Dizhen Dizhi Journal

Investigating Mechanical Properties Sintered Fly ash Aggregate in the Rigid Pavement

Prakash Somai[#1], Dr. Arun Gaur[2], Dr. Pankaj Dhemla[3]

[#1]Research Scholar, Malaviya National In statute of Technology Jaipur, Rajasthan 302017

[2]Associate Professor, Malaviya National In statute of Technology Jaipur, Rajasthan 302017

[3]Associate Professor, Poornima College of Engineering Jaipur, Rajasthan 302022

[1]prakashsomani197@gmail.com

Abstract— **The primary focus of this study revolves around the utilization of sintered fly ash (SFA) aggregate as a partial replacement for coarse aggregate in concrete pavement. The aim is to improve the environmental sustainability of concrete pavement while still maintaining its structural integrity under mechanical loads. By incorporating SFA aggregate, notable enhancements in the thermal behaviour of rigid pavement can be achieved, attributed to the increased void content and reduced thermal conductivity of the material. Through a series of experiments, coarse aggregate was systematically substituted with SFA aggregate in intervals of 10%, up to a 40% volumetric replacement ratio. The design of the rigid pavement adhered to Indian standards, with a consistent water-cement ratio of 0.36, aiming to attain a minimum compressive strength of 40 N/mm². Various mechanical properties essential for pavement sustainability were examined, including compressive strength, abrasion resistance, and impact strength. Notably, a slight reduction in compressive strength was observed as SFA was introduced into the concrete mix. A similar trend was identified in the concrete's abrasion and impact resistance behaviour. In summation, the study concludes that incorporating SFA leads to a marginal decline in the mechanical performance of concrete. However, this reduction remains within an acceptable range. More importantly, utilizing SFA within specific limits contributes positively to the sustainability of the pavement. Notably, it enhances permeability and thermal conductivity, crucial aspects of pavement performance, especially when considering environmental factors. Therefore, when judiciously employed, SFA holds promise as a valuable component in concrete pavement construction, balancing the need for mechanical robustness with improved environmental considerations.**

Keywords—**Sintered fly ash aggregate, Rigid Pavement, Impact Resistance, Abrasion Resistance, Mechanical Strength**

I. Introduction

The construction industry plays a pivotal role in shaping the infrastructure and development of nations. In this context, pavements are fundamental components that facilitate transportation and connectivity. The conventional approach to pavement construction, predominantly employing concrete, has demonstrated commendable mechanical strength under various loads[1]–[3]. However, the adverse environmental impact associated with its production and usage has prompted researchers and practitioners to explore sustainable alternatives that strike a balance between structural integrity and environmental consciousness[4].

One such promising alternative is the incorporation of sintered fly ash (SFA) aggregate in concrete pavement construction[5]. Fly ash, a byproduct of coal combustion in thermal power plants, has garnered attention as a supplementary cementitious material due to its pozzolanic properties[6], [7]. When subjected to controlled sintering, fly ash can be transformed into aggregates, offering an eco-friendly alternative to traditional coarse aggregates in concrete mixtures[8]–[10]. The potential benefits of SFA in rigid pavement construction have garnered significant interest in recent years[11].

This investigation aims to delve into the mechanical properties of concrete pavement when SFA aggregate is utilized as a partial replacement for conventional coarse aggregate. Specifically, the focus lies on comprehending how the introduction of SFA aggregates influences crucial mechanical attributes, such as compressive strength, abrasion resistance, and impact strength. By systematically analyzing these properties, a comprehensive understanding of the performance of SFA-enhanced concrete pavement can be gained.

The research not only contributes to the knowledge surrounding sustainable construction materials but also addresses the evolving demands of infrastructure development. The outcome of this study could potentially provide valuable insights into designing pavements that exhibit enhanced mechanical performance while mitigating the environmental burdens associated with traditional construction materials. As nations strive for a more sustainable future, embracing innovative materials like SFA aggregates could herald a new era in pavement engineering, redefining the way we construct and maintain our transportation networks.

II. Materials and Methodology

A. Raw Ingredients

In this study, sintered fly ash aggregate replaces a portion of conventional coarse aggregate, following ASTM C-330 guidelines. The sintered fly ash aggregate composition includes 61% Silica, 14% Al_2O_3, 9.0% CaO, 8% Fe_2O_3, and minor alkalis. Pictorial and microscopic images of the aggregate are depicted in Figure 1. Natural coarse aggregates of 10mm and 20mm sizes, with a specific gravity of 2.67, were used. Fine aggregates comprised river sand of Zone – II quality as per IS 383-2016 [11]. Table 1 presents the summarized physical properties of the aggregates. Ordinary Portland cement (OPC) of grade 43, complying with IS 8112-1989 [12], served as the binder.

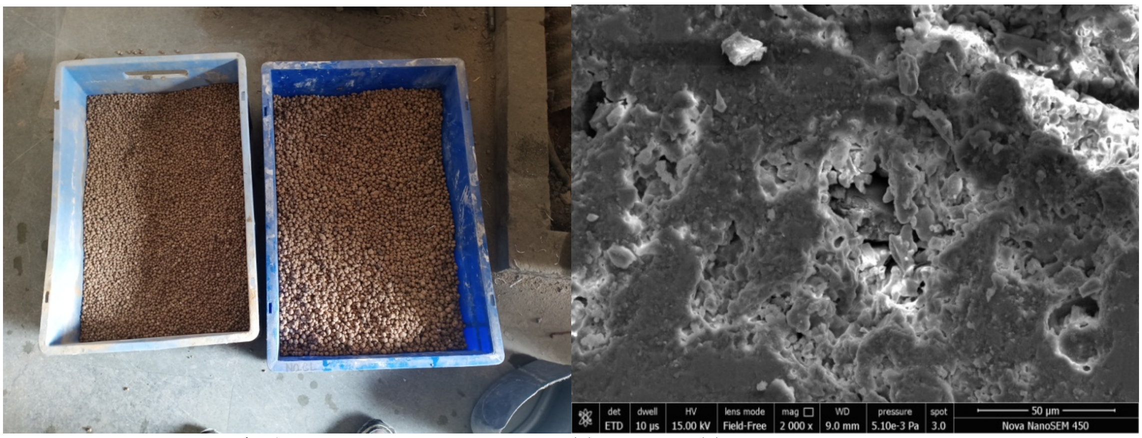

Fig. 1. Sintered fly ash aggregate (a) Pictorial (b) Microscopic image

TABLE I Physical properties of the aggregates.

Property	Crushing strength (MPa)	Loose Bulk density (Kg/m³)	Specific Gravity	Water Absorption (%)	Fineness Modulus	Porosity (%)
SFA	9.8	845	1.53	15	-	39
Coarse Aggregate	-	-	2.67	0.8	-	-
Fine Aggregate	-	-	2.62	1.2	2.52	-

B. Mixing Details

This study focuses on evaluating the impact of Sintered Fly Ash (SFA) in concrete pavement using M40 grade concrete. The investigation involved replacing coarse aggregate (10mm size) with SFA in increments of 10%, reaching up to 40% replacement. The water-to-cement ratio was consistently maintained at 0.36 for all mixtures. The specific mix proportions for each mixture are outlined in Fig. 2.

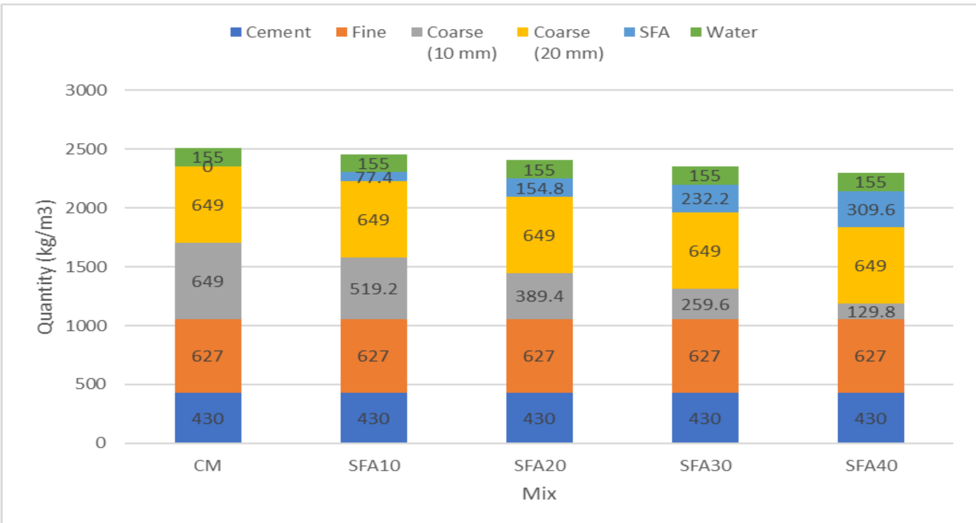

Fig. 2. For M40 grade concrete with SFA replacement, mix design details

C. Experimental Program

A structured experimental program was devised to comprehensively assess the mechanical characteristics, adhering closely to the established guidelines. The concrete's compressive strength was determined in accordance with IS 516 [12] directives, involving 100 mm cubes subjected to a 28-day curing regimen. To evaluate abrasion resistance, concrete cubes cured for 28 days were subjected to testing as per IS 1237:2012[13] standards. Prior to testing, these cubes underwent a three-day oven drying period at 110°C ± 5°C. Additionally, following a 28-day curing duration, the impact resistance strength of concrete was evaluated according to the stipulations set forth by ACI Committee 544[14].

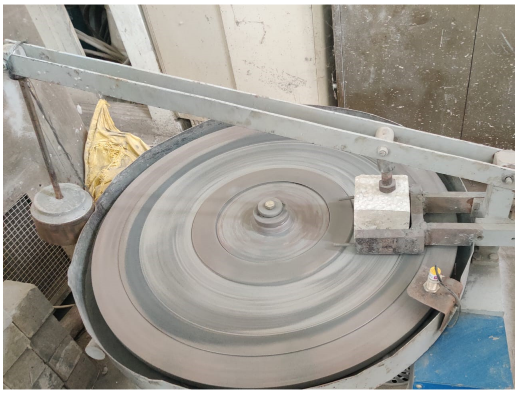

Fig. 2. Abrasion Resistance Test Setup

III. Results and Discussion

A. Compressive Strength

The compressive strength of concrete significantly influences its practicality and attractiveness for various applications. The findings of the compressive strength assessment carried out on concrete samples featuring the substitution of Sintered Fly Ash (SFA) for natural aggregate are elucidated in Figure 3. The observed reductions in compressive strength are quantified as 6.44%, 9.05%, 12.68%, and 17.3% respectively for SFA replacement levels of 10%, 20%, 30%, and 40%.

This decrease in compressive strength within SFA-infused concrete samples can be attributed primarily to the comparatively lower crushing strength exhibited by the SFA aggregate[2][15]. Notably, the compressive strength values for the SFA 30 and SFA 40 mixtures are recorded as 43.4 MPa and 41.1 MPa, respectively, both surpassing the required strength threshold of 40 MPa. This indicates that even with the reduction in compressive strength attributed to SFA incorporation, the resulting mixtures continue to meet or exceed the requisite strength standards[6].

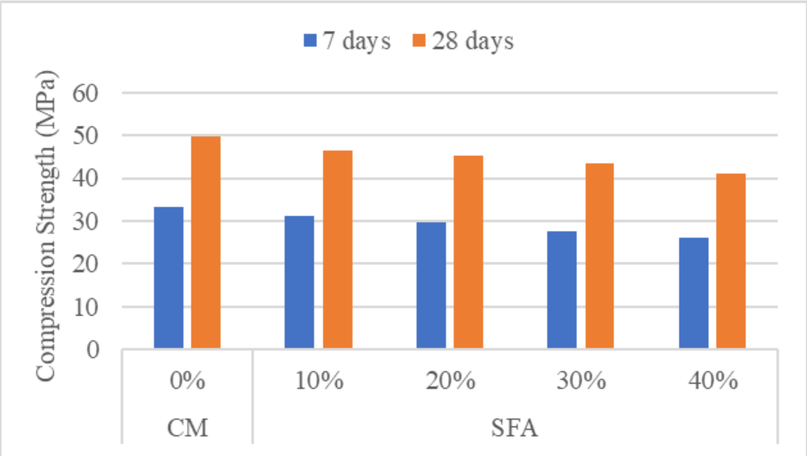

Fig. 3. Compressive strength for various SFA mixed concrete

B. Abrasion Resistance Strength

Illustrated in Figure 4 is the discernible impact of Sintered Fly Ash (SFA) on the abrasion depth of concrete subsequent to its establishment. Corresponding to the trends observed in compressive strength, the same resistance-to-abrasion tendencies were evident. Notably, the depth of abrasion exhibited a consistent rise with the augmentation of SFA content within the samples. Specifically, the increments in abrasion depth are quantified at 3.0%, 9.1%, 21.2%, and 27.3% for SFA replacement levels of 10%, 20%, 30%, and 40%, respectively

.

The rationale behind this progressive rise in the depth of abrasion can be attributed to the relatively lower hardness value inherent in SFA when compared to conventional aggregate. This difference in hardness contributes to the observed increased susceptibility of the SFA-incorporated concrete to abrasion, as it experiences greater wear and tear in response to external forces[8], [10], [16].

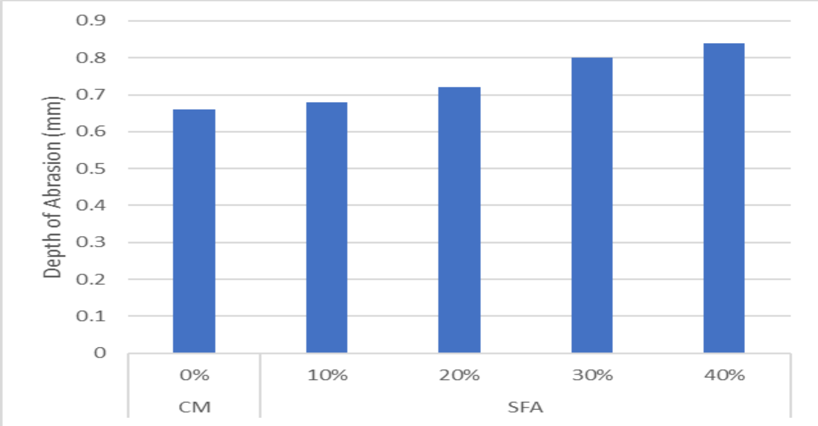

Fig. 4. DEPTH OF ABRASION FOR VARIOUS SFA MIXED CONCRETE

C. Impact Resistance Strength

Figure 5 vividly illustrates the outcomes of impact resistance strength testing conducted on concrete samples incorporating Sintered Fly Ash (SFA). As depicted, a distinct decrease in initial impact resistance values is evident, with figures dropping from the control mix's 1692.42 kJ to 1425.20 kJ, 1247.05 kJ, 1068.90 kJ, and 979.82 kJ for SFA replacement levels of 10%, 20%, 30%, and 40%, respectively. A similar trend is mirrored in the final impact resistance strength values. The control mix reaches a maximum final impact resistance of 2048.72 kJ, while the mixes with 10%, 20%, 30%, and 40% SFA replacements exhibit final impact resistance values of 1826.03 kJ, 1647.88 kJ, 1514.27 kJ, and 1291.58 kJ, respectively.

This observed reduction in impact resistance strength aligns with the trends seen in compressive strength. The underlying cause can be traced to the distinct characteristics of SFA, such as a weaker Interfacial Transition Zone (ITZ) and higher porosity. These features contribute to a compromised bridging function, allowing cracks to initiate more readily under external loads.

The concept of ductility, a material's capacity to withstand plastic deformations while subjected to loads, is commonly evaluated through tests measuring tensile and flexural strength. This concept's applicability to impact tests involves calculating the ratio of initial to final impact strength, termed the ductility ratio. Previous research has employed this metric to investigate the potential of modifying concrete behaviour from brittle to ductile under impact loading[11]. As demonstrated in Figure 6, the ductility index values for SFA concrete specimens demonstrate decreasing ductility and increasing brittleness with higher SFA content within the concrete[5]. This suggests that as SFA content increases, the material becomes less capable of absorbing energy through plastic deformations and is more prone to brittle fracture.

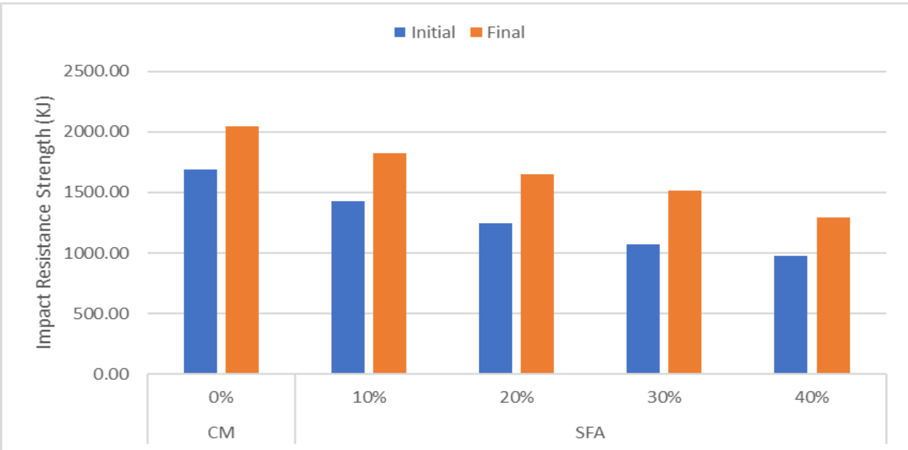

Fig. 4. IMPACT RESISTANCE STRENGTH FOR VARIOUS SFA MIXED CONCRETE

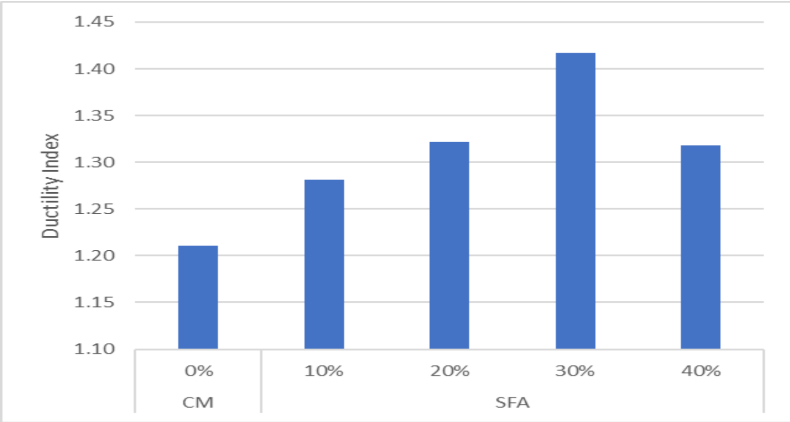

Fig. 5. DUCTILITY INDEX FOR VARIOUS SFA MIXED CONCRETE

IV. CONCLUSIONS

In conclusion, this comprehensive study sheds light on the intricate interplay between Sintered Fly Ash (SFA) and various mechanical properties of concrete pavement. The investigation underscores that while SFA incorporation leads to reductions in compressive strength, abrasion resistance, and impact resistance, the resulting concrete mixtures continue to meet or exceed required strength standards. These outcomes are attributed to the distinct characteristics of SFA, including its relatively lower crushing strength, hardness, and weaker Interfacial Transition Zone (ITZ), all of which contribute to the observed changes in mechanical behavior.

However, within these findings lies a potential avenue for innovation and sustainability in concrete pavement construction. The reduced environmental impact of utilizing SFA, a byproduct of coal combustion, combined with its capability to enhance permeability and thermal conductivity, introduces a paradigm shift towards more environmentally conscious infrastructure. While some mechanical properties may exhibit reductions, the performance still aligns with the requisite standards for many applications, thus suggesting a pragmatic compromise between mechanical robustness and sustainability.

The benefits of incorporating SFA in concrete pavement construction are far-reaching. By utilizing a waste material as a partial substitute for conventional aggregates, the environmental burden associated with aggregate extraction is diminished. This not only conserves natural resources but also reduces landfill waste. Additionally, the enhanced permeability and thermal conductivity brought about by SFA contribute to improved drainage and temperature management, which are vital factors in maintaining the durability and longevity of pavements.

In essence, the utilization of Sintered Fly Ash in concrete pavement presents a promising path forward, where a reduction in certain mechanical properties is outweighed by the environmental benefits and improved material behavior in terms of permeability and thermal conductivity. This study underscores the potential for a more sustainable approach to infrastructure development, setting the stage for a more environmentally conscious and innovative construction industry.

REFERENCES

[1] P. Somani and A. Gaur, "Evaluation and reduction of temperature stresses in concrete pavement by using phase changing material," *Mater. Today Proc.*, vol. 32, pp. 856–864, Apr. 2020, doi: 10.1016/j.matpr.2020.04.214.

[2] P. Somani and A. Gaur, "Inspection of Thermo-Mechanical Behavior on Sintered Fly Ash Aggregate in Pavement Quality Concrete," *Key Eng. Mater.*, vol. 951, pp. 167–172, Aug. 2023, doi: 10.4028/P-BZLZA9.

[3] L. A. Balan, B. R. Anupam, and S. Sharma, "Thermal and mechanical performance of cool concrete pavements containing waste glass," *Constr. Build. Mater.*, vol. 290, p. 123238, Jul. 2021, doi: 10.1016/J.CONBUILDMAT.2021.123238.

[4] P. Somani and A. Gaur, "Temperature sensitivity analysis on mechanical properties of phase changing material incorporated rigid pavement," *Mater. Today Proc.*, Aug. 2023, doi: 10.1016/J.MATPR.2023.07.362.

[5] P. Dhemla, P. Somani, R. K. Satankar, and B. L. Swami, "Mechanical and Microstructure Properties of Plain and Blended Cement Structural Lightweight Aggregate Concrete Using Sintered Fly Ash Aggregates," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1149, no. 1, 2023, doi: 10.1088/1755-1315/1149/1/012008.

[6] P. Dhemla, P. Somani, and B. . Swami, "Comparative analysis and performance of light weight concrete with varying water cement ratio using plain and blended cement," *Mater. Today Proc.*, Jul. 2023, doi: 10.1016/J.MATPR.2023.07.037.

[7] P. Sukontasukkul *et al.*, "Thermal properties of lightweight concrete incorporating high contents of phase change materials," *Constr. Build. Mater.*, vol. 207, pp. 431–439, 2019, doi: 10.1016/j.conbuildmat.2019.02.152.

[8] G. Balotiya, A. Gaur, P. Somani, and A. Sain, "Investigating mechanical and durability aspects of concrete incorporating Wollastonite and bottom ash," *Mater. Today Proc.*, Jun. 2023, doi: 10.1016/J.MATPR.2023.06.048.

[9] A. Kumar, P. Somani, A. Sain, and A. Gaur, "Enhancing thermal behaviour of concrete pavement by incorporating vermiculite," *Mater. Today Proc.*, Aug. 2023, doi: 10.1016/J.MATPR.2023.07.302.

[10] A. Kumar Mandrawalia and A. Gaur, "Compressive and sorptivity characteristic of concrete modified with wollastonite fibre and waste granite fines," *Mater. Today Proc.*, vol. 42, pp. 1012–1016, Jan. 2021, doi: 10.1016/J.MATPR.2020.12.005.

[11] P. Dhemla, B. L. Swami, and P. Somani, "Experimental Investigation of Light Weight Concrete Using Sintered Fly Ash Aggregates," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 795, no. 1, 2021, doi: 10.1088/1755-1315/795/1/012032.

[12] IS 516, "Method of Tests for Strength of Concrete," *Bur. Indian Stand.*, pp. 1–30, 1959.

[13] IS:1237, “Cement concrete flooring tiles - specification,” *Bur. Indian Stand.*, p. New Delhi,India, 2012.
[14] H. N. Marsh *et al.*, “Measurement of Properties of Fiber Reinforced Concrete.,” *Publ. SP - Am. Concr. Inst.*, vol. 89, no. Reapproved, pp. 433–439, 1984.
[15] K. J. Mun, “Development and tests of lightweight aggregate using sewage sludge for nonstructural concrete,” *Constr. Build. Mater.*, vol. 21, no. 7, pp. 1583–1588, Jul. 2007, doi: 10.1016/j.conbuildmat.2005.09.009.
[16] R. K. Goyal, V. Agarwal, R. Gupta, K. Rathore, and P. Somani, “Optimum utilization of ceramic tile waste for enhancing concrete properties,” *Mater. Today Proc.*, vol. 49, pp. 1769–1775, 2021, doi: 10.1016/j.matpr.2021.08.011.