EFFECT OF FLY ASH AND SLAG ON THE COST OF CONCRETE

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ABSTRACT

Although it is generally accepted that the incorporation of extenders into concrete does reduce its material cost, there is little literature of work done to establish the cost-reducing extent by using extenders. This paper describes the effect of South African cement extenders on the cost of concrete without compromising the concrete strength, performance, and workability. The cost effect of cement extenders on concrete was evaluated by analyzing concrete mixtures of the same slump height and strength, and concretes of the same cost with different cementitious materials. In this study, concretes of 25, 35 and 50 MPa were prepared with or without 30% fly ash (FA) and 50% ground granulated blast furnace slag (GGBS), using normal (OPC) or rapid hardening cements (RHPC) CEM I 42.5 N, R. Existing market prices of the materials at the time of the study were used.

It was found that generally, for the same 28 - day compressive strength, the extenders reduced concrete material cost by 10 to 25% depending on the strength grade of the concrete and proportion of the extender incorporated. The cost of concrete reduces with increase in replacement level of the extender used. For equal cost of concrete, mixtures containing extenders gave relatively higher late age strengths than the control mixtures.

This study also shows that for the same cost, with or without extenders, RHPC concretes gave higher early age strengths but lower 28 - day strengths compared to the corresponding OPC concretes. These results are consistent with the known cementitious characteristics of the cement types.
Keywords: Fly Ash, GGBS, Concrete cost, Slump height, Concrete grade

INTRODUCTION

The use of cement extenders, FA and GGBS in concrete has gained wide application and is highly promoted with the expectations of reducing the cost of cement along with the need to utilize waste for conservation of environment, improvement of engineering properties such as workability, segregation, bleeding, heat evolution, permeability; mitigation of alkali-aggregate reaction, sulfate attack and enhancement of durability of concrete, generally.

Furthermore, the ecological system is faced with global warming issues which are associated with emission of CO_2 into the atmosphere. It is known that for every ton of Portland cement produced, approximately one ton of CO_2 is released, roughly half a ton from the fuel used for drying the raw limestone, and half a ton from the calcination of limestone. Worldwide, the production of portland cement alone accounts for 6 to 10% of human generated CO_2. To reduce the emission of CO_2 related to cement production, the production and use of Portland cement needs to be done without compromising the performance of concrete. Carbon dioxide emission is only one of the problems facing the construction industry. In the last few decades, there has been significant increase in the volume of construction which has led to rampaging of natural resources, and since these resources are limited deposits, sustainable construction needs to be taken into consideration. One measure is to limit the Portland cement used in concrete by incorporating extenders as partial cement replacements. Field experience in the last century has shown that conventional concrete made with Portland cement alone, can be technically inadequate with particular regard to durability. It allows rapid deterioration of structures, causing high maintenance and repair costs in addition to the related reduced service life of the structure.

In this study, the effect of extenders on cost of concrete is examined. The market prices of cement extenders, FA and GGBS were 16% and 39% of the price of ordinary CEM I respectively, at the time this research was conducted. Some of the drawbacks of concrete with extenders are slow strength develop at early age, longer curing time which leads to extended stripping time of formwork, variation of colour. Cost analysis is conducted for concretes of equal slump height, equal strength at 28 days, and equal cost.

LITERATURE

A limited South African study on the strength of concrete mixes of the same cost with or without fly ash was reported[1], the cost of fly ash being 44% of the cost of OPC. They found that for the same cost, mixes incorporating fly ash gave higher strengths than the OPC concretes, the disparities increasing more widely with increasing in age.

Two set of fly ashes from Canada from different power stations, namely Sundance and Point Tupper were used in the study[2] of cost and strength development for various PFA concretes. The investigation found that concrete of total cementitious content of 300 to 400 kg/m^3 incorporating 50% fly ash of 13% CaO can give sufficient one day strength in the range of 10 MPa and about 40 MPa at 28 days with approximately 20% cost reduction. Coarser fly ash of 4% CaO gave a lower cost reduction of 10% for the same strength. The authors indicated that 30% Sundance fly ash could be incorporated to give one - day compressive strength of 20 MPa for a similar cost as control but added that the fly ash concrete can be expected to gain higher 28 - day compressive strength than the control concrete. It was suggested that the fly ash concrete incorporating 50% FA of similar 28 day strength of 40 MPa, would be 30% less expensive. Similarly for the Point Tupper fly ash, 40% FA in concrete of 350 kg/m^3 cementitious content would cost 14% less than control. The limitation of using high proportions of extenders in the mixtures is the low early strength, which in certain applications can be an important consideration.

Generally, however, there is quite limited literature available on the subject of influence of extenders towards reduction in cost of concrete. For developing economies, the cost factor can be of significance in shaping sustainable development and poverty reduction.

EXPERIMENTAL

Portland cements CEM 42.5 N,R produced to SANS 50197-1 specifications, 19 mm crushed Andesite stone, and crusher sand were used in the concrete mixtures. The aggregates had a specific gravity of 2.7. The investigation was carried out on the basis of equal strength or equal cost as explained:

(1) Cost analysis for concretes of equal strength and slump height
Exiting data for 25, 30 and 50 MPa concretes with or without FA, proportioned to achieve equal strength grades and slumps, were taken from literature[3] of a South African study then treated for cost analysis. The investigation had no data for GGBS concretes.

(2) Concretes made to equal cost concrete
Concrete mix proportioning was done for equal cost of concretes with /without 30% PFA or 50% GGBS. Mixtures of varied water - cementitious ratios (w/cm) were made as shown in Table 1.

Table 1: Mixtures of concretes made to equal unit cost

MIX	CEMENT TYPE	CEMENTITIOUS CONTENT, (KG/M^3)	W/CM	EXTENDER		MATERIAL COST PER KG/M^3 (RANDS)
				TYPE	%	
1	42.5N	306.0	0.72	OPC	0	758.43
2	42.5N	304.5	0.50	FA	30	758.32
3	42.5N	232.5	0.45	GGBS	50	758.36
4	42.5N	315.5	0.61	OPC	0	780.54
5	42.5N	319.5	0.46	FA	30	780.54
6	42.5N	250.0	0.45	GGBS	50	780.46
7	42.5R	274.8	0.72	RHPC	0	780.57
8	42.5R	283.0	0.46	Fly Ash	30	780.54
9	42.5R	226.0	0.52	GGBS	50	780.46

RESULTS AND DISCUSSION

Cost Analysis for Concretes of Same Slump

The cost evaluation of 25, 35 and 50 MPa concretes of the same 60 mm slump height is plotted in Figures 1 to 3. The cost of rapid hardening cement concretes is greater than the cost of corresponding OPC concrete. Although less content of RHPC (compared to OPC) is required to achieve minimum strength, its unit price is high compared to OPC cements, leading to high cost of the RHPC concrete mixtures. The least costly mix is 50OPC /50FA being 544.2 R/m^3 and 590 R/m^3 compared to OPC control of 685 R/m^3 and 775 R/m^3 for 25 MPa and 35 MPa concretes respectively. It can be seen in Table 2 that the use of FA reduces the unit cost of concrete by 10 to 13% for 30% FA mixes, and 20 to 24% for 50% FA mixes. FA effect on cost reduction is similar in both OPC and RHPC concretes.

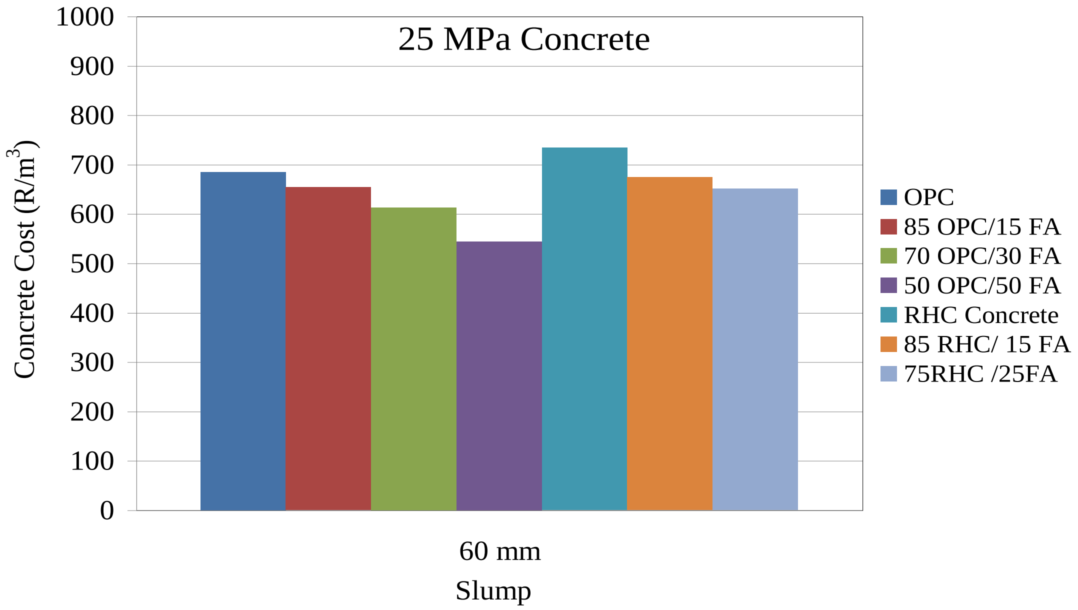

Figure 1: Unit cost of 25 MPa concretes of same slump

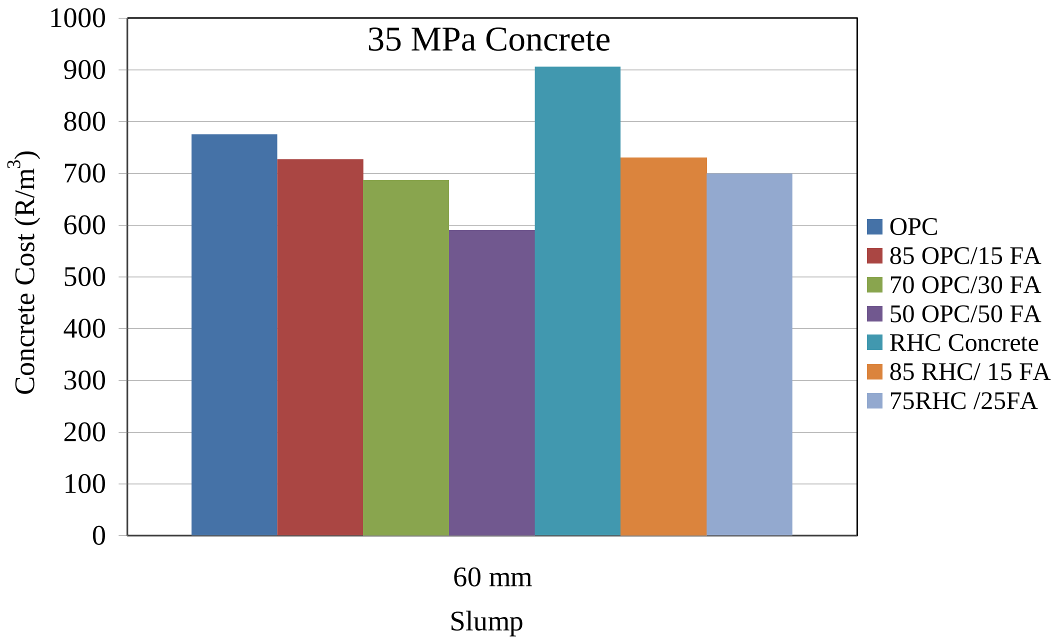

Figure 2: Unit cost of 35 MPa concretes of same slump

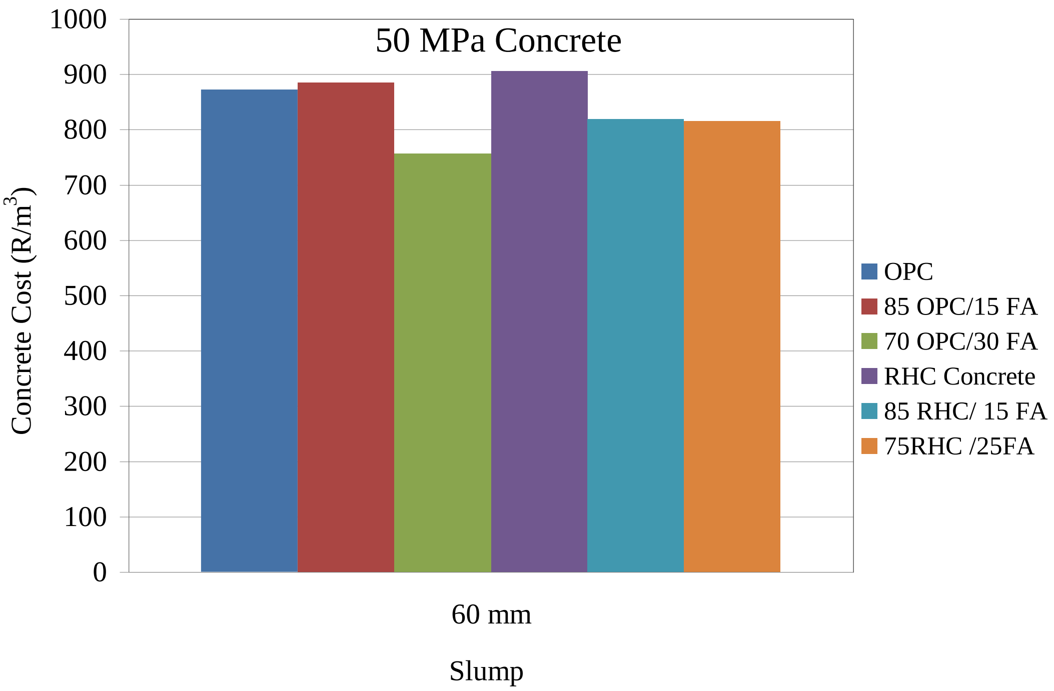

Figure 3: Unit cost of 50 MPa concretes of same slump

Table 2: Reduction in unit cost of concrete resulting from incorporation of fly ash

CONCRETE GRADE (MPa)	UNIT COST REDUCTION (%)			
	OPC /RHPC	OPC/30%FA	OPC/50%FA	RHPC/25%FA
25	Datum	10.5	20.5	11.3
35	Datum	11.4	23.8	11.1
50	Datum	13.2	No data	9.9

Cost Analysis for Concretes of Equal Strengths

The cost of the concretes of 25, 35 and 50 MPa strength grades is shown in Figure 4. Generally, the concrete cost increases with increase in strength. Increase in replacement percentage of extender, decreases the concrete cost significantly as seen with mixes incorporating 15 to 50%FA.

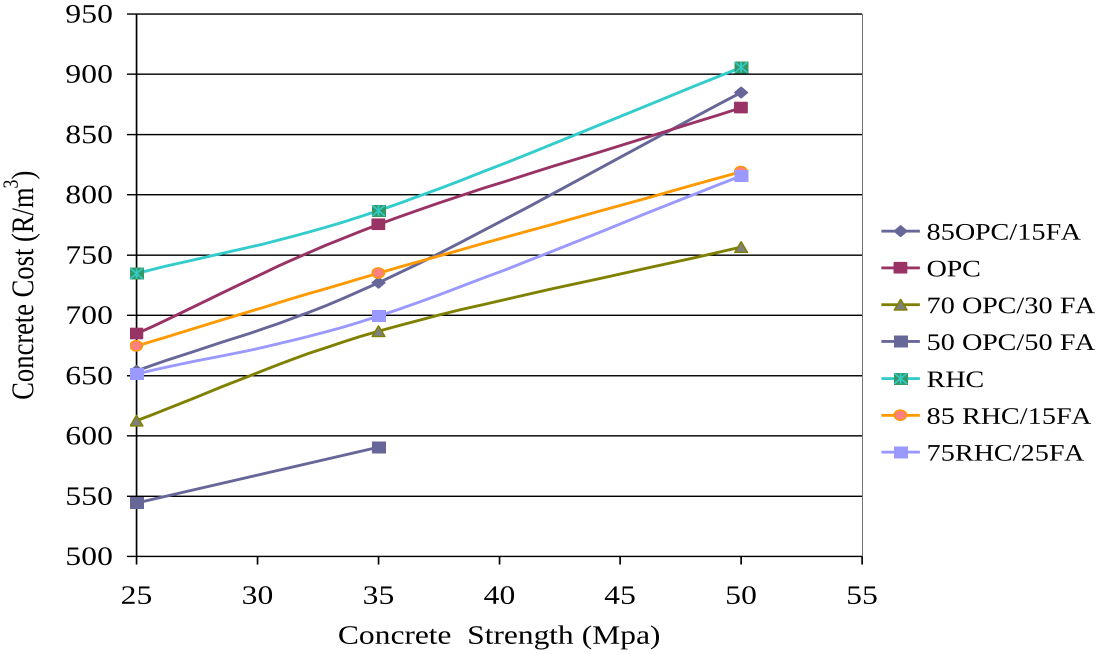

Figure 4: Concrete cost for mixtures of various strength grades incorporating fly ash

Strength Development for Concrete Mixes of Equal Cost

To further examine the cost effect of cement extenders on concrete, a series of compressive strength tests were done to determine strength gain with age. The mixes had different replacement proportions of 30% fly ash and 50% ground granulated blast furnace slag with ordinary and rapid hardening Portland cements of CEM I 42.5. The mix constituents were adjusted to obtain mixtures of equal costs.

Figure 5 gives the strength gain curves for mixtures of concrete cost of 758 R/m^3 with a typical strength grade of 30 MPa. Notably, the mixes containing extenders gave higher 28 - day strengths of 6 to 8 MPa greater than the strength of control mix. The observation underscores the known influence of extenders giving higher late strength gains[1-4]. Similar observations can be seen in Figure 6 giving strength development for mixtures of 780 R/m^3. At the early age of 3 days, RHPC concrete is superior to all other mix designs. Mix 70 OPC /30FA, gains strength much faster than other mixes at early ages of 3 to 7 days, while mix 50 OPC /50GGBS gains strength much faster than other mixes at ages of 7 to 28 days, and has much higher strength than its OPC control mix. From the graph, it can be deduced that the OPC /50GGBS will continue to gain higher strength than OPC /30FA or control at later ages. However, the observations in mixes made with RHPC are quite different. Use of 30% FA or 50% GGBS with RHPC gave lower strengths at all ages. Note that the mixes are not of the same design strength but only of the same cost. The mix adjustments in cement content and W/C (given in Table 1), to achieve same cost, may explain the results seen for the RHPC concretes containing extenders. Results presented in Figure 4, indicate that even for RHPC concretes, mixes of same cost containing extenders should give higher late strengths as seen in the case of concretes made with OPC.

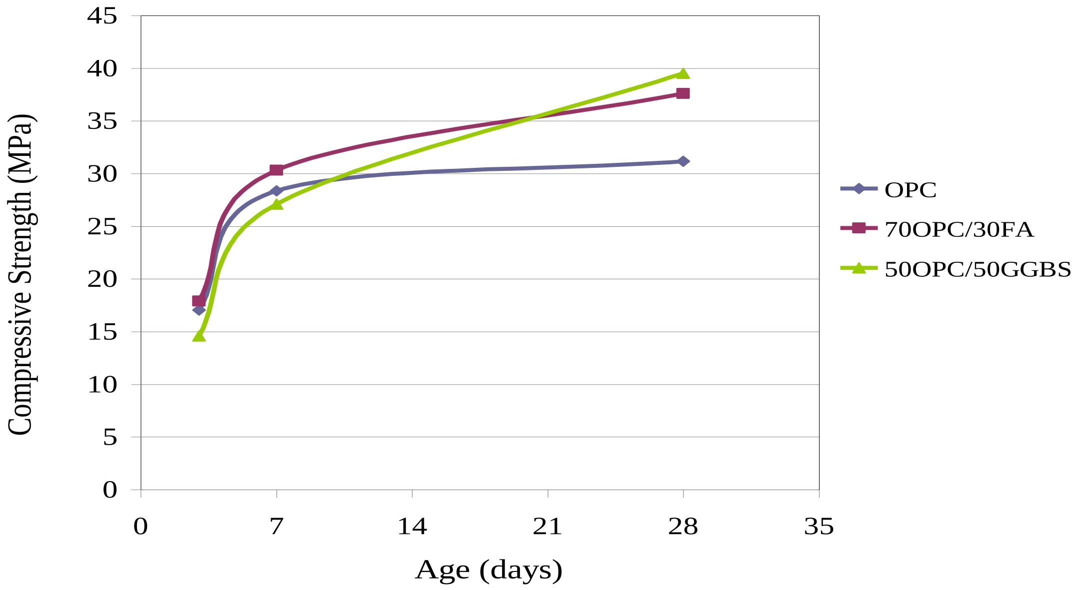

Figure 5: Strength development in OPC /FA /GGBS concretes of equal cost of 758 R/m^3

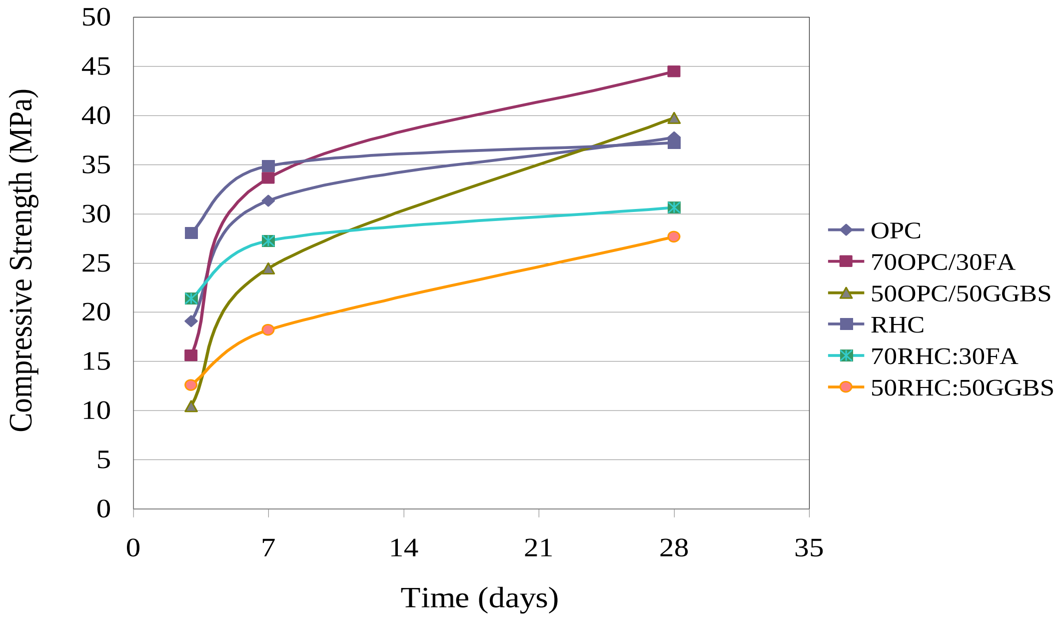

Figure 6: Strength development in OPC /RHPC /FA /GGBS concretes of equal cost of 780 R/m^3

It is may be noted that the market prices used in this study do not account for costs arising from transportation, storage and handling of concrete. Also, additional costs due to use of extenders may arise from operations including additional silo capacity, plant modifications to silos, transfer, batching and weighing equipment; additional batching operations; laboratory trials and materials testing; increased cementitious content relative to Portland cement, additional control testing. Greater quality control and management control may be required for correct use of extenders. The significance of these additional costs will depend on the volume of concrete and proportion of extender incorporated in the concrete. And most of these costs are one - off or short - term costs which may be offset with long - term and high volume cost advantage of using extenders.

CONCLUSIONS

The findings presented in the foregone investigation has led to the following conclusions:

1. Concrete cost increases with increase in concrete strength grade. For concrete mixes of the equal strength, RHPC concrete has a greater unit cost in all concrete grades.

2. Concrete cost decreases with higher replacement percentage of extenders for equal strength. For regular concrete strength grades, reduction in unit cost of concrete in the range of 10 to 25% can be achieved by incorporation of 30% fly ash or 50% slag into concrete. This applies to both ordinary and rapid hardening CEM I cements.

3. For concretes of equal cost, mixtures incorporating cement extenders will always give higher late strengths compared to the corresponding control mixes, despite the relatively lower early strengths of concretes containing extenders.

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