Economics of using marble powder in self-compacting concrete in Egypt

اقتصاديات استخدام بودرة الرخام في الخرسانة ذاتية الدمك في مصر

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الملخص

تهدف هذه الدراسة الى استخدام بودرة الرخام التي تنتج بجانب الإنتاج التي قد يمثل التخلص منها مشكلة بيئية في انتاج الخرسانة ذاتية الدمك لتقليل تكلفة انتاج المتر المكعب. تم استخدام 11 خلطة تصميمية في البرنامج البحثي. خمس متغيرات قد تم مناقشتها في البحث و هي : نسبة بودرة الرخام (15%-30%) و نسبة الملدن الفائق (15%-30%) و نسبة غبار السيليكا (5%-10%) و نسبة الرماد المتطاير (25%-35%) و استبدال غبار السيليكا و الرماد المتطاير ببودرة الرخام. تم انتاج خرسانة ذاتية الدمك عالية الأداء بمدى مقاومة يتراوح بين (440-580) كجم/سم^2 باستخدام بودرة الرخام فقط. كانت أرخص الخلطات و التي حققت متطلبات الوصول لذاتية الدمك باجهادات عالية كانت الخلطات التي تحتوي على بودرة الرخام و التي تم انتاجها بتكلفة تبدأ من (548) جنيه/م^3. كما كانت أقل تكلفة لتحسين خصائص الخرسانة الطازجة و المتصلدة (جنيه/الخاصية) لتلك الخلطات المحتوية على بودرة الرخام.

Abstract:

This study aims to use marble powder as a marginal by-product material (which disposal of it may cause environmental problems) in production of self-compacting concrete (SCC) to reduce the cost of cubic meter (direct cost). 11 mixtures of self-compacting concrete were designed in experimental program. Five variables were studied in this research: amount of marble powder (15% and 30%) , amount of superplasticizer (2% and 3 %), type of mineral Additives (silica fume and fly ash) , amount of mineral additives (Silica fume 5% and 10 %) - (Fly ash 25% and 35 %) and replacement silica fume and fly ash with marble powder. Fresh concrete tests were performed are: slump flow, slump flow at T_{50cm} , V-funnel , V-funnel at T_{5min}, L-box , Fill box and GTM sieve 5mm stability test. Hardened concrete tests were performed are: compressive strength test and bending strength test. High performance SCC can be produced with range of compressive strength about (440-580) kg/cm² with marble powder only. The cheapest mixtures which have the minimum requirements to produce high performance self-compacting concrete with high strengths were that contains marble powder and the costs of them starts at (548) L.E/m³. The least costs of improvement of properties of both of fresh and hardened concrete (LE/property) were these contain marble powder.

Keywords

Self-compacting concrete; Fly ash; Silica fume; Marble powder; and Unit cost.

Introduction

Self-Compacting Concrete (SCC) is considered a result of the technology evolution in the field of concrete admixtures where super plasticizer is considered the primary element to produce this type of concrete. Japanese are the leaders of production of this concrete because they used it in many constructions and many useful applications from 1980 especially in the last ten years [1]. The following properties must be achieved in SCC are: filling ability, high deformability, high resistance of particles segregation, good stability, passing ability, high ability of self-casting and filling in narrow sections and sections crowded of reinforcement steel [2]. Felekoglu, [3] compared quarry waste limestone powder collected by filtration systems (QLP) and powder produced by direct grinding of limestone (PLP). The both of these two powders can be regarded as successful viscosity enhancers (with spread flow test). Finer powder (PLP) improved the spread flow values compared to coarser powder (QLP).QLP can successfully be used in the production stage of proper SCC mixtures.

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Higher strength classes of SCCs (45–50MPa) can be achieved by adding QLP (241kg/m³) but the cement dosage should be increased (470kg/m³). Incorporation of QLP reduced the cost of unit compressive strength of SCCs for all investigated cases by (0.05–0.2) $/MPa/m3. Gupta et al. [4] used marble powder as filler by replacing different percentages of fly ash. He found that the value of Segregation Index is increasing with the increase in the amount of marble powder as a replacement of fly ash. It has also been understood that as the marble powder increases there is a decrease in flow and increase in slump of the self-compacting concrete. Topçu, [5] tried also to add marble dust to the self-compacting concrete as a filler material. The amount of fine materials (cement + fly ash + marble dust) in all mixtures is 550 kg/m3. The mechanical properties of hardened SCC have decreased by using marble dust (MD), especially just above 200 kg/m³ content. It can be said that usage amount below 200 kg/m³ content is suitable for improving all of these properties. Filling capability and passing ability are between acceptable values of SCC containing up to 200 kg/m³ MD content. Uysal et al. [6] performed an experimental study on the properties of self-compacting concrete (SCC). Portland cement (PC) was replaced with fly ash (FA), granulated blast furnace slag (GBFS), limestone powder (LP), basalt powder (BP) and marble powder (MP) in various proportioning rates. The test results showed that among the mineral admixtures used, FA and GBFS significantly increased the workability and compressive strength of SCC mixtures. Replacing 25% of PC with FA resulted in strength of more than 105 MPa at 400 days. It was noted that the strength loss decreased as the replacement of mineral admixtures increased. Bignozzi et al. [7] studied the possibility of utilization of tyre rubber waste in SCC. (SCRC) self-compacting rubberized concrete requires slightly higher amount of super plasticizer than SCC to reach self-compacting properties, keeping constant water / cement and water /powder weight ratios concrete compressive strength and stiffness decrease with increasing amount of rubber phase in the mix, but the obtained values are higher than those of ordinary Portland cement concretes admixed with similar amounts of tyre rubber wastes. Siddique, [8] used class F fly ash in his experimental program. He used different five percentages of fly ash ranging between (15% - 35%) in five mixes. He found that SCC mixes developed 28 day compressive strength between 30 and 35 MPa and splitting tensile strength between 1.5 and 2.4 MPa. The compressive strength increased with a decrease in the percentage of the fly ash and the water-to-cementations materials ratio.

Objectives

Since the emergence of the self-compacting concrete, there is a belief that it is expensive comparing to the conventional concrete and the usage of self-compacting concrete is not economically viable. The cost of unit price of self-compacting concrete (direct cost) has been studied and compared it with the properties of fresh and hardened concrete. Cheap marginal by-product waste material was used to reduce cost of cubic meter of SCC with great effects on concrete properties and give environmental benefits by usage of this powder in concrete.The cost on unit price of self-compacting concrete was investigated with keeping other indirect savings in costs in consideration like total time of project (productivity); there is no time for compaction which results increasing of casting rate per day and reducing the No. of lots in forms of concrete as the height of one lot is increasing due to ability to cast concrete from higher spaces without segregation (that gives two benefits: reducing total project time and save in concrete forms [1], direct labor costs decreases (there is no labor for compaction process which results saving of their salaries), the productivity of existing labor increases (because of there is no vibrators). Also healthy work environment can be made without noise and exhaust, direct costs of vibrators and their fuel can be saved, costs of future maintenance of the surfaces was casted can be saved because there is no pores or defects when SCC is used (Improved durability). SCC is very successful at making fair face surfaces; Structural designers have greater freedom in design of shape and dimension of sections especially thin sections. Also concrete can be cast in urban areas (no noise), and reduction of injuries and sick leave due to absence of noise and hazards caused by using vibrators. The cost of every mixture of self-compacting concrete was calculated from the unit price of ingredients and amount of each ingredient. The fresh and hardened properties of self-compacting concrete were also studied to get the optimum amount of each ingredient which gives us the best properties neglecting the cost. Finally that summarized that: if the unit price of self-compacting concrete is more expensive than conventional concrete, opposite properties were obtained. That will make savings in direct and indirect cost. In other words: the costs of improvement of each property of both of fresh and hardened concrete (L.E/ Unit of measurement) were calculated and the least costs were determined. Also it will be mentioned which fillers and which ratios of ingredients are recommended to use in the production of SCC taking in consideration economic side. The following parameters were considered:

1- Amount of marble powder (15% and 30 %)
2- Amount of superplasticizer (2% and 3)
3- Mineral Additives (silica fume and fly ash)
4- Amount of mineral additives (Silica fume 5% and 10 %), (Fly ash 25% and 35%)
5- Replacement mineral material with marble powder.

Experimental Program

- Materials:

- Cement: Ordinary Portland cement (CEMI 42.5N) were used. Cement complied with the Egyptian specifications of ES 4756/1 (2009) [9] and EN 197-1 (2011) [10]. Table 1 shows the physical and mechanical properties of the cement.

Table 1.Cement properties

Test		**Result**	**(ES 4756/1) 2009& (EN 197/1) 2011 Limits**
Setting Time (min.)	Initial	120	Not less than 60 min
	Final	210	---
Expansion (mm)		1 mm	Not more than 10 mm
Compressive Strength (MPa)	2 day	12.5	Not less than 10 MPa
	28 days	50	(42.5 – 62.5) MPa

- Aggregates: Locally available natural sand was used as fine aggregates. The coarse aggregate (Dolomite) with maximum nominal size of (12.5mm) complied with the Egyptian standard ES 1109(2008) [11] and the limits of the Egyptian code of practice for concrete structures ECP 203(2007) [12]. Table 2 gives the physical properties of the coarse and fine aggregates .

Table 2.Physical properties of the coarse and fine aggregates

Physical Property	Coarse Aggregates	Fine Aggregates
Specific gravity	2.67	2.63
Fineness Modulus	6.85	2.35
Bulk Density (kg\m^3)	1600	1700

- Admixtures: A polycarboxylic ether based superplasticizer complying with ASTM C494 (Type G) was used.

- Mineral Additives: Silica fume used has bulk density of 300 kg/m3. Fly ash with specific gravity of 2.2 was used.
- Powder: Marble powder (Figure 1), was obtained from Shaa' El-Thoaban Mountain- Egypt. It was obtained from crushers are used to crush the small pieces results from cutting the marble from mountains. Marble powder has been sieved with square-mesh sieve of .125 mm size. Table 3 gives the chemical composition and blaine Surface of marble powder.

Fig.1 Marbel powder

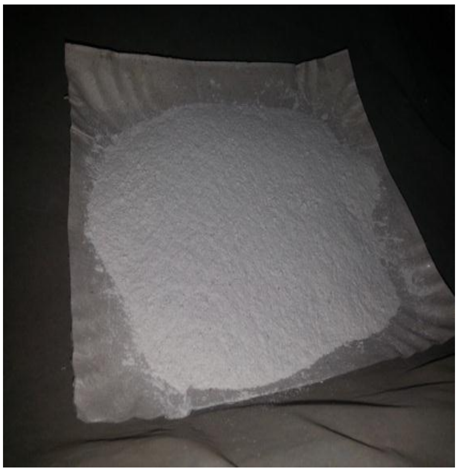

Table 3.Chemical composition and surface area of marble powder

SiO_2 (%)	**3.56**
AL_2O_3 (%)	**0.29**
Fe_2O_3 (%)	**0.88**
CaO (%)	**53.52**
MgO (%)	**0.33**
Loss of Ignition (%)	**41.9**
Blaine Surface (m^2/kg)	**1100**

Materials prices: Table 4 gives the unit price with Egyptian pound and USD on (October\2012):

Table 4.unit price with Egyptian pound and USD on (October\2012)

Material	**Price**	
	(L.E/KG)	**(USD/KG)**
Cement (C)	0.5	0.081
Sand (S)	0.02	0.003
Dolomite (D)	0.05	0.081
Marble Powder (MP)	0.08	0.013
Limestone Powder (LP)	0.08	0.013
Fly Ash (FA)	7	1.14
Silica Fume (SF)	7	1.14
Superplasticizer (SP)	23	3.77

Mix proportions:

11 mixtures were designed with marble powder. Silica fume and fly ash also were used. Superplasticizer used with ratios of 2% and 3% of cementitious materials (C+SF+FA). Fine aggregates/ total aggregates= 0.45 and water /cement ratios = 0.45. Marble powder was used by ratios 15% and 30% of cementitious materials. Silica fume was used with ratios of 5% and 10%. Fly ash was used with ratios of 25% and 35%. Cement content is constant in all mixtures (400kg/m^3). Mixtures proportions and prices are shown in table 5:

Testing and specimens 'preparation

In self-compacting concrete the fresh concrete tests is considered the primary acceptance factor besides the values of hardened concrete tests which must be equal to or higher than those of conventional concrete. The tests will be performed on fresh concrete that the tests which check the performance of self-compacting concrete in the fresh state. Tests will measure 3 main properties: filling ability, passing ability and segregation resistance (stability). Tests performed are slump flow, slump flow at T_{50cm} (Figure 2), V-funnel (Figure 3), V-funnel at T_{5min}, L-box (Figure 4), Fill box (Figure 5) and GTM sieve 5mm stability test (Figure 6) [13-14]. Compressive strength and bending strength will be measured after fresh concrete tests. 12 cubes (10 x10 x 10) cm, 12 cubes (15 x 15 x 15) cm and 6 beams (10 x 10 x 70) cm were casted in order to measure both of compressive strength and bending strength. Bending strength was measured by the machine in (figure 7). Two concentrated loads stress the beam at same space of span (L/3). All specimens were cured from the casting next day to the day of testing (7 days – 28 days)

Table 5.Mixture ingredients (kg/m^3)

M	C	S	D	W	SP	SF	FA	LP	MP	Cost	
										L.E\m^3	USD\m^3
1	400	835	102	180	0	0	0	0	0	269	44
2	400	827	101	180	8	0	0	0	0	452	74
3	400	833	101	180	12	0	0	0	0	545	90
4	400	811	991	180	12.6	20	0	0	0	697	114
5	400	799	976	180	13.2	40	0	0	0	849	139
6	400	742	907	180	15	0	100	50	0	1310	215
7	400	717	876	180	16.2	0	140	54	0	1616	265
8	400	782	956	180	12.6	20	0	0	63	699	115
9	400	750	916	180	12.6	20	0	0	126	701	115
10	400	746	912	180	12	0	0	40	120	549	90
11	400	765	935	180	12	0	0	0	120	548	90

Fig.2.Spread flow test (Mix No.7)

Fig.3.V-Funnel Tst (Mixture No.5)

Fig.4.Concrete flowing after opening the gate (Mixture No. 11)

Fig.5.Fill -Box Test (Mixture No.6)

Fig.6 GTM Sieve 5mm Segregation Resistance test (Mixture No. 6)

Fig.7 Bending strength test

Results

Table 6.shows the results of both of Fresh and hardened concrete tests for all mix trues.

Discussion:

*Comparisons will be in following points***:**

1. Super plasticizer ratio in Mixtures: (M1, M2 & M3)
2. Silica fume ratio in Mixtures: (M3, M4&M5)
3. Marble Powder ratio in Mixtures: (M4, M8& M9) (M3 & M11)
4. Fly ash ratio in Mixtures: (M6, M7)
5. Replacement silica fume with marble powder in Mixtures: (M4, M5 & M11)
6. Replacement fly ash with marble powder in Mixtures: (M7& M10).

In discussion, one variable only (marble powder ratio) was discussed. This variable has the least cost of improvement of each property. Mixtures which didn't reach self-compactability won't be in discussion. Replacement silica fume with marble powder won't be discussed because mixtures contains marble powder saves about 22% of cost of mixtures contains silica fume. Also mixtures contain marble powder are in list (in conclusion part) of the mixtures which reach self-compactability and have the minimum cost.

MIX	Spread Flow		L- Box	V-Funnel		Fill Box	GTM sieve 5mm stability	Compressive Strength (Kg/cm^2) 28 days	Bending Strength (Kg/cm^2) 28 days
	Diameter (mm)	$T_{50\ Cm}$ (sec)	(H2/H1)	T_0 (Sec)	(T_{5min} - T_0) (sec)	Ability of filling	Segeregation Resistance ratio		
1	400	0	0	43	-----	50%	0%	190	41
2	550	3	0	18	32	50%	2%	440	59
3	555	5	0.75	6	12	50%	12%	356	53
4	571	6	0.83	10	12	81%	3%	506	85
5	570	4	0.83	12	3	96%	5%	760	109
6	715	3	1	11	3	99%	10%	498	62
7	740	3	0.94	3	2	98%	13%	520	72
8	660	2	1	12	3	100%	6%	580	80
9	605	4	1	12	2	98%	13%	440	83
10	645	4	1	12	3	100%	8%	418	60
11	695	2	1	11	2	100%	6%	575	79

Table 6.Fresh and hardened concrete results

Marble powder ratio:

- (M4, M8 and M9) with 5% silica fume:

In this part the ratios of 0%, 15% and 30% of marble powder were used with constant super plasticizer ratio of 3% and constant ratio of silica fume of 5%. Marble powder cost is very low comparing with other powders. That caused slight increase in total mixtures costs. Marble powder has positive effects on both fresh and hardened properties of SCC. The viscosity decreased with the increase of marble powder ratio. That happened because of increasing fines ratio and surface area. Strengths reached the highest values with ratio of 15% by 19% (reaching 100%) with ratio of 15% and it reached 98% using ratio of 30% marble powder. (figure 11). Segregation resistance measured by GTM sieve 5mm stability test increased by 3% (reaching 6%) using ratio of 15% marble powder and increased by 10% (reaching 13%) using ratio of 30% marble powder (figure 12). marble powder. Spread diameter increased by 15.7% and 6% with adding marble powder with ratios of 15% and 30% respectively (figure 8). T_{50cm} decreased by 66.66% and 33.33% with adding marble powder with ratios of 15% and 30% respectively (figure 9). T_0 (V-funnel) results raised from 10 seconds (0% marble powder ratio) to 12 seconds with marble powder (15% and 30%). (T_{5min}-T_0) decreased by 66.66% and 33.33% with adding marble powder with ratios of 15% and 30% respectively (figure 10). L-box results raised from 83% (0% marble powder ratio) to 100% with marble powder (15% and 30%). Fill-box results increased

Adding 15% marble powder caused increase in all strengths at all ages except bending strength at 28 days. With 15% marble powder, compressive strengths increased by 2% and 14.6% at ages of 7days and 28 days respectively. With 15% marble powder bending strength increased by 11.6% at 7 days and decreased by 6% at

28 days. With raising ratio from 0% to 30%, compressive strength decreased by 12.5% and 13% at ages of 7days and 28days respectively (figure 13). Bending strength increased by 9.8% and decreased by 2.3% at ages of 7days and 28days respectively (figure 14).

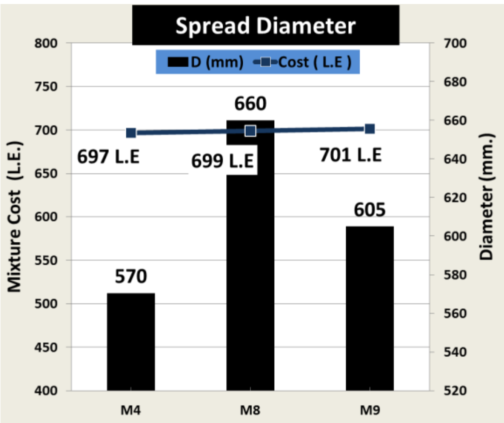

Fig.8. Diameters and costs [variable no.3 (marble powder 1)]

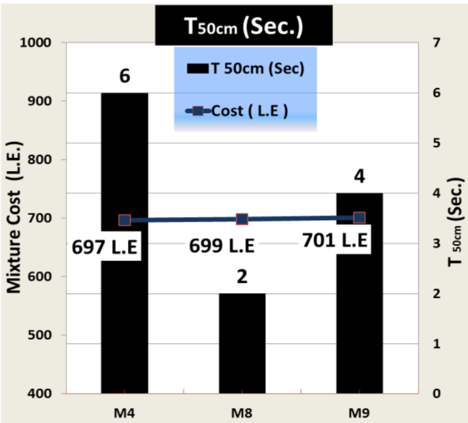

Fig.9. T_{50cm} and costs [variable no.3 (marble powder 1)]

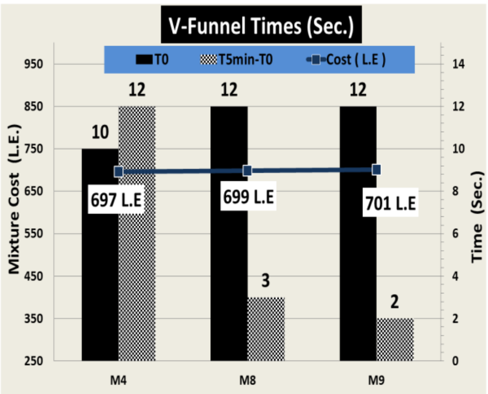

Fig.10. V-funnel times and costs [variable no.3 (marble powder 1)]

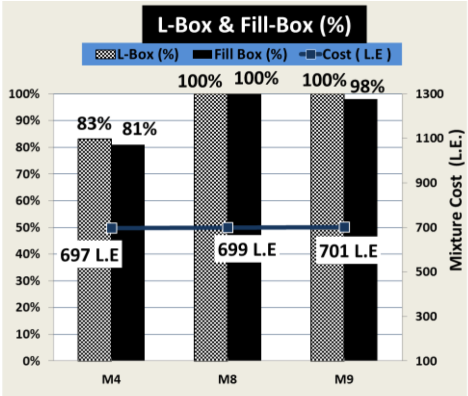

Fig.11. L-box, fill-box and costs [variable no.3 (marble powder 1)]

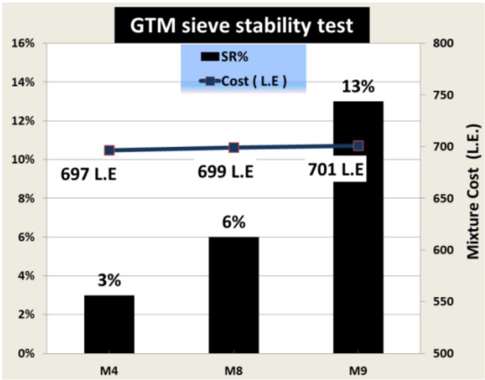

Fig.12. GTM sieve 5mm stability test and costs [variable no.3 (marble powder 1)]

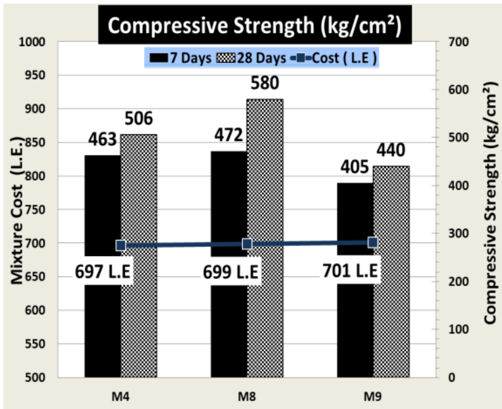

Fig.13. Compressive strength and costs [variable no.3 (marble powder 1)]

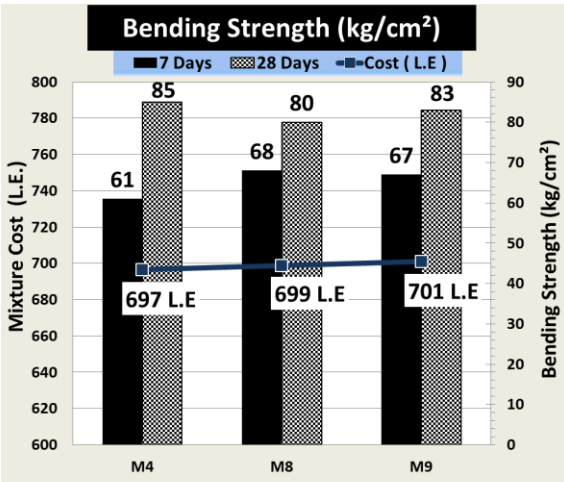

Fig.14. Bending strength and costs [variable no.3 (marble powder 1)]

- (M3 and M11)

In this part marble powder with ratio of 30% was used with a constant ratio of superplasticizer of 3%. There is a slight difference in cost with adding of marble powder. All properties of fresh concrete improved due to decreasing viscosity. That happened because of increasing fines ratio and surface area. Hardened concrete improved using marble powder. Spread diameter increased by 25.2% (figure 15). T_{50cm} decreased by 60% with marble powder (figure 16). T_0 increased by 83% with marble powder. (T_{5min}-T_0) decreased by 83% with marble powder (figure 17). L-Box and fill-box results increased by 25% and 50% respectively (figure 18). Segregation resistance measured by GTM sieve 5mm stability test decreased by 6% (figure 19). Compressive strength increased by 45.5% and 61.5% at ages of 7 and 28 days respectively (figure 20). Bending strength increased by41.6% and 49% at ages of 7 and 28 days respectively (figure 21). That happened because of decreasing voids ratio and reaching complete compact.

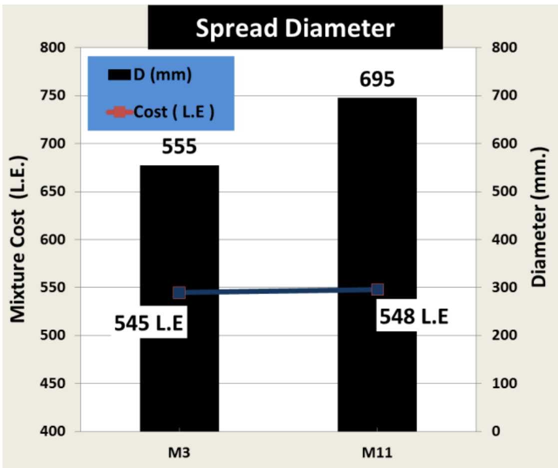

Fig.15. Diameters and costs [variable no.3 (marble powder 2)]

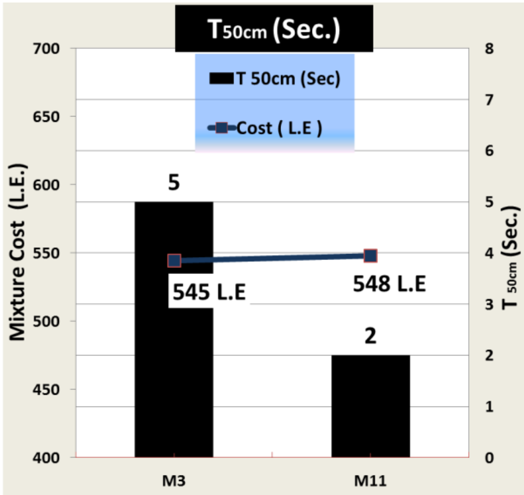

Fig.16. T_{50cm} and costs [variable no.3 (marble powder 2)]

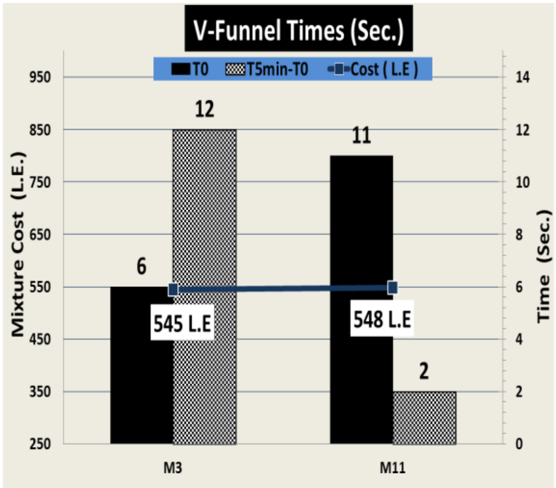

Fig.17. V-funnel times and costs [variable no.3 (marble powder 2)]

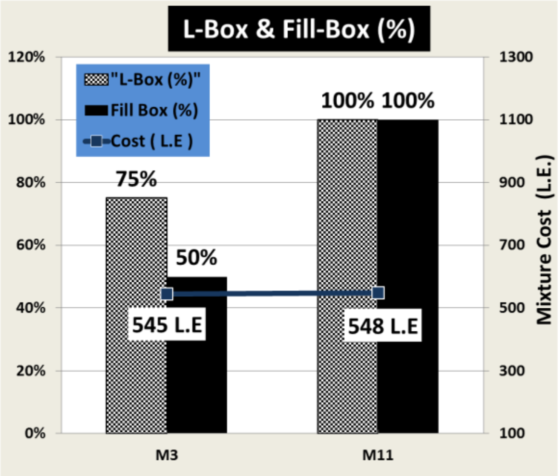

Fig.18. L-box, fill-box and costs [variable no.3 (marble powder 2)]

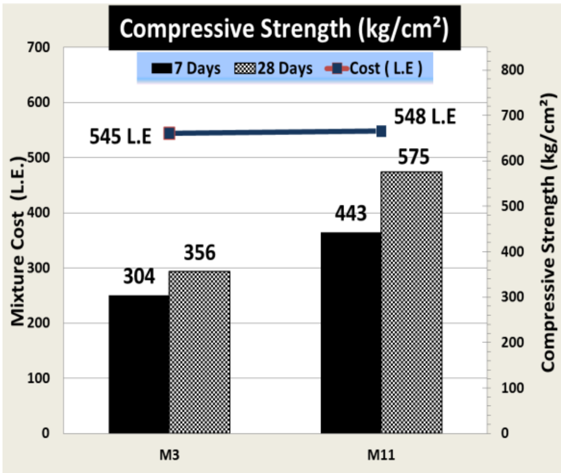

Fig.20. Compressive strength and costs [variable no.3 (marble powder 2)]

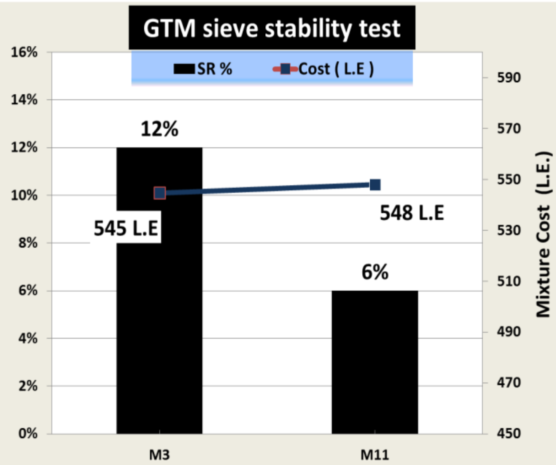

Fig.19. GTM sieve 5mm stability test and costs [variable no.3 (marble powder 2)

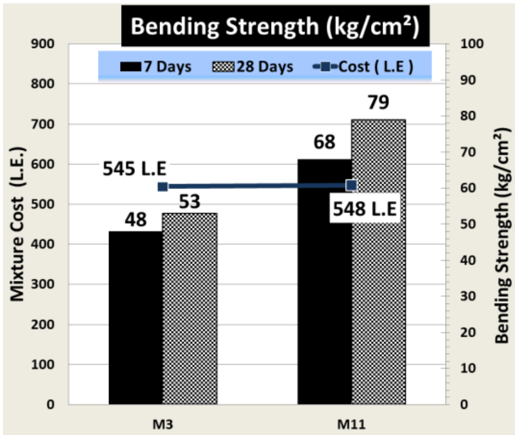

Fig.21. Bending strength and costs [variable no.3 (marble powder 2)]

- Costs of improvement of each property (LE/ Unit of measurement) for all mixtures:

In the following table 7, the costs of improvement of each property (LE\Unit of measurement) of all mixtures are shown. The sign of following costs depends on the tests results and which mixture result became better (positive sign) or worse (negative sign) with increasing cost. That comes by making the cost and result of most expensive mixture in the comparison comes first in order to make the negative sign means that the property got worse with increasing cost.

Table 7.Costs of improvement of each property (LE/ Unit of measurement) for all mixtures

Variable	Comparison	Fresh Concrete Tests							Hardened Concrete Tests	
		Spread Flow		L-Box (LE / 1%)	V-Funnel (LE / Sec.)		Fill Box (LE / 1%)	GTM sieve 5mm stability test (LE / 1%)	Compressive Strength [LE / (Kg/cm2)]	Bending Strength [LE / (Kg/cm2)]
		T_{50cm} (LE / Sec)	Dia. (LE / mm.))		T_0	$T_{5min} - T_0$				
SP%	M2 than M1	61.1	1.22	0	7.33	-----	0	91.65	0.73	10.18
	M3 than M1	55.1	1.78	3.68	7.45	-----	0	23	1.66	23
	M3 than M2	-46.3	18.52	1.23	7.71	4.63	0	9.26	-1.1	- 15.43
SF%	M4 than M3	-151.9	9.8	18.98	-38	0	4.9	-16.87	1.01	4.74
	M5 than M3	304.6	20.3	38.07	-50.7	33.84	9.82	-33.84	0.75	5.44
	M5 than M4	0	79.3	0	-79.3	17.62	10.57	79.3	0.62	6.6

Continuous

Table 7.Costs of improvement of each property (LE/ Unit of measurement) for all mixtures

Variable	Comparison	Fresh Concrete Tests							Hardened Concrete Tests	
		Spread Flow		L-Box (LE / 1%)	V-Funnel (LE / Sec.)		Fill Box (LE / 1%)	GTM sieve 5mm stability test (LE / 1%)	Compressive Strength [LE / (Kg/cm2)]	Bending Strength [LE / (Kg/cm2)]
		T_{50cm} (LE / Sec)	Dia. (LE / mm.))		T_0	$T_{5min} - T_0$				
MP%	M8 than M4	0.5	0.02	0.11	-1	0.22	0.1	0.66	0.03	-0.4
	M9 than M4	2.25	0.13	0.26	-2.25	0.45	0.26	0.45	-0.06	-0.9
	M9 than M8	-1.25	-0.04	0	0	2.5	-1.25	0.35	-0.01	0.83
	M11 than M3	1.1	0.02	0.13	-0.66	0.33	0.07	-0.55	0.02	0.12
FA %	M7 than M6	0	12.24	-50.98	38.24	305.9	-305.9	101.97	13.9	30.59
SF & MP	M5 than M4	0	79.3	0	-79.3	17.62	10.57	79.3	0.62	6.6
	M4 than M11	-37.15	-1.19	-8.74	148.8	-14.86	-7.82	-49.5	-2.15	24.76
	M5 than M11	-150.5	-2.4	-17.7	-301.1	-301.1	-75.27	-301.1	1.62	10.03
FA & MP	M7 than M10	1066.3	11.22	-177.71	118.47	1066.3	-533.15	213.26	10.45	88.85

Conclusion:

1- Maximum strengths were obtained by M5 which contains 10% silica fume and 3% superplasticizer.

2- Mixtures contain fly ash have a cost over (1000) L.E/m³. That produced expensive self-compacting concrete.

3- Mixtures contains silica fume is expensive mixtures (650-1200) L.E/m³ due to silica fume's high cost.

4- Using superplasticizer only without one of (silica fume, fly ash, and marble powder) at least didn't make concrete meet the requirements of achieving self-compactability.

5- High performance self-compacting concrete can be produced with range of compressive strength about (440-580) kg/cm² with marble powder only (547) L.E/m³ or with silica fume (700) L.E/m³.

6. Some mixtures of self-compacting concrete which passed all fresh concrete tests and exceeded the characteristic strength (300 kg/cm²) were produced. Compressive strengths were in range of (440-760) kg/cm². Cost range of those mixtures was in range of (548-850) L.E/m³. Those mixtures have the minimum requirements to produce high performance self-compacting concrete with high strengths. The cheapest mixtures which passed the fresh concrete tests were the following mixtures (Ascending due to mixture cost):

1) **M11**: contains 3% superplasticizer and 30% marble powder and its cost was about (547.5) L.E/m³.
2) **M10**: contains 3% superplasticizer, 10% limestone powder and 30% marble powder and its cost was about (549.4) L.E/m³.
3) **M8:** contains 3% superplasticizer, 5% silica fume and 15% marble powder and its cost was about (698.9) L.E/m³.
4) **M9:** contains 3% superplasticizer, 5% silica fume and 30% marble powder and its cost was about (701) L.E/m³.
5) **M5:** contains 3% superplasticizer and 10% silica fume and its cost was about (849.3) L.E/m³.

7. The most expensive units were that of replacing marble powder by fly ash and that of increasing fly ash ratio.

8. Marble powder is very successful in production of economic high performance self-compacting concrete. The least cost of improvement of properties of both of fresh and hardened concrete was that of the variable (marble powder ratio) [comparison no.2 (M3 than M11)] when marble powder were added by ratio of 30% to the mixture. The second least cost of units was that of variable (marble powder ratio) [comparison no.1 (M8 than M4)] when marble powder were added by 15% to mixture. That caused improvement of most results with the minimum unit of cost for each property as shown in the following table 8

[Table 8.The Least Costs of improvement of each property (LE/ Unit of measurement)

Test	Costs of improvement of each property (LE/ Unit of measurement)								
	Fresh Concrete Tests							Hardened Concrete Tests	
	Spread Flow		L-Box (LE / 1%)	V-Funnel (LE / Sec.)		Fill Box (LE / 1%)	GTM sieve 5mm (LE / 1%)	Compressive Strength [LE / (Kg/cm^2)]	Bending Strength [LE / (Kg/cm^2)]
	T_{50cm} (LE / Sec)	Dia. (LE / mm.)		T_0	$T_{5min} – T_0$			28 Days	28 Days
M11 than M3	1.1	0.02	0.13	-0.66	0.33	0.07	-0.55	0.02	0.12
M8 than M4	0.5	0.02	0.11	-1	0.22	0.1	0.66	0.03	-0.4

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