



## ROLE OF POLYMERS AND NANO MATERIALS IN ENHANCING ENGINEERING PROPERTIES OF CEMENT CONCRETE

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### ABSTRACT

Cement concrete is the only material which has been used maximum for construction of buildings. Now the construction technology is accommodating new materials day by day, Inclusion of polymers and nano materials in cement concrete is getting more attention. Polymers and nano materials are improving the engineering properties of the cement and concrete. Newer kinds of cement concrete composites have more compressive and flexural strength along with improved as chemical resistance, impact resistance and temperature resistance. The polymers which have been commonly used are styrene butadiene rubber, polyvinyl acetate. Acrylic polymers and epoxy polymers have been tested for aggressive exposure such as, for high temperature, chemicals exposures etc. with promising results. Nano materials such as ZnO, nano TiO<sub>2</sub>, nano ZrO<sub>2</sub>, nano Al<sub>2</sub>O<sub>3</sub>, nano CaCO<sub>3</sub> have also shown improved water resistance, flexural strength, compressive strength and in reducing cement cracks. This article presents an analytical review of enhancement of mechanical properties ; such as compressive strength and tensile strength, due to addition of polymers and nano composites with cement mortar and concrete.

**KEY WORDS:** Epoxy resin, nano ZnO, nano Al<sub>2</sub>O<sub>3</sub>, acrylic resin, PMMA



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## INTRODUCTION

Now day's smart materials provided by new technology are getting a lot of attention. Chemistry of Polymers with cement concrete and nano materials are the need of the hour. Green building concept becoming popular day by day. People are trying to find out sustainability in construction materials and technologies. Nano technology is setting new dimensions for construction industry by providing new construction composites with nano and polymeric materials. Different types of polymers have been added into cement concrete to enhance the engineering properties of the cement concrete and mortar. Some of the latest types of cement concrete are developed by using nano materials, polymers are reviewed here.

## THERMAL INSULATION WITH NANO MATERIALS IN BUILDINGS

Nano materials were generally used in space research, pharmaceuticals, and electronics products, but nowadays nanotechnology offers many applications in building constructions also. In this paper some of the nano materials which are used as thermal insulator are discussed. These nano materials are (a) Expanded polystyrene Graphite (EPS Graphite) (b) Aerogel (c) nano particle based vacuumed insulator panel (d) Nano ceramic thermal insulating panels. Heat can be transport by three methods from any conventional materials (i) convection (ii) flux (iii) radiation. Heat transfer depends upon surface material's property (heat transfer coefficient), its thickness etc. EPS Graphite, Aerogel, Vacuum insulator panels having lower thermal conductivity EPS Graphite (Expanded polystyrene Graphite ) with some additive is used in building construction. It may be used outer facade coating of wall or lower side of slab structure. It has good compressive strength(100-150 kPa). Vacuum Insulator panels are made with compressed fumed silica and silicon carbide, sealed with high barrier laminate of polyethylene-terephthalate and this all is coated with 30 nm Aluminium layers. These can be used for insulating flat and high roof, slab structures, facade walls and floors. Aerogels are primarily derived from silica. In today's time these can be prepared from other materials like Alumina, Carbon, Tin dioxide, chrome etc. It can be applied for thermal insulation of slab column, floors. Aerogel blankets are available 2-10 nm thickness. It may be used on translucent and transparent glasses.<sup>1</sup>

## EFFECT OF NANO ZINC OXIDE (ZNO) IN SELF COMPACTING CONCRETE (SSC)

Nano technology showed that by the use of nano particles, the density of cement increases because nano voids are filled by nano materials. The reactivity of materials also increases, because nano particles becomes nuclei for cement particles, which increases the hydration reaction due to their high surface area. Nano zinc oxide exhibits semiconducting and piezoelectric dual properties. Generally, it is added into various composite materials in industries and products. In civil engineering various construction components such as ceramics, glass, cement, paints, sealants this

material is used. In cement concrete, the addition of ZnO improves the resistance of cement concrete against water. Nano Zinc Oxide of average size 30 nm was tested in self compacting concrete. Mechanical properties of cement concrete studied with inclusion of nano ZnO. Addition of ZnO at a concentration of 0.1% to 1.0% improved the compressive strength and tensile strength. To understand the synthesis of composite, scanning electron microscope (SEM), and X-ray diffraction images were taken. Split tensile strength increases at 0.5% of ZnO concentration. By increasing concentration up to 1% of nano ZnO split tensile strength start decreasing to the control sample. Similarly flexural strength is maximum at 0.5% concentration of nano ZnO, and starts decreasing at 1% concentration. Setting Time reduces considerably with increase of ZnO.<sup>2</sup>

## EFFECT OF NANO ZIRCONIUM OXIDE ON STRENGTH OF CEMENT CONCRETE

Nazari et al. in their experiment found the influence of some nano phase oxides of zirconium  $ZrO_2$ . They replaced the cement by 0.5%, 1.0%, 1.5%, and 2.0% by nano zirconium oxide. The average size of nano materials was of 15 nm and purity was 99.9%. Water to binder ratio was kept 0.4 in all cases. Other details were, sand locally available size less than 0.5 mm and Fineness modulus of sand was 2.25, specific gravity 2.58 gm/cm<sup>3</sup>, maximum size of crushed basalt aggregates 15 mm and specific gravity 2.96 gm/cm<sup>3</sup>. Curing of concrete is done for 7, 14, 28, days before testing for their mechanical properties like flexural, tensile, compressive strength. The result showed that maximum improvement in strength is found at 1%. After 28 days of curing, The results in their experiments showed that the compressive strength increases up to 18.4% by adding 1 % of nano  $ZrO_2$ , adding more zirconium oxide the strength value start decreasing. But slump value (workability) decreases by addition of  $ZrO_2$ . It was found that slump value for control mix was 7.8 cm and it reduced to 3.0 cm at 2% addition of nano  $ZrO_2$ . So that to maintain normal workability with nano zirconium oxide super plasticizers were necessary to be added.<sup>3</sup>

## EFFECT OF NANO TITANIUM OXIDE ON STRENGTH OF CEMENT CONCRETE

Titanium dioxide ( $TiO_2$ ) possesses very good sterilizing property and antifouling properties. By photo-catalytic process number of air pollutants present in air (organic and inorganic) captures and breaks down because of  $TiO_2$  coating. Glass is now an important surface covering component for any building. In recent times Nano Titanium Dioxide ( $TiO_2$ ) is being used to coat the glasses for making the glass self cleaning.<sup>4</sup> Nazari (2010) in his experiment partially replaced experimented nano phase  $TiO_2$  particles in cement concrete. (Specifications of  $TiO_2$  were; purity 99.9%, size  $15 \pm 3$  nm, surface area  $155 \pm 12$  m<sup>2</sup>/g density 0.13 g/cm<sup>3</sup>). The change in flexural strength, compressive strength, split tensile strength; slump value and setting time have been studied. Split tensile strength and flexural strength increases up to 66% and 25%, and compressive strength increases up to 17.9%, at 1% of nano  $TiO_2$  and

then reduces at more % of nano TiO<sub>2</sub>. To conclude, up to 2% TiO<sub>2</sub> can be added in cement. But by adding TiO<sub>2</sub> setting time (initial and final setting time) decreases, and workability (slump value) decreases.<sup>5-6</sup>

### **EFFECT OF NANO ALUMINA (AL<sub>2</sub>O<sub>3</sub>) ON STRENGTH OF CEMENT CONCRETE**

The addition of nano-Al<sub>2</sub>O<sub>3</sub> improves the mechanical properties of cement concretes, in terms of higher split tensile and flexural strength. Nano Alumina Al<sub>2</sub>O<sub>3</sub> with higher surface area reacts with Ca (OH)<sub>2</sub> produced from the hydration of Calcium Silicates. It is well known that the rate of chemical reaction is directly proportional to the surface area available for chemical reaction. It is observed that cement can be replaced up to 2% with nano Al<sub>2</sub>O<sub>3</sub> in the concrete. In this experimental investigation nano Al<sub>2</sub>O<sub>3</sub> was taken with cement concrete for test. The specification of nano Al<sub>2</sub>O<sub>3</sub> particle size was, size 15±3 nm, surface area 165± 12 m<sup>2</sup>/g, density 0.1 g/cm<sup>3</sup>, purity 99.9%. Results showed that compressive strength increases up to 16.3%, and split tensile strength increase up to 55.5%, at 1% inclusion of nano alumina and other physical properties setting time decreases and slump value decreases (Nazari, et al., 2010). Arefi (2011) performed experiment on cement mortar with nano Al<sub>2</sub>O<sub>3</sub>. Alumina was taken in different proportions (1%, 3%, 5%, of cement). For compressive strength tested on cube of 5x5x5 cm samples, and for flexural strength size of samples were 40x40x160 mm. Fine aggregates were crushed silica sand with fineness modulus 2.4 and apparent density 3.33 gm/cm<sup>3</sup>. (Average nano particle was size 20 nm, specific surface area 200 m<sup>2</sup>/gm, density 0.9 gm/cm<sup>3</sup>, and purity 99.9%). Super plasticizer of relative density 1.15 was used. Experimental results found that 3% results are the best for flexural, compressive, and tensile strength. At this 3% researchers found that the Ca (OH)<sub>2</sub> is reduced and micro structure was more dense, the Scanning Electron Microscope (SEM) images also reflected the same. At 5% of nano Al<sub>2</sub>O<sub>3</sub>. strength results are less than the control mix, due to agglomeration of nano particles voids are created less than the strength.<sup>7-9</sup>

### **USE OF NANO CALCIUM CARBONATE (CaCO<sub>3</sub>) PARTICLES IN RETROFITTING OF HISTORICAL MONUMENTS**

Experiments show that addition of micro sized CaCO<sub>3</sub> cement reduces the strength but by adding nano particles of CaCO<sub>3</sub> improves the strength. It has been reported that micro hardness improvement in the strength is found when nano-CaCO<sub>3</sub> is added to cement. When about 20% nano-CaCO<sub>3</sub> added to the Ordinary Portland Cement (OPC) micro hardness value increased (Hengyang, et al., 2008, Patel, et al., 2013). Nano lime is being used in the consolidation of lime plaster and lime stone for conservation of historical monuments. It is suspended nano particles of calcium hydroxide in alcohol. It penetrates into porous surfaces and alcohol evaporates after some time and calcium hydroxide converts into calcium carbonate. Thus, nano

technology aids in the preservation and restoration of aged monuments of cultural heritage.<sup>10-14</sup>

### **EFFECT OF POLYMERS ON CEMENT CONCRETE (PC)**

Polymers can be added to cement concrete to replace cement partially or fully. The air voids present in the concrete reduces the strength of concrete, if the voids can be filled by some suitable materials then the strength of concrete can be increased. In polymer concrete, the slight percentage of low viscosity polyester resin is introduced which fills the micro level voids and concrete is tightly packed and so that the strength of concrete get increased. The percentage of polymers may vary from 5 to 15 %. This polymer concrete is especially suitable for use as repair work, weathering resistant concrete, high ductility performance, chemical resistance is required. Epoxy resin (polymer) concrete is new experimentation in concrete to improve the properties of cement concrete. By using epoxy resin the flexural strength can be increased. (it is also called high performance epoxy resin concrete). The chemical resistance of polymer concrete is also better than Ordinary Portland Cement- concrete. By adding polymers and nano materials electrical and thermal properties also affected. It is best suited in the areas such as bridge decks, sea protection works, aerospace launching platforms, seismic resistant structures, pre-cast concrete structures etc.<sup>15-19, 25-26</sup>

### **EFFECT OF POLY METHYL METHACRYLATE (PMMA) IMPREGNATION ON PROPERTIES OF CONCRETE**

The study (Nair et al. 2010) showed that the strength of Polymer impregnated concrete (PIC) samples and chemical resistance were better than those of traditional cement concrete. impregnation of polymers is done by two methods. w/c ratio was taken 0.48. cubes of dimension 50x50x50mm were prepared for compressive strength. For flexural strength moulds of size 40X40X160 mm size were prepared, all specimen were cured for 28 days before polymerization and impregnation. The specimen were dried for 8 hours at 80°C. then samples were immersed in 1% polymer in water bath for 4.5 hour at room temperature. Then samples were polymerized by two methods. (1) keeping the samples in polyethylene terephthalate (PET) bags immersed into 80°C hot water for three hours. (2) keeping these specimen in microwave for two hours, at 80°C. to achieve uniform heating. It is found that compressive and flexural strength increases two folds, water absorption reduces, freezing and thaw resistance increases, chemical resistance increases, microwave impregnation is found better than water bath method.<sup>20</sup>

### **RESISTANCE OF POLYMERS CEMENT CONCRETE WITH AGGRESSIVE THERMAL AND ACIDIC EXPOSURE**

Concrete and cement mortar (repair material) may deteriorate due to many reasons such as excessive loads, temperature variation, moisture, chemical attack etc. Plain cement mortar do not have capacity to bear it

for long-time. Polymer concrete can be the solution of these problems. Polymer concrete has good adhesion and low shrinkage. Polymers can be added in cement concrete mix (polymer modified mortar or concrete) or polymers can be directly mixed with aggregate without cement also (polymer concrete). The choice of polymers depends upon the requirement of the function to be performed. Mortar or repair material not always subjected to room temperature. There may be high rise in temperature or very high temperature continuously, like in chimney, thermal power plants etc. Karde et al. 2009 in their experimental research, studied five different samples- control mix of plain cement concrete of cement and sand in ratio 1:3, with w/c ratio 0.4, other specimen prepared with polymer and sand (1:5 ratio), Acrylic, SBR, Epoxy emulsion, Epoxy resin. Investigations were done for aggressive environment; effect of thermal cycles, influence of high temperature, and effect of acidic exposure. In thermal cycles experiment samples were kept at high temperature of 85° for 8 hours a day then cooled at room temperature. Such 30, 60, 90, 120 cycles are applied. Then samples are tested for the strength. And sample are tested for acidic exposure, in which samples are kept in acid solution (5% sulphuric acid) for 180 days, and found that polymer concrete had best resistance to the acidic exposure and thermal cycles, but exhibited poor resistance for high temperature change. In Compressive strength was least in epoxy resin against acidic exposure. Epoxy emulsion showed best results against higher temperature and best resistance against thermal cycles.<sup>21</sup>

### COMPARISON OF EFFECTS OF DIFFERENT POLYMERS ON STRENGTH OF CEMENT CONCRETE

Aggarwal LK, et al 2007 presented the comparative study of two types of polymer admixtures of cement concrete, epoxy and acrylic emulsions and found that epoxy emulsion is found better than acrylic emulsions as admixtures. is the authors found that when polymers are added, compressive and flexural strength decreases initially, but at higher level of percentage the flexural strength is better than control mix. But at the same time

by adding polymers the other properties like chloride ion, penetration, depth of carbonation, and water absorption decreases. This experiment depicted that the durability of polymer concrete is better than conventional cement concrete

### EFFECT OF VERY HIGH TEMPERATURE ON STRENGTH OF POLYMER CONCRETE

Tumadhir MA 2013 studied the effect of high temperature on polymer concrete when Epoxy resin polymer percentage 5%, 7%, 10%, 15% of cement is used. Temperature raised 200°C, 400°C, 700°C for half hour, and one hour exposure, after 28 days of curing. After Temperature exposure cement concrete is tested for compressive strength and split tensile strength. The result shows that when the best temperature resistant result are on 7% resin mixed in cement concrete. (Variation in strength is least on 7%).<sup>23</sup>

### EFFECT OF REPLACEMENT OF CEMENT BY EPOXY RESIN ON STRENGTH OF POLYMER CONCRETE

Polymer modified Portland polymer concrete possesses good ductility, compressive strength over conventional concrete. In the article by Alkhaleefi AM, 2002 epoxy polymer was used. For flexural test mould of 150x150x600 mm was prepared, for compressive test mould of 150x150x150 mm is prepared, and split tensile cylindrical of diameter 150 a height 300 mm is prepared. The strength of cement concrete was examined by replacing the cement 0, 20, 40, 60, 100 percent by epoxy resin. To examine the mix concrete after addition of polymers following test were performed- compressive strength split tensile strength, four point flexural test, and direct shear test. It was found that improvement in the strength were as following: compressive strength increased 75%, split tensile strength increased 98%, the increment in shear strength was 148%, and the increase in flexural strength was 51%. This experiment showed that suitable polymer can successfully replace cement binder. The fact established that polymer concrete is stronger than conventional cement concrete.<sup>24</sup>

**Table1**  
*Effect of polymers on strength of cement concrete*

Cement replaced by Polymer in concrete percentage (epoxy resin)	Flexural strength of concrete in Mpa (approx)	Compressive strength of concrete In Mpa (approx)	Tensile Strength concrete In Mpa (approx)	Shear strength of concrete In Mpa (approx)
20%	4.0	32	3.8	4.1
40%	5.0	35	4.2	4.5
60%	6.0	38	4.4	5.1
100%	20.0	56	7.0	10.0

### CONCLUSION

From above results we can conclude that nano particles can be advantageously replaced up to 2% only, Setting time decreases due to fast hydration reaction of nano particles. Different types of polymers can replace cement up to certain amount. With cement the polymers content are useful up to 15-20% for strength

enhancement. It is clear from above discussion that we can obtain greater benefits in flexural strength and compressive strength with polymer addition, by adding more polymers mechanical strength starts decreasing. At the same time other properties like chemical resistance, temperature resistance, get increased on the other hand shrinkage, chloride ion penetration, depth of carbonation reduced by use of polymer and nano

materials which is more desirable. Polymer concrete (PC) or Polymer Modified Concrete (PMC) is definitely beneficial for repair work for concrete and for severe chemical exposure. It is clear that the properties of cement concrete is greatly enhanced by polymers and nano materials. However the results of experiments

done by different researchers are not consistent leaving much scope for further research work.

## CONFLICT OF INTEREST

Conflict of interest declared none.

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