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Research on high performance green concrete using nano particles and organic materials: An eco-friendly approach

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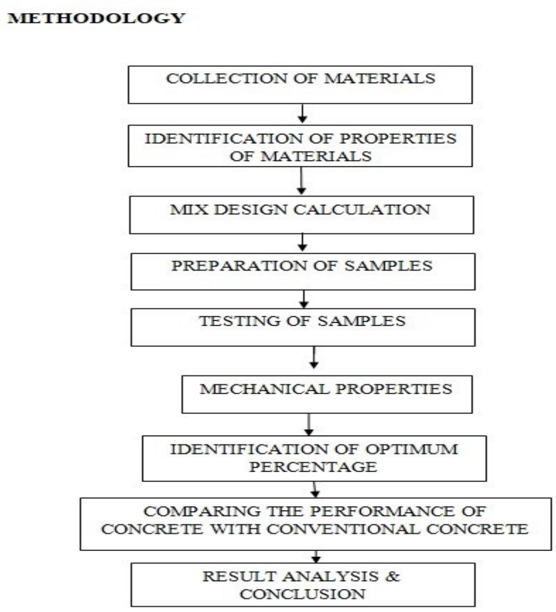
Graphical abstract



Abstract

Since concrete is a fundamental component of all types of construction, many researchers are concentrating on developing High Performance Concrete (HPC) using efficient manufacturing processes. Nano silica is a quartz and silica dust this can be replaced instead of cement to achieve great strength and to produce sustainable concrete. Sustainable concrete is eco-friendly concrete produced by industrial waste materials and other materials, nano silica when substituted instead of concrete produce less carbon emission in environment compare to cement concrete. High performance concrete is one that is strong, durable, and easy to work in. With correct material selection, mix design, and concrete handling from the fresh stage through the hardening stage, HPC can be achieved. This study aims to produce a High Performance Concrete (HPC) using sisal fibres, nano silica and delonixregia pods. M70 mix design was followed to produce a HPC and it is compared with conventional concrete with 0.36 w/c ratio. The pods of delonixregia ash is replaced from 1% to 7% to produce HPC, the delonix regia ash is added in HPC as a corrosion inhibitor. The nano silica is used from 0.5 % - 3.5% and the sisal fibre was replaced from 0.5 -1% and super plasticizer of 2% instead of cement content by volume replacement. The mechanical characteristics are analyzed in this investigation. The test results shows satisfactory results in the performance of HPC with the pods of delonixregia with 5%, nano silica with 2.5% and sisal fibres with 1% of replacement in ternary blended cement concrete with 2% replacement of super plasticizers (M13 mix). The SEM analysis shows the micro structure properties of concrete.

Keywords Green Concrete, Nano particles-Nano-silica and Delonixregia Pods, reduce carbon emission, waste to energy, etc

1. Introduction

The most widely utilised type of construction material in the world is concrete. Cement concrete is a widely used material in the building sector because of its characteristics like workability, cost effectiveness, durability and strength. Industrial wastes its products and organic materials such fly ash, nano silica, silica fume, rice husk ash, metakaoline, granulated blast furnace slag, coconut shell ash, delonixregia ash, baggase ash, etc., have been employed as SCMs in recent years. It is now common practise to add these SCMs as just a substitute for cement in HPC, which can help to reduce global clinker consumption. Fly ash is the most popular cement substitute among these SCMs for making concrete for further than 50 years worldwide. Since 1952, silica fume has been used as a substitute for SCM in the manufacturing of concrete.

Concrete qualities of strength and durability control a wide range of structural characteristics. In order to enhance the performance of the concrete, chemical and mineral admixtures are added to conventional concrete, which is not very effective in terms of durability and performance. Sudarsana Rao (2012) examined the characteristics of high-performance concrete when made with regular materials like superplasticizers and mineral admixtures. In addition to improving the concrete's strength, the use of mineral admixtures also significantly improved its durability.

Utilizing admixtures with in concrete had a significant impact on how easily it could be worked. Referencing Indian standard mix design approach and the High Performance Concrete literature, a mix design method for High Performance Concrete using nano silica, delonixregia ash, sisal fibre and super plasticizer the concrete was prepared. Strength and durability can be improved by pods of delonixregia ash, nano silica, sisal fibres and super plasticizers. The organic material is added in concrete to improve its performance and enhancing its strength and durability is very important in high performance concrete. The main parameters has to be consider in manufacturing concrete are water cement ratio, material replacement, material properties, handling concrete and curing the concrete.

2. Literature review

Thomas *et al.* (2001) investigated the behaviour of concrete including ternary blends of fly ash, silica fume, and Portland cement. It was determined that ternary cementitious blend-produced concrete has a very good resistance to chloride ion penetration. With time, ternary blend concrete's diffusivity decreases. The reductions are very large and have a big impact on the reinforced concrete elements' expected service life when exposed to chloride conditions.

With binary or ternary concrete mixtures, Isaia *et al.* (1997) investigated the microstructural properties, compressive strength, the durability performance of various types of minerals admixtures with varying w/b ratios. The w/b ratio, type of mineral admixtures and quantity of mineral admixture all had significant effects. Therefore, in order to achieve the most benefit from ternary blend concrete, the impact of various replacement rate of admixtures on different aspects in ternary blend cement matrix needs to also be thoroughly researched.

According to Elahi *et al.* (2010), both binary and ternary systems of high-performance concretes containing extra cementitious elements exhibit strength and durability characteristics. Due to strength growth and bulk resistivity, silica fume performed best than other SCMs, according to the data. The ternary mixes that contained silica fume and powdered granulated furnace slag/fly ash outperformed all the others in terms of resistance to chloride diffusion.

Mineral admixtures are typically utilised as replacement ingredients when making concrete. Additionally, several admixtures of minerals such fly ash, pulverised granulated blast furnace slag, and silica fume show pozzolanic interaction with cement. A siliceous or siliceous-aluminous substance that possesses more or less pozzolanic properties is referred to as a pozzolanic material. In the absence of water, the pozzolanic react with released $Ca(OH)_2$ to create more C-S-H gel. This C-S-H gel alters the structure of a concrete and reduces its pore size, increasing its durability and impermeability. The serviceability of concrete structures may be extended as a result of these improvements (Meyer 2009).

The preceding literature makes clear that while numerous studies have been carried out to comprehend various potential methods for creating ternary blended cement for high performance. To close this gap, an organised experimental examination is needed, which is what this project aims to do. Thus, a thorough experimental examination to assess the qualities of the fresh and hardened states.

3. Materials and mix design

OPC 53 grade cement, fine aggregate formed of locally accessible river sand, coarse aggregate 20 mm, pods of delonixregia ash, nano silica, sisal fibres, and super plasticizer are the features of the materials used in this research study and shown in Figure 1. Delonixregia ash and nano silica were mostly employed to partially replace cement in the concrete in the experimental study. Another ingredient, nano silica, filled the biggest gaps in the concrete, significantly lowering its porosity while simultaneously increasing its compactness and density. Additionally, pods of delonixregiaash that acted as a partial cement replacement in each of the concrete mixtures used for the research study were added to each mixture. The presence of nano silica increased the concrete's density or pore-filling capacity. In addition to the mix design of high performance concrete, the effects using sisal fibre as well as the natural fibres delonixregia ash at various proportions were discussed.

Figure 1. Materials for Preparing HPC

3.1. Cement

Cement is a material that serves as a binder in concrete. For this experiment, regular Portland cement, OPC, was chosen as the cement. The different concrete mixtures were made using Ordinary Portland Cement (OPC) of 53-grade adhering to IS 12269 (1987), which was acquired from a local market. Table 1 shows the cement's physical characteristics and setting time, whereas Table 2 shows the chemical composition of OPC.

Table 1. Physical Composition of Cement

Physical Composition	Cement
Grade	OPC 53
Colour	Grey
Specific gravity	3.14
Surface area(cm^2/gm)	2250
Physical state	Solid
Size microns mean	<90
Volume Expansion	3 mm

3.2. Nano silica

Nano silica (NS) is just a manmade substance composed of spherical particles with a size range of 1 to 100 nanometers. In this experiment, rice husk is used to prepare nano silica. Rice husk is heated to 700°C and melted to form ash. The ash is then mixed with a solution of sodium hydroxide (NaOH) and agitated for 2.5 hours at

100 °C before being filtered and washed to produce pure sodium silicate precipitation. Next, HCL is added to the sodium silicate precipitate and dried for 8 hours at 200°C to produce nano silica as shown in Figure 2.

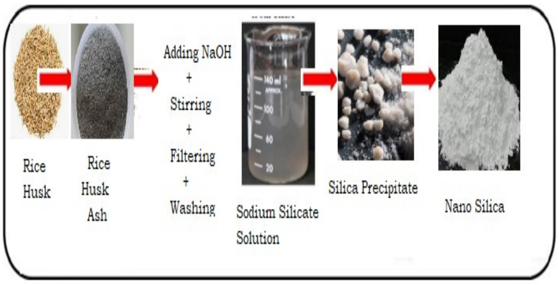


Figure 2. Preparation of Nano Silica

Table 2. Chemical Properties of Cement

Chemical Composition	Cement (%)
SiO_2	20.15
Al_2O_3	4.51
Fe_2O_3	2.57
CaO	61.34
MgO	1.05
Loss on ignition	2.45

Dry powder is the physical condition of nano silica. Workability, strength, durability, shrinkage, and bond are among the qualities that are impacted by nanoscale particles or voids. As a nanofiller, nano silica occupies the crevices between the C-S-H gel's particle. The amount of C-S-H gel produced by the pozzolanic of calcium hydroxide freed during hydration with nano silica rises, leading to increased matrix densification and it is a micro filler. The concrete's strength and longevity are increased by the aforementioned factors. Compared to silica fume, nano-silica speeds up concrete's setting time. Concrete that has micro silica added to it experiences less water bleeding, segregation, and has better cohesion.

Table 3. Physical Composition of Nano silica

Physical Composition	Nano silica
Colour	White
Specific gravity	1.85
Surface area(cm^2/gm)	200
Physical state	Solid
Size microns mean	<45
pH	9.4

Table 4. Chemical Properties of Nano silica

Chemical Composition	Nano silica (%)
SiO_2	99%
C	0.15
Cl	0.02
Al_2O_3	0.03
TiO_2	0.02
Fe_2O_3	0.003

3.3. Pods of delonixregia ash

The pods of Delonix Regia Ash (PDRA) after being burnt it 300°C for 6 hrs for higher silica content. The pods of Delonix Regia Ash (PDRA) Sample after prepared by pyrolysis process as shown in Figure 3 and being extracted by 2.5 N sodium hydroxide generated the yield of pure silica up to 99% as shown Table 4, the concentration of sodium hydroxide had strongly effect on the dissolved from the main product. This delonix regia ash is also used in HPC to analyze the corrosion resistance in concrete.

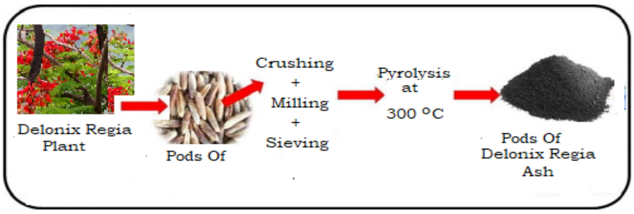


Figure 3. Preparation of Pods of DelonixRegia Ash

The characteristic and position of the peaks are identical by Indhumathi *et al.* (2011). They discovered that the silinol OH groups and adsorbed water were responsible for the main chemical groups contained in silica, which were detected by the FTIR spectra testing broad band around 2800 and 3750 cm^{-1}. Silane group Si-H was the cause of the range 2100. The peaks around are attributed the vibration of the gel network, and the IR spectrum clearly demonstrated pure silica. The major absorbance point at 1320 cm^{-1} was caused by siloxane linkages (Si-OSi). The physical and chemical properties are listed in Tables 5 and 6.

Table 5. Physical Composition of pods of DelonixRegia Ash

Physical Properties	pods of DelonixRegia Ash
Appearance	Powder form
Shape	Spherical Shape
Colour	Black
Size	100-425 micron
Bulk Density	1850– 2200kg/m3
Specific Gravity	2.35

Table 6. Chemical Composition of pods of DelonixRegia Ash

Chemical Composition	Pods of DelonixRegia Ash (%)
SiO2	98.92
Al2O3	0.2 – 2
CaO	0.39
SO3	0.065
ZrO	0.028

3.4. Fine aggregate

River sand was used as fine aggregate (FA) since it was available and cleansed in the area. The utilized sand needs to pass through a 4.75 mm screen and meet IS Grade Zone-II standards from the 383 (1970). The sand utilized in the cementitious materials for the current investigation was silt- and clay-free and fulfilled the previously indicated criteria. Table 7 displays the physical properties of fine aggregate.

Table 7. Physical Properties of River Sand

Physical Properties	River Sand
Appearance	Grainy
Specific Gravity	2.73
Bulk Density	2.75 g/cc
Water Absorption	1.48%
Moisture Content	1.33%
Zone	II
Colour	White
Finness Modulus	1.5
Maximum Grian Size	1.18

3.5. Coarse aggregate

Coarse aggregate(CA) that is readily available locally and has a specific gravity of 2.7, a nominal aggregate size of 20 mm, a water absorption of 0.35 %, moisture content and other characteristics that comply with IS 383-1970 is used to this investigation.

3.6. Super plasticizer

The superplasticizer, also known as the High-Range Water-Reducing Admixture, is the most crucial chemical admixture for processing HPC (HRWRA). Superplasticizers come in four different varieties. Conplast SP430, a super plasticizer (SP) that makes up 20% of cement by weight, is used to make cement more workable. It is based on the qualities stated in Table 8 and described in IS - 9103:1998. Sulphonated naphthalene polymer-based material, brown liquid appearance, specific gravity of 1.22.Superplasticizers is water reducers that have a 30% water content reduction capacity. For the purposes of this experiment, CONPLAST SP430, a superplasticizer, was utilised to produce workable concrete with a low w/b ratio. In terms of HRWRA compliance, CONPLAST SP 430 conforms with IS: 9103-1998, BS: 5075 part 3, as well as ASTM C 494, Type B.

3.7. SISAL FIBRE

Sisal fibre (SF) is a durable substance that doesn't easily fracture when put under typical strain. Its physical appearance is nearly yellow. As a result of improved cellulose crystalline structure, the sisal fibre underwent thermal treatment to improve its mechanical properties, give greater initial strength, and maintain the sisal fiber'slengthy reinforcing action in concrete. For eight hours, sisal fibres were roasted to 150°C in a ventilated oven. The sisal fibre has a size range of 50 to 60 mm. Table 8 displays the sisal fiber's characteristics.

Table 8. Physical Properties of Sisal Fibre

Physical Properties	Sisal Fibre
Cellulose (%)	65
Hemicelluloses (%)	12
Lignin (%)	9.9
Moisture Content (%)	10
Others (%)	3.10
Density (Kg / m3)	1450
Flexural Modulus (GPa)	12.50 – 17.50
Tensile Strength (MPa)	68
Young's Modulus (GPa).	3.77

3.8. Steel reinforcement

The addition of steel reinforcement bars improves the shear and tensile strengths of a concrete. A High Yield Stress Bar (HYSD) is used to evaluate bond strength for casting slabs. The yield strength of the bar is 500 MPa Sizes of HYSD bars in use range between 8mm to 12mm.

3.9. Water

In fact, after cement, water is the second most crucial element in the production of concrete. In addition, it is the least priced. Subpar concrete may be the result of poor water management. Water has three purposes in concrete. It also chemically combines with the cement to generate calcium silicate hydrate or c-s-h gel, and lubricates the mixture to make it easier to work with. The cement is distributed uniformly by this additive. Concrete examples were cast using drinkable water. Oils, acids, and alkalis were not present in the water, which had a chloride concentration approximately 160 mg/lit that was soluble in water.

4. Mix design

Mix design was completed in accordance with the standards and guidelines outlined with in Indian Standards (IS) regulations IS 10262 : 2009, to satisfy the M70 requirements. The ratio of 1: 1.29: 2.18 with 0.36 water cement ratio was obtained from the components of cement 53 grade, fine aggregate, coarse aggregate, nano silica, pods of delonixregia ash, sisal fibre, and super plasticizers characteristics. The mix designation includes cement 53 grade, fine aggregate, coarse aggregate, nano silica, pods of delonixregia ash, sisal fibre, and super plasticizers in the mix proportions stated in Table 9.

Table 9. Mix Design Designation

Mix No	Mix Representation
M1	CC – CONVENTIONAL CONCRETE
M2	0.5% NS+ 1% PDRA + 85.5% OPC+ 0.5% SF + 2%SP
M3	1% NS+ 2% PDRA + 87% OPC + 0.5% SF + 2%SP
M4	1.5% NS+ 3% PDRA + 86.5% OPC + 0.5% SF+ 2%SP
M5	2% NS+ 4% PDRA + 84% OPC + 0.5% SF + 2%SP
M6	2.5% NS+ 5% PDRA + 82.5% OPC + 0.5% SF+ 2%SP
M7	3% NS+ 6% PDRA + 81% OPC + 0.5% SF + 2%SP
M8	3.5% NS+ 7% PDRA + 79.5% OPC + 1% SF + 2%S
M9	0.5% NS+ 1% PDRA + 85.5% OPC+ 1% SF + 2%SP
M10	1% NS+ 2% PDRA + 87% OPC + 1% SF + 2%SP
M11	1.5% NS+ 3% PDRA + 86.5% OPC + 1% SF+ 2%SP
M12	2% NS+ 4% PDRA + 84% OPC + 1% SF+ 2%SP
M13	2.5% NS+ 5% PDRA + 82.5% OPC + 1% SF+ 2%SP
M14	3% NS+ 6% PDRA + 81% OPC + 1% SF+ 2%SP
M15	3.5% NS+ 7% PDRA + 79.5% OPC + 1% SF+ 2%SP

5. Experimental investigation

The mix design proportions are calculated and tested then in both a fresh and hardened state. The specimens were cast in accordance with all IS Standards as depicted in Figure 4. In this experimental work, specimens with dimensions of 150 x 150 x 150 mm were examined for compressive strength. A Compressive Testing Machine (CTM) with the capacity of 1000 KN was employed in this inquiry in accordance with IS: 516-1959. The load is assigned in compliance with IS codal specifications. The experimental setup for compressive strength is shown in Figures 5 and 6.

After the samples are made according to the instructions, the compressive strength is calculated using the formula fck=P/A. The highest compressive strength is found in the M13 mix percentage, which is 2.5% NS + 5% PDRA + 82.5% OPC + 1% SF + 2%SP mix (Table 10).

Figure 4. Casting of Specimens

Figure 5. Compressive Strength Experimental Setup.

Table10. Compression Strength Results

Mix No	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
M1	54.52	62.65	78.56
M2	56.28	64.53	80.65
M3	56.92	65.48	81.28
M4	57.26	66.84	82.57
M5	57.83	67.53	83.95
M6	59.06	69.08	84.56
M7	58.23	68.24	83.26
M8	57.49	67.09	82.56
M9	56.46	64.68	81.26
M10	57.15	64.56	82.56
M11	57.86	66.23	83.45
M12	58.63	66.98	84.34
M13	59.96	67.86	85.98
M14	58.54	65.23	85.23
M15	57.68	64.38	84.48

Concrete specimens were tested for split tensile strength assessment in compliance with IS 5816:1998 criteria. These specimens, which measure 300 mm in height and 150 mm in circumference, were painstakingly cast just for this investigation. A compression testing machine (CTM) was used to evaluate the split tensile strength at three different age intervals: seven, fourteen, and twenty-eight days. It is important to remember that the aforementioned statement includes information on the testing intervals and exact specimen dimensions, as well as a succinct description of a testing technique that complies with a particular standard (IS 5816:1998). Figure 7 depicts the split tensile strength crack pattern and Figure 8 shows the variation in strength, and Table 11 plots the test findings.

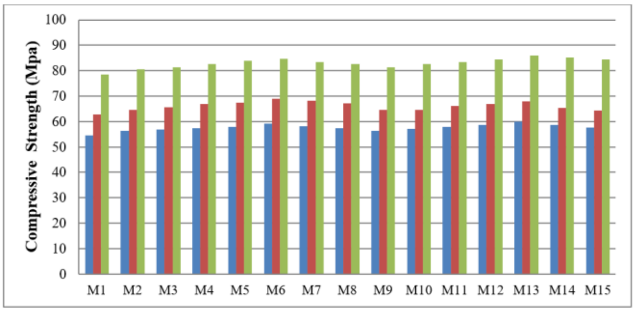


Figure 6. Compressive Strength Variations

Figure 7. Crack pattern of cylinder specimen.

Table11. Split Tension Test Results

Mix No	Tensile Strength (MPa)		
	7 Days	14 Days	28 Days
M1	6.54	7.54	8.48
M2	7.54	7.96	8.59
M3	7.76	8.06	8.61
M4	8.06	8.36	9.26
M5	8.36	8.58	9.67
M6	8.65	8.96	9.85
M7	8.65	8.78	9.63
M8	8.45	8.57	9.74
M9	7.68	8.89	9.85
M10	7.96	9.18	9.58
M11	8.15	9.35	9.39
M12	8.48	9.48	9.45
M13	8.67	9.56	9.64
M14	8.46	9.28	9.36
M15	8.32	8.78	9.25

The M13 mix (2.5% NS + 5% PDRA + 82.5% OPC + 1% SF+ 2%SP) is determined to have the highest Split Tensile strength, and the M6 (2.5% NS+ 5% PDRA + 82.5% OPC + 0.5% SF+ 2%SP) and M12 (2% NS+ 4% PDRA + 84% OPC + 1% SF+ 2%SP) mix proportions are shown to be less similar.

A prism with dimensions of 100 mm by 100 mm by 500 mm was subjected to single point loading conditions in accordance with IS: 516-1959 and its flexural strength was tested at 3, 7, 14, and 28 days using a Universal Testing Machine (UTM). Figure 9 depicts the experimental setup for the flexural strength test. Equation PL/bd2, where L is the specimen's length in millimeters, b is its width in millimeters, and d is its depth at the point of failure, is used to determine the flexural strength. P is the maximum load

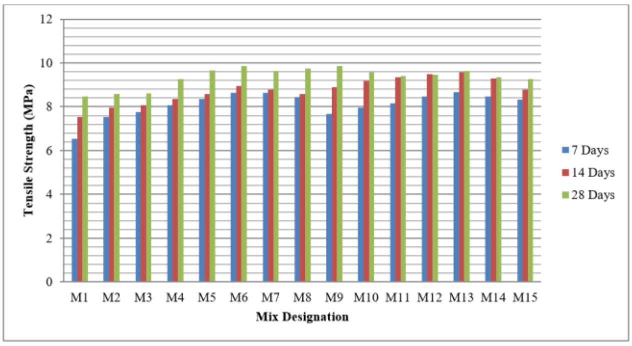


Figure 8. Split Tensile Strength Variations

Figure 9. Flexural Strength Set up and loading pattern

Table12. Flexural Strength Results

Mix No	Flexural Strength (MPa)		
	7 Days	14 Days	28 Days
M1	6.86	7.45	8.36
M2	6.96	7.54	8.46
M3	7.23	7.63	8.53
M4	7.45	7.73	8.64
M5	7.62	7.92	9.16
M6	7.59	8.05	9.36
M7	7.46	8.16	8.84
M8	7.32	7.86	8.63
M9	6.98	7.56	8.76
M10	7.36	7.69	8.58
M11	7.54	7.98	8.69
M12	7.75	8.12	8.76
M13	7.82	8.36	8.84
M14	7.72	8.06	8.54
M15	7.58	7.86	8.26

Scanning Electron Microscope - SEM analysis, examination was used to carry out a microstructure investigation. The investigation was done to determine the best replacement percentage, which was found to be 2.5% nano silica, 5% delonix regia ash pods, 82.5% cement, 0.5% sisal fibre, and 2% super plasticizers.

Figure 11 displays the test findings. The microstructure reveals that the surface is rough, which means that the strength will be strong and the bonding properties will be superior to those of other mixtures. Visual inspection reveals that the concrete sample has very few voids, indicating an excellent bonding quality. It is clear from the interfacial bonding between the cement phase and the aggregate that the bonding is strong.

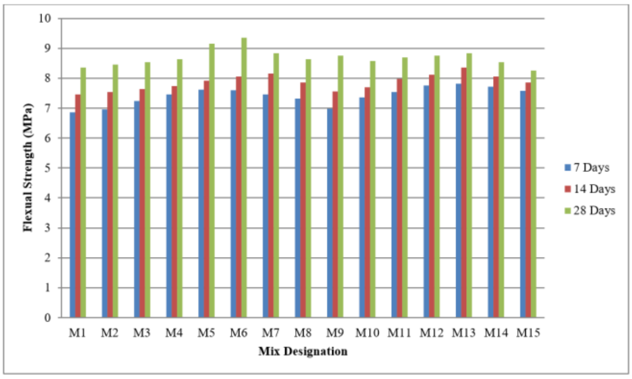


Figure 10. Flexural Strength Variations

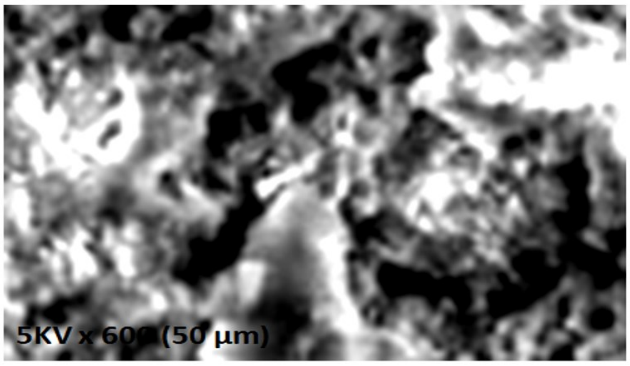


Figure 11. SEM Analysis of M6 mix

6. Results and conclusion

- The materials that have been identified for making HPC are acceptable, including fine aggregate, coarse aggregate, pods of delonixregia ash, nano silica, sisal fibres, and super plasticizer. Due to the size of the delonixregia ash and nano silica pods, it has been confirmed that all these materials could be employed for the production of HPC. Due of its incredibly small size, it fills pores and provides strong bonding.
- The nano silica produced by rice husk is used in this investigation performance is satisfactory
- The compression strength test, split tensile strength test, and flexural strength test are used to determine the mechanical properties in accordance with IS codal requirements.
- When compared to all other mixes designed for making HPC, the 28-day compressive strengths of concrete with the M13 mix proportion were greater. This mix contains 2.5% nano silica, 5% Pods of Delonix Regia Ash, 82.5% cement, 1% Sisal Fiber and 2% Super Plasticizers.
- For concrete with M13 mix proportion, which is 2.5% nano silica + 5% Pods of Delonixregia ash + 82.5% cement + 1% Sisal fibre + 2% Super plasticizers, the 28-day split tensile strengths were greater. The second-highest value is found in the mix of M14, M6, and M12.
- The concrete with M13 mix proportion, which is 2.5% nano silica + 5% Pods of DelonixRegia Ash +

82.5% Cement + 1% Sisal Fiber + 2% Super Plasticizers, had greater 28-day flexural strengths. M6 mix proportions account for the second-highest value.

- By analysing the mechanical characteristics of concrete, it was discovered that 2.5% nano silica, 5% Delonixregia ash pods, 82.5% cement, 1% sisal fiber, and 2% Super plasticizers are the best substitution percentages.
- Sustainable concrete is generated by employing nanosilica in concrete because it reduces the carbon emissions that cement produces.
- Visual inspection reveals that the concrete sample has very few voids, indicating an excellent bonding quality. The microstructure reveals that the surface is rough, which means that the strength will be strong and the bonding properties will be superior to those of other mixtures.

References

ASTM C 494. (1992). Standard Specification for Chemical Admixtures for Concrete, Annual Book of American Society for Testing Materials Standards.

Elahi, Ayub and Basheer, P.A. Muhammed&Nanukuttan, Sreejith&Khan, Qaiser. (2010). 'Mechanical and durability properties of high performance concretes containing supplementary cementitious materials' Construction and Building Materials, vol. 24, pp. 292–299.

Indhumathi P, Syed Shabhudeen S.P. and Saraswathy C.P. (2011). 'Synthesis and Characterization of Nano Silica from the Pods of DelonixRegia Ash', International Journal of Advanced Engineering Technology, vol.2, no.4, pp 421–426.

IS 9103. (1998). Concrete admixtures specifications', Bureau of Indian Standards, New Delhi, India.

IS 10262. (2019). Guidelines for concrete mix design proportioning, Bureau of Indian Standards, New Delhi, India.

IS 1199. (1959). Method of Sampling and Analysis of Concrete, Bureau of Indian Standards, New Delhi, India.

IS 383. (1970). Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi, India.

IS 456. (2000). Indian Standard Plain and Reinforced Concrete Code of Practice, Bureau of Indian Standards, New Delhi, India.

IS 516. (2004). Methods of test for strength of concrete, Bureau of Indian Standards, New Delhi, India.

IS 5816. (1999). 'Splitting Tensile Strength on Concrete - Method of Test', Bureau of Indian Standards, New Delhi, India.

IS: 12269. (1987). Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi, India.

Isaia G.C. (1997). 'Synergic action of fly ash in ternary mixtures with silica fume and rice husk ash', International Congress on the Chemistry of Cement, pp. 481-502.

Meyer C. (2009). 'The Greening of the Concrete Industry', Cement & Concrete Composites', vol. 31, pp. 601–605.

Sudarsana Rao H.M. Somasekharaiah. and V.G. Ghorpade. (2012). 'Residual Compressive Strength of Fly Ash Based Glass Fibre Reinforced High-Performance Concrete Subjected to Acid Attack', International Journal of Engineering Science and Technology, vol. 4, No 1, pp. 71–80.

Thomas M.D.A. and Bleszynski R.F., (2001), 'The use of silica fume to control expansion due to alkali-aggregate reactivity in concrete - A review', Materials Science of Concrete. pp. 377–434.