Effect of Ground Granulated Blast Furnace Slag, Silica Fume and Nano Silica on the Strength & Durability Properties of Concrete: A Contemporary Review

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ABSTRACT: This paper provides a contemporary review of the usage of Ground Granulated Blast-furnace Slag (GGBS), Silica Fume, and Nano Silica in Materialistic form over the deterministic aspects of conventional concrete. The main purpose of this literature learning is to enumerate the effect of GGBS, Silica Fume, and Nano Silica on strength of concrete. The GGBS, Silica Fume and Nano-silica is a restored substitute as compared to orthodox additives like CaCl₂ and SiO₂ because of their effectiveness with a lesser amount of consumption. It was found that the GGBS, Silica Fume, and nano-silica have an optimistic effect on the unconfined compressive strength, flexural strength, split tensile strength of concrete.

KEYWORDS: Ground Granulated Blast-Furnace Slag; Silica-Fume; Nano-Silica; Compressive Strength; Flexural Strength
1. INTRODUCTION

1.1 GENERAL
Investigators everywhere in the world are in constant exploration of novel constituents that can abundantly or partly substitute cement. The use of accompanying cementitious constituents namely fly ash, GGBS, metakaolin, rice shell ash, and silica fume as cement replacement has been in attendance from the previous decade. Nevertheless, utilizing supplementary cementitious constituents has its limitation as the responsiveness of extracts or pozzolans is usually inferior in contrast to cement. Fresh studies presented that fly ash has a twelve-monthly production of 1 billion tons and GGBS partaking a twelve-monthly production of three hundred and sixty billion tons are the universally used supplementary cementitious constituents and a portion of it can accomplish growing demands. So, it has become a global necessity to discover novel ingredients that can be used in spare to cement. Consequently, lessons pointing at the expansion and development of reinforced concrete constructions are of paramount importance. They can help in improving the excellence of materials used and their mixtures for better quality, durability, and protracted provision life.

1.2. GROUND GRANULATED BLAST FURNACE SLAG
Ground Granulated Blast Slag (GGBS), a cementitious remarkable material whose principal usage is in concrete and is a by-product as off, from the blast-furnaces used to manufacture iron. Blast-furnaces functions with temperatures of just about Fifteen hundred degree Celsius and are nourished with a prudently meticulous assortment of iron-ore, coke, and lime-stone. The iron-ore is compacted to iron and the residual constituents produce a slag that glides on the topmost surface. This slag is sporadically tapped-off as a melted fluid and if it is to be rummage-sale for the production of ground granulated blast slag it has to be speedily slaked in huge volumes of water. This progression heightens Cementitious assets and produces particles like coarse sand [1–4]. The quenching enhances the cementitious possessions and yields particles analogous to coarse sand. This granulated slag is then dehydrated and pulverized to an acceptable powder. GGBS is generally a left-out from the blast kiln which is used to produce iron. It is also identified as Slag cement since it has comparable properties as cement clinker.

2. SILICA FUME
Silica fume is a by-product from the manufacturing of silicon metallic alloys or ferrosilicon alloys. One of the greatest advantageous uses for silicon oxide and silicon dioxide is in concrete. For the reason that its biochemical and bodily properties, it is truly a volatile pozzolan. Concrete including silica-fume can have
indistinguishable high-strength. Insertion, concluding, and curative silicon dioxide concrete necessitate superior courtesy on the part of the concrete servicer. Silicon metallic and alloy compounds are shaped in electrical kilns. The fresh materials required for its production are quartz, coal, and wood chips. Conceivably the furthermost significant usage of this substance is as an inorganic replacement in concrete. silica-fume comprises chiefly of non-crystalline silicon dioxide. For the reason of its acceptable particles, huge surface area, and higher silicon dioxide gratified silica-fume is an identical reactive pozzolan when cast-off in concrete [5–9], see table 1.

Table 1: CHEMICAL COMPOSITION OF DIFFERENT SCM’s

| Oxides (%) | Limestone filler | Fly ash | GBBS | Silica fume | Nano Silica |
|------------|------------------|---------|------|-------------|-------------|
| CaO        | >43.8            | 0.5-19.3| 29 – 43.7| 0 – 0.8     | –           |
| SiO2       | 0.4-15.8         | 37–62.1 | 30 – 40| >85         | 90.0 – 98   |
| Al2O3      | 0.29-1.98        | 15.3-35.6| 06 – 19.3| 0 – 1.1     | 0.02 – 0.04 |
| Fe2O3      | 0.2-1.2          | 2.6-24.8| 0.1 – 2.5| 0 – 2       | –           |
| MgO        | 0.4-2.9          | 0 – 5.4 | 0.0 – 19| 0 – 4.5     | –           |
| K2O        | 0.03-0.6         | 0.1 – 7.8| 0.3 – 0.5| 0 – 1.3     | –           |
| Na2O       | 0.01-0.06        | 0.1 – 7.9| 0.0 – 1.2| 0 – 1.3     | 0.5         |
| SO3        | 0.13-0.3         | 0 – 4.9 | 1.0 – 4.0| 0 – 1.3     | 0.02        |
| LOI        | 35.8-43.1        | 0.2 – 32.8| 0.1 – 1.7| 0 – 2.8     | 0.1 – 0.2   |

3. NANO SILICA

Nano-Silica is a whitish or greyish fleecy residual composed of higher limpidness amorphous silica powder. For the reason of its insignificant constituent particle extent, nano-Silica had the compensations of greater precise surface area, robust outward adsorption, greater surface vigor [10–14], higher biochemical concentration, and virtuous dispersion. Nano-silica played an inimitable part in medication, physical science, chemistry, biology, and further other arenas as a result of its exceptional properties. Conferring to the dissimilar hydro-phaticity of Nano Silica, it can be separated into hydro-philia Nano Silica and hydrophobic Nano Silica. Amongst them, the Nano Silica usage in concrete was primarily hydro-philia Nano Silica. This was principally due to the virtuous dispersal of hydrophilic Nano Silica in liquid. The sub-divisional dimensions of Nano-SiO2 used in the experimentation are primarily about 15 Nano-Meter. The nullification of surplus acids (either SULPHURIC or HYDROCHLORIC) produces personalized Nano Silica and hereby the foremost influence that limits down the rate of dissolution of olio-vine in acids at raised temperatures are the olive specific surface area, the temperature, and the pH. Nano silica has silica as its main constituent comprising almost 90 – 98% of it [15–18].

4. LITERATURE VIEW
Effect of GGBFS on properties of Blend concrete:
Researchers studied the properties of Granulated glass furnace slags (GGBS) in the reinforced Geopolymer concrete (RGPC) column [19–23]. The 56 days' strength in all samples was increased by 20% as compared with 28 days' strength. So RGPC columns with GGBS were used in construction purposes. The compressive strength test results were obtained after 1, 2, 7, 28, and 91 days with 75% GGBS and 25% clinkers in 16 different samples of the mortar. The conclusion of that study, the three Rapid tests proved to be greater sensitivity to differences in fineness. The proportion of 10% MS and 20%, 30%, 40%, 50% GGBS were replaced with cement in the samples of the S3 group. The proportion of 15% MS and 20%, 30%, 40%, 50% GGBS were replaced with cement in the samples of the S4 group. The conclusion of this study by the addition of GGBS, concrete reflected a positive response on the workability of the samples as compared with the addition of MS. There was a total of fifteen samples were prepared to achieve this study results. The proportion of GGBS 10%, 15%, 20% and 25%, METAKAOLINE 10% were partially replaced with cement and recycled coarse aggregates 0%, 25% and 50% replaced with natural aggregates. The strength of the samples was increased by 25% of RCA. The slump value and workability were more in G21 and G31 mixes. The overall results of the prepared samples were increased concerning conventional concrete. The study concludes that the followability of the fresh paste decreased with the increase of GGBS proportions due to shape and more calcium proportions. The flexural strength and compressive strength were increased with the increase of GGBS proportions (Song et al., 2020). In this study, the GGBS and SF were partially replaced with cement by proportions of 0%, 30%, 50%, 70%, and 5%. The water-cement ratio used for this study 0.3, 0.4 and 0.5. The compressive strength in all water-cement ratios was increased with 50% GGBS and 5% SF, as compared without replacement of cement and for 0.4 w/c ratios, was better for replacement in all proportions to resistance the chloride ingress. The proportion of steel was used with GGBS. This study concludes that the hardness and tensile strength of the material gained by 35.8% and 63.6% for 3.5% GGBS as compared with normal LM6 alloy. The proportion used in GGBS and dolomite was 70% and 30%. In the conclusion of this study, the compressive strength maximum was detected when GGBS, dolomite, and steel fibers proportions were 70%, 30%, and 0.75%. After increased the percentage of steel fiber the results of compressive strength were reduced due to balling effects. GPC earned 90% compressive strength after 7 days of curing period whereas OPC earned 50% of compressive strength with the same curing. With the addition of steel fibers 0.25-0.75%, the gain in compressive strength was 5-19%. GGBS-dolomite GPC has greater seismic resistance concerning normal OPC with ductile detailing (Saranya, Nagarajan, & Shashikala, 2020b). Researchers mainly investigated the compressive strength of Granulated glass furnace slags-based GPC contained NATURAL POZZOLANS (NP) and silica fume (SF) by GEP analysis. The obtained results could promote the re-use of GGBS for GPC.
development, which in turn will lead to environmental and economic advantages (Shahmansouri, Akbarzadeh Bengar, & Ghanbari, 2020).

Effect of Silica Fume on properties of Blend concrete:
Researchers investigated the outcomes of silica fume (SF) and lime on mechanical and chemical properties of fly ash-based Geo-polymer concrete (GPC). The proportions of lime 5%, 7.5%, 10% and silica fume 1%, 2%, 3% was replaced with fly ash. This concludes that the workability and setting time of the concrete samples was reduced with the addition of lime, while it was increased with the presence of SF. The compressive strength of the sample was maximum with 7.5% lime and 2% SF in it after that it reduces the strength and showed poor bond strength it. Microstructural results concluded that the combined effect of silica fume (SF) and lime in GPC gives densified structure (Das et al., 2020). The proportions of the SF 0%, 2.5%, 5%, and 10% was replaced with cement by weight percent After testing all the samples at different curing age, it concludes that the compressive strength was found maximum with 5% SF in CPB sample at low curing temperature i.e. -1°C, this means that SF decreased the negative effect at low curing temperature. The overall results showed the SF has a good significant consequence on the early age strength of cement paste backfill samples and microstructural analysis showed the amount of SF could refine the pore structure of CPB samples (Xu, Zhang, & Liu, 2020). Researchers studied the enhancement of the concrete and polymer cement mortar (PCM) by using silica fume it was confirmed that the mixing of silica fume into PCM strengthened the interface bonding strength (Mizan, Ueda, & Matsumoto, 2020). the effect of silica fume on the self-compacting concrete (SCC) was studied. The Silica fume proportions 5%, 10%, and 15% were partially replaced with cement. The conclusion comes out that the inclusion of SF and M sand in SCC reduces the demand for normal concrete and also gave satisfactory strength to the structure. The overall result found a maximum with 5% SF present in SCC (Mahalakshmi & Khed, 2020) The SF proportions 0.5% 10% 15% 20% 25% was replaced with cement and w/c ration 0.26 and 0.32 was used. This concludes that the 5% SF showed better results in all samples and increased the strength, workability, durability (Adil et al., 2020). The researcher investigated the effect of silica fume in magnesium phosphate cement. The proportions of silica 0, 10, 15 and 20% were replaced with cement. After tested the samples, the following conclusions were formed, the results of compressive and flexural strength were increased with 15% SF added, but at 20% SF these values go down (X. Xu et al., 2020). In this study, the environmental impacts of silica fume and fly ash-based GPC with the addition of sodium hydroxide and sodium silic acid as alkali activators This study concludes that the compressive strength of the GPC sample was increased with the addition of FA and SF as compared to normal concrete The replacement of sodium silicate by silica fume has led to a further decrease in the environmental impacts of GPC (Bajpai et al., 2020). In this research, the authors have investigated the effect on foamed concrete with the addition of silica fume. it. The strengthened test was
performed after 3, 7, 14, 28 days. Silica fume particles can stabilize foam to a certain extent. The hardened foamed paste with the addition of silica fume particles in the liquid foaming stage has higher density, higher compressive strengths, and a larger compressive strength/density ratio. Its compressive strength/density ratios (Wang, Huang, Dai, Ma, & Jiang, 2020).

Effect of Nano Silica on properties of Blend Concrete:

In this study, to check the effects on MPC with the presence of Nano silica, and were analyzed for the workability and strength properties. The conclusion of this study after performed all the tests when the addition of NS in MPC paste with proportions of 0 to 6% it causes the decreases in fluidity and the setting time of the fresh paste was shortened. Overall, 13% strength was achieved with 4% NS added into MPC paste (Yuantaot Liu, Chen, & Qin, 2020). In this study, some proportions of NS were partially replaced with cement and check the effect of this NS in the HPC with different destructive tests. The proportions of NS 1% 2% 3% 4% and 0.33 w/c ratio was used in this research. The conclusion of this study, when we add NS as a mineral admixture and it improves the workability and consistency of the hard and fresh concrete. It plays a major role and gives good results in terms of strength and reducing the permeability and corrosion effects (Vivek et al., 2020). In this study, the researchers investigated the effect on the concrete with the addition of NS and check the chemical and mechanical properties of concrete. The NS proportions 0, 0.3 0.6% 0.9% and 1.2% was partially replaced with cement and w/c ratio 0.3 was adopted. The study concludes that the NS infuriated the chemical shrinkage of the cement paste After 1, 7, and 60 days the volume shrinkage of concrete was increased by 82.1%, 66.7% and 16.7% this indicated the NS achieved the strength in the early ten days. The addition of NS accelerated the hydration rate and improved the hydration heat release of cement (Jinbang Wang et al., 2020). In this study, the researchers investigated the effect of NS on the passivation process of the galvanized iron bar in cement mortars. The effect of corrosion in the concrete prepared samples with NS was expected to be enhanced (Zheng, Dai, et al., 2020) Tests concluded that the NS reduced the workability of the concrete, it means NS proportions increases and workability decreases. The compressive strength of concrete increases with 5% inclusion of NS as compared with normal concrete but after 5% the strength becomes reduced. The tensile strength of concrete as increased up to 34% with the addition of NS and polypropylene. (Adetukasi et al., 2020) The analysis of the cementitious index of Nano silica (NS) and silica fume (SF) indicates that NS was immediately reacting under the hydration process of cement, but at 60°C temperature, it was more difficult to understand the behavior of Nano silica (NS) and silica fume (SF) at 7h hydration. (Ma et al., 2020) In this study, the researchers investigated the effect of NS on the passivation process of the galvanized iron bar in cement mortars. After performing all the three objectives the results of this study come in such a way that, the passivation of the galvanized iron bar in cement mortars was governed by the incorporation of NS during early age and the surface passive film was established in mortar prepared
with NS was thicker and more protective as compared without the presence of NS. The fracture toughness, Young modulus, and fracture energy were increased in all samples by adding the NS particles and silica percentage by weight. The addition of NS has not been affected by the yield strength of the composites. The outcomes show that oxidation maturing advances the asphaltling aggregates on the outside of the silica aggregates, while the impact of Nano-silica is switched. The surface roughness of the aggregates was more so that it’s enhanced the adhesion strength. studied the geological properties of CPB (cement paste backfill) with the presence of Nano silica (NS). The conclusion after analyzed all the tests, the viscosity and yield stress results for these CPB samples were better than the samples without NS. So, the addition of NS in the cement paste have been improved the strength properties and useful for the construction process, see table 2,3 and 4.

### Table: 2 Outcome From Literature Review For GGBS

| Concrete Type | Material                  | Percentage | Conclusions                                                                 |
|---------------|---------------------------|------------|----------------------------------------------------------------------------|
| Geopolymer concrete | GGBS dolomite Steel fibers | 70% 30% 0.25-0.75% | GGBS-dolomite GPC has greater seismic resistance concerning normal OPC with ductile detailing. |
| LM6 steel alloy | GGBS with steel fibers    | 1.5 2.5 3.5%       | The hardness and tensile strength of the material gained by 35.8% and 63.6% for 3.5% GGBS as compared with normal LM6 alloy. |
| Geopolymer concrete | GGBS dolomite Steel fibers | 70% 30% 0.25-0.75% | GGBS-dolomite GPC has high strength and reduces the cost and construction time due to early age strength. |
| Normal concrete | GGBS silica fume | 0% 30% 50% 70% 5%     | The compressive strength in all water-cement ratios was increased with 50% GGBS and 5% SF and for 0.4 w/c ratios, was better for replacement in all proportions to resistance the chloride ingress. |
| Normal concrete | GGBS                     | 0 to 50%            | Because of irregular shape and high calcium proportions, the strength in flexure and compression grew with the increase of GGBS proportions. |
| Normal concrete | GGBS                     | 10% 15% 20% 25%     | The strength of the samples was increased by 25% of RCA. The overall results of the prepared samples were increased concerning conventional concrete. |
| Normal concrete | GGBS METAK AOLINE        | 10%                 | The addition of minerals admixtures (GGBS and MS) in the concrete was showed better |
results concerning the normal concrete and the overall strengths of the concrete also increased.

| Material                       | Percentage | Conclusions                                           |
|--------------------------------|------------|-------------------------------------------------------|
| Micro silica                  | 5% 10% 15% | results concerning the normal concrete and the overall strengths of the concrete also increased. |
| Normal industrial slag paste  | GGBS       | Rapid tests proved to be greater sensitivity to differences in fineness. The rapid tests results were better than the traditional reactivity indices which were calculated from the chemical compositions. |
| GPC                            | GGBS       | The strength increases as the molarity increases. The 56 days' strength in all samples was increased by 20% as compared with 28 days' strength. |
| Fly ash HMNS                   | GGBS       | The mechanical properties of the FA-based GP concrete with both GGBS and HMNS are improved. |

| Concrete Type                  | Material   | Percentage | Conclusions                                           |
|--------------------------------|------------|------------|-------------------------------------------------------|
| Magnesium phosphate cement     | Nano silica| 0% 2% 4% 6%| The addition of NS in MPC paste with proportions of 0 to 6% it causes the decreases in fluidity and setting time of the fresh paste was shortened. Overall, 13% strength was achieved with 4% NS added into MPC paste. |
| High-performance concrete      | Nano silica| 1 2 3 4%  | It plays a major role and gives good results in terms of strength and reducing the permeability and corrosion effects. |
| Cement in cement-based composites| Nano silica| 0 0.3 0.6 0.9 1.2%| Shrinkage increases with the adding of NS in the cement. After 1 7 and 60 days the shrinkage in volume of concrete grew by 82.1%, 66.7% & 16.7% this indicated the NS gained the strength in early ten days. |
| Galvanized iron bar in cement mortars | Nano silica| 0% 1% 2% | The passivation of the galvanized iron bar in cement mortars was governed by the incorporation of NS during early age and the surface passive film was established in mortar prepared with NS was thicker. |
| Cement in the fiber reinforced concrete | Nano silica Polypropylene| 0% 5% 10% 0.25% 0.5% 0.75 | The strength in compressive of concrete developed with 5% addition of NS as compared with normal concrete but after 5% the strength becomes reduced. The tensile strength of concrete as increased up to 34% with the addition of NS and polypropylene. |
The analysis of the cementitious index of Nano silica (NS) and silica fume (SF) indicates that NS was immediately reacting under the hydration process of cement.

The galvanized coating with mortar was upgraded with the CHZ layer which works as the bonding agent and the presence of the NS was encouraged the formation gap at the inner side of the iron bars.

The viscosity and yield stress results for these CPB samples were better than the samples without NS. So, the addition of NS in the cement paste have been improved the strength properties and useful for the construction process.

| Concrete Type                  | Material          | Percentage | Conclusions                                                                                                                                 |
|-------------------------------|-------------------|------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Fly ash in Geopolymer concrete | Silica fume       | 0% 2% 4% 6%| Compressive strength of the sample was maximum with 7.5% lime and 2% SF in it after that it reduces the strength and showed poor bond strength in it. Microstructural results exhibited that the integrated effect of silica fume (SF) and lime in GPC gives densified structure. |
| Cement in cement paste backfill | Silica fume       | 0% 2.5% 5% 10% | The SF has a good significant effect on the early age strength of cement paste backfill samples and microstructural analysis showed the amount of SF could refine the pore structure of CPB samples. |
| Polymer cement & Concrete     | Silica fume       | 5%         | The shrinkage increases with the adding of NS in the cement. The shrinkage in volume of concrete was increased by the inclusion of NS. After 1, 7 and 60 days the shrinkage in volume of concrete was increased by 82.1%, 66.7% and 16.7% this indicated the NS achieved the strength in early ten days. |
| Cement in self-compact concrete | Silica fume | 5% 10% and 15% | The inclusion of SF in SCC reduces the demand of normal concrete and also gave satisfactory strength to the structure. The overall result found maximum with 5% SF present in SCC. |
|---------------------------------|------------|----------------|--------------------------------------------------------------------------------|
| Cement in pervious concrete     | Silica fume| 0 5 10 15 20 25%| With the increase in rheology, the compressive strength of the pervious concrete increased. Eminent strength was found for samples produced with unwashed coarse aggregate. |
| magnesiu m phosphate cement     | Silica fume| 5% 10% 15% 20% | With the addition of SF, the strength of magnesium phosphate cement was increased. |
| Cement in normal concrete       | Silica fume| 5% 10% 15% 20% 25%| Strength was increased at a sufficient level. |
|                                | Silica fume| 7.5 and 15% | The strength gained up to 80% with the incorporation of silica fume. |
| Cement in GPC                   | Silica fume| 2-3% 13% | The strength in compressive of the GPC sample was increased with the addition of FA and SF as compared to normal concrete. |
| foamed concrete                 | Silica fume| 1% | Silica fume particles can stabilize foam to a certain extent |
5. CONCLUSIONS

This review article examined the usage of Certain Supplementary cementitious materials. The consequences of Supplementary cementitious materials on hydration properties, compressive strength, flexural strength, permeability, and shrinkage were deliberated. Depending upon the literature outcomes, succeeding conclusions are drawn:

- Concerning the outcomes of GGBS, it was found that the GGBS replacement gives lower heat of hydration, improved durability together with the responsiveness to hydrogen sulfate and hydrogen chloride attacks when equated to the standard concrete. Additionally, it correspondingly subsidizes conservational protection as it reduces the usage of cement throughout the manufacturing of concrete. Concrete prepared with GGBS-cement has enhanced compressive and flexure strength results in comparison with the Ordinary Portland Cement concrete.

- The supreme replacement level of 45% is suggested for GGBS and the curative temperature of at least Twenty Degree Celsius is advantageous. The slump of the GGBS-Concrete is unpretentious as compared to Plain Cement concrete and is considerably easier to compress. Due to the enhanced workability of GGBS-concrete, the air content is also dropped.

- Considering the Usage of GGBS, it quickens the hydration of OPC at initial periods of hydration, Steadiness of cement declined with the upsurge in GGBS percentage, Addition of GGBS improved the workability of mortar and concrete, and correspondingly improved the setting time of cement. The strength of mortar integrating with GGBS is associated with the surface area and constituent size spreading of GGBS. Blended cement comprising of slag 50% replacement established greater sulfate resistance as compared to OPC. Usage of GGBS improves the chloride requisite capacity of cement mortar.

- The augmentation is greater when Nano-silica usage is used unaccompanied. Furthermore, it is conceivable to determine that the uppermost compressive strength is accomplished when the self-compressing complexes have an unremitting particle size spreading from the lowest particle size to the largest.

- The development in mechanical behavior accomplished with Nano-Silica is related to the pore refinement due to the pozzolanic reaction and the packing outcome. The pore size reduction was proportionate to the volume of Nano-Silica. In the circumstance of concretes with Silica-fume, the micro-structure formed had a smaller overall permeability.
Silica fume enhances the mechanical and durability properties of concrete, including compressive strength, split tensile strength, and flexural strength, due to the fast-tracked hydration of cement. Intensification of strength can be detected on the substitution of cement with silica-fume up to 25%, also 10%–15%. Furthermore, the durability of silica-fume concrete rises with the upsurge in curing ages in contrast to regular concrete.

Integration of silica-fume up to 30% heightened the hardened properties of concrete. Ideal consequences were detected on substitution of up to 20% cement with silica fume at 28 and/or 56 days of curative remedial. Hardened properties were exaggerated if silica-fume content exceeds 25%.

REFERENCES

[1] Kansal C M, Singla S and Garg R 2020 Effect of Silica Fume & Steel Slag on Nano-silica based High-Performance Concrete IOP Conference Series: Materials Science and Engineering vol 961 (IOP Publishing Ltd)

[2] Arif M, Al-Hagri M G, Shariq M, Rahman I, Hassan A and Baqi A 2020 Mechanical Properties and Microstructure of Micro- and Nano-additives-Based Modified Concrete Composites: A Sustainable Solution J. Inst. Eng. Ser. A 101 89–104

[3] Ma J and Tie S 2018 Effect of Micro- and Nano-silica Powder on Film Formation of Suspended Liquid Film [微纳米硅粉对悬浮液体地膜成膜性能的影响] Cailiao Daobao/Materials Reports 32 93–7

[4] Snehal K and Das B B 2019 Techniques for preparation and dispersion of nano-SiO2 in Cementitious System—A Review Lect. Notes Civ. Eng. 25 397–407

[5] Hosseini A A, Hosseini S H and Abbas Zadeh A R 2012 Study of compress strength and time setting of concrete by additives of silica fume and nano silica Asian J. Chem. 24 903–7

[6] Brescia-Norambuena L, González M, Avudaiappan S, Saavedra Flores E I and Grasley Z 2021 Improving concrete underground mining pavements performance through the synergic effect of silica fume, nanosilica, and polypropylene fibers Constr. Build. Mater. 285

[7] Zieba Z, Witek K and Mońka J 2018 The effect of micro- and nanosilica on the soil permeability coefficient under cyclic freezing and thawing conditions E3S Web of Conferences vol 66, ed M H D J Pilecki Z. Dubinski J. (EDP Sciences)

[8] Imam A, Kumar V and Srivastava V 2018 Review study towards effect of Silica Fume on
the fresh and hardened properties of concrete *Adv. Concr. Constr.* **6** 145–57

[9] Nikravan M, Ramezanianpnour A A and Maknoon R 2018 Technological and environmental behavior of petrochemical incineration bottom ash (PI-BA) in cement-based using nano-SiO2 and silica fume (SF) *Constr. Build. Mater.* **191** 1042–52

[10] Rao K J, Keerthi K and Vasam S 2018 Acid resistance of quaternary blended recycled aggregate concrete *Case Stud. Constr. Mater.* **8** 423–33

[11] Vinothini K, Elangovan R and Vinoth R 2018 Experimental investigation on strengthening of concrete by partial replacement of nano and micro silica *Int. J. Civ. Eng. Technol.* **9** 422–9

[12] Junwei Z, Shijie L and Hongjian P 2021 Experimental investigation of multiscale hybrid fibres on the mechanical properties of high-performance concrete *Constr. Build. Mater.* **299**

[13] Shaban W M, Yang J, Su H, Liu Q-F, Tsang D C W, Wang L, Xie J and Li L 2019 Properties of recycled concrete aggregates strengthened by different types of pozzolan slurry *Constr. Build. Mater.* **216** 632–47

[14] Bernal J, Reyes E, Massana J, León N and Sánchez E 2018 Fresh and mechanical behavior of a self-compacting concrete with additions of nano-silica, silica fume and ternary mixtures *Constr. Build. Mater.* **160** 196–210

[15] Guleria A N and Salhotra S 2016 Effects of silica fume (micro silica or nano silica) on mechanical properties of concrete: A review *Int. J. Civ. Eng. Technol.* **7** 345–57

[16] Fallah S and Nematzadeh M 2017 Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume *Constr. Build. Mater.* **132** 170–87

[17] Kansal C M and Goyal R 2021 Analysing mechanical properties of concrete with nano silica, silica fume and steel slag *Materials Today: Proceedings* vol 45, ed G P Sehgal S. (Elsevier Ltd) pp 4520–5

[18] Fallah-Valukolaee S and Nematzadeh M 2020 Experimental study for determining applicable models of compressive stress–strain behavior of hybrid synthetic fiber-reinforced high-strength concrete *Eur. J. Environ. Civ. Eng.* **24** 34–59

[19] Chaudhary R, Jindal A, Aujla G S, Kumar N, Das A K and Saxena N 2018 LSCSH: Lattice-Based Secure Cryptosystem for Smart Healthcare in Smart Cities Environment
IEEE Commun. Mag. 56 24–32

[20] Mittal M, Verma A, Kaur I, Kaur B, Sharma M, Goyal L M, Roy S and Kim T-H 2019 An efficient edge detection approach to provide better edge connectivity for image analysis IEEE Access 7 33240–55

[21] Singh H and Kumar R 2013 Measuring the utilization index of advanced manufacturing technologies: A case study IFAC Proceedings Volumes (IFAC-PapersOnline) vol 46 (Saint Petersburg: IFAC Secretariat) pp 899–904

[22] Aggarwal S, Jindal A, Chaudhary R, Dua A, Aujla G S and Kumar N 2018 EnergyChain: Enabling energy trading for smart homes using blockchains in smart grid ecosystem Proceedings of the 1st ACM MobiHoc Workshop on Networking and Cybersecurity for Smart Cities, SmartCitiesSecurity 2018

[23] Kumar S, Kumar M and Handa A 2018 Combating hot corrosion of boiler tubes – A study Eng. Fail. Anal. 94 379–95