Review

Reuse of Polymers as Fibers in Concrete: Review

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Abstract

Concrete as a construction material, plays an important role in construction industry, because it has high compressive strength. But it is weak in tension, adhesion and due to porosity it can lead to physical and chemical deterioration. Various types of polymers are available in construction world i.e., PET, HDPE, PVC, LDPE, PP and PS. A detailed study was done on HDPE and PET waste only. The polymer waste collected from various sources are then converted into polymer fibers and added to conventional concrete. The polymer fiber reinforced concrete is used in floorings, water tanks, sumps, swimming pools, silos, drains and septic tanks etc., and also for repair works. This paper briefly reviews the history of polymers in combination with cement as a building material, where the polymer is in the form of fibers, to improve the properties of concrete i.e., compressive, flexural and tensile strengths, degree of workability, durability, etc. Fiber reinforcement can effectively improve all these characteristics of concrete with adding a small quantity to make the concrete as economical construction material in the industry. It also controls the reduction of the shrinkage and shrinkage cracking of concrete associated with hardening and curing.

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Introduction

There is a large variation in use of polymer in construction industry.The synergic action of polymers in cement mortars and concretes offer great improvement for wide range of new and innovative applications increasing tensile strength of composites, less water curing, resistance to cracking, impermeability high impact and good quality proved polymers as best material for the composites [8]. The use of fiber-reinforced polymer (FRP) composites has recently experienced a steep increase in civil engineering applications because of the high mechanical and low-density properties of such materials. In fact, several numerical models and analytical procedures are able to predict the behavior of FRP-confined structural elements subjected to axial or seismic loads and researchers worldwide have experimentally studied and analytically calibrated a wide range of significant variables [5].The combination of Portland cement or mortar with polymers can result in extremely durable, tough and strong buildingmaterial composites that are economical and kind to the environment. Such materials can respond to the many needs of current and future construction. Structures in extreme environments or inaccessible for repairs or subject to impact, cyclic or dynamic loading may all benefit from the use of polymer fiber reinforced concrete. The aging infrastructure can be repaired using polymer fiber reinforced concrete [4]. More effective methods for the recycling of plastics, mixed polymers, more applications of the recycled products in different industrial sectors as buildings and structural applications etc., should be explored.

In addition, more attention has to be focused on the degradation of chains at the end of life or the presence of additives and impurities and minimize any potential problems that might arise with recycled materials. The objectives of the current researches are to develop high strength polymeric materials by recycling the mixed polymers [3]. Superabsorbent polymers (SAP) are a new type of admixture. They can store many times more water than their own weight. They can be used for internal curing of concrete and for mitigation of shrinkage. By adding 0.7% SAP with mass of cement, autogenous shrinkage of low watercement ratio concrete can be suppressed completely[1].

History of Polymers in Concrete

Polymers have been used in constructionindustry since fourth millennium B. C., in the clay brick walls of Babylonia using the mortar mixed with natural polymer asphalt. The temple of Ur-Nina (King of Lagash), in the city of Kish had masonry foundations built with mortar made from bitumen as natural polymer, loam and chopped straw or reeds and its durability is excellent. The walls of Jericho were built using bituminous earth in about 2500 B. C. Other historic applications of polymer mortars in construction have been identified in the ancient Indus Valley cities of Mohenjo – Daro and Harappa around 3000 B. C. and near the Tigris River in 1300 B. C. Many natural polymers have been used in ancient binding mortar, including albumen, blood, rice paste and others. The earliest indication of the use of polymers in concrete was apparently in 1909, in the United States. Synthetic polymers were invented in 1940s in the availability of natural rubber and the increased demand of the war effort. Incorporation of synthetic polymers in Portlandcement mortars and concrete started in the 1950s [4] & [8].

Microstructure of Polymer

Microstructure of polymers differ when interact with cement microstructure depends on the method of polymerization, type of polymer, curing conditions and delivery systems. When the polymers are mixed with fresh concretethenthe polymer particles aredispersed throughout the cement paste.In the matrix, cement hydration starts, saturating the solution with CH there by generating ettringite and huge quantity of CH crystals in the adjacent zone to aggregates. After this, polymer particles deposit on the un-hydrated clinker particles. The accumulating polymer particles, after consumption of water by the hydration process, fill many of the capillary pores in the concrete and coats inner surfaces of partially filled pores. Some polymers participate in chemical reactions with the cement hydration products to the detriment of the composite [4] & [8].

Examples from the Literature

Review Paper 1

M. Schleseret et. al. (2006) paper deals with application of polymers totextile reinforced concrete. The samples prepared by using the polymer modified fine concrete mixture (Portland concrete cement) is based on the mixture PZ–0899–01.With5, 10 and 20% by weight of polymer relating to the binder. The selected shape of samples will have waisted strip specimen or dog–bone shape. After conducting tensionmeter test, good wettability of the reinforcing materials is found due to higher surface tension of glass, in comparison to size. The highest tensile strengths of the filament were obtained with an impregnation of high module reactive systems on the basis of epoxy resin. By increasing polymer content in the roving leads to a decrease of filament ruptures due to improved load transmission between the single filament and the reduction of the effective contact area to the concrete leads to a reduction of the adhesion forces. This paper states that the polymer addition enhances the maximum strains and load due to a difference of the load carrying capacity of the textile. The analysis of SEM image infers the morphology of calcium silicate hydrates (CSH) and calcium hydroxide (CH) differs under the influence of polymer dispersions. The authors conclude that, compared to the non-impregnated roving, the tensile strength can be increased from 920 to 1830 N/mm^2. The authors declaredthe addition of polymer dispersion with an amount of 10 or 20% by weight to the concrete result in a higher tensile strength of the concrete and in an increase of the component failure load of approximately 40%. In this paper authors had not found the optimization of the compound area and not done analysis on the geometry of the used textiles. More tests are required to decide workability and mechanical properties of the concrete samples.

Review Paper 2

Hui Zhao et. al. (2013) studied on various polymers in concrete. By using a water–soluble aminosulfonate–phenol–salicylic acid–formaldehyde (AH) polymer was synthesized by the reaction phenol (P), sodium sulfanilate (ASAA), salicylic acid (S) and 37% concentration formaldehyde (F) with the optimum reaction conditions. The mix proportion of concrete used as 1 : 2.16 : 3.54 for the samples. The concrete is added with AH polymer at 0.3, 0.4, 0.5 and 0.6% dosages. The total concreting mixing period of 6 minutes as maintained for all the samples. Various BIS tests conducted on samples to found the characteristics of concrete. Fourier transformation infrared spectroscopic analysis applied to investigate the function group of AH polymer. Used this analysis and found that AH polymer molecule has $–NH_2$, $–CH_2$, $–C_6H_5$ and $–SO_3$ groups and a new function group (–COOH). The results compared between AH polymer samples and aminosulfonate–phenol–formaldehyde (AS) polymer samples. The application properties of concrete samples made with AH and AS polymer was compared i.e., water reduction percentage, slump preservation, air content, wet density and setting times of cement pastes. The final setting time of concrete has AH polymer with more significance than that of the AS polymer for the same dosage of polymer. The author’s stated that the concrete containing AH and AS polymers yields higher compressive strength than the control mixture at all test periods. This paper concluded that the molecular structure of AH polymer prepared under the optimum reaction conditions was characterized by Gel Permeation Chromatography (GPC) and infrared spectroscopy.

Review Paper 3

Youjiang Wang et. al. (2000) paper on concrete reinforcement with recycled fibers used the waste carpet pieces as fibers in concrete samples. The carpet typically consists of two layers of backing (polypropylene tape yarns), joined by CaCO3–filled styrene–butadiene latex rubber (SBR) and face fibers (nylon 6 and nylon 66 textured yarns) tufted into the primary backing. During the flexural test, the plain concrete samples broke into two pieces at the peak load and the FRC specimens exhibited a pseudo ductile behavior and fibers bridging the beam crack. Because of the fiber bridging mechanism, the energy absorption during flexural failure was significantly higher than that for plain concrete. The author’s observed significant improvement in compressive and flexural strengths and reduced shrinkage cracks by using carpet waste fibers in concrete. Author’s recommended carpet waste fiber reinforced concrete for floor slabs, drive ways and walls of the buildings. The study revealed significant improvement was found in the flexural strength and no significant improvement in bending properties. The compressive stress–strain behavior of concrete was not improved by the polypropylene fiber reinforced concrete. By using of the nylon fibers in concrete, the plastic shrinkage cracks were reduced. The author's stated that the crack widths were significantly reduced in the fiber composites including all recycled fibers except recycled tire rubber composites (RTRC). According to their experimental results, the strength and toughness of concrete increased with the steel shaving fiber dosage rate. The authors found that it was feasible to use recycled HDPE fibers as a secondary reinforcement for temperature and shrinkage influences in concrete structures subjected to extreme freeze–thaw conditions. More study and research work was required to confirm the above statement. Author's concluded that the use of low–cost waste fiber for concrete reinforcement could lead to improved infrastructure with better durability and reliability. Potential applications could include buildings, pavements, columns, bridge decks & barriers and for airport construction such as runways and taxi ways.

Review Paper 4

Medine Ispir (2014) worked on montonic and cyclic compression tests on concrete confined with PET – FRP. The BIS samples and the PET–FRP mechanical properties were determined in accordance with ISO-10406-2008 [Fiber-reinforced polymer (FRP) reinforcement of concrete Test method-Part2: FRP sheets"]. The lateral strain efficiency factor is defined as the ratio of the lateral strain at failure to the ultimate strain provided by the manufacturer, namely, ϵ_{fe} / ϵ_{fu}. In this study, the results are obtained, (1) As the axial strain increases, the nonlinearity interaction between the compressive stress and axial strain increases during the unloading/reloading processes; (2) As the slope at the plastic axial strain point of the unloading approaches zero for increasing axial strain; (3) The deterioration in stress is calculated as the ratio of stress at a common point to the corresponding envelope stress. In the test results, the loading type is not observed to affect Poisson's ratio. In this study, the confined specimens tested under monotonic or cyclic loadings failed due to slippage that occurred in the overlap region and it was found that the inadequate over lapping length and/or the epoxy resin is used for samples. More study was required in this area i.e., overlap length of FRP concretes. The results were indicated that Polyethylene Terephthalate (PET) & Polyethylene Naphthalene (PEN) fibers increase the shear strength and ductility of the columns. This paper concludes that the high deformation capacity of PET, this FRP type is a good alternative in repairing/strengthening applications for seismic safety. More no. of samples required to predict the compression stress-axial strain relationship of PET-confined concrete, was not discussed in this paper.

Review Paper 5

M. C. S. Ribeiro et. al. (2013) states that the experimental results revealed that the glass fiber reinforced plastics (GFRP)and waste filled polymer mortars (PMs) show improved mechanical behavior over unmodified polyester based mortars, thus indicating the feasibility of GFRP waste reuse as raw material in concrete polymer composites. GFRP waste material was obtained from the shredding of the left over's resultant from the cutting and assembly process of GFRP profiles during building sites. GFRP waste material was comprised essentially of an unsaturated polyester resin loaded with calcium carbonate and reinforced with E-glass roving, continuous filament mat and surfacing veils. The collected GFRP waste prepared in two sizes grades to mix into concrete i.e., coarse waste (CW) and fine waste (FW). In this study the three factors were considered i.e., waste type, waste content and silage content. The samples were prepared with GFRP waste at 0%, 4%, 8% & 12% in weight of total mass of concrete. The resin to total aggregate (sand plus GFRP admixtures) weight ratio was kept constant at 1:4 for all samples. The flexural strength was influenced by three factors i.e., silage content, waste content and waste type. The authors concluded that the best combination of factor's levels that maximize both flexural and compressive strengths of modified PMs is achieved for 8% (w/w) of sand replacement by coarse GFRP waste recycles and incorporation of 1% active silage to resin binder.

Discussions

A polymer is a large molecule or macromolecule, composed of many repeated subunits. Because of their broad range of properties, both synthetic and natural polymers play an essential and ubiquitous role in everyday life. Polymers improve adhesion to the old surface, flexural strength, tensile strength and freeze/thaw durability. They also reduce permeability, the intrusion of chlorides, salts and carbon dioxide. They increase abrasion resistance and can be applied in very thin cross sections. Many characteristics of Portland cement remain the same when polymers are added. Super plasticizers (SPs) are essential component to high performance concrete (HPC), where HPC is used for high rise buildings, bridges and offshore structures. Polymer impregnated concrete (PC) is produced by infusing a monomer into the cracks and voids of already hardened concrete. Polymer modified concrete (PMC) or polymer Portland cement concrete (PPCC or PCC) is normal Portland cement concrete with a polymer admixture. Polymers are preferred in the cement composites due to high performance, multi-functionality and sustainability compared to conventional cement concrete. Several types of polymer such as latex, re-dispersible polymer powder, water soluble powder, liquid resins and monomers modified concrete are used. Commonly five types of polymersexist and they are acrylics, styrene-acrylics, vinyl acetate ethylene (VAE), polyvinyl acetate (PVA) and styrene-butadiene resin (SBR). Typically, recycling technologies are divided into primary, secondary, tertiary and quaternary approaches. Primary approaches involve recycling a product into its original form. Secondary recycling involves processing a used product into a new type of product that has a different level of physical and/or chemical properties. Tertiary recycling involves processes, such as pyrolysis and hydrolysis, which convert the waste into basic chemicals or fuels. Quaternary recycling refers to waste–to–energy conversion through incineration. All four approaches exist for textile, plastic and paper recycling. The advantages of using such recycled fibers include generally lower cost to process than new fibers and the elimination of the need for waste disposal in landfills.

A detailed study was conducted on the reuse of HDPE and PET waste as fibers in conventional concrete.The polymer fibers are added to conventional concrete with an increment of 0.5% to the volume of concrete. Samples are prepared using the design concrete mix of proportions 1 : 1.6 : 2.7, with w/c = 0.45. More than 228 BIS samples were casted to study the characteristics of concrete. The average ultimate load for the samples after adding polymer fibers at 0%, 1%, 3% and 4% obtained as 62.4kN, 85.6kN, 94.9kN and 84.4kN respectively. The average displacement at ultimate load for the samples wasobtained as 10.54mm, 7.14mm, 6.98mm and 12.21mm respectively. The ultimate load carrying capacity of polymer fibre reinforced concrete with 1%, 3% and 4%fibres has been increased by 37%, 52% and

35% respectively with that of conventional concrete.The polymer fibre reinforced concrete with 1%, 3% and 4%fibres have controlled the deflections by 39%, 46% and 19% respectively with that of conventional concrete.The polymer fibre reinforced concreteachieved the compressive strength 26% more than that of conventional concrete.

Conclusions

The results of polymer fiber reinforced concrete are satisfactory in agreement with Bureau of Indian Standards. Hence the polymer waste should be reused as fibers in concrete to make fiber reinforced concrete.

Note: Part of this work is presented at ICSEMF, Khammam, India.

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