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STUDY ON STRENGTH AND DURABILITY OF CONCRETE BY PARTIAL REPLACEMENT OF FINE AGGREGATE USING CRUSHED SPENT FIRE BRICKS

BY

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Abstract. Concrete is the most undisputable and indispensable material being used in infrastructure development throughout the world. Umpteen varieties of concretes (FAC, HVFAC, FRC, HPC, HSC, and others) were researched in several laboratories and brought to the field to suit the specific needs. Although natural fine aggregates (*i.e.*, river sand) are so far and/or will be superior to any other material in making concrete, their availability is continuously being depleted due to the intentional overexploitation through out the Globe. Hence, partial or full replacement of fine aggregates by the other compatible materials like sintered fly ash, crushed rock dust, quarry dust, glass powder, recycled concrete dust, and others are being researched from past two decades, in view of conserving the ecological balance. In this direction, an experimental investigation of strength and durability was undertaken to use “Spent Fire Bricks” (SFB) (*i.e.* waste material from foundry bed and walls; and lining of chimney which is adopted in many industries) for partial replacement of fine aggregate in concrete.

Key words: Spent Fire Bricks (SFB), Crushed Spent Fire Bricks (CSFB).

1. Introduction

Aggregates are the important constituents in the concrete composite that help in reducing shrinkage and impart economy to concrete production. Most of the aggregates used are naturally occurring aggregates, such as crush rock, gravel and sand which are usually chemically interactive or inert when bonded together with cement. On the other hand, the modern technological society is generating substantially high amounts of solid wastes both in municipal and industrial sectors; posing an engineering challenging task for this effective and efficient disposal. Hence, partial or full replacement of fine aggregates by the other compatible materials like sintered fly ash, crushed rock dust, quarry dust, glass powder, recycled concrete dust, and others are being researched from past two decades, in view of conserving the ecological balance.

Even though, use of several types of industrial solid wastes like metallurgical waste, glass pieces, fly ash, quarry dust, tyre and rubber waste, crushed concrete waste, sludges and others in making good field concrete is being effectively done at European countries, U.S.A., U.K., and Australia; Asian countries could not gear up to that level to match with those countries . Therefore, resource exploitation and waste disposal problems are currently rocking the sustainable development in those countries (including India).

1.1. Fire Bricks

Fire bricks are the products manufactured (as per IS: 6 and IS: 8 specifications) from refractory grog, plastic, and non plastic clays of high purity. The different raw materials are properly homogenized and pressed in high capacity presses to get the desired shape and size. Later, these are fired in oil-fired kiln at a temperature of 1,300°C. Table 1 shows the physio-chemical properties of the fire bricks.

Table 1

Physico-Chemical Properties of the Fire Bricks

Property	Result
Physical	
Bulk density, [kg/m^3]	2,000
Porosity, [%]	25…30
Size tolerance, [%]	±2
Working temperature, [°C]	1,300…1,400
Crushing strength (cold), [N/mm^2]	24.5…27
Chemical	
Aluminum as Al_2O_3, [%]	30…40
Iron as Fe_2O_3, [%]	2…2.5
Silica as SiO_2, [%]	57…65
Alkalis	Trace

Apart from this, they exhibit excellent non susceptibility to chemicals, thermal shocks, and carbon deposits. The sample fire bricks and its application in furnace are depicted in Figs.1 and 2, respectively.

Fig. 1 – Fire Bricks samples.

Fig. 2 – Fire Bricks used in a typical furnace.

1.2. Spent Fire Bricks

Due to the exposure to continuous high temperature (*i.e.* 1,000… 1,200ºC) for a period of 10 to 15 days, they lose some of the physical and mechanical properties and need to be replaced by fresh fire bricks, and is being done usually done once in fortnight. Then, the SFB is an industrial solid waste to be disposal off properly and Fig. 3 shows the broken SFB.

They were physically cleaned and mechanically crushed to a size gradation conforming to fine aggregates.

Fig. 3 – Broken fire bricks after complete usage.

2. Materials Used

2.1. Cement

The most common cement is used is ordinary Portland cement. The Type *1* is preferred according to IS: 269-1976, which is used for general concrete structures. Out of the total production, ordinary Portland cement accounts for about 80…90%. Many tests were conducted to cement some of them are consistency tests, setting tests, soundness tests, etc.

2.2. Aggregate

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample fraction of aggregates in required proportion such that the sample contains minimum voids. Samples of the well graded aggregate containing minimum voids require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less water, which will further mean increased economy, higher strength, lower shrinkage and greater durability.

Aggregate comprises about 55% of the volume of mortar and about 85% volume of mass concrete. Mortar contains of size of 4.75 mm and concrete contains aggregate upto a maximum size of 150 mm.

2.3. Coarse Aggregate

The fractions from 80 mm to 4.75 mm are termed as coarse aggregate.

2.4. Fine aggregate

Those fractions from 4.75 mm to 150 micron are termed as fine aggregate.

2.5. Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it helps to from the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. In practice, very often great control on properties of cement and aggregate is exercised but the control on the quality of water is often neglected. So quality of water is checked to its purity.

2.6. Crushed Spent Fire Bricks (CSFB)

As the major portion (*i.e.* 70…75% by volume) of the concrete is due to aggregates (both fine and coarse), the long and short term performance of many concretes depend on their physico-chemical parameters. In view of replacing the fine aggregates by CSFB, the various physico-chemical properties and elemental compositions were compared with the sand (Tables 2 and 3).

Table 2

Comparison of Physico-Chemical Properties of Sand and CSFB

Parameter	Result*						
	Sand	CSFB					
		S1	S2	S3	S4	S5	Average
Specific gravity	2.31	2.33	2.45	2.23	2.47	2.38	2.37
Bulk density, [kg/m^3]	1,247 (1,509)	1,306 (1,551)	1,355 (1,555)	1,296 (1,498)	1,322 (1,551)	1,295 (1,497)	1,315 1,530
Moisture content, [%]	0.03	0.95	0.91	0.96	0.99	0.92	0.95
Water absorption, [%]	0.94	0.81	0.85	0.79	0.78	0.89	0.82
Fineness modulus (FM)	2.42	2.40	2.35	2.33	2.21	2.45	2.34
pH	7.2	8.39	8.31	8.22	8.42	8.44	8.36
Electrical conductivity, [dS/m]	–	1.91	1.86	1.82	1.95	1.93	1.89

* Average of three results; bulk density results outside and with in the brackets are, respectively, at loose state and rodded state.

Table 3

Comparison of Elemental Composition of Sand and CSFB

Element	Result*						
	Sand[1]	CSFB					
		S1	S2	S3	S4	S5	Average
Silica as SiO_2, [%]	90…95	58.2	57.1	56.7	56.9	58.9	57.6±0.947
Iron as Fe_2O_3, [%]	2.68..8.25	2.41	2.32	2.59	2.4	2.38	2.42±0.101
Aluminium as Al_2O_3, [%]	0.005…0.01	34.2	34.9	33.7	33.9	34.6	34.3±0.492
Calcium as CaO, [%]	0.9…1.8	2.48	2.56	2.41	2.46	2.76	2.53±0.137
Magnesium as MgO, [%]	0.02…0.7	0.95	0.98	0.91	0.93	0.92	0.94±0.027
Sodium as Na_2O, [%]	0.01…0.1	0.25	0.21	0.22	0.19	0.28	0.23±0.035
Potassium as K_2O, [%]							

* Based on single analysis and 1 – from the literature.

Sand particles generally posses a size range of 4.75 to 0.07 mm and for producing a good concrete, "single-size" aggregates are usually preferred. The particle size distributions for sand and five different samples of CSFB are presented in Table 4 and Figs. 4 and 5, respectively.

Table 4

Particle Size Distributions for Sand and CSFB Samples

IS sieve size mm	Percent fines					
	Sand	CSFB				
		S1	S2	S3	S4	S5
10	100	100	100	100	100	100
4.75	100	100	100	100	100	100
2.36	94.5	92	94	91	94	96
1.18	82.4	79	82	78	84	80
0.60	61	61	60	65	62	58
0.30	11.2	13	11	12	13	10
0.15	1.5	1.5	1.4	1.7	1.6	1.2

From these distributions, the fineness moduli were calculated

(1) $$\mathrm{FM} = \frac{\sum \text{Cumulative weight fraction retained}}{100}.$$

From Figs. 4 and 5, it is seen that both sand and CSFB conforming to zone II (as per IS:2386 (part-III)-1963).

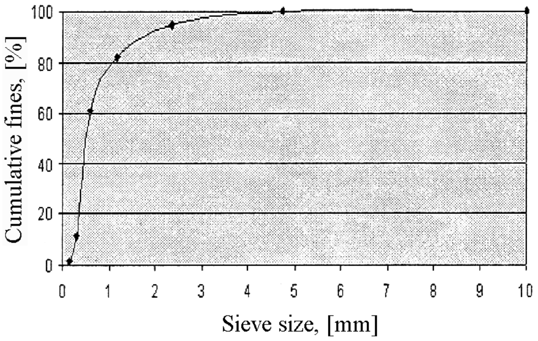

Fig. 4 – Particle size distribution for sand.

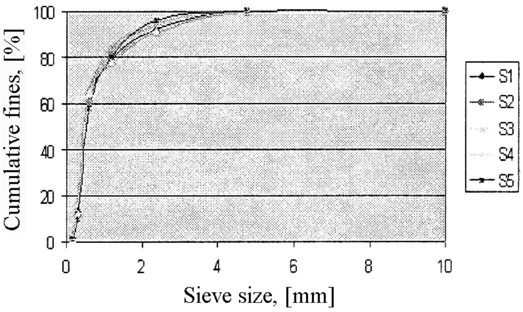

Fig. 5 – Particle size distributions for CSFB samples.

Further, when observed through the high power lenses, CSFB particles were of irregular shapes with sharp edges, which are same as that of natural sand texture. However, detailed SEM analysis is essential to understand their texture, internal pores, pore size, pore volume, and pore distributions. From Table 2, both CSFB and sand appeared to have almost same specific gravity, water absorption, and FM; but the bulk density (at both the states) and pH values were significantly different. This is because of the fact that the CSFB is not as inert as that of sand, but does not affect the quality of concrete. which clearly substantiates the suitability of CSFB in making concrete and the FM of CSFB (*i.e.*, 2.5) is almost same as that of FM of sand (*i.e.*, 2.3) used for comparison.

As the durability and strength (*i.e.*, "Strength-through-Durability" concept is gaining mometum during past one decade) chiefly depend on the factors like micro-structure of particles, alkali–silica reaction, alkali–aggregate reaction, nature and rate of ettingette formation, and others, the knowledge of chemical/elemental composition of the replaced material (*i.e.* CSFB); is highly necessary and a comparative Table 3 is provided. Except iron, calcium, magnesium, sodium and potassium contents in both and CSFB; the silica and aluminum contents in sand are very high and very low with respect to the respective contents in CSFB (Table 3). Also, from Tables 1 and 3, not much difference in silica, iron, and aluminum contents between fire bricks and CSFB were noticed; except a slight increase in calcium content which reveals the usefulness in strength aspect. Further more, as the silica deficiency (*i.e.*, about 34.9%) is compensated by the aluminum enhancement (*i.e.*, 34.3%) in CSFB, the durability and strength could be achieved. In addition to the above, the concrete produced from the partial replacement by CSFB could exhibit substantial enhancement in thermal melting and thermal performance, because of the presence of mullite binding phase mineral in the fire bricks (*i.e.*, by XRD analysis in many refractory fire bricks [9]). This was also evidenced from the recent investigation by [10]. However, further investigations are necessary to understand the micro mechanism of ettingette formation, durability and strength aspects, and extent of replacement level, thermal performance, and others.

3. Mix Design

As per the code book, IS: 10262 –1979, the mix design are found and the amount of materials is calculated. The obtained ratio is 1:1.267:3.368 and the water cement ratio is 0.5. According to the mix ratio, the amount of materials are given below, in Table 5.

Table 5
Mix Proportion

Water	Cement	Fine aggregate	Coarse aggregate
191.6	383	486	1,290
0.5	1	1.267	3.368

The principle of properties of concrete which are of practical importance are those concerning its strength; stress–strain characteristics; shrinkage and creep deformation; response to temperature variation; permeability durability. Of these the strength of concrete assumes a grater significance of hardened cement paste. The voids present in concrete mass have been found to influence greatly the strength of concrete.

4. Details of the Experimental Study

4.1. Strength of Concrete

a) *Compressive strength*

Of the various strength of concrete the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses. Cubes, cylinders and prisms are the three types of compression test specimens used to determine the compressive strength. The cubes are usually of 100 mm or 150 mm side, the cylinders are 150 mm diameter by 300 mm height; the prisms used in France are 100 mm × 100 mm × 500 mm. The specimens are cast, curved and tested as per standards prescribed for such tests. When cylinders are used, hey have to be suitably caped before the test, and operation not required when other types of specimens are tested.

b) *Tensile strength*

Apart from flexure test, the other methods used to determine the tensile strength of concrete can be broadly classified as direct and indirect methods. As the direct method is difficult, the indirect method is commonly used. In general compressive force is applied to a concrete specimen in such way that the specimen fails due to tensile stresses induced in the specimen. The tensile stress at which failure occurs is the tensile strength of concrete. The test can be performed on cubes by splitting a long its middle parallel to the edges by applying two opposite compressive forces through 15 mm square bars of sufficient length in the case of sides-splitting of the cubes; the tensile strength is determined from 0.642 p/s^2.

c) *Flexural strength*

Concrete as known is relatively strong in compression and weak in tension. The determination of flexural tensile strength is essential to estimate the load at which concrete members may crack. The modulus of rupture is determined by testing standard test specimen of 150 mm × 150 mm × 700 mm over a span of 600 mm are 100 mm × 100 mm × 500 mm over a span of 450 mm, under symmetrical two point loading or one point loading. The modulus of rupture is determined from the movement at failures as

$$f_r = \frac{3PL}{bd^2}. \tag{2}$$

5. Results and Discussions

Table 6
Compressive Strength of Cubes

Percentage of CSFB	Compressive strength, [N/mm^2]		
	7 days	14 days	28 days
0	14.25	17.25	21.95
5	11.82	15.28	17.65
10	15.11	17.29	18.22
15	16.08	22.52	23.52
20	22.22	22.84	23.95
25	26.49	25.95	25.65
30	26.22	20.79	22.13

Table 7

Split Tensile Strength of Cylinders

Percentage of CSFB	Split tensile strength, [N/mm^2]		
	7 days	14 days	28 days
0	1.401	1.520	1.980
5	1.386	1.504	1.561
10	1.471	1.760	1.849
15	1.783	1.986	2.079
20	2.001	2.171	2.235
25	2.777	2.582	2.461
30	2.320	2.341	2.390

Table 8

Flexural Strength of Prisms

Percentage of CSFB	Flexural strength, [N/mm^2]		
	7 days	14 days	28 days
0	2.100	2.320	2.652
5	2.517	2.417	2.517
10	2.752	2.652	2.752
15	2.847	2.747	3.127
20	3.147	3.047	3.847
25	3.498	3.298	3.028
30	2.418	2.718	2.818

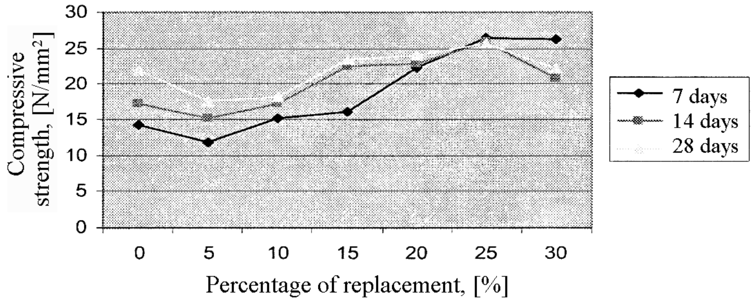

Fig. 6 – Compressive strength of cubes.

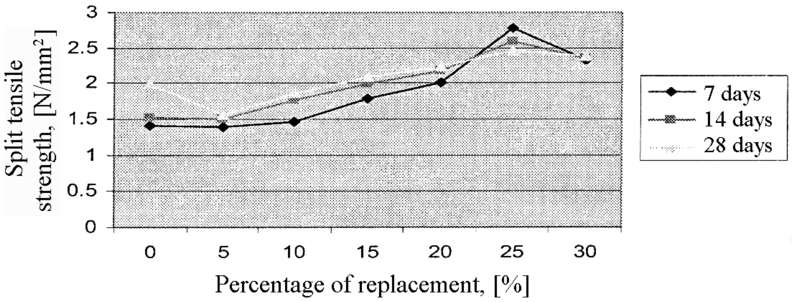

Fig. 7 – Split tensile strength of cylinders.

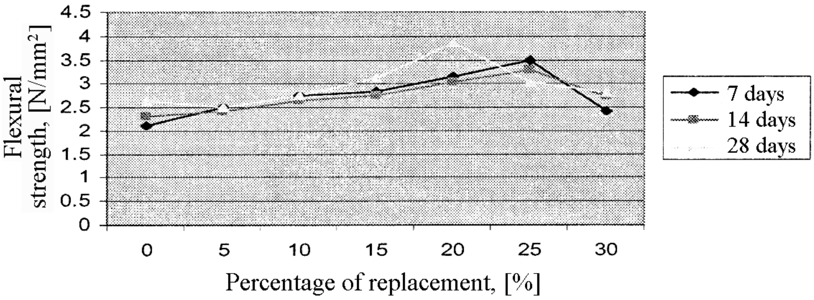

Fig. 8 – Flexural strength of prisms.

6. Conclusions

Based on limited experimental investigation concerning the compressive and split tensile strength of concrete, the following observations are made regarding the resistance of partially replaced hypo sludge.

1. The SFB is a locally available, low cost, and inert industrial solid waste whose disposal is a matter of concern likes construction waste.

2. On an overall, the CSFB can be comparable to the natural river sand.

3. The CSFB satisfies the zone II gradation for not only to partially replace the sand, but for making good concrete,

4. Unit weight of CSFB is higher than that of river sand aggregate in dense condition which, in turn, contributes to the increase in the unit weight of concrete containing CSFB as a fine aggregate. From the obtained results we observe that the maximum strength is achieved by 25% of CSFB replacement in concrete. The 30^{th}% of CSFB replacement in concrete indicates there is no strength gaining after increasing the proportion.

5. The compressive strength of partial replacement of CSFB aggregate concrete is marginally higher than that of the river sand aggregate concrete at age of 7 days, 14 days, and 28 days, respectively.

6. The split tensile strength of partial replacement of CSFB aggregate concrete is higher than that of the river sand aggregate at all ages.

7. The modulus of elasticity of partial replacement of CSFB aggregate concrete is marginally higher than that of the river sand aggregate concrete.

8. The partial replacement of GGBS can be used effectively as fine aggregate in place of conventional river sand concrete production.

7. Future Research

The research carried out so far is only the initial stage of this project. Durability studies have not been done on concrete containing CSFB. Therefore, it is planned that durability properties like alkali–silica reaction, freeze–

thaw, chloride–ion permeability, interaction with air-en- training agents, fatigue strength, etc., of concrete made with CSFB concrete, will be studied.

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STUDIU PRIVIND REZISTENȚA ȘI DURABILITATEA BETONULUI PRIN ÎNLOCUIREA PARȚIALĂ A AGREGATULUI FIN CU DEȘEURI DIN MATERIALE CERAMICE REFRACTARE

(Rezumat)

Betonul este de departe cel mai folosit material de construcție din infrastructură din lume. Numeroase tipuri de betoane (beton cu fibră dispersă, beton polimeric, beton de înaltă rezistență etc.) au fost studiate și dezvoltare în laboratoarele de cercetare și apoi introduse în practică pentru a face față anumitor cerințe. Deși agregatele naturale

din piatră de râu sunt şi vor fi poate superioare calitativ faţă de orice alt material folosit la realizarea betonului, cantitatea disponibilă descreşte rapid datorită supra-exploatării pe întreg mapamondul. De aceea, în ultimele decade au fost investigate numeroase metode şi procedee de înlocuire parţială sau chiar totală a acestuia cu alte materiale compatibile: cenuşă de termocentrală, cenuşă zburătoare, praf de carieră, particule fine provenite din reciclarea sticlei şi/sau a betonului, pentru a ajuta la păstrarea echilibrului ecologic. Având în vedere cele enumerate, lucrarea de faţă se axează pe investigarea rezistenţei şi durabilităţii betonului prin înlocuirea parţială a agregatului fin din piatra naturală cu deşeuri din materiale ceramice refractare (cărămizi refractare utilizate la cămăşuirea pereţilor furnalelor şi a cuptoarelor din topitorii).