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Flexural, shear and bond strength of polymer concrete utilizing recycled resin obtained from post consumer PET bottles

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HIGHLIGHTS

- Polymer concrete (PC) is produced using waste PET as an alternate binding material.
- Flexure/shear and bond behaviour of plain and reinforced PC are studied.
- Properties of PC are compared with plain and reinforced cement concrete.
- PC produced is quite strong in flexure and shear and bond with steel is also good.

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ABSTRACT

The present investigation aims at studying the engineering properties of concrete produced by using waste polyethylene terephthalate (PET) bottles as an alternate binding material in place of the commonly used ordinary Portland cement. The recycled PET plastic waste was depolymerized through glycolysis to produce unsaturated polyester resin which was used as a binder to produce polymer mortar (PM) and polymer concrete (PC). Four sets of PM/PC were produced with PET to glycol ratio of 1:1 and 2:1. The initiator promoter combinations taken were Methyl ethyl ketone per oxide (MEKP) and cobalt naphthanate (CoNp) in one group while Benzoil per oxide (BPO) and *N*,*N*-diethyl aniline (NNDA) were used in another group.

The experimental investigation involves studying the engineering properties of PM, plain and reinforced PC viz. modulus of rupture, modulus of elasticity, stress–strain behaviour, load–deflection characteristics, flexural/shear strength and bond with reinforcing steel. The test results obtained for the four sets of PC have been compared for assessing the performance of PET to glycol ratio and the initiator-promoter combinations. The test results have also been compared with equivalent grade of plain and reinforced cement concrete.

1. Introduction

The enormous production of MSW, of which the major component is the plastic product has led to an environmental catastrophe in the urban regions of India and other developing countries which has spread into the rural areas as well. The production of large amount of PET has created an environmental problem of gigantic proportions as it does not decompose readily in nature due to its slow biodegradability [1–3] and hence could be thought of as a noxious material.

During the last many years research has been carried out to study the effect of PET wastes in concrete and construction material either as a binder or simply as a filler material [4–6]. Choi et al. [7] reported the use of PET wastes as fine aggregate to develop lightweight aggregate concrete with a density of 1390 kg/m^3. The compressive strength of concrete got reduced by 5–30% depending upon the quantity of PET waste used in the mix. However the structural efficiency (compressive strength/density ratio) of such concrete was higher as compared to the conventional concrete without PET. Ochi et al. [8] investigated the use of PET waste as concrete reinforcing fibre and found it to be useful for arresting cracks in concrete. Remadnia et al. [9] studied the effect of PET waste and animal protein in the form of powdered Haemoglobin on the workability and mechanical properties of concrete. The results showed improved workability but the compressive strength was reduced by up to 54%. Marzouk et al. [10] studied the effect of PET waste on the density and compressive strength of concrete.

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Table 1
Details of optimal sets.

Set No.	Chemical composition	
Group – I		
	Type of glycol	Diethylene glycol
	Dibasic acid	Maliec anhydride and phthalic anhydride
	Initiator	Benzoil per oxide (BPO)
	Promoter	*N*,*N*-diethyl aniline (NNDA)
1	PET glycol ratio	1:1
2	PET glycol ratio	2:1
Group – III		
	Type of glycol	Diethylene glycol
	Dibasic acid	Maliec anhydride and phthalic anhydride
	Initiator	Methyl ethyl ketone per oxide (MEKP)
	Promoter	Cobalt naphthanate (CoNp)
5	PET glycol ratio	1:1
6	PET glycol ratio	2:1

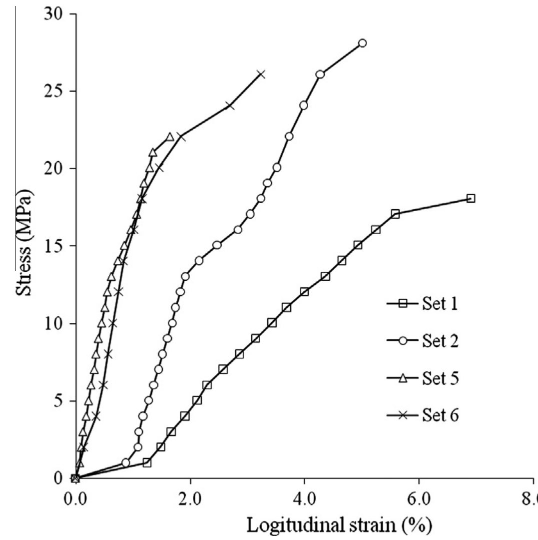

Fig. 1. Stress–strain curves for different sets of polymer mortars.

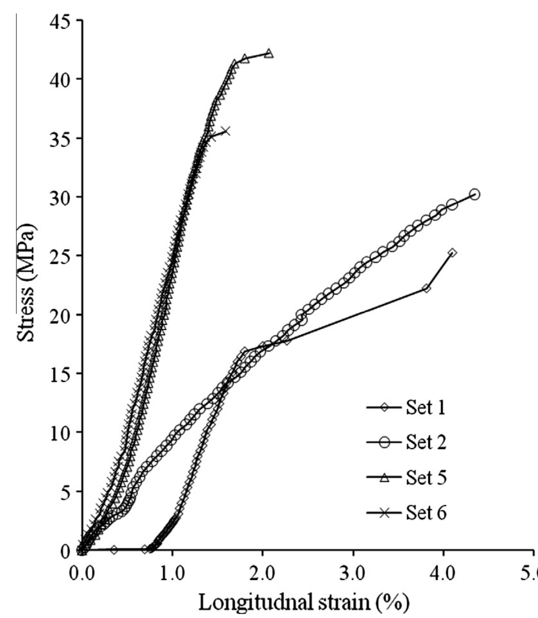

Fig. 2. Stress–strain curves for different sets of polymer concrete.

The study demonstrates that shredded plastic bottles may be used successfully as aggregate in place of sand in cementitious concrete composites. It was found and compressive strength decreased when the PET aggregate exceeded 50% by volume of sand.

It has been reported in the past [11–17] that plastic waste can be used in concrete or mortar as a binder thus replacing cement. Most of the studies carried out for the depolymerization of PET have discussed the role of various types of glycols and metal acetates to be used as catalyst in the process [17–22], whereas an exhaustive study was carried out by the authors [16] so as to ascertain the appropriate PET to glycol ratio and initiator-promoter combinations. It was emphasized that such PC may be effectively used in various structural pre-cast applications such as drains for acid waste, underground vaults and junction boxes, sewer pipes, power line transmission poles, transportation related components such as median barriers, bridge panels and rail road ties. Further, the use of PET waste as binder in the production of PC considerably reduces the cost as compared to the PC produced using virgin resin.

Hisham and Moetaz [23] conducted experiments to study the flexural behaviour of polymer concrete (PC) made with epoxy resin and a polyester with varying percentages. The results show that the modulus of rupture and ultimate compressive strain for PC were much higher thus improving the ductility as compared to the ordinary Portland cement concrete. Ribeiro et al. [24] found that the flexural properties of unsaturated polyester and epoxy mortars are strongly affected by the environmental temperatures. However, except within a limited temperature range, the flexural strength of these mortar formulations decreases drastically with the rise in temperature. Rebeiz and Fowler [25,26] studied flexural behaviour of steel-reinforced PC beams using unsaturated polyester resins based on recycled PET waste. The studies indicated very good flexural and shear strength of reinforced PC so produced. ACI method was found to yield conservative results when applied to reinforced PC and alternative design equations were developed for predicting the shear and flexural strength of steel-reinforced PC beams.

Jo and Kim [27] investigated the mechanical properties of PC produced using resin based on recycled PET and achieved compressive strength of 73.7 MPa, flexural strength of 22.4 MPa, splitting tensile strength of 7.85 MPa, and elastic modulus of 27.9 GPa, at 7 days. The authors later studied uniaxial creep behaviour of the PC [28]. The creep strain at early ages was found to increase in PC more rapidly than in ordinary cement concrete. Creep in PC was the result of molecular movement in the viscoelastic resin binder. The creep values increased with an increase in applied stress, although the values were not proportional to the stress ratio, because of the nonlinear viscoelastic behaviour of the PC. Joe et al. [29] studied the mechanical properties of PC made with recycled PET and recycled concrete aggregates. The PC at a resin content of 9% was nearly unaffected by HCl, whereas the PC with 100% recycled aggregate showed poor acid resistance. Unlike acid, alkali compounds did not attack the PC with 100% recycled aggregate as observed from the weight change and the compressive strength.

In the present study, stress–strain characteristics, flexural and shear strength of polymer concrete (PC), flexural and bond strength of reinforced PC (RPC) have been studied to understand the flexural behaviour of PC beams. The optimal proportions of PET to glycol ratio and initiator-promoter combinations obtained in the previous studies of the authors [16,17] have been used in the production of PC. The optimal proportions in the previous study [16] were obtained based on the compressive and tensile strength of PM and concrete, thermo-gravimetric and SEM analysis.