Effects of nanosilica to improve the mechanical, electrical and durability properties of fiber-reinforced high-volume processed sugarcane bagasse ash cement mortar

Ramasamy Gopalakrishnan1*, Ravi Kaveri1, A. John Kirubahar1
1Department of Physics and Nanotechnology, SRM Institute of Science and Technology, Kattankulathur- 603203, Tamilnadu, India
e_mail: gopalakr@srmist.edu.in

ABSTRACT

Nanosilica (NS) has attracted wide variety of usage as cement ingredients. While many other studies have focused on early cement hydration and hardening properties, there is less data available on the impact of NS on the behavior of fiber-reinforced high-volume sugarcane bagasse cement mortar (HVSCBAM). The effects of NS on the fiber-reinforced durability of HVSCBAM, having the properties of sugarcane bagasse ash/binder in an average of 50% by weight, have been presented in detail in this study. Four NS/binder weight ratio dosages of 0%, 0.5%, 1.0% and 1.5% of and another four total PVA fiber/volume ratio dosages of 0%, 0.2%, 0.5% and 1.0% were used. Compared to 0.2-1 vol.% of PVA fiber–reinforced HVSCBAM, the 1.5 wt.% of NS would enhance the compressive strength further. Various reports on mineralogy and microstructure have demonstrated that NS facilitates fiber/matrix bonding. These conclusions provide an insight into the pozzolanic materials of cement that are used in a large volume in the designs and applications of nanoparticles.

Keywords: Nanosilica, pozzolanic activity, electrical resistivity, durability, sugarcane bagasse ash.

1 Introduction

Construction zone is considered as one of the keystones of universal economic growth, with the cost of making a somewhat greater commitment to electricity and building materials. The cement industry has shown important environment-friendly effect on the processing of nonrenewable
materials (calcium and clay) and made commendable progress in absorbing high carbon dioxide emissions. The production of 1 tonne of Portland cement (PC) emits 0.94 tonnes of anthropomorphic CO$_2$ and absorbs more than 1.5 tonnes of consumables and 2.93-6.28 GJ of thermal energy from 65 to 141 kWh of electricity [2, 3]. During the manufacturing of PC, the sustainability of the environment is highly threatened with high energy usage and raw materials, and massive volumes of CO$_2$ emissions. In order to minimize these serious complications, PCs should be blended with pozzolanic materials [4, 5]. In concrete, high amounts of by-products that generated in the manufacturing process may be used as additional mineral, which can be regarded as additional supplementary cementitious materials (SCMs), having proper quality control. The application of these materials provides significant environmental and economic benefits such as reduction in the emissions of contaminating gases [7, 8] and decrease in the quantity of usual resources [4] that are resultant from the processing of Portland cement.

In many countries, the quantity of agricultural waste has been rising rapidly creating negative impacts on the environment. In addition, a significant of this portion of this waste is contributed by fruit by-products. Considering the effects of resource recycling/reuse on existing social interests for ecological sustainability, identifying practical benefits for producing by-products is one of the efficient ways to take care of the environment and control energy. Natural fibers are composed of cellulose, hemicellulose and lignin, which are easily available, recoverable and sustainable. Unlike synthetic fibers, natural substances are biodegradable, inexpensive, low density, nontoxic, globally accessible, energy efficient and eco-friendly. Brittle materials made from natural substances have shown superior mechanical and economic viability compared to the ones made from synthetic fibers. Moreover, natural fibers have superior mechanical properties, such as high strength and
durability of cement matrices. Therefore for high performance, reinforced cement composites, these fibers fulfill ecological and sustainable requirements.

Sugarcane bagasse ash (SCBA) can be a good example here. This waste material is produced after the burning of bagasse in the sulco-alcohol field after juice is released from sugarcane [9]. It is estimated that 24 kg, or nearly 4 million tonnes, of SCBA, can be acquired through the burning of each tonne of SCB [10, 11]. The final disposal of this waste is carried out in landfills [12], creating many economic and environmental problems. As a result, in recent years, several investigators have suggested the use of SCBAs as SCMs in the countries with the low availability of PC-based compounds [13] as SCBA is made up of amorphous or crystalline silica (SiO$_2$) [14], which enhances its capacity to add minerals to cement compounds [15-18]. In addition to that, using SCBA as SCMs can have lesser impact on environment as clinkers are not used, which helps in reduction in CO$_2$ emissions in the environment as described [19, 20].

Previous research has shown that Portland cement may have been replaced by SCBA to make standard concrete [20-28] and mortar [29, 30]. Cordeiro et al. [16] also concluded that in certain conditions of mortar, the inclusion of SCBA helps to enhance mechanical strength. Castaldelli et al. [31] have shown that SCBA treatment improves mechanical and engineering properties, by adding pozzolanic materials to high levels of PC replacement (25% and 30%). Jiménez-Quero et al. [30] studied the rheological properties of SCBA and fly ash (FA) cement paste. It has been noted that because of a decrease in yield strain, the associated use of these supplements improves the efficiency of pastes.

At early ages, the combination of SCBA and NS accelerates the cement hydration and enhances the durability and compressive strength of cement mortar in the medium- and long-term
curing period. These new materials can be used as a result of interactions between substances in ternary compounds, where individual defects of each product can be compensated. But this type of investigation is still very limited and there is a need to define the gaps in the combined use of NS, PVA and SCBA cement materials and in OPC. The combined treatment, with its physical and/or chemical effects, of NS, PVA and SCBA aims to enhance the properties of OPC. However, the purpose of this study is to improve the environmental performance of the construction sector by proposing alternative methods of agriculture wastes. In this study, a series of experiments were implemented to measure the effect of NS on PVA fiber–reinforced HVSCAM with 50% weight of sugarcane bagasse ash. Four NS/binder ratings of 0%, 0.5%, 1.0% and 1.5% and four volumes of PVA fiber (0%, 0.2%, 0.5% and 1.0%) were used. X-ray diffraction and scanning electron microscopy define hydration products and the morphology of cement mortar.

2. Materials and methods

2.1 Materials

The 53-grade, ordinary Portland cement (OPC) [32] along with raw SCBs that were collected from Dharani Sugars Limited, Vasudevanallur, Tirunelveli district, Tamil Nadu, India, was used in this study. In the production of electricity in the parenting industry, dried bagasse is heated in the oven at temperatures (600°C to 700°C) depending on the humidity of the bagasse. The experiments performed in this study were first grounded for 45 minutes by a ball mill. The ground ash is then burned in a furnace at 400°C for 4 hours. About 85% of raw SCBA particles were passed through a size of 40 μm to reduce their particle size [21]. The NS (VK-SP30) is a commercial product provided by Adinath Industries Co. Ltd. (Rajasthan, India). The report on NS powder provided by the supplier is showed in Table 1. To achieve the optimal cement flow and better distribution of
nanoparticles, superplasticizer (ADVA Cast 207) is used. The chemical composition of OPC and PSCBA is given in Table 2. Raw white PVA fibers were supplied by India Indo Globe Tex Co., Ltd. The physical properties of raw white PVA fibers are given in Table 3. In this study, the fine aggregate used for mortar is in the range of 155 μm to 850 μm in size with a specific gravity of 2,725 [33] with a rate of water absorption of 2.043% and a fine modulus of 4,507 [34].

2.2 Specimen preparation and test methods

2.2.1 Mixing procedures and mix proportions

Four sample series were conducted to measure the result of NS/PVA on the mechanical and durability properties of HVPSCBAM. The ratio of the mixture is summarized in Table 4, in which 50% of the cement replaced by PSCBA is considered to be the control mixture. The mix ID (Table 4) shows two information blocks: the first block shows the NS content at percentage of binding load, while the second block shows the PVA fibers in the mortar supplements. The ratio of water to binder for a mixture of different NS and PVA was set to 0.40, but the amount of superplasticizer was determined to ensure comparable workability. The samples have been prepared for the following steps: type I cement, PSCBA, NS, sand, water, superplasticizer and PVA fiber weighting. (ii) Dry the cement, SCBA and sand in a mortar mixer for 2 minutes. (iii) Then for another 3 minutes of mixing, apply NS-SP suspension to the dry mixture. (iv) To complete the uniform fiber distribution, mix the PVA fiber into the mortar and stir it for another 3 minutes. (v) Transmit samples in steel molds and vibrate them for about 2 minutes on vibration table. (vi) Cover the sample with a polyethylene sheet to prevent moisture loss at room temperature (24 hours before demolding). (vii) The demolished samples were cured at room temperature at 95% ± 5% RH and 25°C ± 2°C for 28 days and recovered until reviewed at 25°C ± 2°C air at 28 days of age [35].

2.2.2 Compressive strength test
According to ASTM-C39 [36], the compressive strength of NS/PVA specimens was calculated at 7 and 28 days in 50×50×50-mm cubes. A 1000-kN universal test machine was used to calculate the compressive strength of the sample. Each sample was placed on a test machine and before the sample failed, a load of 0.05 N/mm²/s was applied. The test machine produced high pressure when the specimen failed and values were recorded. In a compressive strength test, three specimens were tested and the results were averaged.

2.2.3 Transport tests

To examine the absorption capacity of mortar samples by PSCBA, PVA and nanosilica, there are various methods. Water absorption was tested according to BS 1881-Part 122 [37]. Cubic specimens dried for 14 days at 45°C to achieve a consistent weight. The specimens were then immersed in water for 0.5, 1, 24, 72 and 168 hours to measure the weight difference. This method measures the water absorption that occurs in the depths. After immersion, these small pieces were kept in the oven. Alternatively, using nonfilling mortar specimens, capillary absorption is measured. The sample is kept close to the needle fluid during this process. The constant flow state of capillary absorption was calculated by water absorption. The study was performed to assess capillary water absorption as per BS EN 480-5 within 7 and 28 days of capillary absorption testing for PSCBA and NS/PVA specimens [38]. Cubic specimens of 50 mm are oven-dried for 10 days at 45°C ± 5°C. Then they are immersed in water at a depth of 3 ± 1 mm. To prevent water ingress, some substances were covered with a waterproof film. The weight of the suspended water was measured at 3, 6, 24 and 72 hours, respectively.

2.2.4 Rapid chloride permeability test

According to the standard ASTM C1202 [39], the total charge is determined by passing the specimen at 60 V for 6 hours with a sample of cylinder mortar with a diameter of 100 mm and a
height of 50 mm for 28 days. Each test result was obtained by measuring an average of three specimens.

2.2.5 Electrical resistivity test

Using the four-probe method, the electrical resistance of the fiber-reinforced NS mortar sample was measured. For power supply, direct current (DC) was supplied. A DC ammeter and a voltmeter were used to test the flow of current (I) between two external electrodes and the power (U) between two internal electrodes, respectively. According to Ohm's law \( R = \frac{V}{I} \), the \( R \) resistance of fiber-reinforced NS mortar specimens was calculated. Electrical resistance of fiber-reinforced NS mortar is measured according to the following equation:

\[
\rho = \frac{RA}{l}
\]  

(1)

where \( \rho \) is the electrical resistivity (\( \Omega \) cm) of mortar, \( R \) is the electrical resistance (\( \Omega \)) of mortar, \( A \) is the cross-sectional area (\( \text{cm}^2 \)) of the mortar, and \( l \) is the length between the internal electrodes (cm) [40].

2.2.6 X-ray diffraction study (XRD)

After 28 days of treatment, the mortar sample was calculated using the BRUKER USA D8 Advance, Davinci method using CuK\( \alpha \) radiation (1.5418 Å). A range of \( 10^\circ < \theta < 80^\circ \) with steps of 0.0170\( ^\circ \) was investigated for powder diffraction, by identifying the peaks achieved using "PEAk search" progress and software-based search matches (Xpert-Highscore plus).

2.2.7 Scanning electron microscopy (SEM)

SEM analysis is a method used to evaluate and determine the characteristic of microstructure of the solid sample. Morphological features of various samples tested by the FEI Quanta FEG 200-high-resolution scanning electron microscope (HRSEM) operating system.
3. Results and discussion

3.1. Compressive strength

Figure 1 shows the effects of the compressive strength found on various systems, including NS and PVA after 7 and 28 days of curing. All NS compounds from this figure showed higher compressive strength than the control sample. The NS 0.5/PVA, NS 1.0/PVA and NS 1.5/PVA mixes showed the compressive strength of 46.4, 47.5 and 48.2 MPa for 28 days. It is 34.8%, 38% and 40.1% greater than the control mix. The compressive strength gain can be attributed not only to the use of nano-SiO$_2$ as a complement to stabilize microstructure formation but also as an activator to promote pozzolanic reactions, thereby accelerating the hydration process and creating a denser microstructure that enhances strength formation. All incorporated NS/PVA systems have higher compressive strength than NS mortar. The compressive strength has grown up by about 48% for each mix when cement-based materials alter PVA fiber coupling to NS. The NS1.5/PVA1.0 composite showed a maximum compressive strength of 65.4 MPa, which is 90% more than the control mix. NS/PVA are added to cement mixing, which stimulates the process of nucleation, growth and separation of hydration products, improving hydration rate and crystal stability, and thereby increasing the mechanical strength of cement materials.

3.2. Transport properties

Water absorption and capillary absorption of nanosilica and PVA samples containing PSCBA mortar were assessed from time to time to examine the transport performance. In essence, the performance of nanosilica was stronger than PSCBA. Increasing the curing time and the amounts of nanoparticles, as noted in Fig. 2, will lead to a reduction in gel pores due to excessive closure and fulfillment of nanomaterial effects. Water absorption rate is reduced by the addition of NS
1.5% in the surface area of nanosilica. The results show that with the use of nanosilica and PSCBA, the percentage of absorption and rate of capillary absorption are reduced. The results of the capillary absorption test for 28 days at different times are shown in Fig. 3. All water absorption in the mixture is reduced in both mixes compared to the control sample. The addition of nanosilica significantly reduced the amount of capillary absorption in specimens at 28 days of age due to its very high surface area. By incorporating a large amount of nanosilica, capillary absorption is enhanced by reducing gel pores.

In combination with PVA, a 28-day capillary absorption test reduced water absorption in some way. The addition of PVA from 0.2% to 1% has resulted in a significant loss of capillary absorption, which is an increase in gel properties. It should be noted that the mixtures of PVA/NS have a significant reduction compared to nanosilica mixtures alone within 28 days. Significant reduction in capillary absorption tests by increasing the content of NS/PVA indicates less gel pores. Ternary specimens showed better output compared to other mixes. NS 1.5/PVA1.0 had a significant decrease in capillary absorption for 28 days among ternary compounds, which were 37.5% lower than the control mortar. The findings showed that the effects of water absorption were significantly correlated with the effects of compressive strength. The waterproofing effects of the SCBA on mortar become more clear after increasing the levels of NS/PVA replacement.

3.3. Rapid chloride permeability test

In fact, to measure the resistance of chloride ion to concrete/mortar at home and abroad, the rapid chloride permeability testing is performed. This method tests the penetration of samples into chloride ions rather than water. However by measuring the charge passed in 6 hours, the strength
of the concrete/mortar can be explained well. The smaller the charge is transferred from the concrete samples, the greater the size, the less connected closure and the larger the size.

For all mortar samples, the results of a rapid chloride penetration test are shown in Fig. 4. It may be observed that the more amounts of NS are incorporated into the mortar samples containing NS, the greater the number of transfers by the samples will be. In particular, the charge mixed with the sample and 1.5% NS was greater than that of the nanomaterials in the control specimen. It is possible to find the same thing in NS/PVA systems. Moreover, it was noted that in all systems, a 6-hour charge transferred from mortar samples mixed with NS 1.5/PVA1.0 was the largest. According to RCPT test results, resistance to chloride ion corrosion of cement-based materials can be strengthened by the use of 1.5% nanomaterials and 1.0% PVA mix.

3.4. Electrical resistivity

Electrical resistivity is the measurement of the electrical resistance caused by the movement of ions in the cement mortar. The graphical representation of the electrical resistivity values of control, NS and NS/PVA is shown in Fig. 5. At 28 days, the electrical resistivity values for the control mix were 7.2 K Ω cm. However in the case of NS 1.5/PVA1.0.0, maximum improvements in electrical resistivity have been reported. At 28 days, the rise in values compared to control was 37.3%. For both of the mixes, improvements in electrical resistivity values have been noticed as compared to the control sample, indicating greater resistance to the ion flow through the cement mortar due to better formation of hydration products during secondary pozzolanic reaction. This refining of the pore structure contributes to the blockage of pathways, which is important in the cement mortar for ionic conduction. The findings are also urged to be in good accordance with mechanical compressive strength.

3.5. Microstructure
The fiber-reinforced PSCBAM nanosilica microstructure as analyzed by scanning electron microscopy (SEM) at a period of 28 days is shown in Fig. 6. The mechanical, electrical and durability characteristics are determined by the microstructure and are specified by the SEM micrographs. Figure 6a shows that reference mortar (NS0/PVA0) will detect a large proportion of PSCBA grains with a smooth surface. A significant number of the SCBA particles covered by the hydration products (aggressive surface) are shown in the mortar at 1.0 wt.% NS (NS1.0/PVA0 in Fig. 6b), indicating the filler effect of NS on hydration of systems—SCBA-cement mortar. Figure 6c–e shows NS on PVA/SCBAM microstructure. With regard to durability properties, it can be concluded from the micrographs that at 28 days, the pore structure of the mixtures with NS1.0/PVA0.5 becomes denser and more packed. The pores become smaller and can cause less water absorption, capillary absorption and penetration of Cl-ion and better electrical resistivity. Regarding the effect of microstructure on transport properties, Beigi et al. [41] reported that the reduction in penetration of chloride ion happens because of high pozzolanic activity, which facilitates the reaction between nanosilica and calcium hydroxide that compacts it to calcium silicate hydrate. This compaction could build and reinforce the mortar microstructure against the penetration of the chloride ion. The pozzolanic effects of PSCBA, NS and PVA, the composite mortar reactions lead to the highest level and the microstructure reaction products show crystalline and, as shown in Fig. 6c (PVA0.5/NS1.0) will achieve an even denser pore structure. The effect of the compressive strength could be defined by this developmental tendency of the pore structure.

As shown in Fig. 6d (NS1.5/PVA0.5) and 6e (NS 1.5/PVA1.0), it is possible to view a layer of small CSH phases that provide good fiber/matrix binding in the mortar. The improved strength of the cement matrix in combination with NS/PVA has also been referred to as the action of nano-SiO2 and PVA particles filling the gaps of CSH gel formation and acting as the nucleus
for binding CSH gel particles, resulting in binding matrix bonding, and expecting to increase the long-term mechanical properties and strength of the cement matrix.

3.6. X-ray diffraction

An X-ray diffraction study was performed with an appropriate criterion for the evaluation of the pozzolanic activity of nanoparticles. Figure 7 shows the XRD pattern of control, nanosilica mixture (NS 1.5/PVA0) and nanosilica/PVA (NS 1.5/PVA1.0) samples at the age of 28 days. The calcium silicate hydrate process could be clarified by a peak of $2\theta = 29^\circ$ in Fig. 7a. The peaks described in the calcium hydroxide process at $2\theta = 28^\circ$, $C_3S$ at $2\theta = 38^\circ$, $C_2S$ at $2\theta = 41^\circ$, $C_3A$ at $2\theta = 50^\circ$ and $C_4AF$ at $2\theta = 60^\circ$ [42]. As noted in Fig. 7b, application of the nanosilica and cement matrix decreased the intensity of the peaks identifiable for calcium hydroxide formation and increased the intensity of the peaks identifiable for calcium silicate hydrate formation. This result shows that pozzolanic activity decreased the formation of calcium hydroxide in the cement samples. The addition of PVA to nanosilica leads to a greater reduction in the formation of calcium hydroxide and an increase in the amount of calcium silicate hydrate, resulting in a stronger uniform, lightweight and homogeneous cement paste matrix and transmission zone (Fig. 7c). The results of X-ray diffraction analysis could point out the improved compressive strength and low water absorption of nanosilica and PVA mixtures well.

3.7. Discussion

The nuclei of NS and PVA will stimulate cement hydration and increase the compressive strength in the cement hydration phase. From Fig. 1, the compressive strength of nanosilica containing PVA fiber was greater than that of the control. With the incorporation of PVA/NS, the filling properties of PVA and the pozzolanic effect of NS can generate the formation of CSH and cement
matrix form more compactly. From Fig. 7c, it can be assumed that additional hydration substances did not occur with the inclusion of NS and PVA. From Fig. 7c, it has been understood that the content of calcium hydroxide (portlandite) is decreased in the matrix containing NS/PVA and simultaneously the CSH content is improved compared to the control mortar, because of pozzolanic activity of nanomaterials. The pozzolanic activity is caused by the reaction of NS and PSCBA with calcium hydroxide at the formation of calcium silicate hydrate gel. Continuous formation of CSH has improved system density and led to better compressive strength. In this study, rapid chloride permeability, electrical resistivity and capillary water absorption were used and evaluate the durability of the mortar. This study has presented that the strength of single-doped PVA and NS systems and compounds’ cement matrix were stronger than those of the control mix. Among them, the mixtures of NS 1.5/PVA0.2, NS1.5/PVA0.5 and NS 1.5/PVA1.0 mixtures were shown to have the best performance.

4 Conclusions

The effects of nanosilica and hybrid fibers on HVPSCBAM structures are discussed in this paper. The following conclusions are made from the results discussed earlier:

1. It was concluded that at both 7 and 28 days of age, the incorporation of NS from 0.5% to 1.5% witnessed a consistent increase in compressive strength in comparison to the control mix. Better performance at both 7 and 28 days of age was obtained by combining NS and PVA. The addition of NS and PVA led to the development at the ages of 7 and 28 days of increased CSH gel. At 28 days, the NS 1.5/PVA1.0 mix pointed to the highest compressive strength.
2. Results obtained from water absorption and capillary tests have shown that the incorporation of SCBA based on nanosilica/PVA has improved the efficiency of the mortar in transport conditions. However, due to the strong durability of filling of nanomaterials, nanosilica/PVA has been found to be more effective as it reduces the pores of specimens.

3. Through the use of nanoparticles, higher resistance was carried out against the penetration of chloride ion. By using NS/PVA, the permeability values of chloride were decreased. With the exception of control, all blends were evaluated in the moderate permeability range of chloride.

4. As per electrical resistivity results, NS mixtures revealed improved electrical resistivity at 28 days. However, nanosilica/PVA found that the electrical resistance of the mortar was effective.

5. In SEM images of nanosilica, a denser microstructure was noted, with the mixture of NS/PVA showing the most change. The formation of the growing CSH gel can be referred to as the densification of the microstructure.

6. The XRD study showed a substantial increase in the CSH peak and a dramatic decrease in the CH peak, in nanosilica/PVA content at 28 days.

7. The use of NS/PVA has shown possible capabilities to increase the durability of HVPSCBA composites.

8. The use of improved high-performance mortars (PSCBA, PVA and nanosilica materials) would lead to environmental (greenhouse gas reduction), mechanical (improved strength and durability) and industrial (cost reduction over the long term) benefits.
This research shows that the use of NS/PVA in the industry has shown the great potential to increase the durability characteristics of HVPSCBAM. It has been noted that the optimal quantity of NS/PVA is not generalized by different studies performed by researchers, and this needs to be further investigated. Working out a homogeneous dispersion of nanosilica in the cement matrix is the greatest problem. Several researchers have proposed alternative methods for achieving a homogeneous distribution of nanosilica, such as the sonication technique. Nevertheless, very little research on the use of nanosilica in conjunction with alternative mineral admixtures and fibers is available. In the future, further investigation on optimization and statistical correlations of the durability properties of mortar mixing NS/PVA is possible.

Compliance with ethical standards

Conflict of interest The author declares no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval Objectivity and transparency are valid in research, and accepted ethical and professional conduct principles have been followed.

References

1. R.J. Galán-Arboledas, J. Álvarez de Diego, M. Dondi, S. Bueno, J. Clean. Prod. 142, 1778 (2017)
2. F. Pacheco-Torgal, Renew. Sustain. Energy Rev. 71, 618 (2017).
3. F.N. Stafford, F. Raupp-Pereira, J.A. Labrincha, D. Hotza, J. Clean. Prod., 137, 1293 (2016)
4. D.O. Koteng, C.T. Chen, Const. Build. Mater. 84, 294 (2015)
5. E.R. Grist, K.A. Paine, A. Heath, J. Norman, H. Pinder, J. Clean. Prod. 93, 26 (2015)
6. C. Shi, A.F. Jiménez, A. Palomo, Cem. Concr. Res. 41,750 (2011)
7. M.F. Alnahhal, U.J. Alengaram, M.Z. Jumaat, F. Abutaha, M.A. Alqedra, R.R. Nayaka, J. Clean. Prod. 203, 822 (2018)
8. S. Praveenkumar, G. Sankarasubramanian, S. Sindh, Const. Build. Mater. 238, 117691 (2020)
9. S.A. Zareei, F. Ameri, N. Bahrami, Const. Build. Mater. 184, 258 (2018)
10. K. Hofsetz, M.A. Silva, Biomass Bioenergy, 46, 564 (2012)
11. J.P. Moretti, A. Sales, F.C.R. Almeida, M.A.M. Rezende, P.P. Grombóni, Const. Build. Mater. 113, 317 (2016)
12. G.C. Cordeiro, P.V. Andreão, L.M. Tavares, Helion, 5, e02566 (2019)
13. E.M.R. Fairbairn, B.B. Americano, G.C. Cordeiro, T.P. Paula, R.D. Toledo Filho, M.M. Silvoso, J. Environ. Manag. 91, 1864 (2010)
14. G.C. Cordeiro, K.E. Kürtsis, Cem. Concr. Res. 97, 41 (2017)
15. M. Frías, E. Villar-Cociña, E. Valencia-Morales, Waste Manag. 27, 533 (2007)
16. G.C. Cordeiro, R.D. Toledo Filho, L.M. Tavares, E.M.R. Fairbairn, Cem. Concr. Compos. 30, 410 (2008)
17. M.A.S. Anjos, A.E. Martinelli, D.M.A. Melo, T. Renovato, P.D.P. Souza, J.C. Freitas, J. Petrol. Sci. Eng. 109, 291 (2013)
18. M.A.S. Anjos, A.E. Martinelli, D.M.A. Melo, Mater. Sci. Eng. 529, 49 (2011)
19. Marcos A.S. Anjos, Tomaz R. Araújo, Ruan L.S. Ferreira, Evilane C. Farias, Antonio E. Martinelli. J. Build. Engg. 32, 101694 (2020)
20. R.A. Berenguer, A.P.B. Capraro, M.H.F. de Medeiros, A.M.P. Carneiro, R.A. De Oliveira, J. Environ. Chem. Eng., 8, 103655 (2020)
21. N. Chuslip, C. Jaturapitakkul, K. Kiattikomol, Const. Build. Mater. 23, 3523 (2009)
22. G.V.P. Bhagath Singh, K.V.L. Subramaniam, J. Clean. Prod. 239, 118024 (2019)
23. J.R. Moreira, V. Romeiro, S. Fuss, F. Kraxner, S.A. Pacca, Appl. Energy, 179, 55 (2016)
24. S. Luo, S. Chen, S. Chen, L. Zhuang, N. Ma, T. Xu, Q. Li, X. Hou, J. Environ. Manag. 168, 142 (2016)
25. K. Thangapandi, R. Anuradha, P.O. Awoyera, Silicon (2020)
26. M.-H. Zhang, J. Islam, Const. Build. Mater. 29, 573 (2012)
27. Q. Li, X. Gao, S. Xu, Cem. Concr. Comp. 72, 201 (2016)
28. G. Li, Cem. Concr. Res. 34 (6), 1043 (2004)
29. P. Hou, K. Wang, J. Qian, S. Kawashima, D. Kong, S.P. Shah, Cem. Concr. Comp. 34 (10), 1095 (2012)
30. V.G. Jiménez-Quero, F.M. León-Martínez, P. Montes-García, C. Gaona-Tiburcio, J.G. Chacón-Nava, Const. Build. Mater. 40, 691 (2013)
31. V.N. Castaldelli, J.C.B. Moraes, J.L. Akasaki, J.L.P. Melges, J. Monzó, M.V. Borrachero, L. Soriano, J. Payá, M.M. Tashima, Fuel, 174, 307 (2016)
32. Indian Standard 12269 – 1993. Specifications for 53 grade ordinary Portland cement.
First reprint, Bureau of Indian Standards, New Delhi, 1993.

33. Indian Standard 2386 – 1997. Method of test for aggregates for concrete, Part 3 – Specific gravity, density, voids, absorption and bulking, Eighth print, Bureau of Indian Standards, New Delhi, 1997.

34. Indian Standard 2386 – 1997. Method of test for aggregates for concrete, Part 1 – Particle size and shape, Eleventh print, Bureau of Indian Standards, New Delhi, 1997.

35. Jing Yu, Min Zhang, Gengying Li, Jiao Meng, Christopher K.Y. Leung. Const. Build. Mater. 239, 117853 (2020)

36. ASTM C39/C39M-18 2018 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

37. BS 1881 1983 Method for Determination of Water Absorption of Concrete; British Standard Institution (London) Part 122

38. BS EN 480-5, 2005. Admixtures for Concrete, Mortar and Grout. Test Methods. Determination of Capillary Absorption.

39. C. Andrade, M. Castellote, C. Alonso, C. González, Relation between colourimetric chloride penetration depth and charge passed in migration tests of the type of standard ASTM C1202-91. Cem. Concr. Res. 29(3), 417 (1999)

40. Zuhua Zhang, Hao Wang. "Optimization on the piezoresistivity of alkali-activated fly ash/slag mortar by using conductive aggregates and carbon fibers. Cem. Concr. Comp, 114, 103735 (2020)

41. M.H. Beigi, J. Berenjian, O. Lotfi Omran, A. Sadeghi Nik, I.M. Nikbin Mater. Des. 50, 1019 (2013)

42. S. H. Bahmani, B. B. K. Huat, A. Asadi, and N. Farzadnia, Const. Build. Mater. 64 (2014) 350
Table 1. Physicochemical properties of powdered NS.

| Appearance   | Silica content | Diameter | Specific surface area | pH value |
|--------------|----------------|----------|-----------------------|----------|
| White powder | 99.9%          | 25±5nm   | 210±20m$^2$/g         | 5-7      |

Table 2. Chemical composition of materials (in mass)

| Oxide   | OPC (%) | SCBA (%) |
|---------|---------|----------|
| SiO$_2$ | 20.50   | 20.10    |
| Al$_2$O$_3$ | 4.10 | 4.10 |
| Fe$_2$O$_3$ | 4.50 | 5.01 |
| CaO    | 62.12   | 63.20    |
| MgO    | 0.17    | -        |
| K$_2$O | -       | -        |
| Na$_2$O | -       | 0.12     |
| TiO$_2$ | -       | -        |
| MnO    | -       | -        |
| P$_2$O$_5$ | - | - |
| SO$_3$ | 3.50    | 3.21     |
| Insoluble residue | 1.00 | 0.98 |
| Loss on ignition | 0.70 | 0.50 |
Table 3. Physical properties of raw white PVA fibers.

| Length (mm) | Diameter (mm) | Tensile strength (MPa) | Elastic modulus (GPa) | Density (g/cm$^3$) |
|-------------|---------------|------------------------|-----------------------|--------------------|
| 14          | 0.040         | 1550                   | 45                    | 1.5                |
Table 4. Mix proportions

| Series | Mix ID       | Specimen name | Binder by weight | Sand/Binder | Water/Binder | PVA fiber (vol. %) |
|--------|--------------|---------------|-------------------|-------------|--------------|-------------------|
|        |              |               | Cement | SCBA | NS |       |                   |
| Series I | NS 0/PVA0  | M1          | 0.50   | 0.50 | 0  | 2    | 0.4   | 0               |
|         | NS 0.5/PVA0 | M2          | 0.495  | 0.50 | 0.005 | 2    | 0.4 | 0               |
|         | NS 1.0/PVA0 | M3          | 0.490  | 0.50 | 0.010  | 2    | 0.4 | 0               |
|         | NS 1.5/PVA0 | M4          | 0.485  | 0.50 | 0.015  | 2    | 0.4 | 0               |
| Series II | NS 0/PVA0.2 | M5         | 0.50   | 0.50 | 0  | 2    | 0.4 | 0.2             |
|         | NS 0.5/PVA0.2 | M6       | 0.495  | 0.50 | 0.005 | 2    | 0.4 | 0.2             |
|         | NS 1.0/PVA0.2 | M7       | 0.490  | 0.50 | 0.010 | 2    | 0.4 | 0.2             |
|         | NS 1.5/PVA0.2 | M8       | 0.485  | 0.50 | 0.015 | 2    | 0.4 | 0.2             |
| Series III | NS 0/PVA0.5 | M9        | 0.50   | 0.50 | 0  | 2    | 0.4 | 0.5             |
|         | NS 0.5/PVA0.5 | M10      | 0.495  | 0.50 | 0.005 | 2    | 0.4 | 0.5             |
|         | NS 1.0/PVA0.5 | M11      | 0.490  | 0.50 | 0.010 | 2    | 0.4 | 0.5             |
|         | NS 1.5/PVA0.5 | M12      | 0.485  | 0.50 | 0.015 | 2    | 0.4 | 0.5             |
| Series IV | NS 0/PVA1.0 | M13       | 0.50   | 0.50 | 0.50 | 2    | 0.4 | 1.0             |
|         | NS 0.5/PVA1.0 | M14      | 0.495  | 0.50 | 0.50 | 2    | 0.4 | 1.0             |
|         | NS 1.0/PVA1.0 | M15      | 0.490  | 0.50 | 0.50 | 2    | 0.4 | 1.0             |
|         | NS 1.5/PVA1.0 | M16      | 0.485  | 0.50 | 0.50 | 2    | 0.4 | 1.0             |
Fig. 1. Compressive strength of mortars with varied NS/PVA hybrid at the age of 7, 28 days.

Fig. 2. Water absorption of mortars with varied NS/PVA hybrid at the age of 28 days.
Fig. 3. Capillary absorption of mortars with varied NS/PVA hybrid at the age of 28 days.

Fig. 4. Rapid chloride permeability of mortars with varied NS/PVA hybrid at the age of 28 days.
Fig. 5. Electrical resistivity of mortars with varied NS/PVA hybrid at the age of 7, 28 days.

Fig. 6a

Fig. 6b

Fig. 6c

Fig. 6d
Fig. 6e

Fig. 6. SEM photograph of (a) control mixture (b) Mixture (NS1.0/PVA0) (c) Mixture (PVA0.5/NS1.0) (d) Mixture (NS1.5/PVA0.5) (e) Mixture (NS1.5/PVA1.0)

Fig. 7a
Fig. 7. XRD Pattern of (a) control mixture (b) Mixture (NS1.0/PVA0) (c) Mixture (NS 1.5/PVA1.0)