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A COST-REDUCTION OF SELF-COMPACTING CONCRETE INCORPORATING RAW RICE HUSK ASH

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Abstract

The higher material cost of self-compacting concrete (SCC) as compared to normal vibrated concrete is mainly due to its higher cement content. In order to produce economical SCC, a significant amount of cement should be replaced with cheaper material options, which are commonly found in byproduct materials such as limestone powder (LP), fly ash (FA) and raw rice husk ash (RRHA). However, the use of these byproduct materials to replace the high volumes of cement in an SCC mixture will produce deleterious effects such as strength reduction. Thus, the objective of this paper is to investigate the optimum SCC mixture proportioning capable of minimizing SCC's material cost. A total of fifteen mixes were prepared. This study showed that raw rice husk ash exhibited positive correlations with fly ash and fine limestone powder and were able to produce high compressive and comparable to normal concrete. The SCC-mix made with quaternary cement-blend comprising OPC/LP/FA/RRHA at 55/15/15/15 weight percentage ratio is found to be capable of maximizing SCC's material-cost reduction to almost 19% as compared with the control mix

Keywords: Self-compacting concrete, Powder, Additives, Strength, Cost reduction.

1. Introduction

Self-compacting concrete (SCC) is described as an innovative concrete with the ability to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need for any vibration whilst maintaining homogeneity [1]. Self-compacting ability is achieved by employing high volume of paste made possible by blending cement with mineral additives such as limestone powder (LP), fly ash (FA), silica fume (SF), ground-granulated blast-furnace slag (GGBS), rice husk ash (RHA), or meta-kaolin (MK) [2].

Incorporating mineral additives in SCC is found to be capable of not only regulating the cement content but also enhancing the fresh state properties [3].

LP is reported to reduce cost and environmental load due to cement production and to enhance all engineering properties [4, 5]. High economic impact is reportedly gained with 70% to 85% FA addition in low strength SCC [6], while SCC containing 15% SF is reported to produce high compressive strength [7]. Hence, these additives have long found usages in actual concrete applications. RHA on the other hand, is an agricultural by-product obtained from burning the husk under controlled temperature of < 800ºC. The process produced about 25% ash containing 85%–90% amorphous silica plus about 5% alumina which made it highly pozzolanic. As reported, for about 1000kg of paddy milled, 55kg of RHA was produced. India, being the highest rice-producing country, generates about 20 million tons of RHA annually [8, 9]. Thus, the potential of using RHA in concrete production could become an important economic endeavour. It was reported that concrete containing up to 30% RHA attained a compressive strength of 30MPa [10]. They were discovered that a binary blend powder material comprising 85% ordinary Portland cement (OPC) and 15% RHA in an SCC mix produced compressive strength of 42.5MPa after 90 days of water curing and flexural strength of 6.5 MPa.

Meanwhile, a number of researchers associate RHA addition with increased compressive and flexural strengths [11-13], but the most useful characteristic of RHA is that it is derived from cultivated crops making it a value-added product due to its capacity as a renewable mineral additive. Despite the advantages and potential that RHA could offer as cement replacement material, cement and concrete manufacturers in the developed regions of the world are concerned with the problems of transportation and production [14].

Few researchers have explored ways of producing low-cost concretes by incorporating unprocessed or raw RHA (RRHA) with some measures of success. Brown [15] revealed that it is possible to use RRHA obtained from uncontrolled burning of rice husk to produce concrete that achieves similar strength to that of a control mix. Sua-iam and Makul [16] revealed that incorporating a FA/RRHA blend in ternary SCC improves compressive strength development due to the smaller particles of FA filling voids, thus; decreasing porosity and water demand.

This research shall expand the field of knowledge on RRHA by incorporating it in binary, ternary and quaternary SCCs so that its influences in low, medium and high volume cement replacement SCCs can be evaluated. The findings shall shed lights on the potential of CO_2 emissions reduction into the atmosphere due to concrete production, the production of cost-effective SCC and the utilization of cheaper RHA in bulk quantities. The uniformity of an SCC mixture reduces permeability and enhances the overall durability of the concrete. One of the most important benefits of SCC is the increase durability associated with the effects of mineral addition because it enhances the lifespan of the SCC beyond that of conventional concrete thereby reducing the environmental footprint on a unit time basis [17]. These are vital economic and environmental benefits which will help SCC to achieve the status of a sustainable construction material.

2. Materials

The basic constituents of an SCC mix were similar to that of normal vibrated concrete, i.e., powder, water, fine & coarse aggregates and super-plasticizer (SP). The base powder material was Type 1 OPC, manufactured by Tasek Cement Corporation Berhad, whilst the additives were fine limestone powder (LP), pulverized fuel ash (FA), silica fume (SF) and raw rice husk ash (RRHA) by rice milling plant, Permatang Pauh, Penang; all obtained from local sources (Fig. 1). The physical and chemical properties of OPC and additives are shown in Table 1.

(a) Fine Limestone powder (Pulai Calcium Sdn. Bhd., Johor)

(b) Fly ash (Infinity Global Carbonate Venture, Kuala Lumpur)

(c) Silica fume (ScanFume Sdn. Bhd.Kuala Lumpur)

(d) Raw rice husk ash (Bee Guan Rice Mill, Penang)

Fig. 1. Additives used in the mixture.

Table 1. The physical and chemical properties of OPC and additives.

	OPC	LP	FA	SF	RHA
Oxide Composition (%)					
SiO_2	21.28	1.84	56.2	90.36	92.99
Al_2O_3	5.60	1.37	20.17	0.71	0.18
Fe_2O_3	3.36	-	6.69	1.31	0.43
CaO	64.64	52.98	4.24	0.45	1.03
MgO	2.06	0.42	1.92	-	0.35
SO_3	2.1	0.08	0.49	0.41	0.10
Physical properties					
Specific gravity	3.15	2.80	2.20	2.10	2.16
Blaine (m^2/kg)	340	443	290	20,000	351

Washed river sand was sieved to produce fine aggregates with a maximum particle size of 4.75 mm. The sand gradation test, shown in Fig. 2 was performed in accordance with ASTM C33 [18]. Crushed granite, graded between 4.75 mm to 12.5 mm, was used as coarse aggregate. The SP was ADVA 181; a high range water-reducing polymer-based admixture and was formulated in accordance with BS5075 Part 3:1985 specification [19]. The water used was piped water supplied by the local authority.

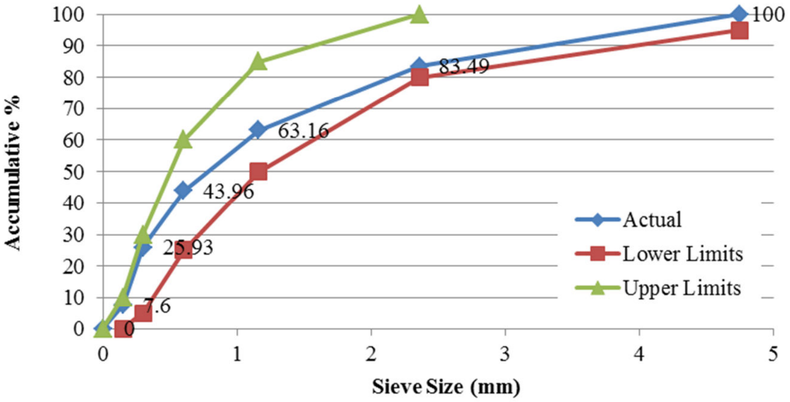

Fig. 2. Sand sieve analysis performed in accordance with ASTM C33.

3. Mixture Composition and Experimental Setup

A total of fifteen mixes were prepared comprising one control mix (designated CM), four binary SCC mixes (designated BM), six ternary SCC mixes (designated TM) and four quaternary SCC mixes (designated QM). Mixture proportioning for the control mix and SCC mixes is presented in Table 2. CM contained the maximum amount of OPC, 475 kg/m^3. Binary SCC mixes contained 403.75 kg/m^3 OPC, 15% lower as compared with the CM. The reduction in OPC is replaced with equivalent weight of LP, FA, SF or RHA. Ternary SCC mixes contained 332.5 kg/m^3 OPC, 30% lower as compared with the CM. The reduction in OPC is replaced with equivalent weight of two mineral additives. Quaternary SCC mixes contained 261.25 kg/m^3 OPC, which is 45% lower as compared the CM. The reduction in OPC is replaced equivalent weight of three mineral additives.

All materials which used for the production of SCC mixes are stored in dry and covered area and kept under room temperature. Prior to the actual process, fine and coarse aggregates are sieved accordingly. All solid constituent materials; OPC, LP, FA, SF, RHA, sand and crushed granite rocks are weighed in accordance with the requirement of each they are prepared for Mixing water and SP are then made available for use. The water to blended cement ratio is set at 1.0 by volume, which is in accordance the proposal made by Okamura and Ouchi [2] and guidelines in EPG [3].

The mixing process starts by placing fine and coarse aggregates in an appropriate concrete mixer. Once the aggregates are thoroughly mixed, OPC and/or appropriate mineral additive/s are added to the aggregates' mixture. The concrete mixer is left to run for about five minutes or until coarse and powder particles are fully blended. Once this happens, water is gradually added to the dry mixture until the mixture starts to show sign of viscosity. Small dosages of SP are gradually to the mixture while observing the fluidity and viscosity of the wet mixture. Water and/or SP are continually added while maintaining visual observation on the physical state of the wet mix. The wet mix is cast into 100 mm cubic moulds and left to stand for 24 hours under room temperature. After 24 hours, the hardened specimens are demoulded and immersed in a container filled with water.

Table 2. Mixture compositions.

Symbol	Label	OPC	LP	FA	SF	RRHA	Sand	G
		kg/m^3						
CM	100C	475	-	-	-	-	1005	838
BM1	85C/15LP	403.75	71.25	-	-	-	1000	834
BM2	85C/15FA	403.75	-	71.25	-	-	990	826
BM3	85C/15SF	403.75	-	-	71.25	-	988	824
BM4	85C/15RRHA	403.75	-	-	-	71.25	989	825
TM1	70C/15LP/15FA	332.5	71.25	71.25	-	-	986	822
TM2	70C/15LP/15SF	332.5	71.25	-	71.25	-	983	820
TM3	70C/15LP/15RRHA	332.5	71.25	-	-	71.25	985	821
TM4	70C/15FA/15SF	332.5	-	71.25	71.25	-	973	812
TM5	70C/15FA/15RRHA	332.5	-	71.25	-	71.25	975	812
TM6	70C/15SF/15RRHA	332.5	-	-	71.25	71.25	972	810
QM1	55C/15LP/15FA/15SF	261.25	71.25	71.25	71.25	-	970	809
QM2	55C/15LP/15FA/15RRHA	261.25	71.25	71.25	-	71.25	972	810
QM3	55C/15LP/15SF/15RRHA	261.25	71.25	-	71.25	71.25	969	808
QM4	55C/15FA/15SF/15RRHA	261.25	-	71.25	71.25	71.25	959	800

Legend:
OPC – ordinary Portland cement; LP – limestone powder; FA – fly ash; SF – silica fume; RRHA – raw rice husk ash; G – crushed granite rock; CM – control SCC mix; BM – binary SCC mix; TM – ternary SCC mix; QM – quaternary SCC mix.

Compressive strength tests are performed after 7, 14, 28, 60 and 90 days, in accordance with BS EN 12390-3:2009. The tests using a universal testing machine (UTM) are represented in Fig. 3. Three 100 mm cubic specimens used in dry in dry density tests are reused for compressive strength tests.

Fig. 3. Compressive strength test using universal testing machine.

4. Compressive Strength

Figure 4 represents the development of compressive strength with age for the binary SCC mixes. As shown, the control mix exhibited high hydration activities on the first 10 days where it gained 82% of the 90-days strength and increased by a mere 2% after 28 days. Hence, the control mix gained a further 18% of the 90-days strength during late ages. Meanwhile, BM1 and BM2 are shown to gain 90% and 94% of their respective 90-days compressive strengths after 14 days, while BM3 and BM4 gained 91% and 94% of their respective 90-days strength after 28 days.

BM4 exhibited moderate rates of strength gain at an early age but is able to sustain the rate till around 28 days. RRHA has large amounts of water stored in its porous particles which is released to the surrounding concrete matrix when needed for further hydration of anhydrous cement grain. The water released from the pores of the RRHA particles is also utilized for RRHA-lime reaction which provides additional strength to hardening SCC. Thus, the combined effects of slow cement hydration, constant supply of water from porous RRHA particles and RRHA-lime pozzolanic reaction enable BM4 to sustain a moderate rate of strength gain from early age up to 28 days, and to generate further gains up to and beyond 90 days. BM1 and BM2 exhibited relatively high rates of strength gain during early ages which are sustained up to 14 days. Both mixes continued to generate strength gains up to and possibly beyond 90 days. Since LP is inert while FA-lime pozzolanic reaction to occur during later ages [20], then early age compressive strengths are generated by cement hydration primarily and the physical effects of LP and FA additions.

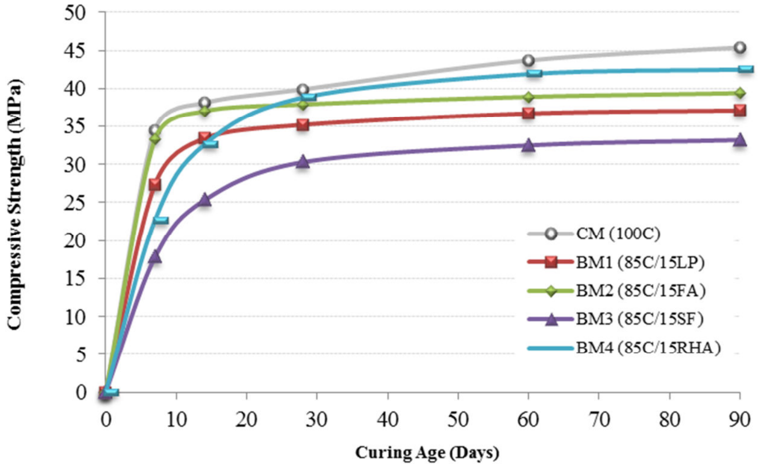

Fig. 4. The compressive strengths of the control mix and binary SCC as a function of curing age.

The development of ternary SCCs compressive strengths with maturing ages is represented graphically in Fig. 5. Although the synergic effects of FA/RRHA are able to produce higher 90-days compressive strength as compared with those of LP/RRHA and FA/SF additions, the later additions have the advantage of being able to generate measurable linear gains during the late ages which, in a probabilistic point of view will enable their compressive strengths to surpass that of TM5 in due course. TM3 exhibits linear strength gain of 9.5MPa between day-28 and day-90 which corresponds to a daily increase of approximately 0.15MPa. If it is able to sustain the rate of linear gain for another month, its compressive strength would be higher than those of the control and TM5.

Thus, in the view point of compressive strength development, LP/RRHA additions exhibited better synergic effects as compared with FA/RRHA and LP producing better physical effects than FA. When LP replaces part of OPC, it produces a dilution effect on the cement particles due to its chemically inert characteristic. This effect increases the distance between each cement grain in the paste solution and increases their specific surface that come in contact with water. As a result greater numbers of cement particles are hydrated and greater numbers of CaOH crystals are thus made available for RRHA-lime pozzolanic reaction. Hence, the physical effect of LP particles is able to enhance the chemical effect of RRHA particles. However, the main cause for using LP in concrete is to enhance particles packing density through its filler effect where its fine particles are used to fill up large pores between the aggregates causing them to be segmented into finer pores and their volume reduced significantly.

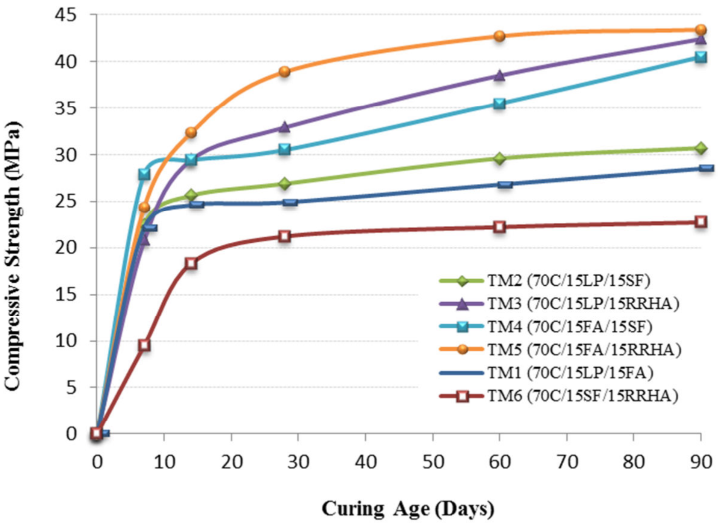

Fig. 5. The compressive strengths of ternary SCC as a function of curing age.

TM4, which incorporates FA/SF addition exhibited a similar mode of strength development with TM3, except in the early period of 7 days, it generated higher strength gain. The mechanism of early strength gain for TM4 may be explained as follows; dissolution of cement grains due to physical reaction with water, deflocculation of cement particles in cement paste due to physical effects of FA particles, hydration of cement grains and SF-lime pozzolanic reaction. This mechanism is enhanced by synergic effects of FA/SF additions resulting in high strength gain in the early age.

During late ages, FA is more reactive chemically when FA-lime reaction starts to take place while SF is more reactive physically when its un-reacted ultra-fine particles fill the interfacial transition zone (ITZ) between aggregates and cement paste. Thus, FA-lime reaction provides additional strength during late ages and SF's physical effect densifies the ITZ leading to increased bondage between aggregates and paste. Therefore, the synergic effects of FA and SF additions during late ages are able to generate significant increases in compressive strength.

The development of quaternary SCCs with maturing ages is represented in Fig. 6. QM3 and QM4 exhibited relatively high rates of strength gain during the early ages and yield 33.5MPa and 32.3MPa respectively after 28 days, enabling them to be classified as G30 strength grade concretes. Both mixes continue to generate measurable strength development during the late ages up to and possibly beyond 90 days. QM1 and QM2 are also shown to exhibit similar mode of strength development but yield lower compressive strengths during the early period causing them to obtain lower ultimate strengths as compared with QM3 and QM4

Based on Fig. 4, it is revealed that the incorporation of LP/SF/RRHA additions to replace 45% of OPC produces optimum synergic effects leading to better performing SCCs from a compressive strength development perspective, while the incorporation of FA/SF/RRHA additions produces the next best performance. The main observation when viewing the ingredients of both mixtures is the inclusions of SF and RRHA in each mixture. Despite their apparent incompatibility when mixed in ternary cement-blend, they showed optimum co-operation and interaction when a less reactive additive is included in quaternary mixture. Hence, it is shown that the inclusion of a less reactive additive is able to overcome the deleterious effects of SF/RRHA mixture.

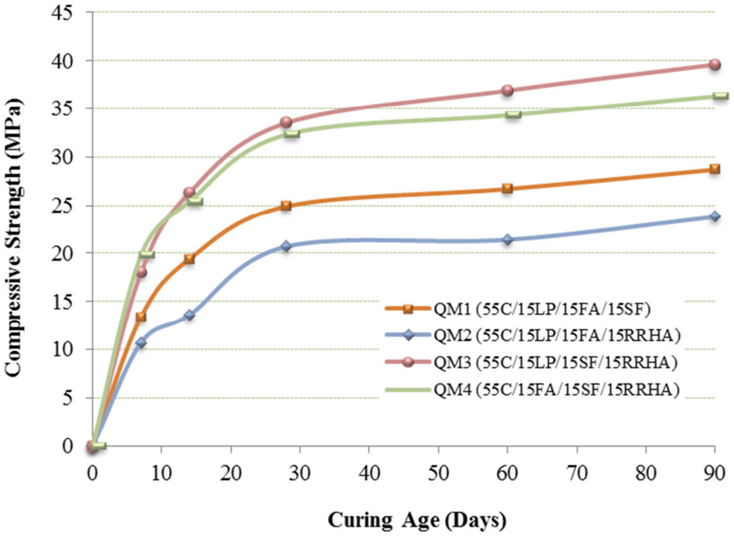

Fig. 6. The compressive strengths of ternary SCC as a function of curing age.

5. Material-Costing

The cost of every individual material used in this study is given as a ratio from OPC's cost in Fig.7. The cost is represented as a dimensionless quantity. It shows that the majority of the materials are cheaper than OPC except for the SF and SP.

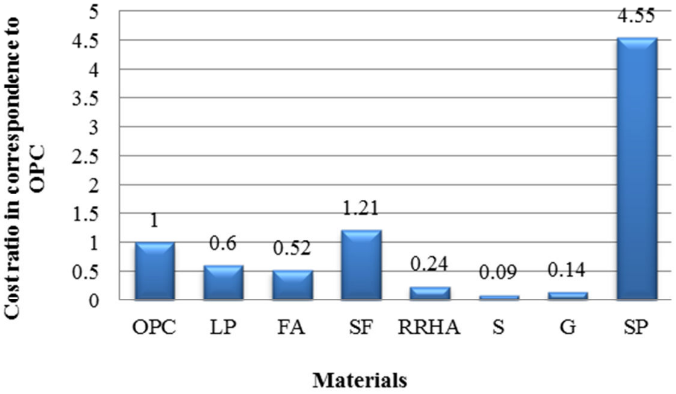

Fig. 7. Cost individual materials as a ratio of OPC's cost.

5.1. Material-costing for the binary SCC mixes

The material-costs for the control and binary SCC mixes are presented in Fig. 8. The cost is represented as a dimensionless quantity and is expressed as a ratio of the control mix. As shown, the material-cost for the control mix is $1/m^3$, while those of BM1, BM2, BM3 and BM4 are $0.918/m^3$, $0.919/m^3$, $1.01/m^3$ and $0.921/m^3$ respectively. Thus, the incorporations of LP, FA and RRHA in binary SCC mixes is able to reduce SCCs cost by around 8% as compared with the control mix.

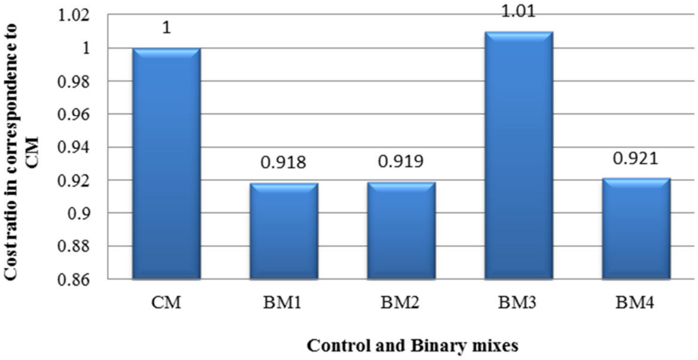

Fig. 8. Material-costs for one cubic meter of the control and binary SCC mixes.

Mineral additives affect SCCs costing in a number of ways based on their varying retail prices, their effects on SP's consumption and their effects on aggregate's volume. The costs of LP, FA and RRHA are cheaper than that of

OPC compared to SF. Therefore, the more the amount of OPC that is replaced with LP, FA and/or RRHA the greater will be the reductions in material-cost, whereas replacement with SF will be associated with increases in material-cost. The incorporation of different types of mineral additive is also found to affect the amount of SP required in the given mixtures. By replacing 15% of OPC's weight with LP is shown to require 3.75L/m^3 of SP which is 6.75L/m^3 lower as compared with that of the control mix. Since SP is an expensive chemical admixture, any reduction in its amount of usage can produce a significant impact on SCC's costing. Apart from LP, the incorporation of FA is also found to cause significant reduction in SP's requirement, but little effects are observed with the incorporations of SF and RRHA.

5.2. Material-costing for the ternary SCC mixes

The material-costing for ternary SCC mixes are presented in Fig. 9. TM2, TM4 and TM6 are mixes which include SF as one of the additions and their cost is between 5.2% and 6.7% cheaper in comparison with the control mix, while TM1, TM3 and TM5 are mixes without SF as one of the additions and their cost is between 11.7% and 13.1% cheaper. Among ternary SCC mixes, TM5 which incorporates FA/RRHA mineral additive mixture to replace 30% of OPC's weight is shown to exhibit the highest amount of saving in material-cost as compared with other SCC mixes. The breakdown of savings in cost is as follows: 12.4% reduction from replacing 30% of OPC's weight with FA/RRHA mixture, 1.1% reduction due to reduction in aggregate's volume and 0.4% increase in cost due increase in SP's dosage. Hence, the incorporation FA/RHA mixture in ternary SCC mix produces a net cost-saving of 13.1% as compared with the control mix and more than 90% of the saving comes from incorporating cheaper mineral additives such as FA and RRHA. When SF is incorporated as one of the additions, saving in material-cost is reduced by almost 50% due its high retail price.

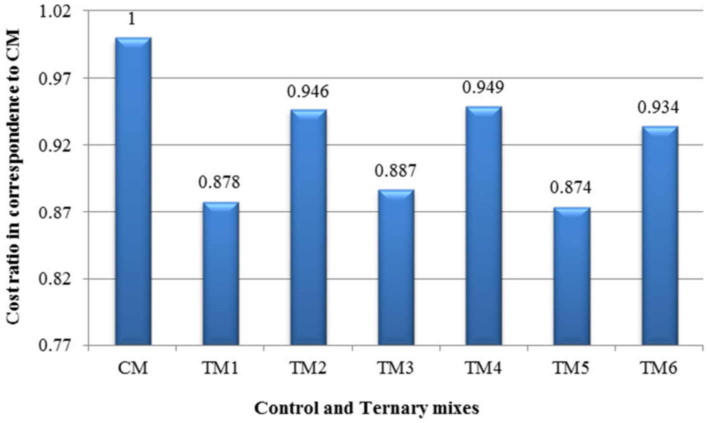

Fig. 9. Material-costs for one cubic meter of ternary SCC mixes.

It is shown that incorporating mineral additives in ternary SCC allows up to 13% saving in material-cost as compared with the control mix. Most of the saving comes from utilizing cheaper mineral additives such as LP, FA and RRHA. But the saving is reduced to almost half when SF is included as one of the additions.

5.3. Material-costing for the quaternary SCC mixes

The material-costs for quaternary SCC mixes are presented in Fig. 10. QM1, QM3 and QM4 are quaternary SCC mixes which incorporate SF are found to be between 9.4% and 12.1% cheaper as compared with the control mix. On the other hand, QM2 is found to be 18.8% cheaper as compared with the control mix.

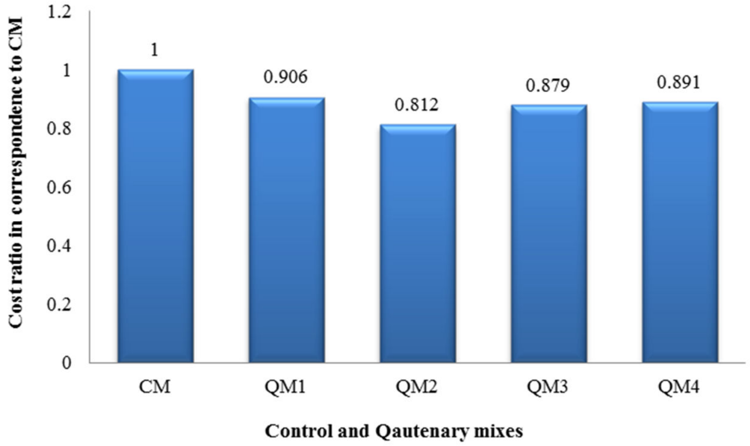

Fig. 10. Material-costs for one cubic meter of quaternary SCC mixes.

One of the important reasons for replacing OPC with mineral additives in SCC's production is to reduce the material-cost by employing ingredients which are cheaper than OPC such as LP, FA and RRHA. Thus, the greater the amount of OPC that is replaced by these additives the lower will be the cost of SCC's. One of the ways in which higher amounts of OPC may be replaced is by employing a mixture of three mineral additives to form a quaternary cement-blend. Therefore, when 45% of OPC's weight is replaced with a quaternary cement-blend comprising of OPC/LP/FA/RRHA at 55/15/15/15 weight percentage ratio, material-cost for the quaternary SCC mix is found to be reduced by 18.8% as compared with the control mix. Hence, SCC's components that influence the total material-cost are cement-paste, chemical admixture and aggregate. With respect to QM2 mix, it is thus revealed that 85% of the total reduction in material-cost is due to the reduction in the cost of cement-paste, 10% is due the reduction in the cost of chemical admixture, while the remaining 5% is due the reduction in aggregate's volume. However, in order to enhance SCC's engineering properties it may be advantageous to incorporate a highly reactive component in the quaternary-cement blend, such as SF even though it is at the expense of its material-cost. As a result, QM1, QM3 and QM4 all of which incorporate SF as one of the additions are found to be between 8.3% and 11.6% more costly than QM2 which does not include SF as one of the additions.

6. Conclusions

Analysis of test results for binary SCC mixes revealed that RRHA possesses great potential as a cement replacement material and better than LP, FA and SF. SCC mix which is made with ternary cement-blend that comprises of OPC/LP/RRHA at 70/15/15 weight percentage ratio is found to have produced optimum mixture proportioning due to its ability to produce the highest performance with respect to SCC's engineering properties. SCC mix which is made with quaternary cement-blend comprising OPC/LP/FAS/RRHA at 55/15/15/15 weight percentage ratio is found to be capable of maximizing SCC's material-cost reduction to almost 19% as compared with the control mix. Hence, the goals of reducing a significant amount of OPC in the production of SCC and of producing economical SCC are achievable when RRHA is incorporated as one of the additions in ternary and quaternary cement-blends.

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