T50 flow time. All T20 and T40 flow time values are within the target range T20 <1.5 s and T40 <3.5 s suggested by Jaramillo et al. [38]. The flow times T20 and T40 are good indicators of the viscosity, this means that mixtures including MP have lower viscosity compared to the control mixture. Alyamac et al. [27] showed that the addition of MP resulted in higher viscosity and consequently the v-funnel time increased. Some authors reported that SCC made with MP showed an increase in the flow time by increasing MP content [36, 39].

Dynamic segregation

The results of the sieve segregation test are illustrated in Fig. 10. This figure shows that increasing the amount of MP increased the segregation ratio, the values obtained are 5.1, 6.3, 6.1, 11.2 and 13.5% for the 0MP, 5MP, 10MP, 15MP, and 20MP SCC mixtures, respectively. These values indicate that all the tested mixtures have good resistance to dynamic segregation (5% ≤ IS ≤15%) [32].

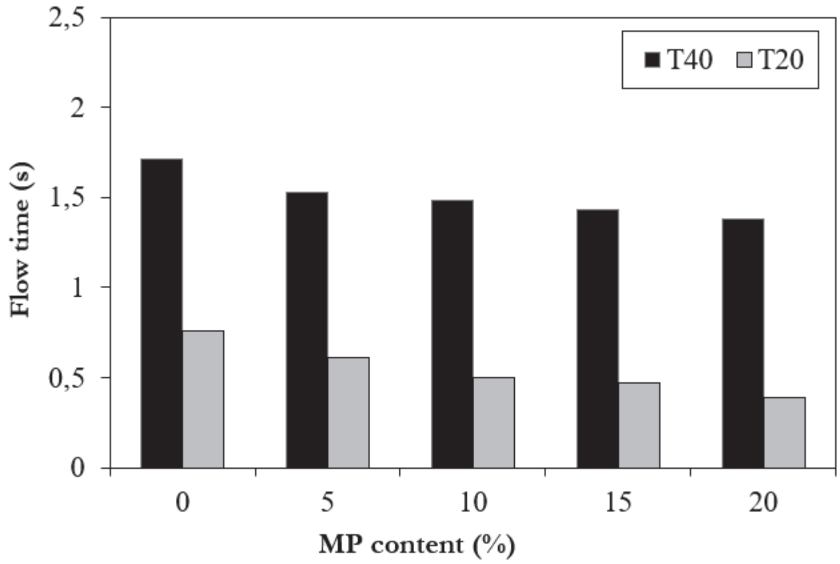


Figure 9: T20 and T40 flow times in L-box of SCC mixtures vs MP content.

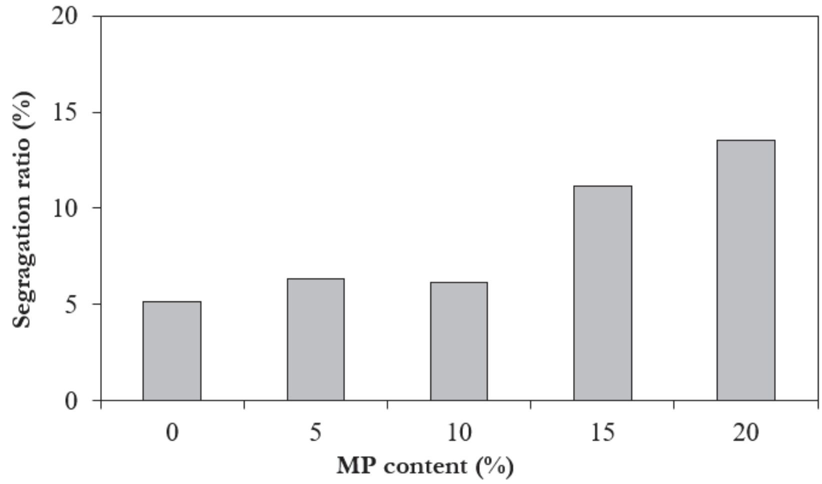


Figure 10: Dynamic segregation ratio of fresh SCC mixtures vs MP content.

The control mixture has developed the highest resistance to segregation. However, using MP reduced the resistance to segregation. The lower segregation ratio for the control mixture is due to its high viscosity. The increase in the segregation ratio of the other mixtures is attributed to their low viscosity.

Compressive strength

Fig. 11 shows the compressive strength of SCC mixtures at 7 and 28 days. The compressive strength decreased as the amount of MP increased. This may be attributed to the use of MP, which has no pozzolanic property; therefore, it cannot chemically contribute to the development of the strength at later ages. Also, the low water retention which characterizes the MP induces a significant amount of water in the mixture which contributes through the dilution effect to decrease of the compressive strength. Besides, the reduction of the volume of C_3S and C_2S that are responsible for the development of strength, as the cement is partially replaced by MP, decreases also the compressive strength. It has been noted that compressive strength values are between 19-28 MPa at 7 days and 26-37 MPa at 28 days. The mix with 5% of MP developed a similar strength to the reference mix at 28 days. Furthermore, the control mix had the highest strength at all the curing ages due to the high amount of OPC (470 kg/m^3). The 20MP mixture with 380 kg/m^3 of OPC had the same compressive strength as conventional concrete with 350 kg/m^3 of OPC which is the most used cement dosage in Algerian construction sites.

These results are close to those reported in the literature [30, 40]. However, Tennich et al [15] reported contradictory results. The authors found that the presence of waste fillers from marble in the composition of SCC, at a dosage of 350 kg/m^3 increased the compressive strength by about 6.7% in comparison to ordinary cement vibrated concrete. In recent work, Toubal et al. [41] have shown that wet curing of pastes made with MP leads to higher compressive strength compared to air curing. They also reported that increasing wet curing duration helps to improve the compressive strength by reducing the percentage of water evaporated and the porosity.

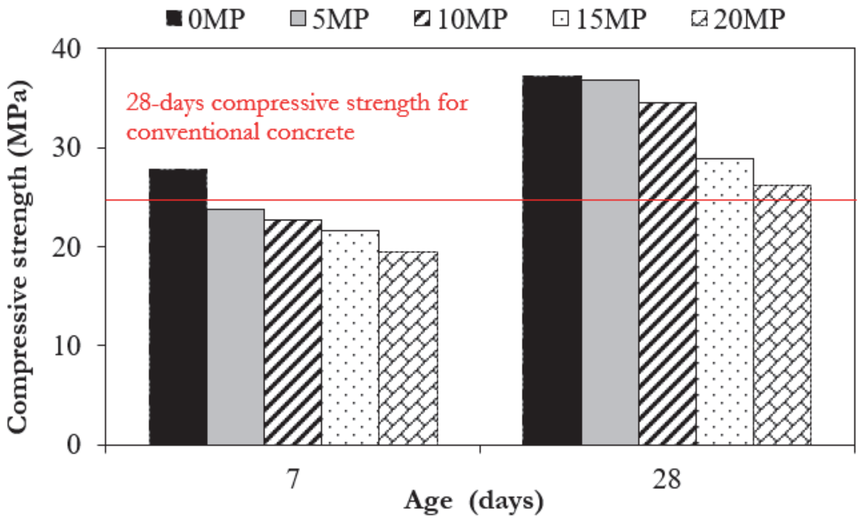
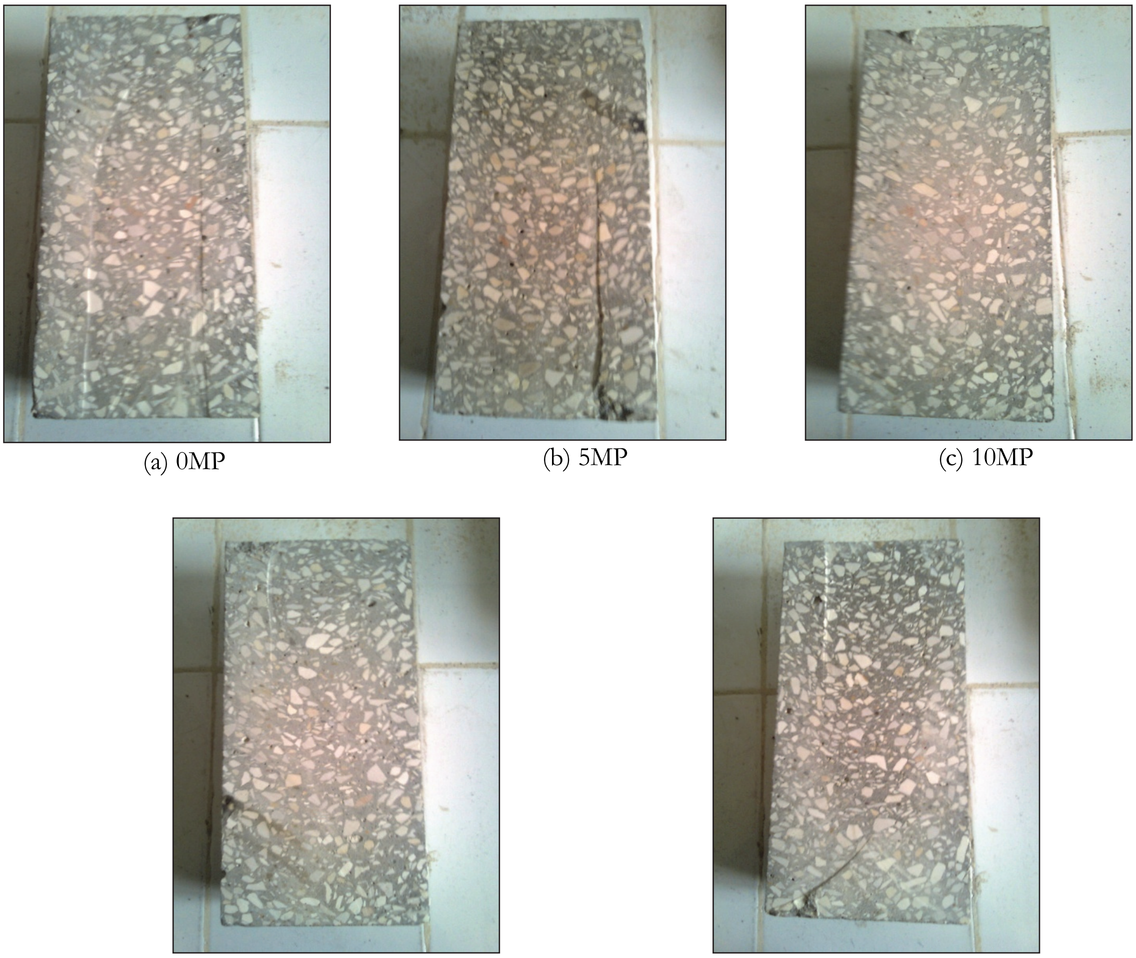


Figure 11: Compressive strength of SCC mixtures vs MP content.

Static segregation
Fig. 12 illustrates a visual examination of the static segregation of cylindrical specimens. The figure indicated that all mixtures have a regular and homogeneous distribution of coarse particles in all parts and for all levels of MP. No bleeding was noted at the top of the specimens. It can be concluded that all tested mixtures have good resistance to static segregation.


(a) 0MP (b) 5MP (c) 10MP

(d) 15MP (e) 20MP

Figure 12: Visual control of static segregation in SCC mixtures.

Production cost of SCC
Until now, the use of SCC in building constructions is limited due to the high production cost stemming from the use of superplasticizers and large amount of cement. The superplasticisers enable the concrete to obtain the desired fluidity.

The use of SCM reduced the demand of superplasticizer and the quantity of clinker, which allows decreasing the cost of SCC and therefore increasing its use. In this context, this study was carried out to examine the effect of MP on the production cost of SCC. The production cost of one cubic meter of the various concrete mixes is given in Tab. 6. It can be shown that adding MP decreased the production cost of SCC. Increasing MP content from 5 to 20% reduced the cost of SCC by 3 to 13 %, compared to the plain cement mixture.

Constituents		Mix. ID				
		0MP	5MP	10MP	15MP	20MP
Cement ($)		50.25	47.90	45.55	43.20	40.74
Marble powder ($)		0	0.22	0.44	0.66	0.89
Sand 0/5 ($)				2.21		
Coarse aggregate ($)	8/1 -			4.93		
	3/8			2.34		
Water ($)				0.72		
Superplasticizer ($)				5.08		
Global cost ($) / 1 m³		65.54	63.40	61.27	59.14	56.90
Production cost gain (%)		0	3.27	6.52	9.77	13.18

Prices are considered for Algerian market

Table 6: Production cost for 1 m³ of all SCC mixtures.

The concept of SCC Performance index

The performance of each SCC mixture was evaluated by measuring the performance index (PI) [42]. This approach is adopted to facilitate the determination of the suitable replacement rate of MP that complies with the researched performance criteria. The required characteristics depend on the concrete application and are generally defined by the consumer. The first step in this approach is to calculate the weight ranking (W_i) of all the selected criteria from Eqn. (1).

$$W_i = \frac{Measured\ performance\ for\ each\ mixture}{Best\ measured\ performance} \tag{1}$$

The mixture with the best test value in a certain criterion scores 1.00, while the remaining mixtures have test values proportional to the best test value (<1.00). In the second step, a numerical index (R_i) is calculated. The highest value of (R_i) is equal to 5.00. For each mixture, the corresponding numerical index is the product of the previously calculated weight ranking Wi and 5.00 as given in Eqn. (2).

$$R_i = 5 \times W_i \tag{2}$$

Mix. ID	Fluidity retention		Compressive strength		Cost production gain	
	W_i	R_i	W_i	R_i	W_i	R_i
0MP	0.92	4.60	1.00	5.00	0.00	0.00
5MP	0.96	4.82	0.99	4.94	0.25	1.23
10MP	0.98	4.89	0.93	4.64	0.50	2.48
15MP	0.98	4. 91	0.77	3.87	0.74	3.71
20MP	1.00	5.00	0.70	3.51	1.00	5.00

Table 7: Performance indices for individual criteria.

In this study, three performance principal criteria have been selected: fluidity retention, compressive strength, and cost production. Tab. 7 gives the weighted ranks and numerical indices of all SCC mixtures. According to the required performance criteria, the related numerical index is multiplied to get a mixture score (S_{in}) as given by Eqn. (3). The mixture with the highest score is the most appropriate in terms of the required multiple criteria.

$$S_{in} = R_{i1} \times R_{i2} \times \ldots\ldots\ldots \times R_{in} \tag{3}$$

Tabs. 8 and 9 present the performance indices for multiple criteria and the suitable MP content for different performance criteria. With regards to the fluidity retention and compressive strength requirements (PI-1), using 5% of MP was found to be more suitable. For constructions that require fluidity retention and production cost gain (PI-2) (or compressive strength and production cost gain (PI-3)), a substitution level of 20% is considered the best. If all of the three characteristics (fluidity retention, compressive strength and production cost gain) are required (PI-4), adding 20% of MP is the appropriate substitution level.

Multiple performance criterion	Mix. ID				
	0MP	5MP	10MP	15MP	20MP
PI-1	22.99	23.79	22.68	19.02	17.56
PI-2	0	5.95	12.11	18.22	25.00
PI-3	0	6.09	11.48	14.36	17.56
PI-4	0	29.36	56.14	70.55	87.81

Table 8: Performance indices for multiple criteria.

Performance index	Required performance criteria	MP (%)
PI-1	Fluidity retention + compressive strength	5-10
PI-2	Fluidity retention + production cost gain	20
PI-3	Compressive strength + production cost gain	20
PI-4	Fluidity retention + compressive strength + production cost gain	20

Table 9: Appropriate MP content for different performance criteria.

CONCLUSIONS

Based on the experimental results and evaluation of SCC with MP using the concept of a performance index, the following conclusions can be drawn :

- All SCC mixtures have satisfactory self-compacting properties at fresh state. The use of MP in SCC enhances the filling and passing abilities.
- The addition of MP seems to reduce the need for superplasticizer and water to obtain a similar fluidity to the SCC control mixture. This not only reduces the production cost, but also the w/c ratio, which allows to enhance the performance of hardened SCC.
- The time to retain the fluidity of SCC can be extended by using MP, this will be very helpful when transporting concrete over long distances.
- At a hardened state, the 28-days compressive strength of SCC with MP ranged from 26 to 37 MPa. This means that is possible to used MP in SCC for construction requiring medium strength. An examination of the risk of static segregation shows that all the mixtures tested are homogeneous and have good resistance to the static segregation.
- The use of MP as a partial replacement for cement reduced the production cost and CO_2 emissions, which means that MP is an interesting material to produce an eco-friendly SCC.
- The characteristics of SCC may be assigned numerical performance Index values. These values may constitute a reliable means for concrete producers in finding the rate of cement replacement by other cementitious materials. According to the performance index results, the inclusion of 20% of MP in SCC mixtures was beneficial for most of the targeted performance criteria.

REFERENCES

[1] Bajad, M.N. Modhera, C.D and Desai, A.K. (2011). Effect of glass on strength of concrete subjected to sulphate attack, Civ. Engin. Res. Develop., 1(2), pp. 1-13.

[2] Behim, M. Cyr, M and Clastres, P. (2011). Physical and chemical effects of El Hadjar slag used as an additive in cement-based materials, Euro. J. Envir. Civ. Engin., 15(10), pp. 1413-1432. DOI: 10.1080/19648189.2011.9723352

[3] Celik, M.Y and Sabah, E. (2008). Geological and technical characterization of Iscehisar (Afyon-Turkey) marble deposits and the impact of marble waste on environmental pollution, Envir. Manag., 87, pp. 106-116. DOI: 10.1016/j.jenvman.2007.01.004

[4] Safiuddin, M. West, J.S and Soudki, K.A. (2011). Flowing ability of the mortars formulated from self-compacting concretes incorporating rice husk ash, Constr. Build. Mater., 25(2), pp. 973-978. DOI: 10.1016/j.conbuildmat.2010.06.084

[5] Brulliard, C. Cain, R. Do, D. Dornom, T. Evans, K. Lim, B. Olesson, E and Young, S. (2012). The Australian recycling sector. Report of Department of Sustainability, Environment, Water, Population and Communities. Available at: https://www.environment.gov.au/system/files/resources/dc87fd71-6bcb-4135-b916-71dd349fc0b8/files/australian-recycling-sector.pdf.

[6] Laidani, Z.E.A. Benabed, B. Abousnina, R. Gueddouda, M.K and Kadri, EH. (2020). Experimental investigation on effects of calcined bentonite on fresh, strength and durability properties of sustainable self-compacting concrete, Constr. Build. Mater., 230, pp. 1-11. DOI: 10.1016/j.conbuildmat.2019.117062

[7] Boukhelkhal, A and Benabed, B. (2019). Fresh and hardened properties of self-compacting repair mortar made with a new reduced carbon blended cement, Silic. Bas. Compos. Mater., 71(4), pp. 108-113. DOI: 10.14382/epitoanyag-jsbcm.2019.19

[8] Santos, S. Da Silva, PR and De Brito, J. (2019). Self-compacting concrete with recycled aggregates – A literature review, J. Build. Eng., 22, pp. 349-371. DOI: 10.1016/j.jobe.2019.01.001

[9] Boughamsa, O. Hebhoube, H. Kherref, L. Belachia, M. Abdelouahed, A and Rihia, C. (2020). Valorization of marble's waste as a substitute in sand concrete, Adv. Concr. Constr. 9 (2), pp. 217-225. DOI: 10.12989/acc.2020.9.2.217

[10] Ouldkhaou, Y. Benabed, B. Abousnina, R and Kadri, E.H. (2020). Experimental study on the reuse of cathode ray tubes funnel glass as fine aggregate for developing an ecological self-compacting mortar incorporating metakaolin, J. Build. Engin., 20, pp. 1-11. DOI: 10.1016/j.jobe.2019.100951

[11] Boukhelkhal, A. Azzouz, L. Benabed, B and Belaïdi, A.S.E. (2017). Strength and durability of low-impact environmental self-compacting concrete incorporating waste marble powder, Build. Mater. Struc., 4, pp. 31-41. DOI: 10.5281/zenodo.1134146

[12] Alipour, P. Namnevis, M. Tahmouresi, B. Mohseni, E and Tang, W. (2019). Assessment of flowing ability of self-compacting mortars containing recycled glass powder, Adv. Concr. Constr., 8(1), pp. 65-76. DOI: 10.12989/acc.2019.8.1.065

[13] Baghabra, Al Amoudi O.S., Shamsad, A. Khan, S.M.S and Maslehuddin, M. (2019). Durability performance of concrete containing Saudi natural pozzolans as supplementary cementitious material, Adv. Concr. Constr., 8(2), pp. 119-126. DOI: 10.12989/acc.2019.8.2.119

[14] Djelloul, O.K. Menadi, B. Wardeh, G and Kenai, S. (2018). Performance of self-compacting concrete made with coarse and fine recycled concrete aggregates and ground granulated blast-furnace slag, Adv. Concr. Constr., 6(2), pp. 103-121. DOI: 10.12989/acc.2018.6.2.103 103.

[15] Tennich, M. Kallel, A and Ben Ouezdou, M. (2015). Incorporation of fillers from marble and tile wastes in the composition of self-compacting concretes, Constr. Build. Mater., 91, pp. 65-70. DOI: 10.1016/j.conbuildmat.2015.04.052

[16] Sadek, D.M. El-Attar, MM and Haitham, A.A. (2016). Reusing of marble and granite powders in self-compacting concrete for sustainable development, J. Clean. Prod., 121, pp. 19-32. DOI: 10.1016/j.jclepro.2016.02.044

[17] Siddique, R. (2016). Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self-compacting concrete containing coal bottom ash, Constr. Build. Mater., 47, pp. 1444-1450. DOI: 10.1016/j.conbuildmat.2013.06.081

[18] Boukhelkhal, A. Azzouz, L. Kenai, S. Kadri, E.H and Benabed, B. (2019). Combined effects of mineral additions and curing conditions on strength and durability of self-compacting mortars exposed to aggressive solutions in the natural hot-dry climate in North African desert region, Constr. Build. Mater., 197, pp. 307-318. DOI: 10.1016/j.conbuildmat.2018.11.233

[19] Jalal, M. Pouladkhan, A. Harandi, O.F and Jafarid, D. (2015). Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self-compacting concrete, Constr. Build. Mater., 94, pp. 90-104. DOI: 10.1016/j.conbuildmat.2015.07.001

[20] Ardalan, RB. Joshaghani, A and Hooton, RD. (2017). Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume, Constr. Build. Mater., 134, pp. 116-122. DOI: 10.1016/j.conbuildmat.2016.12.090
[21] Boukhelkhal, A. Azzouz, L. Belaïdi, A.S.E and Benabed, B. (2016). Effects of marble powder as a partial replacement of cement on some engineering properties of self-compacting concrete, Adhes. Sci. Technol., 30(22), pp. 2405–2419.
[22] Assi, L. Carter, K. Deaver, E. Anay, R and Ziehl, P. (2018). Sustainable concrete: building a greener future, J. Clean. Prod., 198, pp. 1641-1651.DOI: 10.1016/j.jclepro.2018.07.123
[23] Kim, Y. Hanif, A. Usman, M. Munir, MJ. Kazmi, SMS and Kim, S. (2017). Slag waste incorporation in high early strength concrete as cement replacement: environmental impact and influence on hydration and durability attributes, J. Clean. Prod., 172, pp. 3056-3065. DOI: 10.1016/j.jclepro.2017.11.105
[24] Ishak, SA and Hashim, H. (2015). Low carbon measures for cement plant - a review, J. Clean. Prod., 103, pp. 260-274. DOI: 10.1016/j.jclepro.2014.11.003
[25] Boukhelkhal, D. Boukendakdji, O. Kenai, S and Kadri, E-H. (2018). Combined effect of mineral admixture and curing temperature on mechanical behavior and porosity of SCC, Adv. Concr. Constr., 6(1), pp. 69-85. DOI: 10.12989/acc.2018.6.1.069.
[26] Singh, M. Choudhary, K. Srivastava, A. Sangwan, KS and Bhunia, D. (2017). A study on environmental and economic impacts of using waste marble powder in concrete, J. Build. Eng., 13, pp. 87-95. DOI: 10.1016/j.jobe.2017.07.009
[27] Alyamac, KE. Ghafari, E and Ince, R. (2017). Development of eco-efficient self-compacting concrete with waste marble powder using the response surface method, J. Clean. Prod., 144, pp. 192-202. DOI: 10.1016/j.jclepro.2016.12.156
[28] Ashish, DK (2019). Concrete made with waste marble powder and supplementary cementitious material for sustainable development, J. Clean. Prod., 211, pp. 716-729. DOI: 10.1016/j.jclepro.2018.11.245
[29] Guneyisi, E. Gesoglu, M and Ozbay, E. (2009). Effects of marble powder and slag on the properties of self-compacting mortars, Mater. Struc., 42, pp. 813-826. DOI: DOI: 10.1617/s11527-008-9426-2
[30] Toubal, NS. Mellas, M. Sadowski, L and Żak, A. (2018). Effects of marble powder on the properties of the air-cured blended cement paste, J. Clean. Prod., 183, pp. 858-868. DOI: 10.1016/j.jclepro.2018.01.267
[31] European Standared EN 1097-6 (2013) Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption.
[32] EFNARC(2002).Specification and Guidelines for Selfcompacting Concrete. European Federation of Producers and Applicators of Specialist Products for Structures, EFNARC, Norfolk, UK, pp.32.
[33] EN 12390-3. (2012). Essais pour béton durci - Partie 3 : résistance à la compression des éprouvettes de béton durci.
[34] AASHTO PP58 (2008). "Static segregation of hardened self-consolidating concrete cylinders." American Association of State Highway and Transportation Officials, Washington, DC.
[35] Yahia, A. Tanimura, M and Shimoyama, Y. (2005). Rheological properties of highly flowable mortar containing limestone filler-effect of powder content and w/c ratio, Cem. Concr. Res., 35(3), pp. 532–539. DOI: 10.1016/j.cemconres.2004.05.008
[36] Uysal, M. and Yilmaz, K. (2011). Effect of mineral admixtures on properties of self-compacting concrete, Cem. Concr. Com., 33, pp. 771-6. DOI: 10.1016/j.cemconcomp.2011.04.005
[37] Topçu, I. Bilir, T and Uygunoglu, T. (2009). Effect of waste marble dust content as filler on properties of self-compacting concrete, Constr. Build. Mater., 23, pp. 1947-1953. DOI: 10.1016/j.conbuildmat.2008.09.007
[38] Arbelaez Jaramillo, C.A. Rigueira Victor, J.W. Marti Vargas, J.R., Serna Ros, P and Pinto Barbosa, M. (2003). Reduced models test for the characterization of the rheological properties of self-compacting concrete (SCC), Proceedings of the Third International Symposium on Self-Compacting Concrete, Reykjavik, Island, 17-20 August.
[39] Alyousef, R. Benjeddou, O. Khadimallah, M.A. Mohamed, A.M. Soussi, C (2018). Study of the Effects of Marble Powder Amount on the Self-Compacting Concretes Properties by Microstructure Analysis on Cement-Marble Powder Pastes. Advan Civ Eng. DOI: 10.1155/2018/6018613.
[40] Corinaldesi, V. Moriconi, G and Naik, TR. (2010). Characterization of marble powder for its use in mortar and concrete, Constr. Build. Mater., 24, pp. 113-117. DOI: 10.1016/j.conbuildmat.2009.08.013
[41] Toubal, NS. Mellas, M. Sadowski, L and Żak, A. (2019). The effect of curing conditions on the properties of cement-based composites blended with waste marble dust, Mine. Met. Mater. Soc., 71(3), pp. 1002-1015. DOI: 10.1007/s11837-018-3254-9.
[42] El-Dieb, A.S and Kanaan, D.M. (2018). Ceramic waste powder an alternative cement replacement–Characterization and evaluation, Sustain. Mater. Techno., 17, pp. 1-11. DOI: 10.1016/j.susmat.2018.e00063.