Research Article

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Development of Self-compacting Geopolymer Concrete Paver Blocks Using Sustainable Materials for Medium Traffic Conditions

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ABSTRACT

Self-compacting geopolymer concrete (SCGC) pavers are developed using sustainable material sources to reduce environmental impacts. In this research, four SCGC mixes of Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Nano Silica (NS) were fabricated to enhance the performance. The mix design is 50 % FA and 50 % GGBS, with the NS dosage ranging from 0 to 3% at 1% intervals with a 1:2.5 ratio of sodium silicate to sodium hydroxide and a 14 M concentration of sodium hydroxide. The alkaline binder ratio was kept constant at 0.5, (54 kg/m^3) of water content and (9 kg/m^3) of superplasticizer. The SCGC paver blocks were evaluated for their mechanical properties, including compressive strength, splitting tensile strength, and flexural strength, along with water absorption characteristics after 7 and 28 days of ambient curing. The results show that adding nano-silica significantly improved the compressive strength by up to 43.44%, the splitting tensile strength by up to 44.68%, and the flexural strength by up to 43.39% after 28 days. In addition, water absorption decreased by up to 28.6% with increasing NS content, which can be attributed to improved density and reduced porosity. The SCGC pavers can be regarded as environmentally friendly and feasible for medium-traffic conditions where lower environmental impact is combined with higher performance.

Keywords: Self-compacting geopolymer concrete; Sustainable materials; Nano-silica; Paver blocks; Mechanical properties.

1. INTRODUCTION

Paver blocks rank among the more significant and very important components in urban infrastructure and have become a critical component of roadways, pavements, and other public space (Borghetti *et al.* 2024). Their module nature, strength, and ease of installation make them very appropriate for application in stations with medium vehicular and pedestrian traffic loads both on roadways and on pedestrian pathways (Lin *et al.* 2023). Such paver blocks should, therefore be able to keep up with moderately intense vehicular and pedestrian traffic and must, therefore have excellent mechanical properties and long-term durability (Majer *et al.* 2024). However, the traditional production of paver blocks often consumes Portland cement, which is an energy-intensive material with a high contribution to global carbon dioxide (CO_2) emission. In the construction industry, alternative materials are gaining increasing interest as a way to decrease environmental impact while still matching or surpassing similar conventional performance characteristics (Maheswaran *et al.* 2023). Currently, geopolymer concrete has gained widespread acceptance as a sustainable alternative to conventional concrete, replacing traditional cement binders with industrial by-products such as fly ash and ground granulated blast furnace slag (GGBS). Geopolymer concrete utilizes waste materials to offer a sustainable solution that significantly reduces the carbon footprint associated with construction materials without compromising strength or durability (Kanagaraj *et al.* 2024a). Apart from sustainability, workability is an important element in the efficient construction of paver blocks (Kiran *et al.* 2024). Self-compacting concrete (SCC) is a class of concrete that flows and consolidates under its own weight without the aid of mechanical vibration (Velumani and Venkatraman, 2024). This would enhance the workability of the mixture, reduce labor costs, and enhance the quality of the final product by reducing defects from inadequate compaction (Peng *et al.* 2024). Applied to geopolymer concrete, self-compacting geopolymer concrete (SCGC) combines geopolymer technological environmental benefits and practical self-compacting properties, qualifying it for mass production of paver blocks under medium traffic conditions (Bheel *et al.* 2024; Luo *et al.* 2023). Where the traffic is a bit high, it requires paver blocks to have good compressive and flexural strength considering its mechanical properties (Ahmed and Ibraheem, 2024). Compressive and flexural strengths ensure service loads for the blocks and prevent cracking as well as deterioration of the blocks (Shivaraj *et al.* 2024). Thus, the parameters concerning durability, including absorption of water, are also important because excessive absorption decreases strength and increases

susceptibility to environmental degradation (Fanijo *et al.* 2023). In areas exposed to freeze-thaw cycles and moisture, the restrictions on this promising element are higher (Jamshidi, 2024). Therefore, to ensure a long-term durability, low absorption of water is essential (Rathivarman *et al.* 2025; Choudhary *et al.* 2024). This study assesses the mechanical properties (compressive, split tensile strength and flexural strength) of SCGC paver blocks at 7 and 28 days, and water absorption at 28 days. This study uses a mix design with 50% FA, 50% GGBS, and NS from 0 to 3% at 1% intervals in the mix design, and a ratio of sodium silicate to sodium hydroxide is fixed at 1:2.5 and the concentration of sodium hydroxide at 14 M. Alkaline binder ratio was fixed at 0.5, with 12% water content and 2% superplasticizers.

2. MATERIALS AND METHODS

Fly ash (class F) was collected and used for the present research study project from the Tamil Nadu Coal-fired Thoothukudi power plant (Jeyaraj and Sankararajan, 2023). The specific gravity of the FA is 2.1. The GGBS was acquired from the JSW plant in Madurai (Pandiaraj and Sankararajan, 2024). It had a specific gravity of is 2.9. Nano silica (NS) with a specific gravity of 2.4 and particle size of 9 micrometers was used as an additive, purchased from Astra Chemicals, Chennai, India (Jindal and Sharma, 2020). The alkaline solution with a ratio of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as 1:2.5 with the specific gravities of 1.47 and 1.6 for NaOH and Na_2SiO_3, respectively. Coarse aggregate (12.5 mm size, 7.16 fineness modulus, and 2.83 specific gravity) and fine aggregate (Manufactured sand with a specific gravity of 2.73 and 2.65 fineness modulus) were uses in the study. In this research, the superplasticizer (MasterGlenium Sky 8233), a new generation polycarboxylic ether-based additive, supplied by Astra Chemicals in Chennai, with 1.08 relative density was used.

2.1. Mix Proportion

The mix designs as per the EFNARC guidelines were carried out for developing SCC was presented in Table 1 (Kanagaraj *et al.* 2024b). A total binder content of 450 kg/m^{3}with 50% of FA and 50% of GGBS and NS dosages varying from 0 to 3% at 1% intervals with a 1:2.5 ratio of Na_2SiO_3 to NaOH and with 14 M concentration of NaOH. The alkaline binder ratio was maintained constant at 0.5 throughout the study. Workability properties of SCGC, 54 kg/m^{3}of water content, and 9 kg/m^3 of superplasticizer were maintained throughout this study.

Table 1. Mix proportion of SCGC paver blocks

Mix ID	Mix Proportion kg/m^3								
	FA	GGBS	NS	Fine Aggregate	Coarse Aggregate	NaOH + Na_2SiO_3	Molarity	SP	EW
NS-0%	225	225	0	961.07	786.33	225	14	9	54
NS-1%	225	225	4.50	961.07	786.33	225	14	9	54
NS-2%	225	225	9	961.07	786.33	225	14	9	54
NS-3%	225	225	13.50	961.07	786.33	225	14	9	54

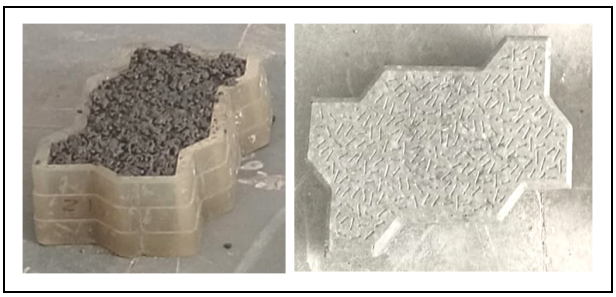


Fig. 1: Casting and curing process of paver blocks

2.2. Bleeding, Casting and Curing

The aggregates were dry-mixed for three minutes, after which the fine powder materials comprising GGBS and NS were added to the mixer. The alkaline activator solution along with MasterGlenium SKY 8233 superplasticizer and water were added. The entire mixture was blended for approximately five minutes until a homogeneous consistency was achieved. The mechanical behavior of the paver blocks was analyzed after ambient curing periods of 7 and 28 days. Fig. 1 shows the casting and curing process of paver blocks.

3. EXPERIMENTAL SECTION

3.1. Compressive Strength of Paver Blocks

The compressive strength of the paver blocks was determined by IS 15658:2006 (Nandi *et al.* 2024). This test was carried out on the paver block specimen by placing it between two steel bearing blocks in Compression Testing Machine (CTM). Care was taken to align the specimen properly so that uniform loading

could be provided during its testing. The loading rate was controlled to 15 MPa per minute up to the failure of the paver block. Fig. 2 shows the compression test of the paver blocks.



Fig. 2: Compression test

3.2. Split Tensile Strength Test of Paver Blocks

The splitting tensile strength of the paver blocks was determined in accordance with IS 15658:2006. The specimen was aligned along its longest breaking edge on the CTM as seen in Fig. 3. The specimen, at a controlled rate of 2.2 MPa per minute, was subjected to load until failure of the specimen occurred.



Fig. 3: Split tensile test

3.3. Flexural Strength Test of Paver Blocks

The flexural strength of the paver block was determined by IS 15658:2006 using the flexural testing machine in which the specimen was held as shown in Fig. 4 (Alagarsamy *et al.* 2024). The specimen was placed on two roller supports with load applied at the top of the block through a moving beam head. The load was applied continuously at the rate of 6 KN per minute until failure occurred.



Fig. 4: Flexural strength test

3.4. Water Absorption Test of Paver Blocks

Water absorption of paver block based on IS 15658:2006 consisted of the immersion of the specimen in water for about 24 hours, as shown in Fig. 5 (Alagarsamy *et al.* 2025). Specimens were then removed from the water, dried for 1 minute, and wiped to remove surface moisture. The weight of the wiped specimens was then recorded as Ws. The specimens were then oven-dried at 107°C for 24 hours. The weight of the paver block was then recorded and drying was continued until the weight loss became less than 0.2 percent. The final weight was recorded as W_d.

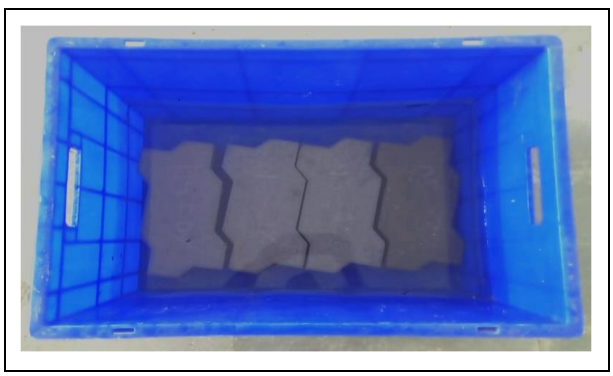


Fig. 5: Water absorption

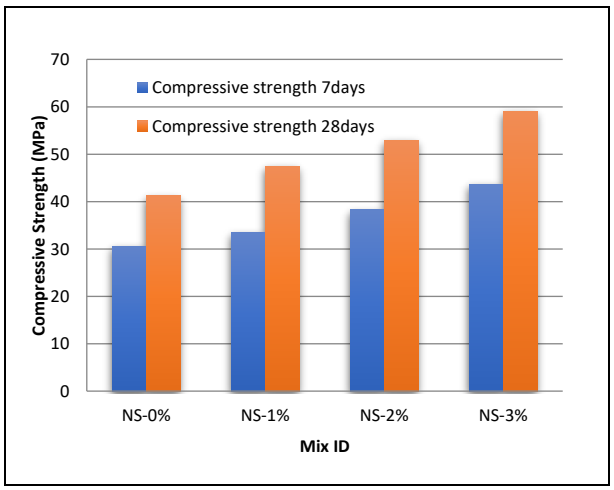


Fig. 6: Compressive strength of paver blocks

4. RESULT AND DISCUSSION

4.1. Compressive Strength of Paver Blocks

Fig. 6 shows the compressive strength of pavers after 7 and 28 days for different NS proportions of 0%, 1%, 2%, and 3%. Addition of NS substantially increases compressive strengths for the two curing time periods, with higher percentages showing significant differences. NS-1% shows a percentile increase of 9.15% within 7 days and 15.29% within 28 days compared to NS-0%. The compressive strength increases to 25.16% after 7 days and 28.39% after 28 days with the content of NS-2%. NS-3% increased the compressive strength on increasing the curing period (42.81% after 7 days and 43.44% after 28 days).

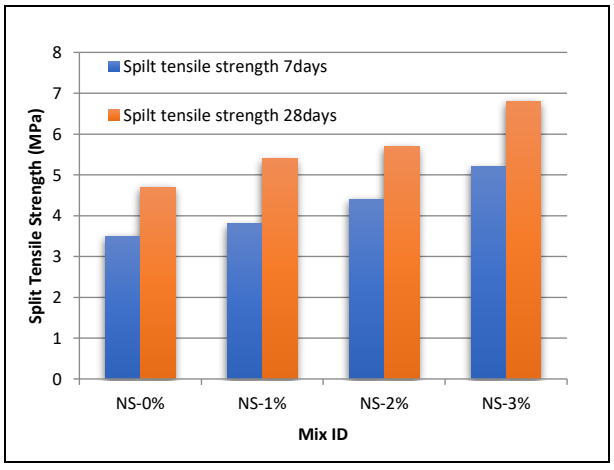


Fig. 7: Split tensile strength of paver blocks

4.2. Split Tensile Strength of Paver Blocks

Fig.7 shows the split tensile strength of paver blocks after 7 and 28 days for different NS contents (NS-0% to NS-3%). After 7 days of curing, the tensile strength for the NS-1% mix increased by 8.57% compared to that of NS-0%, the tensile strength for the NS-2% mix increased by 25.71%, and that of the NS-3% mix improved by 48.57%. After 28 days, the NS-1%, NS-2% and NS-3% mixes showed an increase of 14.89%, 21.27% and 44.68%, respectively, compared to the NS-0%. These results indicate that NS increases both early and long-term tensile strength, with the NS-3% mix showing the most significant improvement.

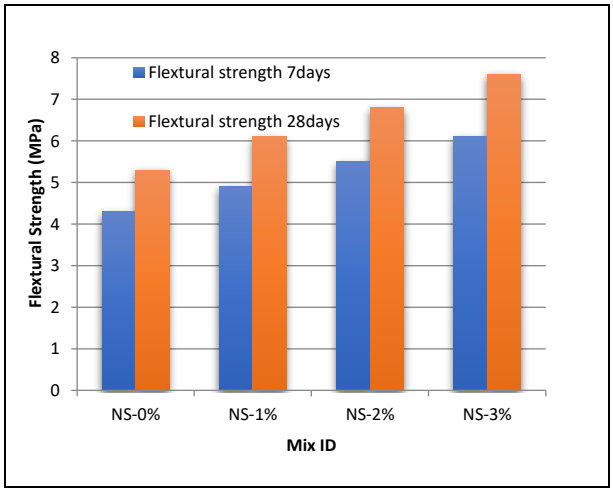


Fig. 8: Flexural strength of the paver blocks

4.3. Flexural Strength of Paver Blocks

Fig. 8 presents the flexural strength of the pavers after 7 and 28 days for different mix ratios NS-0% to NS-3%. At the age of 7 days, the NS-1% mix increased the flexural strength by 13.95% compared to the NS-0%. Mixes NS-2% and NS-3% also performed well with 27.90% and 41.86%, respectively. At the end of 28 days, in comparison to NS-0%, NS-1%, NS-2%, and NS-3% showed rises of 15.09%, 28.30%, and 43.39%, respectively. The recorded data show that the use of NS improved the flexural strength both during the early and long periods. In this respect, significant improvement was recorded for NS-3%.

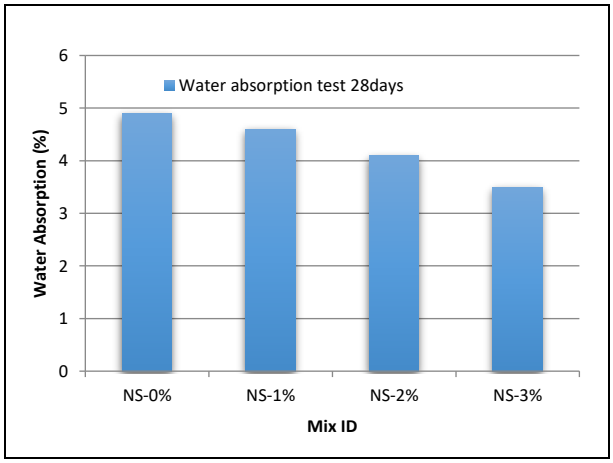


Fig. 9: Water absorption test of paver blocks

4.4. Water Absorption Test of Paver Blocks

Fig. 9 shows the water absorption of the pavers for NS-0% to NS-3%. The mixture NS-0% had the highest value of water absorption which was 4.9%. The addition of NS-1% reduced the water absorption by 6.1%, resulting in an absorption rate of 4.6%. The addition of NS-2% reduced the water absorption to 4.1%, which is 10.8% lower than that of the mix with NS-0%. The mixture with the highest amount of NS-3% absorbed only 3.5%. This represents a reduction of 28.6% compared to the mixture with NS-0%. This reduction in absorption at higher proportions of the additive is related to better compaction and density, reducing porosity and capillary action.

5. CONCLUSION

Incorporation of NS-3% to SCGC paver blocks shows significant improvement in their mechanical strength and durability. There is a phenomenal improvement of 43.44% in compressive strength, 44.68% increase in split tensile strength, and 43.39% increase in flexural strength after 28 days when compared to the conventional control mix. Apart from the mechanical properties, the mixture NS-3% shows significant reduction in water absorption by 28.6% as compared to the control, which corresponds with high reduction in porosity. This results in a denser material and a matrix that is well cemented. Sustainability in SCGC paver blocks can be achieved through the use of FA, GGBS, and NS as binders. Indeed, they offer a greener alternative to the traditional Portland cement. Furthermore, these industrial waste products not only reduce waste and energy but also present low emissions of CO_2. NS-3% SCGC paver blocks have been found to possess superior mechanical properties along with lower water absorption and superior durability for applications like walkways and residential driveways that receive moderate traffic volumes.

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CONFLICTS OF INTEREST

The authors have no conflict of interest to declare.

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