Effect of Polymer modification on mechanical and structural properties of concrete – An experimental investigation

Sivakumar.M.V.N
Department of Civil Engineering, Birla Institute of Technology & Science, Pilani –
Hyderabad Campus
Hyderabad – 500078, India.
sivakumar.mvn@gmail.com
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ABSTRACT

This paper presents the effect of different polymers on structural and mechanical properties of concrete. The aim of this study is to investigate the mechanical and flexural properties of polymer modified concrete. Two different types of polymers are used at different dosages to modify the cement concrete matrix. Besides, a series of tests without modification was also carried out. By means of four-point loading method, the flexural strength and flexural properties of polymer modified concrete are measured. The influence of different polymers and its optimum dosage in respect of flow and strength characteristics are found. A comparative study has been carried out to highlight the effect of two different polymers on fresh and hardened properties of polymer modified concrete. Based on these results, recommendations are made in respect of its dosage, chemical characteristics and suitability.

Keywords: Concrete-polymer composites, Polymer-modified concrete, Polymer concrete

1. Introduction

For the past few decades, active research has taken place in polymer-modified concrete, polymer concrete and polymer-impregnated concrete. Currently the same is used as popular construction materials because of comparative high performance, multifunctionality and sustainability compared to conventional cement concrete. Concrete-polymer composites are environment-conscious and confirm to concerns of saving of natural resources, the longevity of infrastructures and the environmental protection.

Adding aqueous polymer emulsions or redispersible polymer powders in the fresh concrete mix makes polymer modification of concrete. The polymer emulsion is stabilised by surfactants, and each polymer has its own film forming properties within the applicable temperature range and the physico-chemical conditions during hardening and curing. The surfactants and the low film forming ability of most emulsions are generally hindering the building of highly performing and durable microstructures in the PCC.

The process allows building up of composite polymer-cement microstructures on a nano-scale, which can avoid the negative influences of the polymer-admixtures-cement interactions on the shape and distribution of the cement hydrate crystals, and on the transition zones between cementitious binder matrix and aggregates. This modified cement concrete contains two types of binder: the system based on hydraulic cement and the polymer system. An interpenetrating network of polymer and cement hydrates is generated in which the aggregates are embedded. Polymer modification is a frequently used technique to overcome
some of the shortcomings of conventional concretes such as poor tensile and impact strength, limited resistance to corrosion, poor behavior under severe conditions and poor adhesion of fresh mortar or concrete to old concrete. Some polymers are soluble in water and their low solubility causes difficulties in respect to the application concrete modifier. For water soluble polymers, one of the major advantages is the absence of surfactants to keep the polymers in solution. The polymer molecules are supplied on a molecular scale, improving the approach of the relative large cement grains (up till 80 μm) by the polymers. In the absence of surface active agents, the film formation on the hydrate crystals may proceed more easily and uniformly and the material properties can be better tuned and modeled.

There are various classes of water-soluble polymers that can be used for the modification of cement mortars and concrete. The first class consists of non-ionic polymers with an oxygen or nitrogen in the backbone of the polymer. Examples are polyethylene oxide (PEO) and polyethylene imine (PEI). These polymers can be synthesized with molecular weights up to the millions. Secondly, there are water soluble non-ionic polymers containing an acrylic group, e.g. polyacrylic acid (PAA) and polyacrylamide (PAAm). The water-soluble polymer polyvinyl alcohol (PVA), frequently used for the modification of concrete, belongs to the class of the water-soluble non-ionic polymers containing a vinyl group. The workability of the fresh mixture is markedly improved over that of ordinary concrete, because of plasticizing and air-entraining effects of the polymers. The modified systems show higher water retention than the ordinary systems. This may contribute to an improvement in the workability and the prevention of dry-out, and it also leads to superior adhesion to porous substrates such as ceramic tiles, mortars and concrete. In such cases, this type of polymers hardly contributes to an improvement in the strength of the modified system.

As a part of this study, a detailed literature survey is conducted and it reveals that, by varying the nature and concentration of polymer materials, concrete property can be varied across a wide range that makes polymer modified concrete versatile in its applications. Then, the results of the primary tests conducted in the laboratory reported that the use of PMC is rich in specific applications. However, with the increasing demand being made on concrete technology to serve the needs of society, experts are responding positively by proposing new formulations using other materials. Hence it is understood that, incorporating polymer materials into the concrete has, to some extent, contributed to this demand.

In this paper presents a comparative performance of two different polymers on conventional concrete. The selected polymers are from two different groups. The modification is brought by adding different dosages of polymers (by cement) to the conventional concrete. The behaviour of concrete is studied with respect to its mechanical and structural properties by varying the two polymer dosages. The optimum dosage of the individual polymer is found from the experimental details. Finally recommendations are made based on the experimental investigations.

2. Literature review

Polymers with different kinds of fillers are used as construction materials. They have good binding properties and good adhesion with aggregates. They have long-chain structure, which helps in developing long-range network structure of bonding. In contrast, cement materials provide short-range structure of bonding. As a result, polymer materials usually provide
superior compressive, tensile and flexural strength to the concrete compared to Portland cement. Some polymer materials may provide good adhesion to other materials as well as resistance to physical damage (abrasion, erosion, and impact) and chemical attack. The choice of polymer mainly depends on the application.

Conventional concrete materials combined with polymers could yield composites with excellent mechanical and physical properties. Polymer materials with wide variations in properties could provide complex properties to polymer-modified concretes, and thus, present an opportunity to design structural materials with tailored properties.

Mandel and Said (Mandel, 1990), conducted research on the effect of an acrylic polymer on the mechanical properties of mortar and found that the mechanical properties of mortar and the adhesion between mortar and a steel fiber improved with the addition of an acrylic polymer into the system.

Kim et al. (Kim, 1995), studied the properties of polyvinyl alcohol (PVA) modified mortar and concrete with up to 2% polymer by weight based on cement and compared the structure and properties of polymer-modified concrete with those without polyvinyl alcohol. The interfacial transition zone and fractured surface were examined with both polarizing optical microscopy and scanning electron microscopy. They concluded that polyvinyl alcohol modified mortar showed slower absorption of water as compared to the unmodified mortar, which was an indication of lower permeability of the polymer modified mortar.

Muthukumar and Mohan (Muthukumar, 2005), studied the mechanical properties and chemical resistance of Furan-based polymer concretes and concluded that they were cost-effective materials for construction in civil engineering applications.

Aggarwal et al. (Aggarwal, 2007), studied the properties of polymer-modified mortars using epoxy and acrylic emulsion, and found that these materials had superior strength properties and better resistance to the penetration of chloride ions and carbon dioxide than PMCs based on vinyl acetate, copolymers of vinyl acetate–ethylene, styrene–butadiene, styrene–acrylic, and acrylic-styrene-butadiene rubber emulsions.

Ohama et al. (Ohama, 1994), investigated the effect of the monomer ratio on the typical properties of polymer-modified mortars with styrene-butyl acrylate latexes. They found that the properties (pore-size distribution, flexural and compressive strengths, water absorption, and drying shrinkage) were affected largely by both monomer ratio and polymer-cement ratio.

Hence in this study an attempt is made to compare the effect of different polymer dosages on mechanical and structural properties of concrete in fresh and hardened state. Based on the experimental results, the optimum dosages are also reported.

3. Different polymers and its mechanism

Concrete has high compressive strength but is relatively weak in tension and adhesion, and its porosity can lead to physical and chemical deterioration. Polymers, on the other hand, are weaker in compression but can have higher tensile capacities, and provide good adhesion to other materials as well as resistance to physical (i.e., abrasion, erosion, impact) and chemical
attack. Combinations of these two materials can exploit the useful properties of both and yield composites with excellent strength and durability properties.

The combination of Portland cement concrete or mortar with polymers can result in extremely durable, tough, and strong building-material composites those are economical and kind to the environment. Structures in extreme environments, or inaccessible for repairs, or subject to impact, cyclic, or dynamic loading may all benefit from the use of PMC. The aging infrastructure can be repaired using PMC.

It is seen that the incorporation of polymers in various forms can significantly improve these shortcomings along with the increased adhesion to steel and / or old concrete, corrosion prevention, impermeability, etc. Polymers in concrete are subdivided in the following three categories.

1. Polymer impregnated concrete (PIC)
2. Polymer concrete (PC)
3. Polymer Portland cement concrete (PPCC)

In this paper an attempt is made to discuss mainly the mechanism, use and the applications of PPCC which is gaining overall popularity because of its ease of handling, inexpensive cost, efficiency and satisfactory results. However, it would be appropriate to discuss in brief PC and PIC. The section criteria of two types of polymers systems of modifying concrete were governed by their viscosity. The two polymers used here are Latex Polymer and Styrene Acrylic Polymer.

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids</td>
<td>68% - 69%</td>
</tr>
<tr>
<td>Viscosity</td>
<td>1300 to 1500 Centipoises</td>
</tr>
<tr>
<td>pH</td>
<td>9.00 to 10.00</td>
</tr>
<tr>
<td>Weight / Gallon</td>
<td>8.8 lbs</td>
</tr>
<tr>
<td>Appearance</td>
<td>Milky White Liquid</td>
</tr>
<tr>
<td>Particle Size Avg</td>
<td>Less than 0.5 microns</td>
</tr>
</tbody>
</table>

3.1 Mechanism involved

Polymerization is a process of reacting monomer molecules together in a chemical reaction to form linear chains or a three-dimensional network of polymer chains. There are many forms of polymerization and different systems exist to categorize them.

Generally, polymers are added to the fresh mixture as an aqueous dispersion. Polymers dispersions consist of very small polymer particles (0.05 - 5 μm), dispersed in water, and are generally formed by emulsion polymerization. The spherical particles with a high molecular
weight are held in dispersion with the aid of surface active agents. The surfactants are not only added to allow emulsification during the production process of the dispersion but also to preserve stability of the dispersion until coalescence of the polymer particles in the material takes place. Afterwards, the surfactants badly influence the hydration reactions of the cement, the quality of the formed hydrates and the polymer film formation.

Table 2: Physical Properties of Styrene Acrylic

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids</td>
<td>44% - 46%</td>
</tr>
<tr>
<td>Viscosity</td>
<td>50 to 400 Centipoises</td>
</tr>
<tr>
<td>pH</td>
<td>9.00 to 10.00</td>
</tr>
<tr>
<td>Weight / Gallon</td>
<td>9.3 lbs</td>
</tr>
<tr>
<td>Appearance</td>
<td>Milky White Liquid</td>
</tr>
<tr>
<td>Particle Size Avg</td>
<td>Less than 0.2 microns</td>
</tr>
</tbody>
</table>

The favorable properties of the presence of the polymer at the interface between aggregates and binder can be counteracted by additional air entrainment due to the presence of the surfactants. The properties of the fresh mixture are influenced to a large extent by the surfactants, present at the surface of the polymer particles.

The cement particles are better dispersed in the mixture and a more homogeneous material is formed. In most cases, a better workability of the fresh mixture and a lower mixing water requirement is noticed. The hydration of the cement particles is also influenced by the presence of the surfactants. The surfactants hold the water, needed for hydration, more thoroughly than in the case of the unmodified mixtures. The water is partly bound to the hydrophilic part of the surfactants by hydrogen bonds. The release of water takes time, so hydration is retarded.

Additionally, at places where the polymer film starts to develop, the cement hydrates may be partly or completely covered by the polymer film and hydration may be stopped temporarily or completely.

So, in the modified mortar or concrete, the presence of surfactants can lead to an excessive air entrainment, improved workability reduced bleeding, retention of the water and retarded cement hydration. In this respect, nonionic surfactants or high polymer protective colloids are preferable to anionic or cationic surfactants to stabilize the dispersion if used in combination with cement.

The workability of the fresh mixture is markedly improved over that of ordinary cement mortar and concrete, because of plasticizing and air-entraining effects of the polymers. The modified systems show higher water retention than the ordinary cement systems. This may contribute to an improvement in the workability and the prevention of dry-out, and it also leads to superior adhesion to porous substrates such as ceramic tiles, mortars and concrete.
4. Experimental Study

The concrete mix M30 investigated in this study is prepared with standard 43 grade Portland cement and polymers which are conformed to Indian standards. Mix design was carried out according the IS 10262: 2009.

Continuously graded crushed basalt aggregate with a nominal particle size of 20 mm was used. Well-graded quartzite sand, with a fineness modulus of 2.74, was employed. The relative density values of the coarse aggregate and sand were 2.90 and 2.56, and their absorption rates were 0.8% and 1%, respectively. The grain-size distributions of the coarse aggregate and the sand are given in Table 3.

Table 3: Grain size of coarse aggregate and sand

<table>
<thead>
<tr>
<th>Sieve size in mm</th>
<th>28</th>
<th>20</th>
<th>14</th>
<th>10</th>
<th>5</th>
<th>2.5</th>
<th>1.25</th>
<th>0.63</th>
<th>0.31</th>
<th>0.16</th>
<th>0.075</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-5 mm</td>
<td>100</td>
<td>97</td>
<td>65</td>
<td>37</td>
<td>9.7</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sand</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>92</td>
<td>71</td>
<td>58</td>
<td>24</td>
<td>1.7</td>
<td>0</td>
</tr>
</tbody>
</table>

All concrete mixes were prepared in batches in a rotating planetary mixer. The batching sequence consisted of homogenizing the sand and coarse aggregate for 30 s, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. The mixer was covered with plastic bags to minimise the evaporation of the mixing water and to let the dry aggregates in the mixer absorb the water. After 5 min, the cement and polymer are added and mixed for another minute. In this investigation, different categories of concretes are selected to cast specimens. Plain (conventional) concrete (PC), polymer modified concrete (PMC), with different dosages of polymers.

To gain the certain compressive strength (40MPa) in all categories of concrete was the first attempt in this investigation because through this test the proportion of different materials in the concrete mixes were identified and fixed.

4.1 Compressive strength

Standard cube specimens are casted and tested for compressive strength after 7 days and 28 days. After obtaining the certain strength for nominal concrete and fixing the dosages of polymer proportion, casting of specimens for modified concrete are taken place. 24 hours after placing the concrete in the moulds, they were demolded and kept in the curing system for 28 days. But, for polymer based composites to complete the polymerization process, dry curing is mandatory. The specimens cured 24 hours more in the air to form a continuous and coherent polymer film which coats the cement hydration products, aggregate particles and even the capillary pores.

The compressive strength was obtained on cubes of 150 x 150mm x 150 mm size according to IS: 516-1959. Specimens were demolded 1 day after casting and then cured in water until testing was carried out at 7 and 28 days’ age. Six specimens of each mixture were tested and the mean value was reported.
Compressive strength development of mixtures from 7 days to 28 days for different dosages of polymer content has been presented in Figure 1 and Figure 2 respectively. It is clear that a rapid strength development is obtained by increasing the latex polymer dosage from 5% to 15% later it is showing reducing. The similar trend is observed with styrene acrylic polymer also. The experimental results evidently shows that the characteristic compressive strength of polymer modified concrete increases with the increase of polymer dosage from 5% to 15% , after reaching its optimum percentage dosage around 15% it started decreasing.

4.2 Flexural strength

The flexural strength was determined at 7 days and 28 days on beams of size 100 x 100 x 5000 mm are cured in water until the date of test according the IS:516-1959. Three specimens of each mixture were tested and the mean value was reported. The results of these flexural tests have been presented in Figure 3 and Figure 4 respectively. The performance of the polymer modified concrete increases as the polymer dosage increases from 5% to 15% in both cases i.e. in latex polymer case as well as styrene acrylic case.

4.3 Split tensile strength

The splitting tensile strength of conventional concrete and polymer modified concrete is determined at 7 days and 28 days on cylinders measuring 150-mm diameter and 300-mm height, these are cured in water until the date of test according the IS:5816-1999. Three specimens of each mixture were tested and the mean value was reported. The results shown the similar trend as that of above, tending increase in tensile strength values as the polymer dosage increases later it slows down. These results have been presented in Figure 5 and Figure 6 respectively.

![Figure 1 & 2: Details of 7 days and 28days compressive strength](image-url)
5. Results and discussion

From the results it is evident that the performance and structural characteristics of polymer modified concrete is superior to conventional concrete. It is observed that not only in hardened state but also in its fresh state. Compressive strength results envisage that the modification at optimum dosages is well advantageous and attaining superior results in early age. A dosage of 15% polymer is observed to be the optimum dosage in both the cases to achieve complete polymerization and subsequent improvement in performance.

The important feature of this material is that a large proportion of the void volume is filled with polymer, which forms a continuous reinforcing network. The concrete structure may be impregnated to varying depths or in the surface layer only, depending on whether increased strength and/or durability is sought. This results in a remarkable improvement in tensile, compressive and flexural strength of polymer modified Portland cement concrete.
Modification of concrete with a polymer latex (colloidal dispersion of polymer particles in water) and styrene acrylic polymer results in greatly improved properties, at a reasonable dosages and cost. Therefore, a great variety of latexes is now available for use in polymer cement concrete products. The main application of latex-containing polymer cement concrete is in floor surfacing, as it is non-dusting and relatively cheap. Applications of polymer modified concrete in building and construction include structural floors, high performance structures, Food processing buildings, Sewer pipes, Storage tanks for seawater, desalination plants and distilled water plants, Marine structures, wall panels, Tunnel liners, prefabricated tunnel sections and swimming pools. On the other hand this concrete is used for the protection of bridges and concrete structures against deterioration and repair of deteriorated building structures, such as ceiling slabs.

6. Conclusions

This paper describes the results of an experimental study performed to gain insight into the performance of polymer modified concrete and its mechanism. In addition to this the optimum dosage of polymer that influences the mechanical and structural properties are reported. At last the styrene acrylic polymer has shown its superiority over latex polymer because of its fine particle size and relatively less viscous.

7. References


8. ACI Committee, (1995), State-of-the-Art Report on Polymer Modified Concrete, American Concrete Institute, ACI 548.3R-95, 1-47.