EXPERIMENTAL INVESTIGATION ON STRENGTH AND DURABILITY PROPERTIES OF TERTIARY BLENDED CONCRETE

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Abstract. In this project work, an experimental investigation is carried out on Tertiary Blended Concrete by replacing 40% by weight of cement with Supplementary Cementitious Materials (SCM) combinations in proportions of (30% FA+ 5% SF+ 5% BFS) and (25% FA+ 7.5% SF+ 7.5% BFS) respectively. Standard cube and cylindrical specimens were cast and tested for compressive and split tensile strength properties and the results are compared with control concrete mix of C30 grade. Durability tests on specimens subjected to high temperature of 150º C for 6 hours and rapid chloride penetration are carried out. The study show that concrete mix with SCM proportions of (25% FA+ 7.5% SF+ 7.5% BFS) represented the best performance in terms of workability, strength, and durability properties.

Keywords. Supplementary cementitious materials; Tertiary blended concrete; Fly ash; Silica fume; Blast furnace slag; Slump; Compressive strength; Spilt tensile strength; High temperature; and Rapid chloride penetration.

INTRODUCTION

It is well known that, each one ton of cement emits about 900Kg of CO_2 to the atmosphere causing environmental pollution. To save the environment, studies have been done on reducing the use of cement in the concrete as much as possible. A study in concrete technology have discussed the effect of cement on the natural environment and mentioned the possible alternatives such as the use of Supplementary Cementitious Materials SCM like fly ash, silica fume, Blast furnace slag or Metakaoline [1]. Another author found through his study that the SCMs could successfully replace the cement in concrete for up to 30% by weight [2]. Also it has been stated that the SCMs such as silica fume, fly ash and blast furnace slag could play an important role in enhancing the strength properties of the concrete when replaced by weight of cement for the same percentages [3]. It is known that the combinations of these SCMs are termed as blended cement. A group of researchers have shown that the use of single Supplementary Cementitious Material only to partially replace the cement in small replacement levels of 10% or 20% may not be able to advance the strength and durability properties of concrete [4]. At the same time another group of authors found that the ternary blends has a greater affect on enhancing the general durability properties of the concrete than using of what called binary blends [5].In this project, an attempt is been done to study the characteristic compressive strength and split tensile strength of tertiary blended concrete containing fly ash, silica fume, and blast furnace slag combinations. 40% by weight of cement is replaced with SCM combinations in proportions of (30% FA+ 5% SF+ 5% BFS) and (25% FA+ 7.5% SF+ 7.5% BFS) respectively. C30 Grade reference mix is designed and tested for strength comparison. Specimens are also cast to determine durability properties of high temperature and chloride penetration characteristics. Moreover, workability test is also carried out.

METHODOLOGY

The methodology espoused including the experimental investigation conducted by using the study materials can be represented as follows:

Materials Used

Aggregates

Crushed rocks of maximum size of 37.5 mm and 20 mm were used as a course aggregate and natural washed sand with maximum size of 5 mm and 2.36 mm was used as a fine aggregate. Both types are mixed together and added to the concrete mix.

Water

Normal clear water was used for concrete mixing as well as curing of specimens.

Cement

Ordinary Portland Cement of 53 Grade was obtained from Aturki Cement Products LLC having the physical properties mentioned in Table 1 below.

Table 1. Cement Physical Properties

Properties	Surface Permeability	Initial Setting Time	Final Setting Time	Compressive Strength N/mm²		
Values	301 M²Kg	137 minutes	174 minutes	2 days	7 days	28 days
				19.5	33.5	45.4

Admixture

Rheo-Build chemical admixture of type RH-857 was added with 1.4% (weight) during concrete mixing to enhance the workability properties of the concrete.

Fly Ash

The fly ash used in the investigation was imported from India and purchased from Alturki Cement Products LLC. The physicochemical properties of the fly ash are as presented in Table 2.

Table 2. Fly Ash Physicochemical Properties

Physical Properties	Moisture Content	Fineness	Water Requirement	Strength Factor
	0.23 %	9.69 %	94.3 %	94.79 %
Chemical Properties	Loss on Ignition	Chloride	Sulphuric Anhydride	Calcium Oxide
	0.95 %	0.029 %	0.72 %	1.52 %

Silica Fume

The silica fume used in the experimentation was taken from Muscat Company LLC for materials supply and the physicochemical properties of the silica fume are as mentioned in Table 3 below.

Table 3. Silica Fume Physicochemical Properties

Physical Properties	Bulk Density	Specific Gravity	Specific surface	Pozz. Activity Index
	0.48Kg/m³	2.2g/cm³	22.8 M²/g	131
Chemical Properties	Moisture	Equivalent Alkalies	SIO_2	Loss on Ignition
	0.16%	0.34 %	94.53 %	2.63 %

Blast Furnace Slag

The ground granulate blast furnace slag was also obtained from Muscat Company LLC for materials supply having the physicochemical properties represented in Table 4.

Table 4. GGBS Physicochemical Properties

Physical Properties	Moisture Content	Initial Setting Time	Final Setting Time	Compressive Strength N/mm²		
	0.48 %	285 minutes	350 minutes	2 days	7 days	28 days
				23.6	41.0	55.5
Chemical Properties	Al_2O_3	Fe_2O_3	Na_2O	CaO	MgO	SO_3
	13.2 %	0.7 %	0.47 %	40.9 %	6.2 %	0.05 %

Preparation of Specimens

In this experimental investigation, the total number of specimens casted is 30 specimens consist of 18 cubes and 12 cylinders. Table 5 shows the details and numbers of specimens. Cubes and cylinders casting procedures were conducted according with BS EN 12390-2:2009. For casting the specimens, C30 grade concrete was used to produce the control mix M1 with (0%FA+0%SF+0%BFS) as well as the mixes having cement partial replacement levels of M2 with (30%FA+5%SF+5%BFS) and M3 with (25%FA+7.5%SF+7.5%BFS). The water/cement ratio range used to produces the concrete mixes was 0.45 and the density of the concrete used was 2400 kg/m³. For carrying out the compressive strength test and high temperature durability test, cube specimens of 150mmx150mmx150mm were casted and three cubes for each mix to be tested for more accuracy. To conduct the splitting tensile strength test and the rapid chloride penetration test, cylindrical specimens of 150mm dia. and 300mm height were casted as well. All the produced specimens were left outside in moulds for 24 hours earlier to being de-moulded and then kept in clear water for being cured for duration of 28 days before being tested.

Table 5. Details of Specimens Cast

Tests	M1	M2	M3	Specimens Type	Curing Age
Compressive strength	3	3	3	Cubes	28 days
Splitting tensile	3	3	3	Cylinders	28 days
High temperature	3	3	3	Cubes	28 days
RCPT	1	1	1	Cylinders	28 days

Experimental Programme

Prior to specimens casting, slump test was conducted according to BS EN 12350-2:2009 to determine the workability of the concrete. Then, to examine the strength properties of the concrete mixes compressive strength test was carried out in accordance with BS EN 12390-3:2002 and tensile splitting strength test was also conducted in according to BS EN 12390-6:2000 but only after determining the density of the concrete by following a standard procedure of density determination. To determine the durability properties, high temperature test was conducted to check the concrete performance at heat and rapid chloride penetration test was also carried out based on ASTM C 1202:2010 to test the chloride diffusion property of the concrete mixes. All the tests were conducted on the control mix M1 as well as the two designed mixes M2 and M3 in order to compare the results and identify the increase or the decrease of the test results.

RESULTS AND DISCUSSION

Slump Test Results

The results of the slump test conducted on each mix are as shown in Table 6 and Figure 1. The concrete mix M3 which contains the highest percentage of Silica Fume and Blast Furnace Slag gave the smaller value of slump of 75 mm with the higher workability. This is may be due to the presence of SF and GGBS that have higher surface area of particles which means more water demand than the other mixes with smaller percentages of these SCMs. The mix with less percentage of SF and GGBS have given a slightly higher slump value of 80 mm while the control mix M1 gave the highest value of slump with 95 mm as it is made with only OPC and no any blends were added to enhance its workability. Since all the slump results came in the range of 100±25 mm, all the test results are accepted as per the standard. All the slumps were true therefore, workability results are satisfactory.

Table 6. Slump Test Results

Concrete Mix Name	Slump (mm)	Slump Type
M1 (0%FA+0%SF+ 0%BFS) Ref.Mix.	95	True slump
M2 (30%FA+5%SF+5%BFS)	80	True slump
M3 (25%FA+7.5%SF+7.5%BFS)	75	True slump

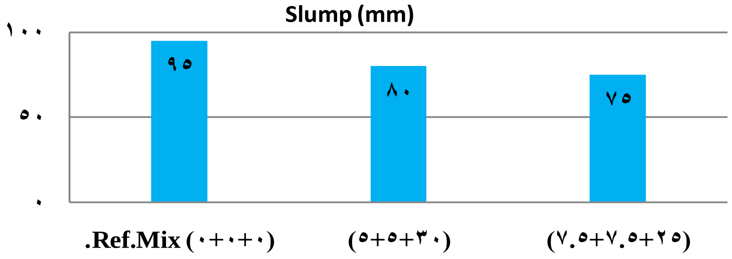

Figure 1. Slump Test Results

Compressive Strength Test Results

The compressive strength test results for all the concrete mixes after 28 days of curing were as represented in Table 7 and Figure 2. The compressive strength of the concrete found to be decreasing as the cement replacement level with SF and GGBS is increasing and the cement replacement percentage with FA decreasing. The reference mix M1 with only OPC recorded the highest compressive strength of 45 N/mm² while the mixes M2 of (30%FA+5%SF+5%BFS) and M3 of (25%FA+7.5%SF+7.5%BFS) have shown an observable decrease in the results by 25% and 26.7% in comparison with the control mix result with compressive strength values of 33.5 N/mm² and 33 N/mm² respectively.

Table 7. Compressive Strength Test Results

Concrete Mix Name	Compressive Strength (N/mm²)	% Increase or Decrease w.r.t Ref.Mix
M1 (0%FA+0%SF+ 0%BFS) Ref.Mix.	45.0	-
M2 (30%FA+5%SF+5%BFS)	33.5	- 25%
M3 (25%FA+7.5%SF+7.5%BFS)	33.0	- 26.7%

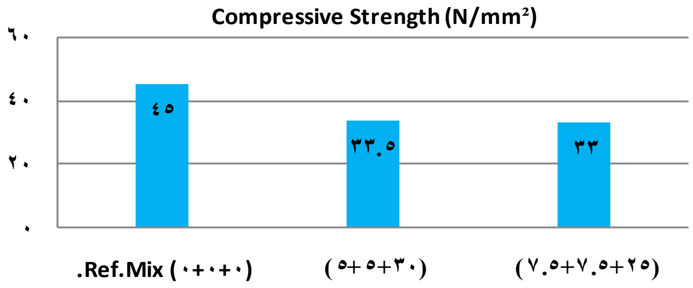

Figure 2. Compressive Strength Test Results

Split Tensile Strength Test Results

The tensile splitting strength test results for all the concrete mixes after 28 days of curing were as represented in Table 8 and Figure 3. The split tensile strength of the concrete found to be decreasing as the cement replacement level with SCMs is increasing. The reference mix M1 with only OPC recorded the highest split tensile strength of 3.2 N/mm² while the mixes M2 of (30%FA+5%SF+5%BFS) and M3 of (25%FA+7.5%SF+7.5%BFS) have shown an equal decrease in the results by 12.5% in comparison with the control mix result with a tensile splitting strength value of 2.8 N/mm² equitably.

Table 8. Split Tensile Strength Test Results

Concrete Mix Name	Split Tensile Strength (N/mm²)	% Increase or Decrease w.r.t Ref.Mix
M1 (0%FA+0%SF+ 0%BFS) Ref.Mix.	3.2	-
M2 (30%FA+5%SF+5%BFS)	2.8	- 12.5%
M3 (25%FA+7.5%SF+7.5%BFS)	2.8	- 12.5%

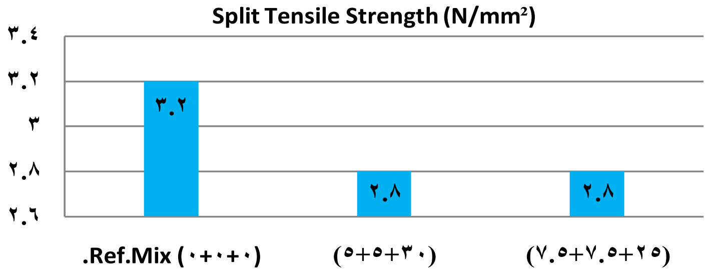

Figure 3. Split Tensile Strength Test Results

High Temperature Test Results

The strength test results for all the concrete mixes after 28 days of curing and heating at 150º C for 6 hours were as shown in Table 9 and Figure 4. The strength of the concrete under heating condition found to be decreasing as the cement replacement level with SCMs is increasing in the mix. The reference mix M1 with only OPC gave the highest compressive strength of 40 N/mm² while the mixes M2 of (30%FA+5%SF+5%BFS) and M3 of (25%FA+7.5%SF+7.5%BFS) have shown an equal decrease in the results by 15% with respect to the control mix result having equivalent compressive strength value of 34 N/mm².

Table 9. High Temperature Test Results

Concrete Mix Name	Strength (after heating @150º C for 6 hours) (N/mm²)	% Increase or Decrease w.r.t Ref.Mix
M1 (0%FA+0%SF+ 0%BFS) Ref.Mix.	40.0	-
M2 (30%FA+5%SF+5%BFS)	34.0	- 15%
M3 (25%FA+7.5%SF+7.5%BFS)	34.0	- 15%

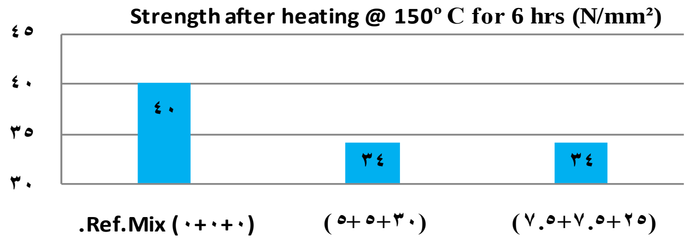

Figure 4. High Temperature Test Results

Rapid Chloride Penetration Test Results

RCPT results for all the concrete mixes were as shown in Table 10 and Figure 5. Chloride diffusion in the concrete found to be decreasing as the cement replacement level with SF and GGBS increasing and the presence of FA decreasing. The reference mix M1 gave the highest value of rapid chloride penetration of 3813 Coulombs while the mixes M2 of (30%FA+5%SF+5%BFS) and M3 of (25%FA+7.5%SF+7.5%BFS) resulted a significant decrease in chloride penetration by 74.7% and 81.2% with respect to the control mix result having RCPT values of 965 and 715 Coulombs respectively. The results show that the addition of SCMs such as SF and GGBS has an important role in enhancing the durability properties of the concrete.

Table 10. RCPT Results

Concrete Mix Name	RCPT (Coulombs)	% Increase or Decrease w.r.t Ref.Mix
M1 (0%FA+0%SF+ 0%BFS) Ref.Mix.	3813	-
M2 (30%FA+5%SF+5%BFS)	965	- 74.7%
M3 (25%FA+7.5%SF+7.5%BFS)	715	- 81.2%

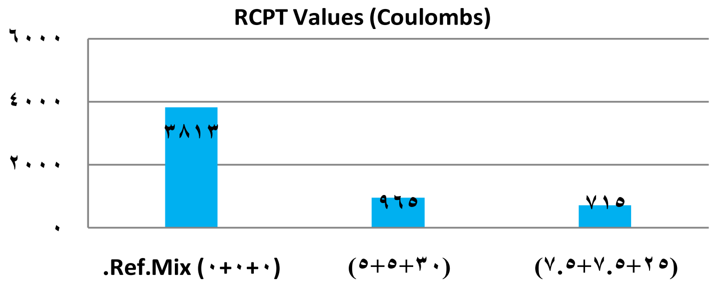

Figure 5. RCPT Results

CONCLUSION

1. The experimental investigation approved the ability of the industrial by-products such as Fly Ash, Silica Fume, and Blast Furnace Slag to partially replace the cement for up to 40% by giving a satisfactory workability, strength, and durability results.
2. The use of SCMs in the concrete could play a great role in improving the workability properties of the concrete.
3. The mix having highest percentages of SF and GGBS of (25%FA+7.5%SF+7.5%BFS) gave the lowest slump value of 75 mm and the mix with less amount of SF and GGBS of (30%FA+5%SF+5%BFS) gave a little bit higher slump of 80 mm while the reference mix containing only OPC gave the highest slump of 95 mm.
4. An overall decrease in the strength tests results occurred as the cement replacement percentage with SF and GGBS increases and the presence of the FA in the mix decreases.
5. The reference mix gave the highest compressive strength of 45 N/mm² and the other two mixes with replacement levels of (30%FA+5%SF+5%BFS) and (25%FA+7.5%SF+7.5%BFS) showed a strength decrease of 25% and 26.7% with strength values of 33.5 N/mm² and 33 N/mm² respectively.
6. The reference mix also gave the highest split tensile strength of 3.2 N/mm² and the other two mixes with replacement levels of (30%FA+5%SF+5%BFS) and (25%FA+7.5%SF+7.5%BFS) showed an equal strength decrease of 12.5% with a strength value of 2.8 N/mm² equitably.
7. The use of SCMs could enhance the durability properties of the concrete and as the percentage replacement of cement with these SCMs increases the durability of the concrete improves.

8. The reference mix recorded the highest compressive strength after heating @ 150º C for 6 hours with a strength of 40 N/mm² and the other two mixes with replacement levels of (30%FA+5%SF+5%BFS) and (25%FA+7.5%SF+7.5%BFS) showed an equal strength decrease of 15% with a strength value of 34 N/mm² equitably.
9. The mix having highest percentages of SF and GGBS of (25%FA+7.5%SF+7.5%BFS) gave the lowest rapid chloride penetration value of 715 Coulombs and the mix with less amount of SF and GGBS of (30%FA+5%SF+5%BFS) gave a little bit higher RCP value of 965 Coulombs while the reference mix containing only OPC gave the highest RCP value of 3813 mm.
10. The chloride diffusion in the mixes having replacement levels of (30%FA+5%SF+5%BFS) and (25%FA+7.5%SF+7.5%BFS) found being decreased by 74.4% and 81.2% respectively. This significant decrease shows the important of SCMs in enhancing the durability properties of the concrete.

ACKNOWLEDGEMENT

After thanking Allah, with his willingness this job has come to completion. I would like to give special thanks to my Leader Dr. B.S. Krishna Murthy for his technical help and continues support. Also I would like to thank my Family and Friends for their unlimited support and motivation.

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