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ENHANCEMENT OF SELF COMPACTING CONCRETE USING WASTE MARBLE POWDER

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ABSTRACT

Finding a self-compacting concrete (SCC) mix side by side with minimizing trial to its cost is the goal of this research. SCC mixes often use large amounts of powder materials, viscosity modifying agents and superplasticizer for creating a very fluid mixture. These fillers explain the reason. So, this experimental study works on partial substitution of cement with different percentages of marble waste powder and pozzolanic material up to 15% and 10% respectively on different seven SCC mixes. Experimental result showed that the best replacement could be up to 20% to get compressive strength above 40 MPa while preserving the viscosity, slump flow, and passing ability due to EFNARC (European Federation of National Associations Representing for Concrete).

KEYWORDS: Self-Compacting Concrete, Marble Waste Powder, Silica Fume, Strength, Fresh Properties, Hardened Properties.

تحسين الخرسانة ذاتية الدمك باستخدام بودرة الرخام

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الملخص

إن العثور على مزيج من الخرسانة ذاتية الدمك (SCC) جنبًا إلى جنب مع محاولة التقليل لتكلفتها هو هدف هذا البحث. فغالبًا ما تستخدم خلطات SCC كميات كبيرة من مواد المسحوق وعوامل تعديل اللزوجة والملدنات الفائقة لإنشاء خليط سائل للغاية. تمثل

هذه الإضافات سبب ارتفاع التكلفة. لذلك تعمل هذه الدراسة التجريبية على الاستبدال الجزئي للأسمنت بنسب مختلفة من مسحوق بودرة الرخام والمواد البوزولانية حتى 15٪ و 10٪ على التوالي على سبع خلطات مختلفة من الخرسانة ذاتية الدمك. أظهرت النتائج التجريبية أن الاستبدال الأمثل يمكن أن يصل إلى 20٪ للحصول على قوة ضغط فوق 40 ميجا باسكال مع الحفاظ على اللزوجة والتدفق والقدرة على التمرير طبقا للمبادئ التوجيهية التى حددت بواسطة الاتحاد الأوروبي للرابطات الوطنية الممثلة للخرسانة (EFNARC).

الكلمات المفتاحية : الخرسانة ذاتية الدمك، بودرة الرخام، السيليكافيوم، المقاومة، الخصائص الطازجة، الخصائص المتصلدة.

1. INTRODUCTION

Self-compacting concrete (SCC) is a unique kind of concrete created in the late 1980s in Japan [1, 2]. Because of its high workability and high-flow nature, it relies just on its own weight and not on any outside compacting tools, thereby helping to reduce the demanding on-site employment, filling the casted elements even if they have high reinforcement intensity without hearing honeycombing problems such as in conventional concrete. In large scale, SCC is a potential solution for concrete construction beneath water, where workability is defined as the concrete's ability to flow and self-compact within a given amount of time. [3]. SCC can be pumped to great heights like columns and walls preserving its self-leveling property without segregation. This technology has overcome concrete problems on site. But reaching a homogeneous concrete mix is not easy, it is sensitive to the materials used, the proportions of the materials and the way they are prepared. SCC is not as well-liked in the building sector because of the cost of its manufacturing. That results from the high content of plasticizers or powder content to reach the required workability of the mixture. Typical powder content due to EFNARC is in the range of 360-500 kg/m^3 [4]. High powder content implies high cement content leading to thermal stress and shrinkage problem. The idea of lowering down the cost and the negative effects of high cement content is of prime concern. Many of researchers aimed to utilize potential waste materials as fillers in SCC. Potential waste materials are widely available on the planet, whether they come from the building or product industries. Prior studies on SCC demonstrated that SCC mixtures containing fine powders, like chalk and limestone powder, have good fresh state properties and those containing pozzolanic fine powders such as fly ash, silica fume…etc. have better hardened state properties that improve the performance of concrete [5,6,7,8,9]. Limestone powder is a finely ground powder made from the sedimentary rock limestone. Limestone is a non-reactive material used in a wide range in the industry and construction field. Limestone is added in with clay and heated to form cement. Portland cement can have up to 35% limestone added to it [10]. Calcium silicates are the primary constituents of Portland cement. Limestone is the main source of calcium. Waste marble powder (WMP), about 86% of its mineral additives constituted, is the calcite.

On the other side, Silica fume (SF) finds its greatest application in concrete. Its physical and chemical characteristics make it an extremely reactive pozzolan. Concrete that contains silica fume has the potential to be extremely strong and long-lasting. The main component of silica fume is silicon dioxide (SiO_2). The size of each individual particle is minuscule comparing to the size of cement particle. When used in concrete, silica fume is a highly reactive due to its fine particles, large surface area, and high SiO_2 content. A pozzolan is a siliceous material. It has little or no cementitious value but, when finely reacts chemically with $Ca(OH)_2$ at room temperature in the presence of moisture, forms compounds with cementitious features. This has made many researchers focusing on them as a substituent additives for cement by weight. Some of Previous researches on SCC using WMP found that replacing it with cement lowers the compressive strength and others who tried to preserve the hardened properties by using different pozzolanic materials worked on low replacement levels. WMP and SF, in this study, are the powder substituents for cement and the aim of the experiment is to study the high replacement levels up to 25% and to revolve the best appropriate percentage of replacement from the point of both fresh and hardened states' view to obtain the desired mix.

2. EXPERIMENTAL PROGRAM

This chapter provides a thorough overview of the program implemented to achieve the research aims. The following are the program goals:

a- To investigate the effect of both WMP and SF on SCC as powder substituents for cement by weight and estimate to which limit for substitution the SCC mix can preserve its properties.
b- To gain SCC mix with compressive strength exceed 40 MPa.
c- To provide important information that facilitates the implementation of self-compacting concrete in the field and avoids errors may happen when producing this type of concrete.

In the experimental program accomplished at the Concrete Research Laboratory at Al-Azhar University, Seven mixes were performed and the necessary tests were done for them whether fresh or hardened.

2.1. Materials and material properties

The materials used in casting of the reinforced concrete specimens are:

- 42.5 N Grade Ordinary Portland Cement (CEM I):

  It was brought from a local dealer and it satisfies the egytian standard specification (E.S.S. 4756-1/2013) [11].

- Coarse aggregate (CA) :

  In the form of crushed dolomite stones with maximum size of 20 mm. It satisfies the requirements outlined in the Egyptian code (E.S.S. 1109/2008) [12].

- Fine aggregate (FA):

  In the form of natural clean sand. It also satisfies the requirements outlined in the Egyptian code (E.S.S. 1109/2008).

- Pure water devoid of contaminants was used for mixing and curing specimens.

- Waste marble powder (WMP):

It was also brought from Shaq-Althoban, Otostrad, Cairo, Egypt. The chemical and physical properties of the used WMP are presented in table 1 & table 2.

- Silica fume (SF):

It was brought from Sika Egypt For Construction Chemicals Co. Table 3 & table 4 provide the chemical and physical properties of the used SF.

- Sikament 163 m :

The superplasticizer (SP) which was utilized to preserve the workability and lower the water requirement for the SCC mixes. It meets the requirements for superplasticizers according to ASTM C-494 type A&F [13] and B.S. 5075 part 3[14]. It appears with a brown liquid form with a specific gravity of 1.2 t/m^3 .

The specific gravity for CEM I, FA, CA, WMP and SF was 3.14, 2.6, 2.7, 2.68 and 2.2 t/m^3 respectively. The form of granules of SF and WMP used in the mixes is shown in figures 1(a), 1(b) and 1(c).

Fig.1. Form of granules of the substitute powder materials used in SCC mixes: (A) silicafume; (B) waste marble powder and (C) marble waste powder vs. silicafume.

Table 1. Chemical composition of the WMP used

Oxide	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Content %	3.5	0.88	0.3	53.4	0.33

Table 2. Physical properties of the WMP used

Test	Result
Specific gravity (t/m^3)	2.68
Specific surface area (m^2/kg)	1100
Color	white

Table 3. Chemical composition of the SF used

Oxide	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	H_2O
Content %	96.6	0.6	1.01	0.2	0.17	0.65	0.22	0.2	0.25

Table 4. Physical properties of SF used

Test	Result
Specific gravity (t/m^3)	2.2
Specific surface area (m^2/ kg)	18×10^3
Color	Light grey

2.2. SCC mix proportions

To finally obtain the control mix several trial mixes were prepared according to EFNARC specification. The impact of replacing cement with SF and WMP was investigated at various proportions through six ternary mixes apart from the control mix. A water to powder ratio (w/p) of 0.49 was used in the creation and placing of the seven different mixes. The control mix was cast with only CEM I as the powder content while the other ternary mixes were made at (5% and 10 %) replacement level for SF with various replacement levels of (5% ,10%, 15%) for WMP. The SCC mixes are in detail in table 5 showing the amount of materials by weight of kilogram for one m^3.

Table 5. Mixing proportions for seven different SCC mixes that start with the control mix and rest mixes are having silicafume and marble waste powder with different percentages.

Mix	w/p	Water (Kg/m^3)	Powder (Kg/m^3)	CEM I (Kg/m^3)	SF (Kg/m^3)	WMP (Kg/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	SP (Kg/m^3)
SF 0%+WMP 0%	0.49	247	500	500	-	-	810	740	11
SF 5%+WMP 5%	0.49	247	500	450	25	25	810	740	11
SF 5%+WMP 10%	0.49	247	500	425	25	50	810	740	11
SF 5%+WMP 15%	0.49	247	500	400	25	75	810	740	11
SF 10%+WMP 5%	0.49	247	500	425	50	25	810	740	11
SF 10%+WMP 10%	0.49	247	500	400	50	50	810	740	11
SF 10%+WMP 15%	0.49	247	500	375	50	75	810	740	11

2.3. Testing procedure

Fresh properties

Concrete mixes were performed under the same conditions in terms of processing and duration of mixing before and after adding water. First, the required quantities were prepared for each mixture. Before placing any substance in the mixer, the mixer was hydrated with water. Then the dry ingredients were placed and mixed for a minute to ensure homogenization. Then sikament 163 m was added in the water and then added to the mixing. The mixer continued for about 3-5 minutes to ensure uniformity in distribution throughout the concrete mixture. The tests for fresh properties were conducted on mixes separately after the mixing operation completed to estimate the slump flow diameter, T500 time, L-Box height ratio, and V-funnel flow time. Test apparatus for the estimation of fresh state properties appear in figures 2(a), 2(b), 2(c) and 2(d). They were manufactured to follow the standard dimensions of British Standard EN 12350 parts 9,10 and 12 [15][16][17]. Slump apparatus was for examining the flowability of the SCC mixtures. V-funnel was for donating viscosity. L-box and j-ring were as an indication of passing ability. The aim of these tests is to ensure the availability of basic properties that distinguish the self-compacting concrete from others. The results for fresh properties tests were compared with EFNARC limitations.

Fig. 2. Testing SCC at fresh state for examining the flowability, viscosity and passing ability according to EFNARC: (A) slump flow test; (B) j-ring test; (C) v-funnel test and (D) l-box test.

Hardened Properties

After performing the fresh tests on each mix, the concrete was casted in 100 mm cubes. Nine cubes for the ages of 28, 56 and 92 days were casted for each mix .Then cubes were demolded after 24 hours and left for curing in water till the required date of test. Every mix was tested for compressive strength using three cubes on each test date, and the average result was then reported. Figure 3 illustrates the testing machine used for the measurement of compressive strength.

Fig. 3. Compression test machine used for donating the compressive strength on 100 mm cubes for each mix at 28, 56 and 92 days.

3. RESULTS AND DISCUSSION

3.1. Fresh tests results

After the mixing process was finished and the tests at fresh state were executed following the guidelines for SCC, the experimental results for each test were recorded in tables starting with the control mix in table 6 then followed by the other six SCC mixes in tables 7, 8, 9, 10, 11 and 12 below showing the acceptance to EFNARC and the type of class according to its limitation.

Table 6. The experimental fresh recorded results for mix 1 (control mix) of 0% SF and 0% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	740 mm	SF2 (660-750)mm
T500	1.5 sec	≤ 2 sec (class 1)
V-funnel	3.1 sec	≤ 8 sec
L-box	0.99	0.8-1
J-ring	2 mm	(0-10) mm

Table 7. The experimental fresh recorded results for mix 2 of 5% SF and 5% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	700 mm	SF2 (660-750)mm
T500	2 sec	≤ 2 sec (class 1)
V-funnel	4 sec	≤ 8 sec
L-box	0.9	0.8-1
J-ring	4 mm	(0-10) mm

Table 8. The experimental fresh recorded results for mix 3 of 5% SF and 10% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	710 mm	SF2 (660-750)mm
T500	1.8 sec	≤ 2 sec (class 1)
V-funnel	3.8 sec	≤ 8 sec
L-box	0.9	0.8-1
J-ring	3 mm	(0-10) mm

Table 9. The experimental fresh recorded results for mix 4 of 5% SF and 15% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	725 mm	SF2 (660-750)mm
T500	1.75 sec	≤ 2 sec (class 1)
V-funnel	3.4 sec	≤ 8 sec
L-box	0.96	0.8-1
J-ring	3 mm	(0-10) mm

Table 10. The experimental fresh recorded results for mix 5 of 10% SF and 5% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	595 mm	SF1 (550-650)mm
T500	2.5 sec	> 2 sec (class 2)
V-funnel	5.2 sec	≤ 8 sec
L-box	0.8	0.8-1
J-ring	8 mm	(0-10) mm

Table 11. The experimental fresh recorded results for mix 6 of 10% SF and 10% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	615 mm	SF1 (550-650)mm
T500	2.3 sec	> 2 sec (class 2)
V-funnel	5 sec	≤ 8 sec
L-box	0.8	0.8-1
J-ring	5 mm	(0-10) mm

Table 12. The experimental fresh recorded results for mix 7 of 10% SF and 15% WMP

Test	Recorded result	Limit (EFNARC)
Slump flow diameter	635 mm	SF1 (550-650)mm
T500	2 sec	≤ 2 sec (class 1)
V-funnel	4.7 sec	≤ 8 sec
L-box	0.85	0.8-1
J-ring	5 mm	(0-10) mm

After mixing, it was observed that the mixtures were homogeneous, well flowing, acceptable and within specifications recommended by EFNARC.

From previous results and they are in more detail in figures 4 and 5, it was observed that using WMP resulted in increasing the flowability of SCC mixes. It was observed while comparing the results of mix 2, 3 and 4 and mix 5, 6 and 7 similarly. Mix 4 in which the cement content was 400 $kg/m^3$and WMP 75 kg/m^3 recorded a higher flow than mix 3 in which the cement content was 425 kg/m^3 and WMP 50 kg/m^3 which in turn was higher flow than mix 2 in which the cement content was 450 kg/m^3 and WMP 25 kg/m^3. The higher flow means higher values of slump flow diameters and less ones in T500 time. As mix 4 recorded diameter 725 mm higher than mix 3 with 710 mm diameter and T500 time of 1.75 sec less than 1.8 sec of mix 3. The same for mix 3 which recorded diameter 710 mm higher than mix 2 with 700 mm diameter and T500 time of 1.8 sec less than 2 sec of mix 2. All at the same SF content which was 5% replacement. So when the final diameter of slump recorded the increasing results of final slump diameter and decreasing of T500 time of each mix with the increase of WMP replacement level and when the comparison was made with the same view for mix 5, 6 and 7 which had 10% replacement level of SF, it was found that mix 7 in which the cement content was 375 kg/m^3 and WMP was 75 kg/m^3 recorded a higher flow than mix 6 in which the cement content was 400 kg/m^3 and WMP was 50 kg/m^3, which in turn was higher than mix 5 in which the cement content was 425 kg/m^3 and WMP was 25 kg/m^3. As mix 7 recorded diameter 635 mm higher than mix 6 with 615 mm diameter and T500 time of 2 sec less than 2.3 sec of mix 6. The same for mix 6 which recorded diameter 615 mm higher than mix 5 with 595 mm diameter and T500 time of 2.3 sec less than 2.5 sec of mix 5.

Unlikely, the effect of SF when comparing mix 2 with mix 5 of the same replacement level of WMP of 5% or mix 3 with mix 6 of the same replacement level of WMP of 10%

or mix 4 with mix 7 of the same replacement level of WMP of 15% showed a decreasing of flowability. Decreasing the flowability means less flow diameters and higher T500 time. For further clarification, mix 2 recorded 700 mm diameter higher than mix 5 of 595 mm diameter and T500 0f 2 sec less than mix 5 of 2.5 sec. Also, mix 3 recorded 710 mm diameter higher than mix 6 of 615 mm diameter and T500 0f 1.8 sec less than mix 6 of 2.3 sec. As well as, mix 4 recorded 725 mm diameter higher than mix 7 of 635 mm diameter and T500 of 1.75 sec less than 2 sec of mix 7. The reason behind this could be the extremely fine silica fume granules of SF. So the combination of SF and WMP was better for preserving fresh and strengthened characteristics together.

Images of variation of V-funnel time and L-box ratio are given in figures 6 and 7. They assessed the acceptance of mixes to be SCC. Values of v-funnel time classified the mixes as class one The SCC mixtures having V-funnel time less than or equal 8 sec are classified as viscosity class one (VF1) and those having L-box height ratios between 0.8 and 1 are categorized as class two (PA2).

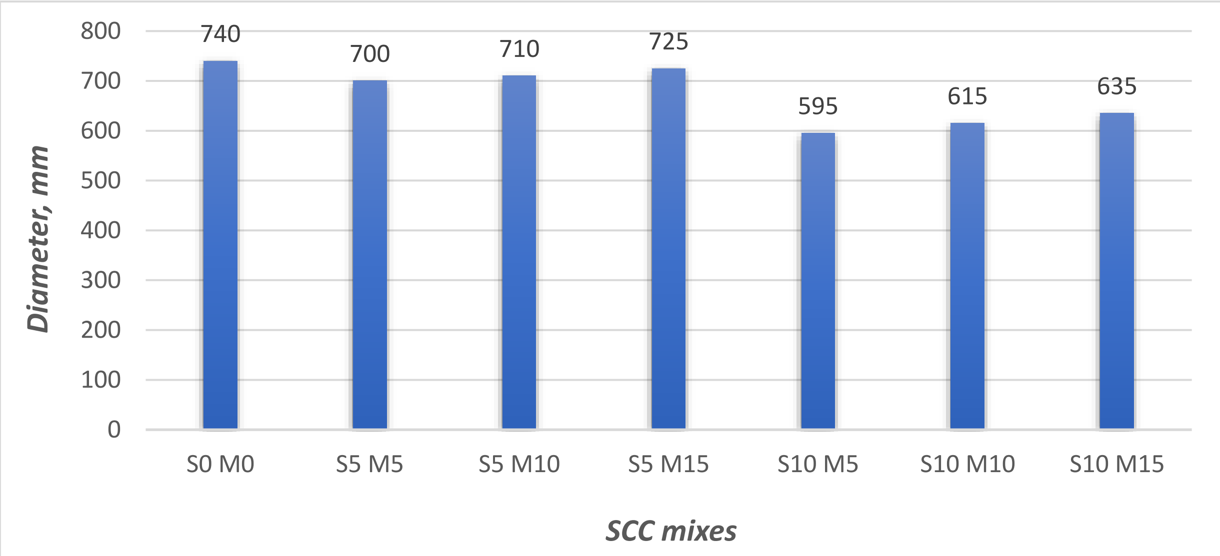

Fig. 4. Variation of slump flow final diameters of SCC mixes obtained at fresh state testing.

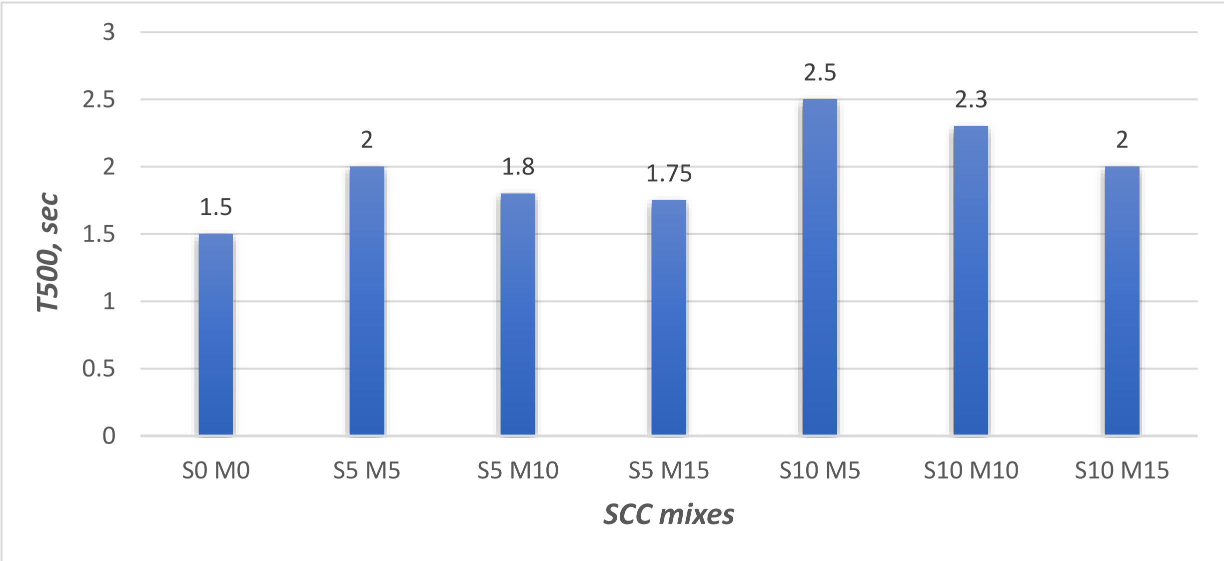

Fig. 5. Variation of T500 time at which SCC mixes reach 500 mm diameter at slump test.

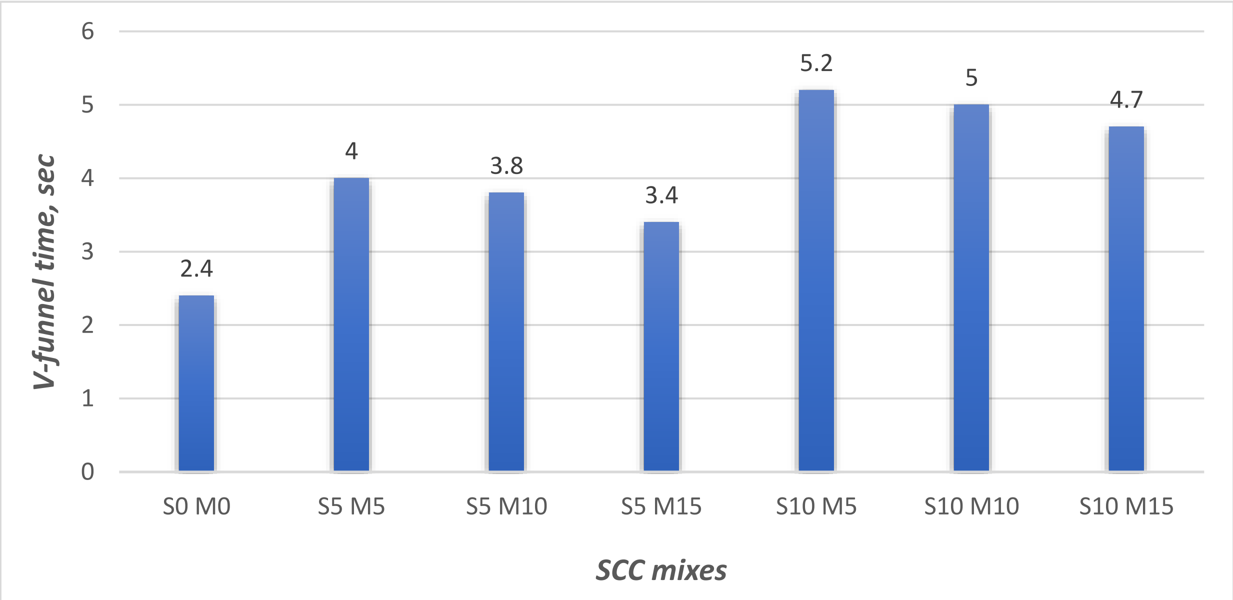

Fig. 6. Variation of v-funnel time at which SCC mixes almost leave the funnel totally through the gate and light can be seen from top of the funnel.

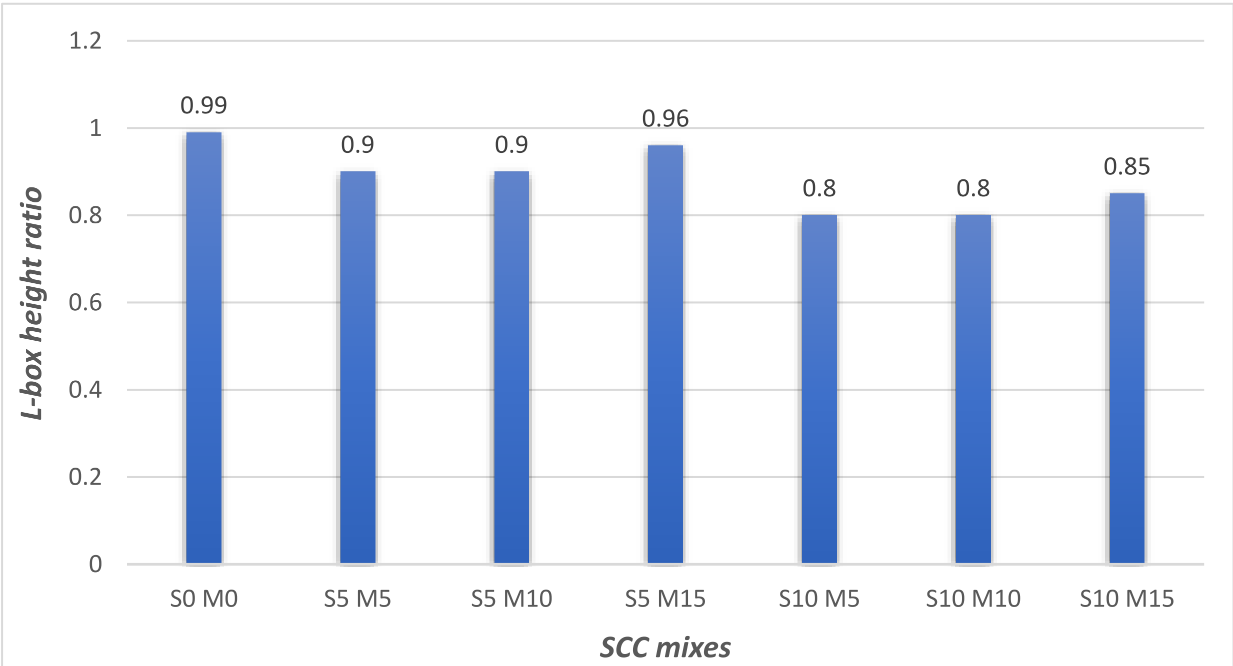

Fig. 7. Variation of l-box height ratios of SCC mixes (the ratios between the height of the SCC mixes after and before passing the gate).

3.2. Hardened test results

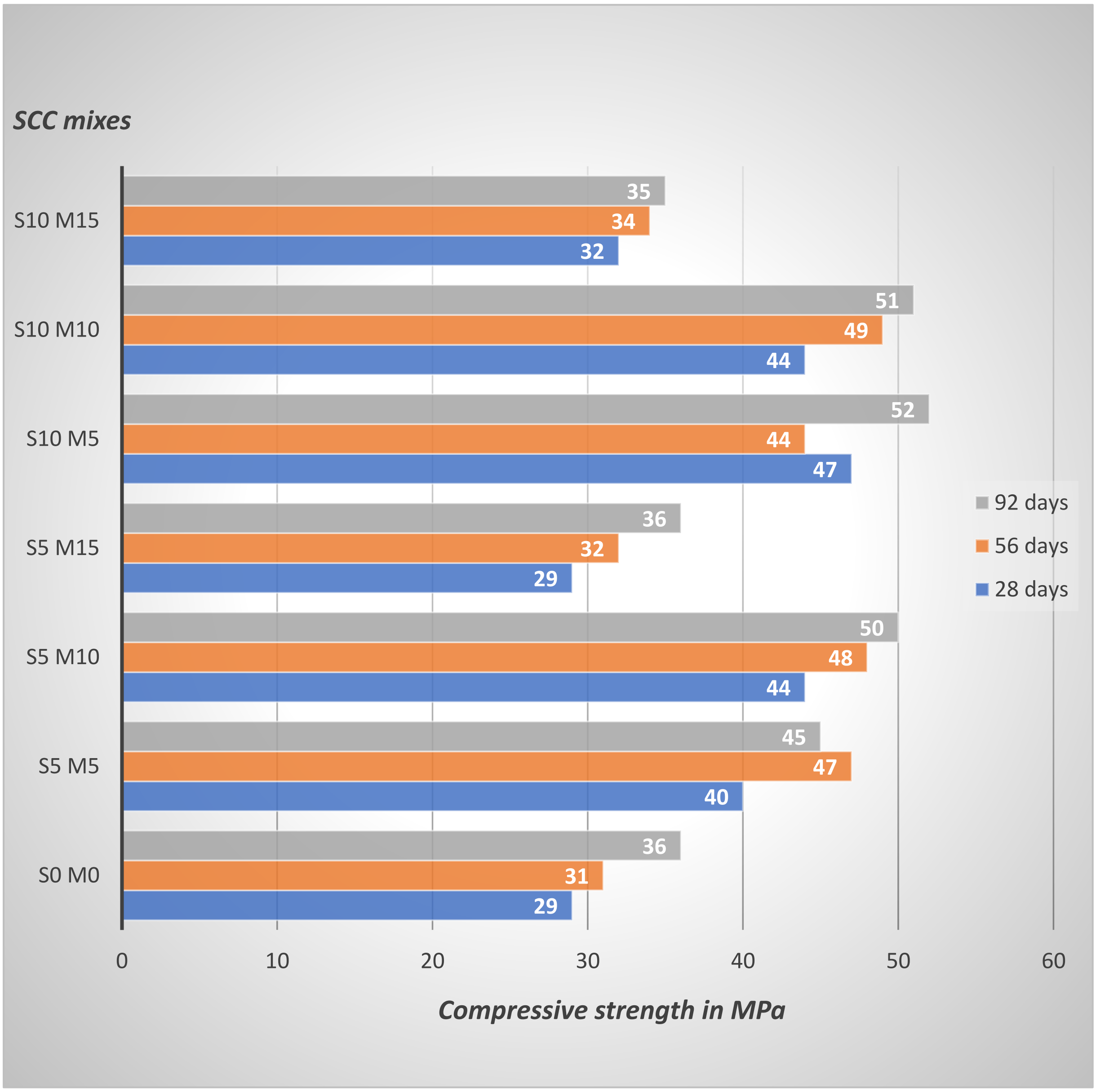

Fig. 8. Compressive strength of SCC mixes obtained at 28, 56 and 92 days.

The bar chart shown in fig. 8 shows the result of compression test of SCC mixes at ages 28, 56 and 92 days .The stated result is the average value of three tested cubes taken after the curing age which represents the testing date for each mix and left until being dry and then tested until failure. The ultimate load was read and then the compressive strength was calculated. By comparing the control mix with the other mixes, it is clearly that the replacement of cement with both SF and WMP enhanced the compressive strength until 25% replacement level. But the optimum replacement level which gave the most value of 47 MPa was 15%.To study the effect of SF or WMP in separate behavior, the comparison is made with constant replacement level of the another material.

The effect of increasing the replacement level of WMP was noticed by checking the recorded strength result of mixes 2, 3 and 4 which had the same SF content of 25 kg/m^3 or and repeating that for mixes 5, 6 and 7 of the same SF content of 50 kg/m^3.

For example, mix 5 which contained 25 kg/m^3 WMP recorded 47 MPa higher than mix 6 which contained 50 kg/m^3 WMP and recorded a strength value of 44 MPa. Also, mix 6 of 50 kg/m^3 WMP recorded 44 MPa higher than mix 7 which contained higher WMP content of 75 kg/m^3 and recorded 32 MPa value. This explains that increasing WMP replacement is inversely proportional with the compressive strength as it works on reducing the cement paste which in turn reduces the strength. and that matches with the other previous researchers who stated that.

In contrast, the effect of increasing SF replacement level is directly proportional with the compressive strength. This is obvious by comparing mix 2 with mix 5 which had the same replacement of 5% of WMP or mix 4 with mix 7 which had the same replacement of 15% of WMP. Mix 5 of 50 kg/m^3 SF content recorded 47 MPa higher than mix 2 which contained 25 kg/m^3 and recorded 40 MPa. Also, mix 7 of 50 kg/m^3 SF content recorded 32 MPa higher than mix 4 which contained 25 kg/m^3 and recorded 29 MPa. The effect of SF on concrete mixes matches with the other previous researchers who stated that. This is due to the pozzolanic action of SF unlike the WMP which behaved as a filler material only of no significant increase effect stated to the strength of concrete. Utilizing SF in the mixes with WMP was better to enhance the compressive strength side by side with saving cement.

Generally speaking, when compared the mixtures with the control mix , the replacement did not reduce the strength but increased it. This is due to the effective role of SF .The 10% replacement of (5% SF+ 5% WMP) increased the strength from 29 MPa to 40 MPa with apercentage of about 38% improvement. The 15% replacement rate for mix 3 of (5% SF+ 10% WMP) increased the strength from 29 MPa to 44 MPa recording an improvement of about 52%. However, mix 5 of the same rate but of (10% SF+ 5% WMP) recorded an increase from 29 to 47 MPa with 62% improvement level. The 20% replacement rate represented by mix 4 of (5% SF+ 15% WMP) showed no significant improvement. This could be due to the increase of WMP in the mix compared to SF. The 20% replacement rate represented by mix 6 of (10% SF+ 10% WMP) increased the strength from 29 MPa to 44 MPa with about 52% improvement. The 25% replacement rate represented by mix 7 of (10% SF+ 15% WMP) made a slight increase from 29 MPa to 32 MPa with about 10% improvement only.

What can be summed up is that the best replacement rate was 15% (10% SF+ 5% WMP) which achieved the highest improvement by 62%, followed by the replacement rate of 20% of (10% SF+ 10% WMP) which achieved an improvement of 52%.

4. CONCLUSIONS

1- WMP can be used with SF as substitute materials for cement to gain self-compacting concrete mixes of high workability comparing to conventional concrete. That, in turn, will work on reducing cost and pollution resulting from accumulation of marble residues.
2- The fresh properties of the created mixes met the required SCC criteria.

3- With increasing replacement percentage of WMP ,T500 and V-funnel time decreased.
4- The diameter of the developed SCC mixes increased with the increase of WMP replacement level.
5- The properties of SCC can be enhanced in both the fresh and hardened stages by both WMP and SF.
6- Replacement cement with WMP only improves fresh properties only. Also replacement cement with SF only improves hardened properties. Replacement cement with (WMP + SF) in range between 15-20% will give good results for both stages but the increasing replacement level will reduce the cement paste needed for the cohesion of components of the mixture together which in turn will give weak mixture or in high volumes will break up these components.
7- The optimum mix is of 15% replacement (10% SF+ 5% WMP) which achieved the highest strength at 28 days showing an improvement of 62% for the compressive strength.
8- The replacement level can be 20% of (10% SF+ 10% WMP) which means that about fifth of the amount of cement can be redeemed achieving an improvement of 52% compressive strength.
9- The concrete includes WMP can be called green concrete because it contributes to reducing CO2 output emissions from producing concrete mixes.
10- The experimental work of this study to develop SCC mixes requires trial and error process. The experience and knowledge of concrete technology are very necessary especially for the application of this type of concrete as it is very sensitive to the components, their quantity and the way they are mixed.

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