Strength and durability evaluation of Nano blend concrete matrix for sustainable development.

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Abstract:

The present research study characterised the performance of various types of nanomaterial concrete for the evaluation of strength and durability performance by conducting compressive strength, water absorption and sorptivity. The durability test measures the amount of water that penetrates the matrix when exposed to aggressive environmental agents. The formulated concrete blends is made by partially replacing ordinary Portland Cement (OPC) with nanomaterials such as multi-walled carbon nanotubes (MWCNT), titanium dioxide (TiO_2) and copper oxide (CuO) in various proportions. The nanomaterials are replaced 0.1%, 0.25% and 0.5% in OPC. The destructive strength analysis is done at 28 days of curing and durability was tested upto 56 days in the interval of 28 days curing period. The results were interpreted with the analysis using ANSYS software by applying the various preliminary conditions. From the analysed results, the mix with 0.5% of the Carbon Nano Tubes, TiO_2 and CuO present by weight of the cementitious materials exhibited noticeably less water absorption value of less than 3% and less sorptivity value. According to the analysis done, the mixture that has Nano materials added at a rate of 0.5% is the best composition. The same mixture has also shown to be extremely durable making it suitable for use as engineering concrete in challenging conditions.

Keywords: Multi walled carbon nanotubes, Compressive strength, sorptivity, water absorption, ANSYS.

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Introduction:

Cement concrete is one of the construction industries most flexible building materials.More frequently, in a variety of ways nano materials are added to concrete which has the effect of in beneficial changes to material objects. Carbon nanotubes remarkable mechanical qualities have drawn a lot of attention to their potential use in high performance cementitious compositions. Previous research indicates that including MWCNT in the mix design alters the concrete compressive strength and significantly alters the properties of other ingredients as well. It is anticipated that MWCNT will be evenly distributed throughout the cement and will properly binds the cement and MWCNT interface following the strength performance and durability over regular concrete with the inclusion of MWCNT.

The research study focuses on utilising two nanomaterials in addition with MWCNT namely copper oxide and titanium oxide. Plants frequently contain titanium, which ranks as the ninth most frequent element. It changes into titanium oxides when it comes into contact with oxygen. When utilized as a UV-protecting component in sunscreen, titanium dioxide aids in UV ray protection. The high demand for titanium dioxide in photo catalysts is a result of its oxidative characteristics. It increases the effectiveness of electrolytic ally by acting as a photo catalyst. When exposed to UV light, it becomes more hydrophilic; this can be used for anti-fog coats.

When the combined hydrogen or carbon monoxide are mixed at high temperatures results in copper-oxide which is a nanoparticle that resembles a brownish-black powder. They are dangerous to people it is harmful to the environment and having an impact on aquatic life several studies are mentioned below which performed a research on concrete composites using nano materials for achieving its strength and durability.

S. S. Lucas etal. [1] Studied the effects of microstructure on the characteristics and photocatalytic activity of titanium dioxide nanoparticles added to mortars, because the qualities of the mortars hardened state are unaffected by the nano additions, it has been shown that photocatalytic mortars can be used in both new and ancient structures. R. Siddique and A. Mehta [2] studied the effect of carbon nanotubes on cement mortar characteristics and states that CNTs are successfully used in numerous research projects that significantly enhance the mechanical properties of cement mortars. B Ma etal [3] used SEM, X-ray diffraction and mercury intrusion porosimetry to examine the impact of nano-TiO_2 (NT) on the microstructures and mechanical characteristics of cement mortars (MIP). The water absorption and water vapour permeability of cement-based products to discuss their durability. The results reveal that adding 3% NT can significantly increase the compactness and durability of cement-based materials by reducing the water absorption ratio by 40–65%, water absorption coefficients by more than 40%, and water vapour permeability coefficients by 43.9%. D. H. T.M. Mendes & W.L. Repette [4] has reviewed the nanoparticles in cement based materials and demonstrated that the optimum volumetric contents considering the relative strength gain by using nano materials. S. H. Jang et al. [5] investigated how the mechanical and electrical properties of MWCNTs in cement paste changed as a result of their clustering. Different MWCNT concentrations in cement pastes (up to 0.5% by cement mass) with or without surfactant were identified, results shows that the surfactant-containing composites had greater compressive strength, tensile strength, and electrical conductivity than those without surfactant at all MWCNT concentrations.

The study of B. M. Miyandehi et al. [6] examines the impact of nano-CuO (NC) and rice husk ash (RHA), a cement substitute on the durability performance, strength and permeability characteristics of mortars which gives a mixture scheme which provides relatively satisfactory properties improvement with positive environment credential as suggested. A. Ghanei et al. [7] Investigated the engineering features of fiber-reinforced mortars including metakaolin and nano-CuO (NC), as the amount of NC particles in the combination increased, the samples of water absorption significantly decreased. The strengths of cement mortars were further increased and their water absorption values decreased when PP fibers were introduced. The mechanical and durability performance of the hydrated matrix is enhanced by the use of Carbon Nano Tubes, a type of nanoscale material. It serves as a nanoscale reinforcing material by halting the growth of cracks [8,9,10]. Li et al. [11] and Hon Seung Lee et al.[12] deduced that reinforced mortars function better due to the matrix finely tuned pore structure and the CNTs' provision of bridging.

Concrete durability can be defined as the ability of concrete to withstand weathering, chemical attack, and abrasion while maintaining desirable engineering properties. Different concretes require different levels of durability depending on the environment they are exposed to and the properties they require.

Alum sludge, micro silica, and crushed granulated blast furnace slag were all used in the development of binary and ternary blended concrete by Haider M. Owaid et al. [13]. The created mixtures were assessed for resistance to sulphate chloride penetration, sorptivity and water absorption. It was concluded that concrete containing 15% of alum sludge performed better than concrete containing 20% alum sludge. Ali Hendi et al. [14] investigated the impact of adding glass and micro silica in varying amounts on the sulphate attack on the concrete. He developed the durability index in order to determine the durability performance, where it was concluded that the integration of glass powder and micro silica at 6% demonstrated resistance to deterioration.

Lou Chen et al. [15] examined the sorptivity of the matrix created would change if cement were partially replaced with metakaolin and lime stone. With the densification it was implied that the development of micro structure in the late ages helped to increase sorptivity. H.Y. Leung et al. [16] concluded from the experimental research that there is an increase in strength when mineral admixtures such fly ash and silica fume are used in place of cement, In comparison to the control mix, a decrease in water absorption and sorptivity was seen when silica fume and flyash were present together in the mix.

The limited amount of research have been carried out and published pertaining to the performance evaluation of the blended concretes reinforced with the combination of Carbon Nano Tubes, titanium di oxide and copper oxide. Moreover, to the best of the author's knowledge a comprehensive study on the durability performance and analytical interpretation using finite element software (ANSYS) of the quaternary blended concrete with Carbon Nano tubes, titanium di oxide and copper oxide as supplementary cementitious nano materials has never been ventured by the researchers.

With this research gap, the formulated concrete blends is made by partially replacing ordinary Portland Cement (OPC) with nanomaterials such as multi-walled carbon nanotubes (MWCNT), titanium dioxide (TiO_2) and copper oxide (CuO) in various proportions such as 0.1%, 0.25% and 0.5% to study the properties of strength and durability.

Experimental Materials and Methodology

Materials

Ordinary Portland cement:

In order to create the mixes, ordinary port land cement (OPC) meeting the requirements of IS 12269 was used to essential for fusing the components together. The specific gravity of cement is 3.15 and X-ray Fluorescence (XRF) examination was carried out to ascertain the chemical composition. According to the particle size analysis, 85% of particles are smaller than 46.5 μm. The loss on ignition is found to be about 1.04%. Table 1 represents the chemical composition of OPC 53 grade cement.

Modules	OPC 53

Table 1:

Chemical Composition in oxides (%)	Silica (SiO_2)	18.91
	Alumina (Al_2O_3)	4.51
	Iron (Fe_2O_3)	4.94
	Magnesium (MgO)	0.87
	Sulphur (SO_3)	2.5
	Calcium (CaO)	66.67
	Sodium (Na_2O)	0.12
	Potassium (K_2O)	0.43
	Loss on ignition (60 min)	1.04

Chemical composition of cement

Multi walled carbon nano tubes:

Multi walled carbon nano tubes (MWCNT) with diameters ranging from 5 to 20 nm and lengths ranging from 2 to 10 μm were used as shown in the **figure 1**. Platonic Nanotech located in Jharkhand provided the Carbon Nano Tubes with a purity of 98% and specific surface area using Blains permeability apparatus is 264 m^2/g.

Fig.1: Multi walled carbon Nano tubes

Titanium di oxide:

The nano titanium di oxide (TiO_2) used in this research is 15nm with a hydrogen potential of l.6 and purity more than 99%. The material is non-reactive powder with white appearance as shown in **figure 2**.

Fig.2: Nano titanium di oxide

Copper oxide:

The copper oxide (CuO) nano material was used with an average particle size of 15nm and the specific surface area using blain's permeability apparatus is 46 m^2/g. the nano copper oxide has density less than 0.16 and purity above 99%. **Figure 3** shows the nano copper oxide in dry powder form.

Fig.3: Nano Copper oxide

Aggregates:

The crushed stone sand of zone II gradation is adopted as a fine aggregate for the research study and a coarse aggregate of 20 mm size granite stone obtained from the nearest quarry is used in the composite. The sieve analysis, specific gravity and water absorption is performed as basic material tests for aggregates and the results are shown in Table 2. The coarse aggregates gives the strength and volume stability to concrete by filling is angular pores with crushed stone sand, hence the condition of aggregates were taken in saturated surface dry to exempt from the absorption through porosity [17,18,19].

Table 2: Physical properties of aggregates

Modules		**Fine Aggregate**	**Coarse Aggregate**
Physical Properties	Specific gravity	2.64	2.62
	Fineness modulus	2.84	3.56
	Water Absorption	1.25%	0.86%

Mix proportions and Specimen preparation

In this experimental investigation, the mix was designed for the grade of 20MPa (M20) [20, 21], nine mixes were prepared by varying the dosage rate of nanomaterials such as MWCNT, CuO and TiO_2 which were added in the percentages of 0.1, 0.25 and 0.5 by weight of cement in addition with the conventional cement.The adopted w/c is 0.5 and Table 3 represents the mix design proportions. The specimens of dimensions 100 mm diameter and 50 mm height were prepared from the formulated mixes to evaluate for sorptivity test and 150 mm cubes were prepared to evaluate compressive strength and water absorption test. After 24 h of casting, the moulds are removed and the specimens are immersed in the curing tank for 28 and 56 days.

Table 3: Formulated Mix proportions in kg/m^3

Modules		**Cement+ NM**	**FA**	**CA**	**Water**
CM	0%	394.32	616.11	1087	197.16
MWCNT 1	0.1%	393.93+0.39	616.11	1087	197.16
MWCNT 2	0.25%	393.34+0.98	616.11	1087	197.16
MWCNT 3	0.5%	392.35+1.97	616.11	1087	197.16
TiO_2 1	0.1%	393.93+0.39	616.11	1087	197.16
TiO_2 2	0.25%	393.34+0.98	616.11	1087	197.16
TiO_2 3	0.5%	392.35+1.97	616.11	1087	197.16
CuO 1	0.1%	393.93+0.39	616.11	1087	197.16
CuO 2	0.25%	393.34+0.98	616.11	1087	197.16
CuO 3	0.5%	392.35+1.97	616.11	1087	197.16

Experimental Methods:

Compressive strength:

Compressive strength is defined as its resistance to failing under compressed loading and influencing its operational effectiveness. This test was performed as per IS 516 [note] specification on the prepared concrete samples of different compositions. The test was performed on 150 mm X 150mm X 150mm cubic samples at 28 days of curing using a 3000 kN digital Compression Testing Machine manufactured by AIMIL. The application of load should be done without shock and taken as 140 kg/cm^2/min. The application of load is done using 0.58 Kn/s.

Water Absorption:

The ability of concrete to absorb water through its pores at desired curing ages and in its hardened form is determined by its water absorption characteristic [22]. The percentage values obtained provide a measurement of the amount of water absorbed by the reinforced and unreinforced quaternary blended concrete sample. The test was conducted and results were evaluated as per ASTM C 642 at the curing age of 56 days as shown in **figure 4**. After completion of the desired curing age, the specimens are removed from the water and saturated weight is recorded as W_{ssd}. After which the samples were over dried at a temperature of $105^0 \pm 5^0$ C until the mass of the specimen gets constant and weight is noted at W_{ds}. The formula for water absorption is as follows.

$$\text{Water absorption} = (W_{ssd} – W_{ds} / W_{ds}) \times 100$$

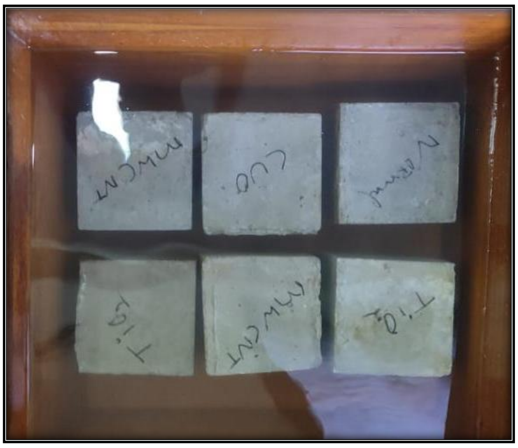

Fig.4: Water absorption samples

Sorptivity:

The sorptivity is the measure of capillary ascent of water into the specimen body through the pore structure. The preliminary condition of the 100mm x 50mm specimens were dried in an oven for three days maintain a temperature of 50^0 C. The dried samples were kept in a desiccator to maintain the room temperature and it is sealed using any sealant material like wax or brown tape. The sealing is done all the sides except the bottom portion from which the water is allowed to percolate. The initial sample weight was recorded and the specimens were then submerged to a depth of 5 mm in a tray of water as depicted in **figure 5**. After taking the specimen from the water and wiping off any extra water that may have remained on it, its weight is recorded at various time intervals such as 1,3, 5, 10, 20, 40, 60, and 120 minutes and continue upto three days i,e 72 hours after specific curing time.The same procedure is done at various time intervals. The specimen's mass per unit area and the square root of time should be plotted on a graph [23]. The sorptivity value was then determined using the computed slope. Since it is one of the durability parameter which should be performed long term, hence after 56 of water curing the sorptivity values of all the specimens are determined using the following formula.

$$I= S \times t^{1/2}$$

Where I is the water absorbed per unit area (m^3/m^2), S is the Sorptivity ($m/s^{1/2}$) and t is the exposure time (s).

Fig.5: Water sorptivity specimens

Finite Element Modelling of Concrete Cube:

A numerical approach called Finite Element Analysis (FEA) offers solutions to issues that would be challenging to solve in any other way. A commercial program called ANSYS was used to carry out the numerical analytical research. This software is a collection of potent engineering simulation tools based on the finite element approach that can resolve issues ranging from the most difficult non-linear simulations to relatively basic linear assessments. The Analysis is done on 150mm cubic specimen by applying the boundary conditions to find the load, deformation, stress and strain.

Results and Discussions:

Compressive strength:

The results pertaining to the compression test for the nano materials blended concrete mixes reinforced with MWCNT, CuO and TiO_2 at curing period of 28 days are compiled in Table 5 with different percentage of replacement. An enhancement in the compressive strength was observed with the increase in dosage percentage of the MWCNT, TiO_2 and CuO. It was inferred that the strength value increased with increase with the nano materials incorporation up to 0.5%. Compared to the conventional reference mix (0% of NM) which is 24.6 MPa, there is an increase in strength of about 2.84%, 12.6% and 20.3% with the dosage of 0.1%, 0.25% and 0.5% at a curing period of 28 days. Similarly the strength nature in also observed in case of TiO_2 and CuO mixes at 28 days of curing as shown in **figure 6** and statical data was computed using the above values[24]. The strength of all the mixes has significantly risen with the longer curing times. The increase in strength is attributed to the filler material's densification of the interfacial transition zone during the development of the nano material blended concrete. In addition, the additional nano materials were crucial in preventing the nano scale cracks, which in turn helped to increase compressive strength. In comparison with all the blends of nano material the MWCNT behaves better than TiO_2 and CuO which is 20.3% at 0.5% replacement.

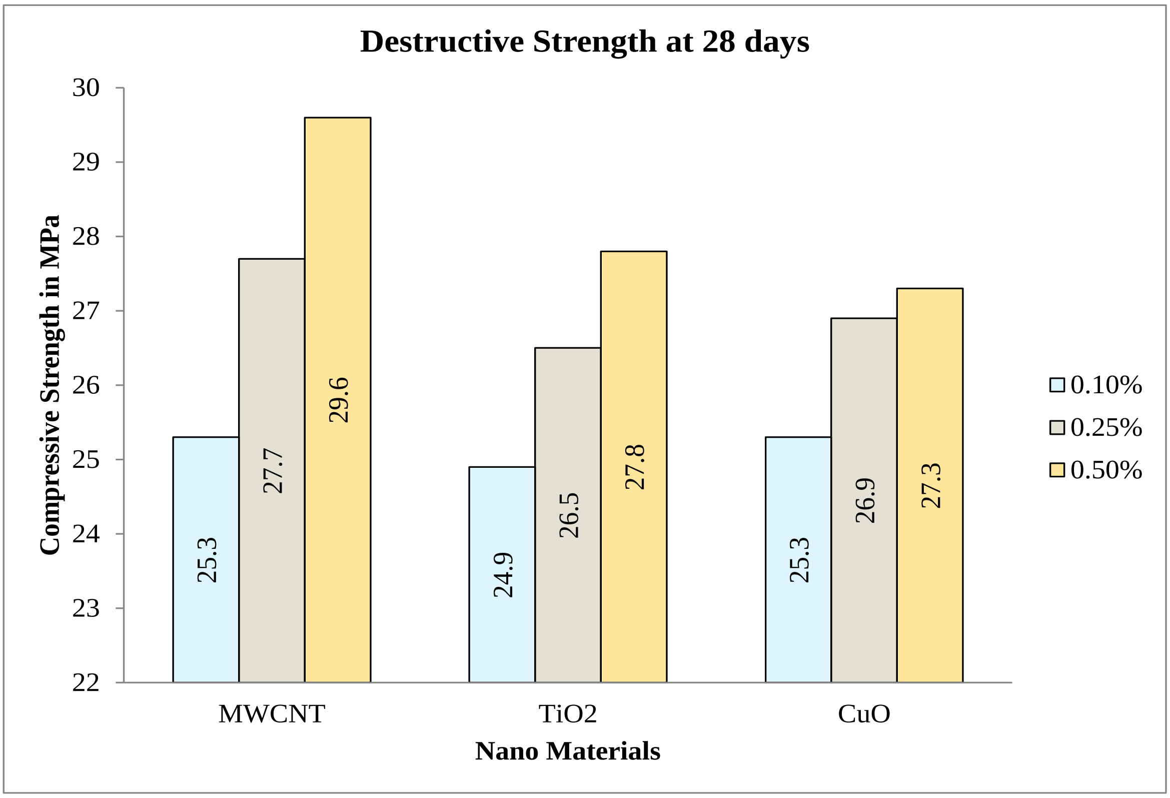

Fig.6: Compressive strength results at the age of 28 days

Water Absorption:

The water absorption values obtained were presented in figure 7. From the results, it was observed that the water absorption for the mix reinforced with MWCNT, CuO and TiO_2 at different proportions showed lesser values compared to the conventional blended concrete mixes. The observed values are 2.64%, 2.7% and 2.82% upto 0.5% addition of MWCNT, TiO_2 and CuO. When compared these values with the conventional concrete after 56 days of curing period, it can be inferred that the quaternary blended concrete reinforced with 0.5% of the NM served to be an optimum mix as at this percentage of addition, the mix exhibited the lower water absorption rate compared to any other system of mixes formulated. Hence it was evident that the synergic effect of the mineral admixtures have not only served to be a Nano filler, but also accelerated the pozzolanic activity by forming a CSH gel which contributed towards the refining of the pore structure and formation of a denser composite [25].The formation of the dense microstructure have reduced the permeability of the cement composite thereby proving to have enhanced durability performance compared to conventional mix. The results are shown in the **figure 7**.

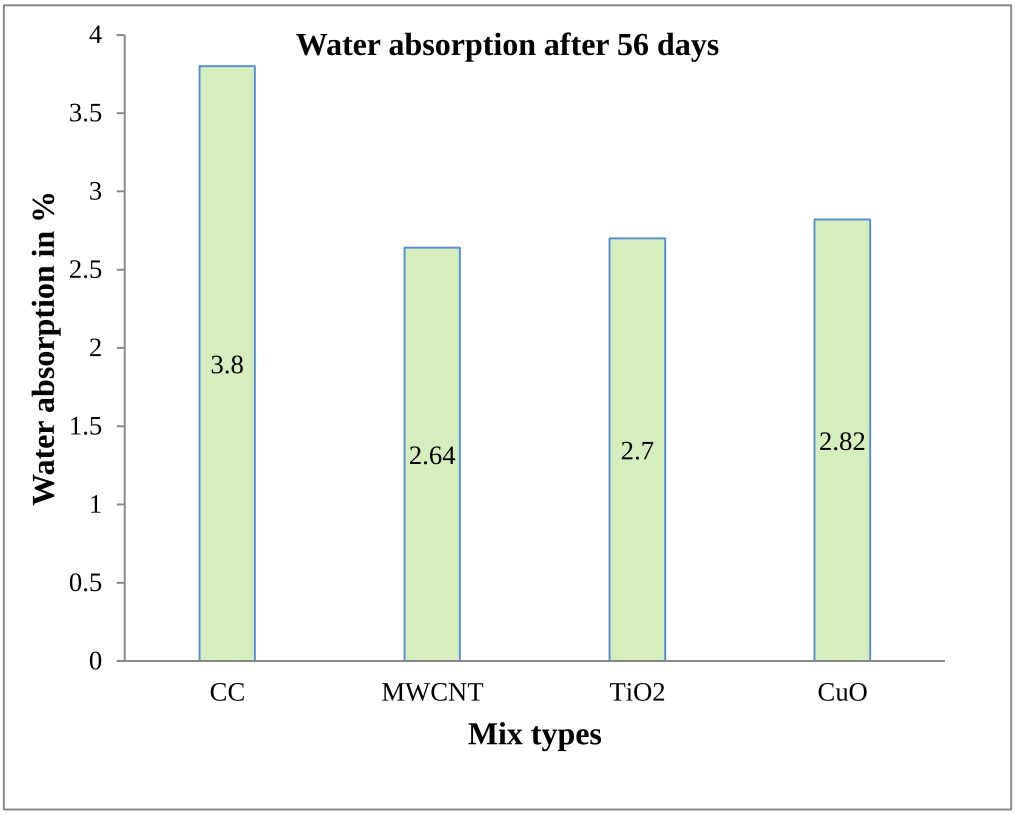

Fig.7: Compressive strength results at the age of 28 days

Sorptivity:

Sorptivity which is an indication for the capillary rise of water through the porous structure was found to be higher for the conventional concrete in unreinforced condition compared to all other nano material blended mixes. The water which was absorbed per unit area for all the formulated mixes were plotted against the square root of the time are presented in the **figure 8**. The value was found to be least in case of the mix MWCNT bearing 0.5%. The highest value observed in case of conventional mix may be due to the porous nature. The decreased values of the sorptivity in case of the mixes reinforced with NM up to 0.5% was attributed to the accelerated pozzalanic activity exhibited which forms the dense microstructure.

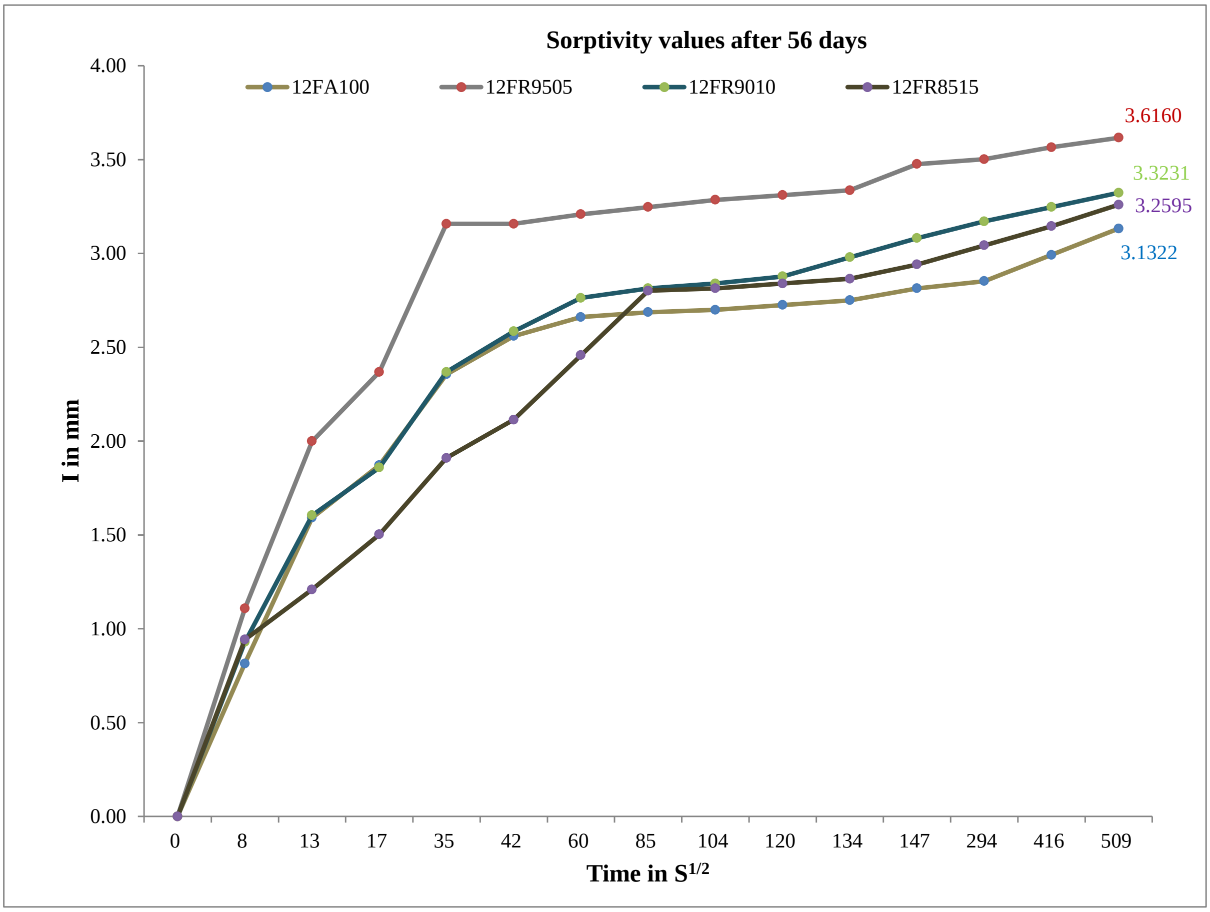

Fig.8: Sorptivity values after the curing age of 56 days

Finite Element Analysis:

The finite element analysis study included modelling a concrete cube with the dimension of 150 mm x 150mm x 150mm and properties to create the finite element model in ANSYS 22. There are multiple tasks that have to be completed for the model to run properly. Models can be created using command prompt line input or the Graphical User Interface. For this model, the graphical user interface was utilized to create the model. This section describes the different tasks and entries to be used to create the finite element calibration model.

For the model to be constrained and produce a singular solution, displacement boundary conditions are required. Boundary conditions must be used at the places of symmetry and where the supports and loadings are present in order to guarantee that the model behaves in the same way as the experimental beam. First, boundary criteria for symmetry were established. The model being used has one plane on which it is symmetrical.

The cube analysis was done mainly for the nano blended materials considering elastic modulus as 30 GPa and Poisson’s ratio of 0.2 with a density of 2400 kg/m^3. Table 4 shows the static loading which results in Average deformation, stress and strain. MWCNT gives good observation as shown the **Figure 9 to 12**.

Table 4: FEM results of Nano materials blended concrete

NM		**Load in KN**	**Deformation in mm**	**Stress in MPa**	**Strain**
MWCNT	0.1%	569.25	0.06224	24.62	0.0008212
MWCNT	0.25%	623.25	0.06814	26.96	0.000899
MWCNT	0.5%	666	0.0728	28.81	0.00096
TiO_2	0.1%	560.25	0.06125	24.24	0.000808
TiO_2	0.25%	596.25	0.0651	25.8	0.000859
TiO_2	0.5%	625.5	0.0683	27.1	0.000902
CuO	0.1%	569.25	0.0622	24.62	0.000821
CuO	0.25%	605.25	0.0661	26.18	0.000873
CuO	0.5%	614.25	0.0671	26.57	0.000886

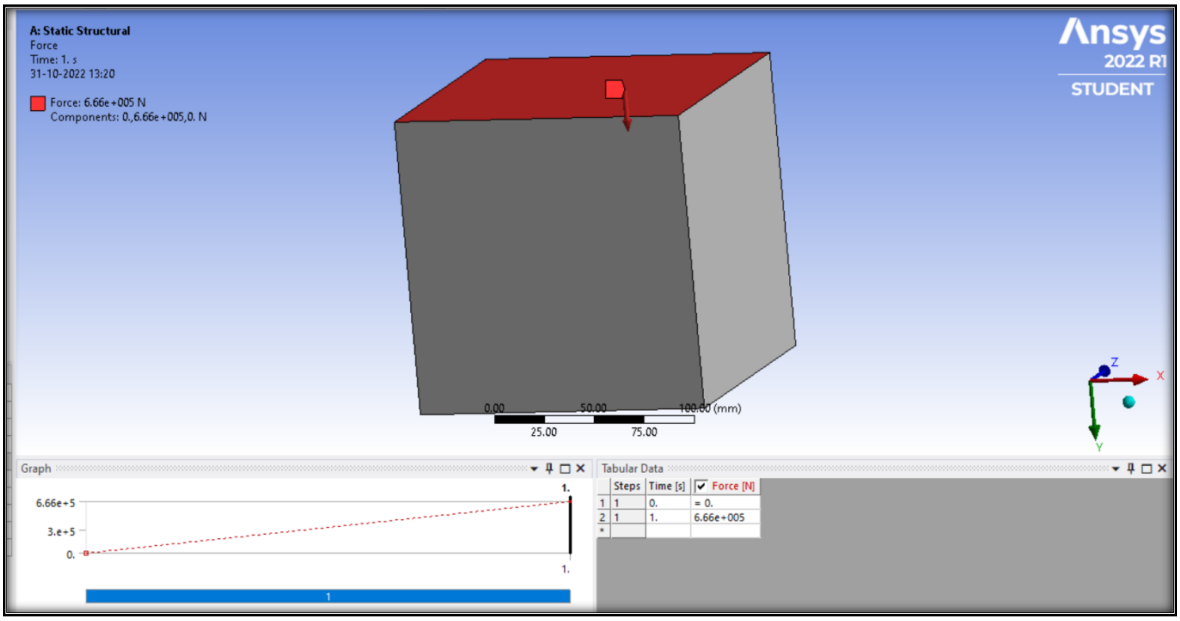

Fig.9: Model of MWCNT at 666 KN loading

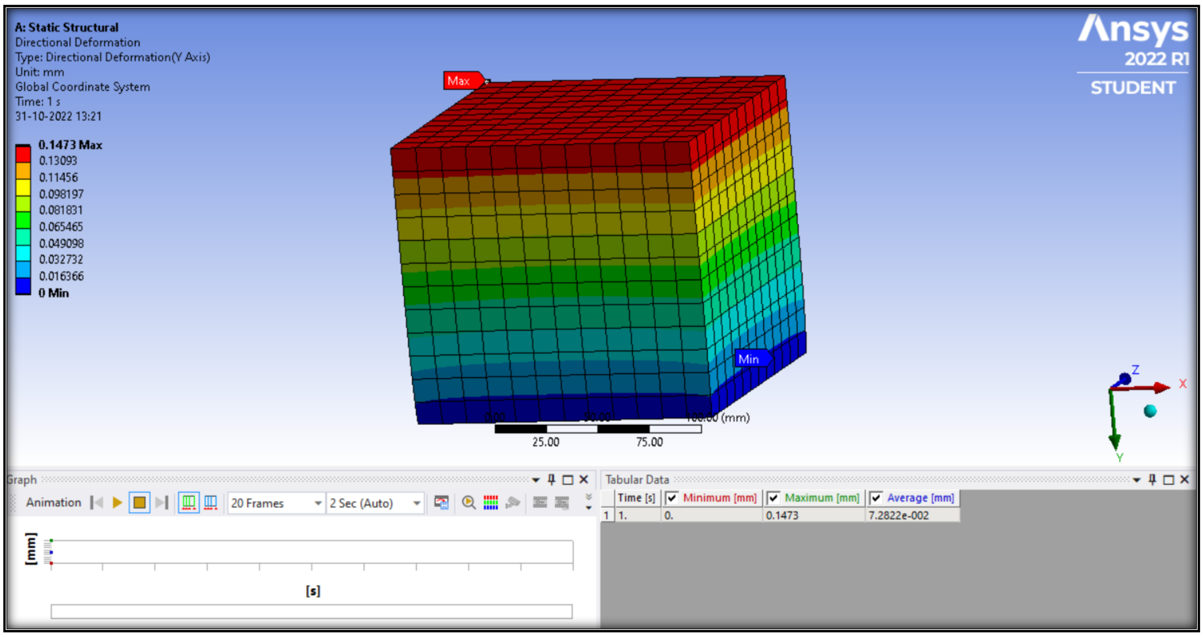

Fig.10: Deformation of MWCNT at 666 KN loading

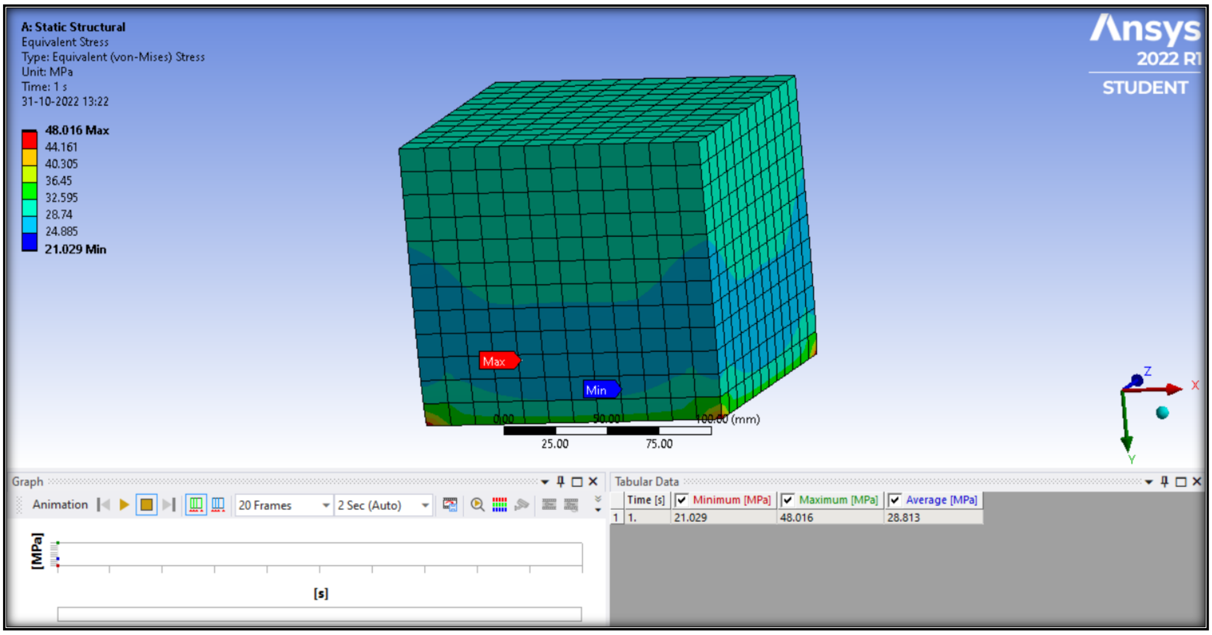

Fig.11: Stress values of MWCNT at 666 KN loading

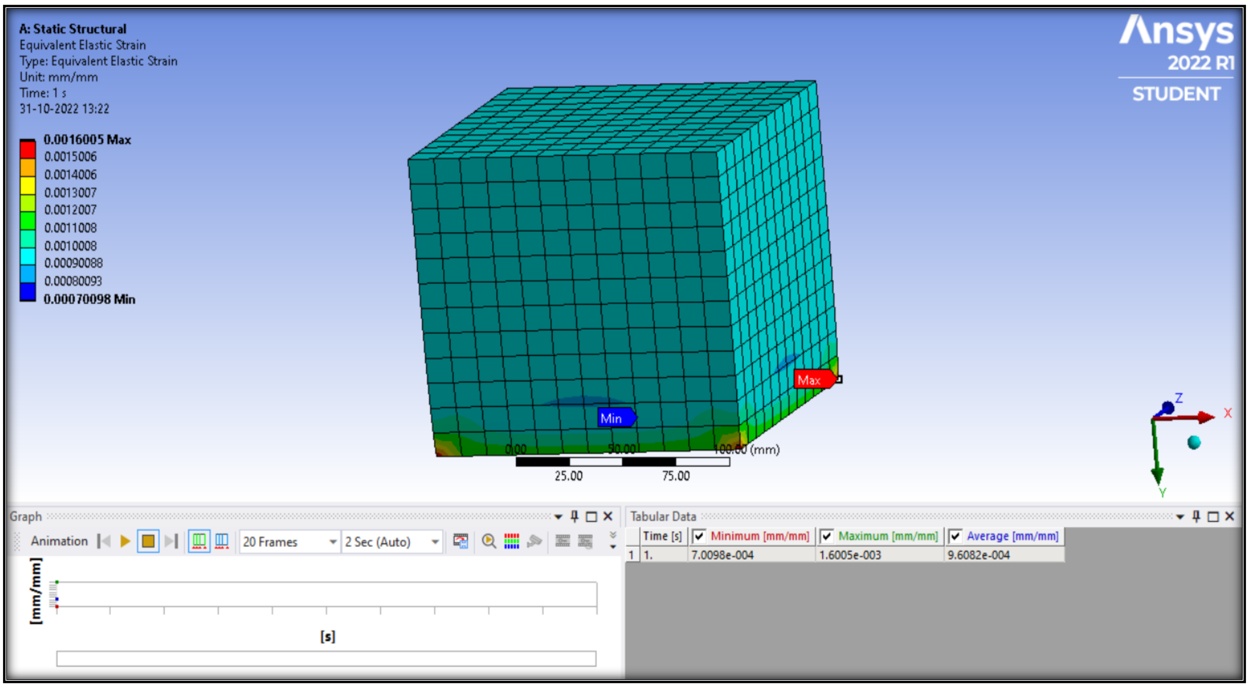

Fig.12: Strain values of MWCNT at 666 KN loading

Conclusions

1. The compressive strength value for all the nano material based mixes were higher when compared to the conventional mix. The mix with dosage of 0.5% of the Multi Walled Carbon Nano tubes exhibited higher value of 29.6 MPa at 28 days of curing period.

2. The mix MWCNT bearing the dosage rate of 0.5% exhibited the lower water absorption value in contrast to TiO_2 and CuO. But all the mixes are less than 3% compare to conventional mix.

3. The coefficient of the water absorption was also found to be very less for the nano blended mixes owing to the refinement of the pore structure by the synergic effect of the mineral properties in the composition.

4. The results using ANSYS software shows the marginal stress value with experimental values. Among all the mixes MWCNT with 0.5% is found optimum with a stress of 28.81 MPa.

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