International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Experimental Study on Strength and Durability of Concrete using Sintered Fly Ash as Partial Replacement of Coarse Aggregate

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Abstract: ***This project investigates the potential of using sintered fly ash, a waste by-product of thermal power plants, as a partial replacement for coarse aggregate in m25 grade concrete. The study aims to address sustainability in construction by reducing natural aggregate consumption and utilizing industrial waste effectively. Concrete mixes were prepared with sintered fly ash replacing coarse aggregate at varying levels (5%, 10%, 15%, and 20%) to analysis its influence on mechanical and durability properties, well as durability characteristics such as water absorption and permeability. The findings will contribute to understanding the optimal sfa content for achieving desired concrete performance while promoting the utilization of industrial byproducts. The study involves designing concrete mixes with varying percentages of sfa replacing coarse aggregate. Mechanical tests, including compressive and tensile strength tests, will be conducted on these mixes at different ages (e.g., 7, 14, and 28 days) to assess strength development. Durability tests, such as water absorption and permeability tests, will be performed to evaluate the concrete's resistance to moisture and other environmental factors. The results will be analyzed to determine the optimal sfa content that maximizes strength and durability while minimizing any negative impacts. This research is crucial for promoting sustainable construction practices by effectively utilizing sfa in concrete production.***

Keywords: sintered fly ash, sustainable concrete, aggregate replacement, concrete durability, construction waste reuse

1. Introduction

In the manufacture of cement, the clinker production process requires a great amount of energy and emits a large amount of carbon dioxide (co2) into the atmosphere. The increase in co2 emissions has led to the greenhouse effect and an increase in the temperature of the earth. To reduce the environmental problems, industrial and agricultural by-products such as fly ash, rice husk ash, silica fume metakaolin, granulated blast furnace slag, etc., have been used as supplementary cementing material to reduce the production of cement, thus reducing the emission of co2 and the use of energy. Moreover, the incorporation of these cement replacement materials in concretes has been reported to improve the mechanical properties and penetration resistance of the concrete.

Natural or river sand are weathered particles from rocks which are of various shapes and sizes depending upon the weathering action of rivers. In the present scenario, natural sand with required properties is not easily/locally available. In most of the situations, the natural sand is being brought from faraway places to the construction site. Such type of transporting the river sand from faraway places will increase the construction costs. Also, this natural river sand is also becoming unavailable due to many reasons. Hence it is very essential to find an alternate material that can substitute the natural river sand either partially or fully. In tamil nadu, stone quarries are found in abundance and are widespread across the state. They are the good source for the coarse aggregate and manufactured fine aggregate. There is a need to make use of the stockpiles of quarry fines generated in those crushers.

Sintered fly ash (sfa) is a lightweight aggregate derived from fly ash, a byproduct of coal combustion in thermal power plants. It is manufactured through a process that involves pelletization and sintering. In the pelletization stage, fine fly ash particles are mixed with water or binders like lime or cement to form spherical pellets. These pellets are then heated to high temperatures, typically between 1100°c and 1300°c, in furnaces such as rotary kilns, causing the particles to fuse together. The sintering process transforms the fly ash into durable, porous aggregates that can be used as a substitute for coarse aggregates in concrete.

The use of sintered fly ash as a partial replacement for coarse aggregate in concrete offers numerous benefits. It reduces the overall density of the concrete, producing lightweight structures that are particularly advantageous in high-rise buildings and precast components. The porous nature of sfa improves the bond between the aggregates and the cement matrix, which enhances the compressive and tensile strength of the concrete. Additionally, concrete made with sfa demonstrates improved durability, offering resistance to chemical attacks, abrasion, and freeze-thaw cycles. From an environmental perspective, utilizing sfa helps in managing fly ash waste, conserving natural stone resources, and reducing the carbon footprint associated with traditional concrete production. However, its porous structure also increases water absorption, which have careful control of the water-cement ratio. Despite challenges like limited availability of sintering facilities, sfa has proven to be an innovative and sustainable alternative for use in modern construction projects.

The chemical composition of sintered fly ash (sfa) is primarily influenced by the fly ash from which it is derived, with its main constituents being silicon dioxide (sio₂), aluminum oxide (al₂o₃), and iron oxide (fe₂o₃). Silicon dioxide, typically comprising 40-60% of the composition, plays a crucial role in forming calcium silicate hydrates (c-s-h) during the hydration process, which is essential for concrete's strength and durability. Aluminum oxide, present in the range of 20-30%, enhances pozzolanic activity, reacting with calcium hydroxide to form calcium aluminate hydrates, thereby contributing to early strength development. Iron oxide, accounting for 5-15%, improves thermal stability and resistance to sulfate attacks while also imparting a characteristic reddish hue. Calcium oxide (1-10%) reacts during hydration to strengthen the material but must be carefully monitored, as excess free lime can cause expansion and instability. Magnesium oxide (less than 5%) offers similar benefits but, like calcium oxide, can lead to unwanted expansion if overabundant. Sulfur trioxide, typically below 3%, can harm durability if present in large amounts by forming expansive gypsum compounds. Alkalis such as potassium oxide and sodium oxide, found in small quantities (1-3%), may induce alkali-silica reactions if reactive aggregates are present, while the loss on ignition (loi), representing unburnt carbon and volatiles, is kept below 5% to ensure minimal adverse effects on workability and water demand. These chemical properties collectively determine sfa's suitability and performance as a partial replacement for coarse aggregates in concrete.

1.1 Objective

The objective of the project titled "experimental study on strength and durability of concrete using sintered fly ash as partial replacement of coarse aggregate" is to investigate the impact of sintered fly ash on the mechanical properties and durability of concrete.

The project aims to evaluate the effects of sintered fly ash as a partial replacement for conventional coarse aggregates on the compressive, tensile, and flexural strength of concrete, as well as its workability and ease of handling. Additionally, the study will assess the durability of concrete incorporating sintered fly ash by examining its resistance to sulphate attack, acid attack, chloride penetration, and freeze-thaw cycles.

A key objective is also to explore the environmental benefits of using sintered fly ash as an eco-friendly alternative, contributing to sustainable construction by reducing the use of natural resources and promoting waste management.

1.2. Material Properties

The properties of all the materials used in this study are given below.

a) Cement

Ordinary portland cement of 53 grades conforming to is: 12269-1987 was used for the present experimental investigation. The cement was tested as per the procedure given in Indian standards is 4031 – 1988.

Table 1.2.1: Physical Properties of Cement

S. No	Property	Result
1	Normal consistency	32%
2	Setting times • Initial setting time • Final setting time	 65 min. 250 min.
3	Specific gravity	3.15
4	Fineness of cement (by 90 micron sieve)	5 % retained
5	Soundness of cement (le chatlier expansion value)	2 mm

b) Sintered fly ash

Sintered fly ash (sfa) is a processed form of fly ash, a byproduct of coal combustion in thermal power plants. It is produced by heating (sintering) raw fly ash at high temperatures (around 1000–1200°c) until the particles fuse into porous, lightweight aggregates or granules.

Table 1.2.2: Physical properties of sintered fly ash

S. No	Property	Result	Permissible limit as per Is: 12269 - 1987
1	Specific gravity	1.9	1.8 – 2.3
2	Abrasion value	8%	Not more than 10%
3	Crushing value	25%	Not more than 30%
4	Water absorption	4%	Not more than 10%

c) River sand

Natural river sand conforming to zone ii as per is 383 -1987 was used. The fineness modulus of sand used is 2.64 with a specific gravity of 2.6. The physical properties and sieve analysis of fine aggregate are presented in table

Table 1.2.3: Physical properties of river sand

S. No.	Properties	Experimental value
1	Specific gravity	2.60
2	Fineness modulus	2.64
3	Bulk density	1800 kg/m^3
4	Void ratio	0.55

d) M-sand

The physical properties and sieve analysis of m-sand are represented in the table 3.4

Table 1.2.4: Physical properties of m-sand

S. No.	Properties	Experimental value
1	Specific gravity	2.73
2	Fineness modulus	2.84

e) Coarse aggregate

The physical properties coarse aggregate are represented in the table

Table 1.2.5: Physical properties of coarse aggregate

S. No.	Properties	Experimental value
1	Specific gravity	2.66
2	Impact value	17.6%
3	Water absorption	1.54%

f) Water

Fresh potable water, which is free from acid and organic substance, was used for mixing the concrete.

1.3 Fresh Concrete Properties

The following tests were conducted to determine the fresh concrete properties.

a) Slump cone test

This test is performed to measure the workability of fresh concrete as per is 1199-1959. The apparatus for conducting the slump test essentially consisted of a metallic mold in the form of a frustum of a cone having the internal dimensions of 200 mm bottom diameter, 100 mm top diameter, and 300 mm height. The thickness of the metallic sheet for the mold should not be thinner than 1.6 mm. Sometimes, the mold was provided with suitable guides for lifting up vertically. For tamping the concrete, a steel tamping 0.6m long rod of 16 mm diameter along with a bullet end was used. The internal surface of the mold was thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. If the concrete slumps evenly, it is called true slump. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mold and the average value of the subsidence. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation. The concrete slump test is an empirical test that measures the workability of fresh concrete. It measures the consistency of the concrete in that specific batch. The slump cone test on fresh concrete shown in figure 3.1

b) Compacting factor test

Compaction factor test is the workability test for concrete conducted in laboratory. The compaction factor is the ratio of weights of partially compacted to fully compacted concrete. It was developed by road research laboratory in united kingdom and is used to determine the workability of concrete as per is1199:1959 compaction factor test apparatus consists of two conical hoppers and a bottom cylinder which is arranged steel rod of 1.6cm diameter with a length of 61cm is used to tamp the concrete and a weight balance is used to weight the concrete. The compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete

Table 1.3.1: Workability of Fresh Concrete

% of replacement	Slump value (mm)	Compaction factor(mm)
Cc	71.3	86.8
Cm	73.9	88.2
Sfa-1	71.2	91.3
Sfa-2	70.4	92.9
Sfa-3	66	94.2
Sfa-4	61.7	91.6

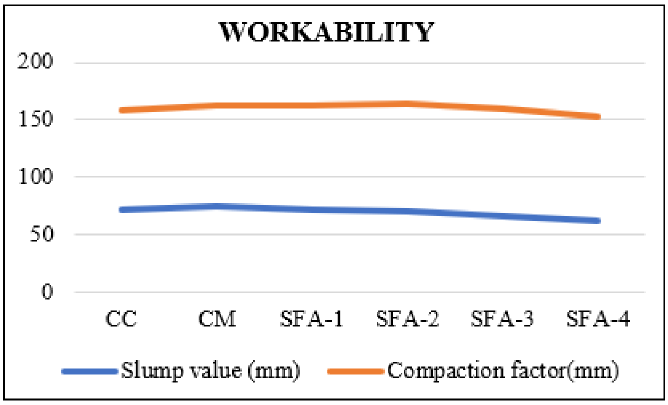

Figure 1.3.1: Workability

Where,
cc - conventional concrete.
cm - m sand concrete.

1.4 Properties of hardened concrete

The compressive, split tensile, flexural strength, rebound hammer and ultrasonic pulse velocity of m sand concrete with various percentage of pp at various ages are discussed below.

a) Compressive strength test

100 mm cube specimens were tested under compressive load in the respective to the age of curing. All the specimens were tested in saturated surface dry condition, after wiping out the surface moisture. For each mix combination, three identical specimens were tested at the ages of 7, 14, 28 days using compression testing machine of 2000 kn capacity under a uniform rate of loading of 140 kg/cm^2/min. And the compressive strength was calculated as per is: 516 – 1959. Fig. 5.1 shows the experimental set up of compressive testing machine.

$$\text{Compressive Strength Of concrete} = \frac{\text{Maximum compressive load}}{\text{Cross section surface of specimen}}$$

b) Split tensile strength test

This is an indirect test to determine the tensile strength of cylindrical specimens. Split tensile strength tests were carried out on 100 mm dia. X200 mm high cylindrical specimen at the ages of 28 days of moist curing, using compression testing machine of 2000 n capacity as per is 5816-1970. Fig5.2 shows the experimental set up of split tensile strength testing machine.

Split tensile strength (f_t) is estimated from the expression
$f_t = 2p / \pi dl$

Where f_t = split tensile strength of concrete (mpa)
p = ultimate load (newton)
d = diameter of cylinder (mm)
l = length of cylinder (mm)

c) Flexural strength test

In order to determine the flexural strength of concrete, prismatic specimens of a size 100 mm x 100 mm x 500 mm were cast with various proportions of all the concrete mixtures. After 28 days of moist curing the specimens were tested in flexural testing machine under a uniform rate of

Paper ID: MR25726080651 DOI: https://dx.doi.org/10.21275/MR25726080651

loading of 180 kg/cm^2/min. Flexural strength of specimens expressed as the modulus of rupture (f_b) is then calculated using the formula and procedure given in is: 516-1959. When the distance between the line of fracture and the nearer support, measured on centerline of the tension side of specimen ('a' in mm) is greater than 133 mm for prism of size 100 mm x 100 mm x 500 mm, the modulus of rupture (f_b) is then calculated from the equations 3.1 and 3.2.

$$(f_b) = pl/ bd^2 \quad (3.1)$$

for 'a' is less than 133 mm but greater than 110 mm for prism specimen, then modulus of rupture is calculated from the formula.

$$(f_b) = 3pa / bd^2 \quad (3.2)$$

Where,
b = width of the specimen (mm)
d = depth of the specimen (mm)
l = length of the specimen (mm) on which specimen is supported (span)
p = maximum load (newton) applied on the specimen

d) Rebound hammer test

Among the many available ndt procedures, the most generally adopted is the rebound hammer test, otherwise called the schmidt hammer test. Due to the advantage that the device is portable, affordable and simple to use (sanchez, k., and tarranza, n. 2015). The schmidt rebound hammer is a surface hardness test with the little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. This is a basic, handy tool, which can be used to give an advantageous and rapid indication of the compressive strength of concrete. It comprises a spring-controlled mass that slides on a plunger inside a cylindrical lodging (gehlot et al. 2016).

A rebound hammer tests the surface hardness of concrete, which cannot be converted directly to compressive strength. The method measures the modulus of elasticity of the near-surface concrete. The distance travelled by the mass expressed as a percentage of the initial extension of the spring is called the rebound number. The tests were conducted as per bis standards (is13311- part 2- 1992- reaffirmed 2004). The image of the rebound hammer and the rebound hammer positions for testing concrete structures are shown in figures 5.3 and 5.4 respectively.

e) Ultrasonic pulse velocity test

Ultrasonic testing of concrete or ultrasonic pulse velocity test on concrete is a non-destructive test to assess the homogeneity and integrity of the concrete. This test can detect areas of internal cracking, internal delamination, and relative strength parameters. With this ultrasonic test on concrete, the following can be assessed:

- Qualitative assessment of the strength of concrete, its gradation in different locations of structural members and plotting the same.
- Any discontinuity in cross-section like cracks covers concrete delamination etc.
- Depth of surface cracks.

The ultrasonic pulse velocity is done as per the code is 13311 (part 1): 1992 (reaffirmed 2004). The setup of the ultrasonic pulse velocity test and methods of propagating and receiving pulses are depicted in figures 5.5 respectively.

f) Acid attack test

A total number of 36 cubes of size 100 mm × 100 mm × 100 mm were cast and demoulded after 24 hours and then the demoulded specimens were water cured for 28 days. After 28 days curing, the specimens were taken out and allowed to dry for one day. Weights of the cubes were taken. For acid attack, 5% dilute hydrochloric acid (hcl). After that, cubes were immersed in the above said acid water for a period of 60 days.

The concentration of the solution was maintained throughout this period. After 60 days, the specimens were taken from the acid water. The surfaces of the cubes were cleaned, weights of the specimens were registered and then they were tested in the compression testing machine of 2000 kn capacity under a uniform rate of loading of 140 kg/cm^2/min. The loss in compressive strength of the concrete cubes and the improvement of resistance of acid attack of marble concrete cubes were analysed.

2. Results and Discussions

a) Compressive Strength Test

Table 1.5.1: Compressive strength result

Mix Designation	Mix proportion					Compressive strength n/mm^2		
	Cement %	River sand %	M sand%	Sfa	Coarse aggregate	7 Days	14 days	28 days
Cc	100	100	0	0	100	17.8	22.9	27.5
Cm	100	0	100	0	100	18.2	23.7	27.8
Sfa-1	95	0	100	5	100	20.3	24.2	28.2
Sfa-2	90	0	100	10	100	20.9	24.7	28.6
Sfa-3	85	0	100	15	100	18.0	20.3	23.7
Sfa-4	80	0	100	20	100	15.4	19.35	22.5

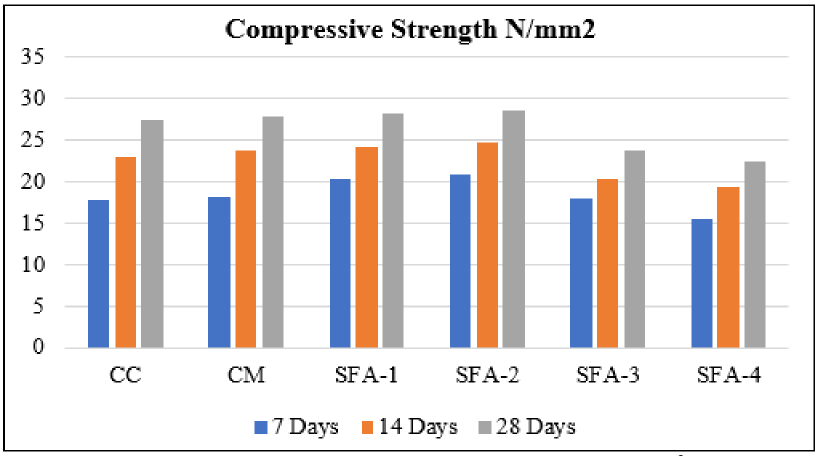

Figure 1.5.1: Compressive strength result in (n/mm^2)

b) Split tensile strength test

Table 1.5.2: Split tensile strength result

Mix Designation	Mix proportion					Split tensile strength n/mm^2
	Cement %	Sfa	River sand %	M sand%	Coarse aggregate	28 days
Cc	100	0	100	0	100	2.83
Cm	100	0	0	100	100	2.9
Sfa-1	95	5	0	100	100	3.1
Sfa-2	90	10	0	100	100	3.34
Sfa-3	85	15	0	100	100	2.65
Sfa-4	80	20	0	100	100	2.57

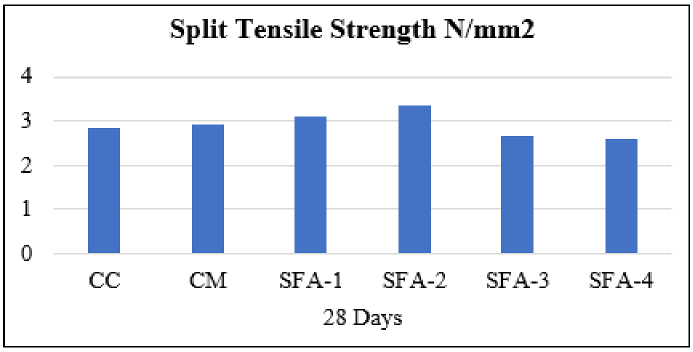

Figure 1.5.2: Split tensile strength result in (n/mm^2)

c) Flexural Strength Test

Table 1.5.3: Flexural strength result

Mix Design Ation	Mix proportion					Flexural strength n/mm^2
	Cement %	Sfa	River sand %	M sand%	Coarse aggregate	28 days
Cc	100	0	100	0	100	4.13
Cm	100	0	0	100	100	4.18
Sfa-1	95	5	0	100	100	4.35
Sfa-2	90	10	0	100	100	4.47
Sfa-3	85	15	0	100	100	4.07
Sfa-4	80	20	0	100	100	3.96

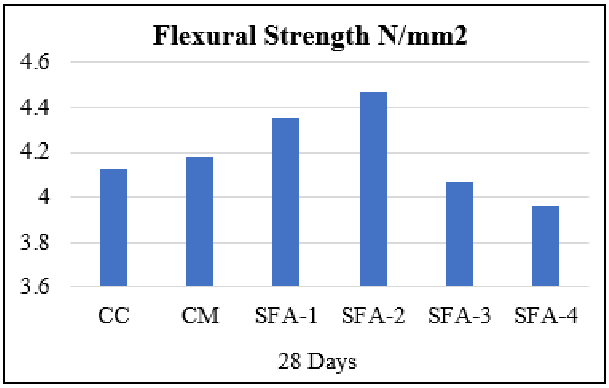

Figure 1.5.3 Flexural strength test result in (n/mm^2)

d) Rrebound hammer test result

Table 1.5.4: Rebound hammer test result

S.no.	Test specimen	Rebound number
1	Cc	26.5
2	Cm	27
3	Sfa-1	28.5
4	Sfa-2	29
5	Sfa-3	25.8
6	Sfa-4	19.3

e) Ultrasonic pulse velocity test result

Table 1.5.5: Ultrasonic pulse velocity test result

S.no.	Test specimen	Upv (km/s)
1	Cc	3.75
2	Cm	3.8
3	Sfa-1	3.85
4	Sfa-2	3.89
5	Sfa-3	3.4
6	Sfa-4	3.2

f) Acid attack test

Table 1.5.6: Acid attack test result (weight loss %)

Si.no.	Test	Weight loss%	
	Specimen	45 days	60 days
1	Cc	6.4	7.3
2	Cm - 0	6.6	7.5
3	Mp1-5	6.3	7.2
4	Mp2-10	6.5	7.4
5	Mp3-15	7.9	8.7
6	Mp4-20	8.2	9.8

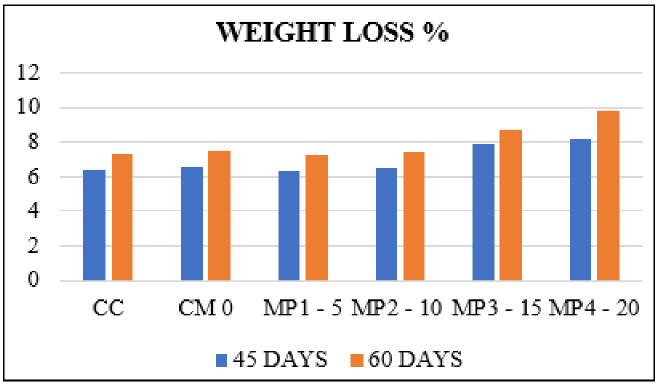

Figure 1.5.4: Acid test (weight loss %)

3. Conclusion

- Due to waste sintered fly ash, it proved to be very effective in assuring very good cohesiveness of mortar and concrete.
- From the above study, it is concluded that the waste sintered fly ash can be used as a partial replacement material for cement; and 10% replacement of marble dust gives an excellent result in strength aspect and quality aspect and it is better than the conventional concrete
- The results showed that the substitution of 10%of the cement content by waste sintered fly ash induced higher compressive strength, and improvement of properties related to durability.
- The best possible way of disposal of waste material like waste sintered fly ash can be by using it in concrete, which will reduce environmental burden.
- The results achieved shows that sintered fly ash is great potential for the utilization in concrete as replacement of cement.
- The optimum percentage 10% of sintered fly ash with m-sand concrete is recommended for structural concrete.

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