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Review Article

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Polymer and Polymer Waste Composites in Nuclear and Industrial Applications

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Abstract

Polymers are commonly used as advanced materials that are contained in virtually every material used in our everyday lives. Due to their applications in various domains of science, technology and industry, from basic uses to biopolymers and therapeutic polymers, the significance of polymers is steadily increasing. The main purpose of this review is to accentuate the pragmatic effect of polymers on human everyday life and the significance of waste polymers as an important type of solid waste that could be useful in various applications such as civilian and construction activities and particularly in stabilization and solidification of radioactive waste when mixing the polymer waste with cementitious materials, thus generating modified composites.

Keywords

Radioactive waste; Pragmatic effect; Polymer; Zeolite

Introduction

Relatively few basic types of materials are available for the manufacture of various articles nowadays required by the modern society. Steel, glass, wood, stone, brick and concrete were heavily used for construction industry, while the manufacture clothing and other textiles typically resorts to the use of cotton, wood, jute and a few other agricultural products. During the last decades, new materials were introduced by the rapid rise in demand for manufactured goods with tailored properties. These new materials, mainly polymers of petrochemical origin, and their effect on our current way of life are indeed manifold. Products made of polymers are omnipresent around us: clothing made of synthetic fabrics (microfiber fleeces), polyethylene cups, fiberglass, nylon bearings, plastic bags, polymer-based paints, epoxy glue, polyurethane foam pillows, silicone blood vessels and Teflon-coated kitchen equipment are just a few examples for the wide utilization of polymeric products from petro chemistry.

Identification of Polymer

The list is almost infinite. The word "polymer" or sometimes "macromolecule" is derived from the classical Greek word “poly”, meaning "many" and indicating "many pieces". Polymer molecules have a very high molecular weight (between 10000-1000000 g/mole) and encompass a number of structural units linked together by chemical bonds.

The expression “polymers”, a word that we hear a lot about it, is very versatile, and without it, one cannot imagine our daily life. Polymers, a broad class of materials, are made up of several small molecules called monomers, which are joined together to form long chains and are used in many of the products and items we use in our everyday lives. Since many years, people have used polymers in their all-day lives, while the expression “polymer” become familiar to a general public only after the Second World War.

As mentioned above, polymers are formed by the chemical reaction of the monomers. Monomers have the ability to react with another molecule of the same kind (homo polymerization) or another kind (copolymerization) in an acceptable environment to form a polymer chain. This mechanism in nature has resulted in the creation of natural polymers (biopolymers), while polymeric materials of petrochemical origin were anthropogenic; these materials, not present in nature, are xenobiotic and not embedded into the natural cycles of carbon [1]. While biopolymers have been among us in the natural world since the very beginning (e.g. cellulose, starch, natural rubber), man-made polymeric materials were researched only since the middle of the 19th century. Only since the last decades, the polymer technology has steadily evolved, and is currently larger than the combined copper, steel, aluminium and many other industries [2].

Polymer Types

Natural polymers themselves are a type of polymer produced by all life forms (microbes, plants or animals). They encompass, in particular, carbohydrates and proteins that exist in plants and animals, and provide the organism mainly structural support. Moreover, the group of nucleic acids are another class of biopolymers present in all living organisms plus in viruses. Polymeric materials such as thermosets, plastics and leather can be obtained from such natural materials. This applies to polymers that are produced by extraction through their bulk form by nature, e.g. cellulose or silicates derived from woods and other plants. Moreover, biopolymers include polymers formed by biological processes, such as bacterial synthesis or fermentation. As polymeric materials, natural polymers can be grouped as addition and condensation polymers on the basis of their biosynthesis process. The majority of natural polymers are condensation polymers created as part of monomeric units which combine to form a small molecule (usually water) a by-product. Important examples of such biopolymers with plastic-like properties are microbial polyhydroxyalkanoate polyesters, generated by the poly condensation of acyl-CoA units in living cells, accompanied by the release of free CoA [3]. In contrast, addition polymers are those generated by a direct combination of the monomers that make up the polymer without any by-product formation [4].

Polymer Waste

The mass processing of polymer products, in particular synthetic, non-biodegradable fabrics, and their widespread use, based on the intrinsic disadvantages (recalcitrance towards biodegradation and composting), make these materials a danger to life on Earth. Polymer

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recycling is known to be one of the most commonly recognized solutions for the danger caused by the high quantities of plastic waste from both the public and scientists. In reality, recycling is correlated with many challenges, such as issues relating to isolation, processing and cleaning activities, lack of fiscal incentives, volatility of limited garbage isolation schemes, high transport and energy costs, quality reduction after each recycling run, etc. Only about 9% of all plastics currently produced undergo recycling, the rest (12%) being simply incinerated for energy production, or even disposed in landfills or in the environment (79%) [5]. Still, a wide segment of society and the government believe in the need and value of recycling to protect the atmosphere and natural ecosystems and services for better future in a sustainable way by recycling raw materials and minimize energy use, urban waste disposal production and emissions. Different strategies to enhance recycling processes are almost infinite in them and require a number of methods, such as restoration, mechanical remodelling, chemical treatment, thermal application, etc. Some innovative methods, such as carbon capture or carbon nanostructure synthesis from plastic waste, are among the latest process technologies for recycling. Among different conventional and successful approaches to the use of polymer waste, this analysis will highlight novel, effective strategies to reduce the environmental effects of plastic waste, combined with mitigation or other hazardous waste streams [6].

Mixtures of Polymeric Wastes with Other Wastes

In order to enhance the properties of asphalt mixtures and reduce the harmful effects of waste materials on nature and the environment, it seems appropriate to introduce a way of reusing waste materials in infrastructure and commercial building projects such as road pavements

Wheel monitoring, moisture susceptibility, durable modulus and drainage experiments were carried out on mixtures comprising different percentages of PET waste as 0, 2, 4, 6, 8 and 10% of bitumen material. By experimentation, the appropriate range for the volume of PET waste was calculated to be 4-6 % by weight of the bitumen material. The findings suggest that the addition of PET waste to the mixture has a major positive impact on the properties of SMA, which may boost the resilience of the mixture to irreversible deformation, increase the stiffness of the mixture, decrease the leakage of the binder and encourage the reuse and recycling of waste materials in a more effective and value-adding manner [7].

Mechanical recycling transforms polymer waste into new polymer goods through the energy recovery process, which releases the energy chemically stored in plastics by combustion, and chemical processing turns waste polymers into raw materials for the manufacture of chemicals/monomers/fuels. Today, the chemical processing of plastic waste is the most notable method for the reuse of polymers. A review provides a literature analysis of the chemical processing processes of various polymers, such as Polyethylene (PE); Low-Density PE (LDPE) or High-Density PE (HDPE), Poly Propylene (PP), or mixtures of these polymers, PET, polycarbonate, and polyurethane. The effect of the reaction parameters on the materials collected, the catalysts and agents used and the equipment used for various chemical recycling methods have been reviewed to summarize the state-of-the-art approaches for the chemical processing of diverse polymers [8].

Degradation of Polymers

The catalytic degradation of polyethylene into fuel oils and of polystyrene into styrene monomer has been researched using strong acids and bases as catalysts. Solid acids such as silica-aluminas and ZSM-5 zeolite have been found to be efficient in degrading waste polyethylene into fuel oils, and solid bases such as BaO and K_2O have been found to be successful in turning waste polystyrene into styrene monomer. The nature of the recyclable polystyrene film will be briefly listed [9]. Sub-or super-critical liquids have used as reaction media for environmental applications according to the twelve principles of green chemistry [10]. Chemical waste plastics disposal is indeed an important problem. Reaction of polymers in water or organic solvents in sub-or super-critical conditions to transform polymers to their monomers has been evaluated. Simple polymers such as PET or nylon 6 have been transferred to their monomers by hydrolysis in supercritical water or alcohol. Some polymers such as phenol resins and Fiber Reinforced Plastics (FRP) have also been decomposed into small molecules by solvent examination [11].

Degradation of Polystyrene

Five degradation models of varying complexity have been created. For all models, conversion between species was represented using standard free radical reactions, including hydrolysis, mid-chain β-scission, end-chain β-scission, 1,5-hydrogen, radical & conjugation attachment, bond nuclear fusion, and disproportionation. The five models varied in their resolution of the structural characteristics of the "dead" and "still" polymeric species and whether they directly tracked low molecular weight species. The most detailed model involved over 4500 reactions and recorded 93 species of polymeric and low molecular weight nature, both dead and active. Programs have been built using the Perl programming language to assemble population balance equations from unique response mechanism feedback to boost model development [12].

Composite of Polymers and other Materials with Cement

Human activities usually increase the production of solid waste, such as plastic waste. The management of such wastes is typically a concern. The goal of this illustration was to explore the feasibility of using plastic and egg shell waste along with cement in the manufacture of floor tiles. Waste was obtained from kitchens and waste disposal facilities. The products were washed and dried, and the plastics shredded while the egg shells were broken. Waste products were then combined in varying amounts with white cement. Compressive strength experiments were carried out to assess the suitability of using such solid waste in the manufacture of floor tiles. Crushed egg shells going through a sieve of 1.2 mm and shredded plastics with an average diameter of 1 to 2 mm were used. Cubes were casted and cured for 28 days. The compressive strength of the cubes was tested using a universal testing unit. The study showed that up to 50% of applied cement resulted in a more than 10-fold improvement in the compressive power of the casting cubes. The inclusion of plastics improved the compressive strength of the cubes while the inclusion of egg shells had a negligible effect on the compressive strength. Increased amounts of plastics and egg shells resulted in increased water absorption, while greater amounts of cement resulted in decreased water absorption. The growth in the quantity of egg shells and plastics resulted in a decreased density. In the presence of plastics, the resistance to abrasion grew and the tiles became less delicate. It is concluded that egg shells can potentially be used as filling material for the manufacturing of floor tiles. Owing to the ability of plastics to reduce the compressive strength of the tiles, they should be used with caution. The study has shown that the use of plastic and egg shell waste in the manufacturing of floor tiles is a feasible alternative for minimizing waste. However, more studies are required to evaluate the chemical interactions involved in floor tile production systems where household and industrial waste, such as plastics and egg shells are used [13]

Light Concrete from Expanded Polystyrene

Expanded polystyrene waste in granular form is used as a lightweight aggregate to manufacture lightweight reinforced concrete with a unit weight ranging from 1600 to 2000 kg/m^3. Polystyrene aggregate concrete was developed by partly replacing the coarse aggregate in the reference (normal weight) concrete mixtures with the same amount of the chemically coated crushed polystyrene granules. The gross aggregate substitution rate used was 30, 50 and 70%. Results of experimental study of engineering properties, such as compressive power, elasticity modulus, shrinkage and creep drying, of polystyrene reinforced the concrete variations in density. The key objectives of this analysis were the effect of density and cement paste composition on the above described properties. The density of concrete mixture for the concrete mixes used was 410 and 540 kg/m^3.

Experimental findings revealed an improvement in the shrinkage and slipping of polystyrene reinforced concrete, while the compressive strength and elasticity modulus improved with a decline in the density of concrete. The compressive power was observed to be more adaptive to density than the elasticity modulus [14]. Crumbled recycled foam polystyrene waste, as well as a broad spherical and fine blown polystyrene waste, is used to create filler for a light thermo-isolating composite, the matrix of which is light foam cement. These fillers are hydrophilic with a surfactant foam solution for greater cohesion. Polystyrene granules and foam concrete contact systems are discussed. The examination of foam cement concrete and polystyrene granule impact zone found that the interaction between these two products was very similar, without any fractures or micro cracks. The adhesion of the two materials depends on the size and form of the granules used. The 'gap' that has formed almost repeats the shape of the granule when a polystyrene granule is torn from foam concrete and polystyrene debris is left in it. This is evidenced by the fact that the foam concrete impact zone is thicker than the polystyrene granule content. When PS granules are included, they disintegrate along the touch region. Such a composite has the lowest adhesion strength but is smoother compared to a composite made of different foam polystyrene granules, supported with greater macrostructure [15].

Lightweight concrete can be created by replacing the usual concrete with a recycled aggregate, either partially or entirely, depending on the density and strength specifications. The present research involves the use of Extended Polystyrene (EPS) beads as a lightweight aggregate in both concrete and mortars containing silica smoke as an external cement material. The key goal of this project is to research the quality and reliability of the EPS concrete. These mixtures were constructed using the quality of the silica smoke at various percentages. The resulting concretes were found to have densities ranging from 1500 to 2000 kg/m^3, with corresponding strengths ranging from 10 to 21 MPa. The increase in strength of these concretes indicates that the improvement in the amount of silica smoke raises the strength of 7 days. This has been Approximately 75, 85 and 95 % of the correlating 28-day strength were observed at the silica smoke replacement levels of 3, 5 and 9 %, respectively. Results of absorption at 30 min and final absorption show that EPS sand mixtures have lower absorption levels compared to mixtures containing normal aggregates. In addition, absorption levels have been shown to decrease with an increase in cement content. The efficiency of these concrete in terms of chloride permeability and corrosion resistance, also at a low level of silica smoke, has been shown to be very strong [16].

Characteristics of Structural Inner-Compacted Lightweight Concrete (SCLC) including Extended Polystyrene (EPS) measured by slump flow, T50, V-funnel and L-box measurements. Fifteen mixtures including various water / binder ratios (W/B), nano-SiO_2 contents and EPS percentages (10, 15, 22.5 and 30 % by volume) were planned. The improvement in slump flow by hauling time was also analyzed and forecast with multiple regression equations. The findings suggest that mixtures with a density of more than 1900 kg/m^3 have some detrimental effects on fresh Self-Compressed Concrete (SCC) but this is to be less for EPS mixtures. Although the EPS-containing SCLC slump decreased by up to 6% by reducing the W/B ratio, T50 and V-funnel times rose by 23-29% and 18-48% respectively. The use of EPS in SCC indicates an improvement of up to 17% in slump preservation. In addition, with the use of nonlinear multiple regressions, the slump flow with transport time can be correct predicted [17].

In this analysis, thermally modified waste EPS foams were used as aggregates. Upgraded waste extended polystyrene aggregates (MEPS) were obtained by heat treatment by holding waste EPS foams in the hot air furnace at 130°C for 15 min. Effects of MEPS aggregate on many properties of concrete have been examined. Six series of concrete samples have been prepared for this purpose. MEPS aggregate was used to supplement the natural aggregate at amounts of 0, 25, 50, 75 and 100% by volume. The density of MEPS is by far smaller than that of natural aggregate; MEPS concrete becomes a lightweight concrete with a density of approximately 900–1,700 kg/m. The 28-d compressive strength of MEPS concrete ranges from 12.58 to 23.34 MPa, which satisfies the strength requirement for lightweight semi-structural concrete. Effects of MEPS aggregate on many properties of concrete have been examined. Six series of concrete samples have been prepared for this purpose. MEPS aggregate was used to supplement the natural aggregate at amounts of (0, 25, 50, 75 and 100 %) by volume. The density of MEPS is far smaller than that of natural aggregate; MEPS concrete becomes a lightweight concrete with a density of approximately 900-1,700 kg/m^3. The 28-d compression strength of MEPS concrete varies from 12.58 to 23.34 MPa, which fits the strength criteria of sub-structural lightweight concrete [18].

Recently, sustainable composite from cement kiln dust with grated poly (styrene) has been improved to produce lightweight concrete [19].

Application of polymer wastes with cement in radioactive waste immobilization

According to the toxicity of radionuclides in environment, treatment and immobilization of radioactive waste is most important [20-26]. Radioactive borate waste simulating to that produced from Pressurized Water Reactors (PWR) has been prepared and solidified after mixing with cement-water extended polyester composite. This composite was prepared from recycled PET waste and cement paste (water/cement ratio of 40%) and subjected to leach tests for both 137Cs and 60Co radionuclides according to the method proposed by the International Atomic Energy Agency (IAEA). The obtained data after 260 days of leaching revealed that after aging are characterized by adequate chemical stability required for the long-term disposal process. The proposed combination of cement with water extended polyester based on recycled Poly Ethylene Terephthalate (PET), is acceptable for immobilization of radioactive borate waste, performs adequately in the final disposal site and permits some secure against the radionuclides back release through the leaching process [27-29].

Cellulose as a natural polymer has been utilized with cement to produce cementitious composites favourable for stabilization of radioactive wastes. Due to the increasing amounts of spinning waste fibres generated from cotton fabrication and the simultaneous shortage in the landfill disposal space with dumping of these wastes, cement mortar composite was developed by hydrating mortar components using the waste slurry obtained from wet oxidative degradation of these spinney wastes. The produced cement mortar composite exhibits acceptable resistance and durability against the freeze-thaw and immersion that could be chosen in radioactive waste immobilization and constructive applications [30-32].

Another type of polymer waste, namely recycled post-consumer PS foam waste, was mixed with cement to produce cement-polymer composite. Radioactive sulfate wastes are generated from Boiling Water Reactors (BWRs) and should be immobilized before their disposing to avoid the back release of their hazardous components. A cement-polymer composite formulated from recycled post-consumer polystyrene foam waste and Portland cement was proposed as an incorporating matrix for solidification/stabilization (S/S) of sulfate waste simulates [33].

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