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Performance Of Polymer Concrete Utilizing Recycled Plastic Waste

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Abstract— **The consumption of cement at present in the construction industry has increased manifold as it is widely used in the production of concrete and mortar, which are the most common construction materials. This has therefore put an immense pressure on the cement industry. This has led to environmental problems and ecological imbalances due to the extensive mining of limestone that has to be used in the production of cement. The engineers and scientists are therefore looking for alternative materials, which may ease the pressure on cement Industry. The production of polymer concrete (PC) using plastic waste is one such material, which besides being cost effective would also greatly solve the environmental problem arising from the disposal of plastic waste.**

I. INTRODUCTION

Concrete at present is the most widely used construction material. The easy mouldability and the versatiiit) of this material, high compressive strength, and the use of steel as reinforcing bars to make up for its low tensile strength has contributed to the large scale use of concrete as a structural material [Sheti;y (1996), Neville (1994)].

Due to extensive knowledge, which is now available to the engineers, the use of cement has increased manifold. This has therefore put an immense pressure on the cement industry, which has to increase the production due to the growing demand of cement. This has led to environmental problems and ecological imbalances due to the extensive mining of limestone that has to be used in the production of cement. The engineers and scientists are therefore looking for alternative materials which may ease the pressure on cement Industry. The production of polymer concrete (PC) using plastic waste is one such material, which besides being cost effective would also greatly solve the environmental problem arising from disposal of plastic waste.

The environmental catastrophe that erupted in the last few decades in the urban regions of India and spread into rural areas is primarily caused due to boom in the production of plastic products. Since plastic is a non-biodegradable material, its disposal remains a real challenge. Plastics have become an indispensable part of modern life. No aspect of human life is untouched by plastics, as these are used in cars, computers, telephones, clothing, packaging etc. The packaging industry is the biggest consumer of plastics. Of various plastics that are being used in packaging, polyethylene terephthalate (PET), thermoplastic polyester is widely used [Medhat, (2002)] in the manufacture of soft drink and mineral water bottles. These PET bottles can be recycled and the resin so obtained after recycling may be used as a binder for the production of polymer concrete.

The concrete produced using cement as a binding material requires water for the hydration process and subsequent hardening and setting of cement. The quality of water used for mixing has a significant effect on the properties of hardened concrete.

Polymer concrete has been used in the construction of structural elements and the applications include wall panels to carry wind and seismic loads, underground vaults for resisting lateral earth pressure, rail road ties to resist the static and dynamic rail loads etc. therefore the structural uses of polymer concrete components include flexure, shear, bearing and deflections, whereas creep, fatigue and service temperatures are important aspects of these mechanisms. Polymer concrete composites can be broadly classified into three types depending on the process technology:

i) Polymer impregnated concrete (PIC)
ii) Polymer modified concrete (PMC)
iii) Polymer concrete (PC)

The above types of PC components consist of a resin binder and inorganic aggregates and sometimes some filler. The binding agent consists of thermosetting polymers. The polymers that are generally used as a binding matrix includes those made from such monomers as methacrylates., epoxy, furan, styrene, trimethylpropane, trimethacrylate, unsaturated polyesters (UPE) and vinyl ester etc. Any one of these monomers in liquid form is mixed with initiator and promoter systems for initiating the polymerization or cross-linking (hardening) of the monomers. Depending upon the type of the resin used as binding agent the polymer concrete may be classified as epoxy polymer concrete, methacrylate polymer concrete, unsaturated polyester polymer concrete, furan polymer concrete etc.

The subject of polymer concrete has been extensively reviewed by Ohama (1997).He discussed the uses of polymer-modified mortar and concrete, polymer mortar and concrete and polymer impregnated mortar and concrete. According to him polymer modified mortar is most widely used in Japan as a construction material for repair work, but polymer modified concrete is seldom used. However in the United States of America, polymer modified concrete is extensively used for bridge deck overlays and patching work. The polyiner mortar and polymer concrete has become an important material for the construction industry in 1970's in Japan and Europe and in 1980's in USA. In general polymer mortar is used for finishing work and insitu applications, while polymer concrete is used for pre-cast products. The commercially available

liquid resins for polymer concrete and polymer mortar include various thermosetting resins, tar-modified resins and methacrylate monomer. Fig. 2.1 illustrates the classification of liquid resins to be used in polymer mortar and polymer concrete. The liquid resins that are used for polymer mortar in Japan are mainly epoxy resins, unsaturated polyester resins (i.e. polyester-styrene, xylene) vinyl ester resins and methyl methacrylate (MMA) monomer, and the most common liquid resin for the polymer concrete is the unsaturated polyester resin (UPER). Whereas the most common type of liquid resin used in USA and Western Europe are methyl methacrylate (MMA) monomer, UPER, and epoxy resins and Furan resin (mainly furfural acetone resin) is used in Russia and Eastern Europe. Epoxy resins that are used for producing epoxy polymer concrete consist essentially of two component systems, the epoxy resin and the other a hardener or curing agent.

Most of the epoxy resins are the condensation products of bisphenol-A and epichlorohydrin and forms a good bond with concrete and steel due to their structure. The two components are generally mixed at a resin to hardener ratio of either 1:] or 2:1 by volume. Epoxy polymer concrete has been used for the manufacture of machine tool bases and Koblischek (1991) has reported various properties of an epoxy polymer concrete used for the above purpose. The compressive and tensile strengths were found to be 120 MPa and 10 MPa respectively and the compressive and tensile moduli were 40 GPa and 28 GPa respectively, whereas the bending tensile strength was 22 MPa.

Methylmethcrylate (MMA) is the primary monomer that is used for the production of methylmethacrylate concrete. It has a low viscosity due to which it possesses excellent wetting properties and hence MMA polymer concrete have very good flow characteristics making it a suitable material for the placement around dense reinforcement and in formworks having narrow cross sections. The polymerization reaction is initiated in the presence of cross-linking agent by the use of initiator and promoter systems. This type of concrete is also used for machine tool bases and again in one of his other wori< Koblischek (199!) has given various properties of such a concrete. The properties reported include a compressive strength of 120 MPa, tensile strength of 11.5 MPa and the modulus of elasticity in tension v/as 24 GPa and 31-40 GPa in bending.

III. EXPERIMENTAL RESULTS

Slump test

The results of the slump tests of waste plastic concrete mixtures are presented in Fig. 2. These results indicate that the slump is prone to decreasing sharply with increasing the waste plastic ratio. The reductions of the slump are 68.3%, 88.33%, and 95.33% for Pl2, Pl3, and Pl4, respectively. This reduction can be attributed to the fact that some particles are angular and others have non-uniform shapes resulting in less fluidity. In spite of the slump reduction, the waste plastic concrete mixtures have easy workability and are suitable for use in precast applications and large sites based on the following consideration:

Workability has a broad range from very low (at slump = 0–25 mm) applied for vibrated concrete in roads or other large sections, to high workability (at slump = 100–180 mm) applied for sections with congested reinforcement (Koehler and Fowler, 2003.

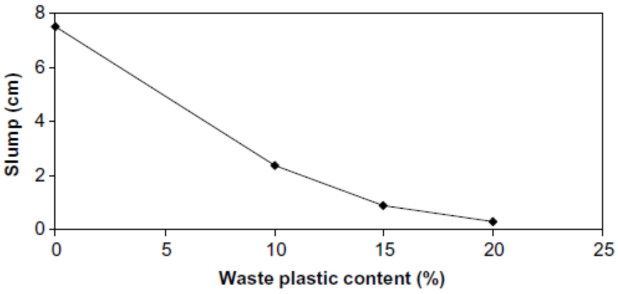

Fig.2. Slump of waste plastic concrete

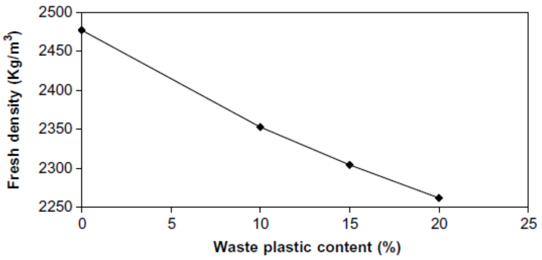

Fig.3. Fresh densities

Compressive strength tests

The results of the compressive strength tests for the waste plastic concrete mixtures are shown in Fig. 5. By increasing the waste plastic ratio, the results show a tendency for compressive strength values of waste plastic concrete mixtures to decrease below the plain mixtures at each curing age. This trend can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste, as well as the particles size of the waste plastic increase. Additionally, plastic is considered to be a hydrophobic material, so this property may restrict the water necessary for cement hydration from entering through the structure of the concrete specimens during the curing period. All of the compressive strength values are higher than the minimum compressive strength required for structural concrete which is 17.24 MPa.

The results are in a good agreement with the findings of Marzouk et al. (2007) and Pezzi et al. (2006) which demonstrated that once the sand volume substituted with aggregates increased, the compressive strength of composites decreased slightly in comparison with the reference mortar.

Flexural strength

The results of the flexural strength tests for the plastic concrete mixtures Pl2, Pl3 , and Pl4 are illustrated in Fig. 6. These results show that the flexural strength of waste plastic concrete mixtures at each curing age is prone to decrease with the increase of the waste plastic ratio in these mixtures. This trend can be attributed to the decrease in adhesive strength between the surface of waste plastic particles and the cement paste, as well as the hydrophobic nature of plastic material which may limit the hydration of cement. Therefore the hydration developed slightly with time. However the flexural strengths of the waste plastic concrete composites compared similarly with those of previous works (Marzouk et al., 2007; Pezzi et al., 2006).

Toughness indices tests: The load–deflection curves of the reference mixtures (Pl1) at all curing ages of 3, 7, 14, and 28 days are illustrated in Fig. 7. This figure illustrates the sudden failure of plain concrete under centerpoint loading on simple beams due to the brittle nature of concrete. The flexural load–deflection results for specimens made of 10%, 15%, and 20% waste plastic are illustrated in Figs. 8–10, respectively. These figures show the arrest of the propagation of micro cracks by introducing waste plastic particles that have fabriform shapes into concrete mixtures. Table 7 presents the toughness indices for waste plastic concrete at all curing ages. The toughness indices (I10:I5) for concrete mixtures made of 10% waste plastic (PI2) are negligible at 3 days curing age and are 1.43, 2, and 3 in 7, 14, 28 days, respectively. The difference in the values of toughness indices for PI2 mixtures at different curing ages may be due to the heterogeneity of the shape of the plastic particles.

By increasing the amount of waste plastic, the distribution of waste plastic becomes more homogenous due to the increase of the fabriform shapes of the plastic particles with broad distribution dimensions. Based on this consideration, less difference was observed in toughness indices values of concrete mixtures made of 15% waste plastic (PI3). By increasing the amount of waste plastic in the concrete mixture to 20% (PI4), no difference in toughness indices values was observed at all curing ages. For all waste plastic concrete mixtures at 14 and 28 days curing periods, the toughness indices reach the plastic behavior according to ASTM C1018. This behavior is desirable for many applications that require high toughness.

CONCLUSIONS

The main conclusions that can be drawn from this study are:

The compressive strength values of all waste plastic concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic ratio at all curing ages. This may be attributed to the decrease in the adhesive strength between the surface of the waste plastic and cement paste. In addition waste plastic is hydrophobic material which may restrict the hydration of cement.

The flexural strength values of waste plastic concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic ratio. A concrete mixture made of 20% waste plastic has the lowest flexural strength at 28 days curing age, viz. 30.5% below the value of the reference concrete mixture.

The dry density values of waste plastic concrete mixtures at each curing age tend to decrease below values for the reference concrete mixture, but they remain averaged to that of the reference concrete mixtures. At 28 days curing age, the lowest dry density (2223.7 kg/m3) exceeds the range of the dry density of structural lightweight concrete.

The fresh density values of waste plastic concrete mixtures tend to decrease by 5%, 7%, and 8.7% for Pl2, Pl3, and Pl4, respectively, below Pl1 but they are still averaged to the reference concrete mixture.

The slump values of waste plastic concrete mixtures showed a tendency to decrease below the slump of the reference concrete mixture. In spite of this decline in the slump of those mixtures, those mixtures are easy to work based on the consideration that workability has a broad range from very low to high workability for different applications.

The load–deflection curves of concrete mixtures that contain waste plastic showed the arrest of the propagation of micro cracks by introducing waste plastic that had fabriform shapes. I10:I5 reached the plastic behavior for Pl3, and Pl4 at all curing ages, but Pl2 reached the plastic behavior at 28 days curing ages only.

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