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Application of photonics in determining the strength characteristics of composite concretes

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ABSTRACT

For the sustainable developments of the construction industry, there is a growing need for reducing the usage of the rapidly depleting natural resources in building concrete structures. Re-utilisation of conventional wastes such as different grades of polymeric particulates derived from municipal wastes is being explored as a partial replacement of natural aggregates in making concretes. This poses new challenges to researchers as methods to evaluate the effects of new host particles on the mechanical strength characteristics of composite concretes at microscale and their subsequent effects on their bulk strength are not yet well established. In this research work, municipal polymeric wastes in various forms and fly ash from incineration of municipal solid wastes are used together as secondary raw materials for the preparation of concrete mixtures. The influence of various forms of polyethylene (PE) substitution on the local and global shear stress distribution are sensed whole-field on the cylindrical and notched concrete beams using the principles of photonics. The generic methodology reported here would be of great interest in measuring the strength of concretes and other cementitious composite materials under different loading environments in future. Furthermore, an improved understanding on both microscale stress (/strain) evolution and macro strength characteristics could form a basis to develop new strength theories of composite concretes.

1. INTRODUCTION

One of the fundamental challenges to overcome in developing and designing new composite concretes is to understand the mechanical strength characteristics of concretes at both micro (local) and macro (global) scales. The current strength-evaluation tests, including strain and stress measurements, mostly pertain to global strength measures [1].

For concretes subjected to external loading conditions, micro-scale strain measurements are generally made using electrical strain gauges and rosettes [2,3]. Fibre optic sensors could help to make strain measurements inside concretes, but with some intrusion effects of the sensor [4]. Other methods such as holographic interferometry [5] and acoustic emission [6] are used to measure strains and crack length in concrete structures. Infrared (IR) thermography [7] and digital image correlation (DIC) [8-10] have been used to detect displacements and crack formation on the surface of concretes. Optical stress analysis has been reported to detect strain field on materials by studying the birefringent (/photonic) properties of coatings applied on their surfaces under mechanical loading [11]. Each method has its advantages and disadvantages.

In this presentation, we study on the distribution of maximum shear stress (/shear strain) on standard concrete samples using some of the ingredients of municipal wastes. The cylindrical samples were subjected to axial compression test and the rectangular notched beams was subjected to the flexural strength test as per ASTM standards. Using this information, more precise evaluation of the fracture processing zone could be made, and this in turn could help to evaluate the fracture toughness of composite concretes.

2. Materials and Method

In this study, high density and low density polyethylene (HDPE and LDPE respectively) granules, obtained from a typical municipal waste-processing, unit were added into concrete mixes in controlled proportions for making the concrete samples (Table-1). The expanded details on the preparation and the evaluation of material properties of the different concrete mixes used here can be found elsewhere [12]. Two types of samples were considered here: cylinders (200mm length and 100mm diameter) subjected to compression (ASTM C39), and notched beams (160 x 40 x 40 mm having a 1mm notch size at the middle) subjected to three-point bending (ASTM C78) to evaluate fracture toughness. The experimental methodology to sense the maximum shear stress distribution whole field on the samples under the mechanical loading is based on reflective photo-stress analysis and an expanded details of this can be found elsewhere [13]. The strain optic coefficient of the birefringent coating was 0.06 m/m/(m/m), i.e., in the unit of retardation/thickness/strain.

Table-1: Mix ID and the composition of the concrete samples [12]

Mix ID	Constituents
1	Pozzolanic materials containing fly ash and silica fume – 20%
2	Pozzolanic materials – 20%, steel fibre – 2%
3	Pozzolanic materials – 20%, steel fibre – 1%, recycled LDPE fibre – 1%
4	Pozzolanic materials – 20%, steel fibre – 2%, virgin LDPE granule – 10%
5	Pozzolanic materials – 20%, steel fibre – 2%, virgin HDPE granule – 10%
6	Pozzolanic materials – 20%, steel fibre – 2%, recycled LDPE granule – 10%
7	Pozzolanic materials – 20%, steel fibre – 2%, recycled HDPE granule – 10%

3. Results

The compressive strength test results of the composite concrete mixtures are presented in Fig.1. As seen from the compressive strength test results, the concrete mixtures including virgin high density polyethylene or recycled low density polyethylene waste particles have same compressive strength values with the control mixture which is different from some published studies [14]; however consistent with other studies on using plastic particles with cementitious materials [15]. Furthermore, as seen in this figure, the compressive strength of the control mixture was lower than the fiber reinforced concrete mixtures at the early stage, 7 days, which indicates that the fiber addition accelerated the hydration and consequently improved the early age compressive strength in fibre reinforced mixtures. However, at 28 and 90 days, the control mixture has gained more strength than the fibre reinforced mixtures which could have resulted from the low interfacial bonding of polyethylene fibre in the mixtures, though some mixes resulted only marginally low compressive strength in comparison. However

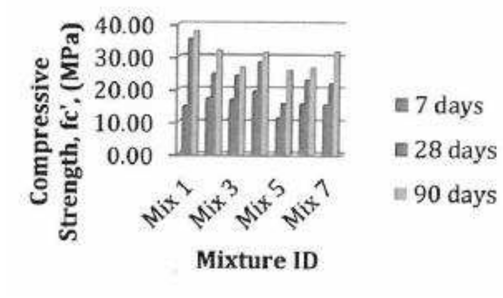

Figure 1: Compressive strength of the concrete samples

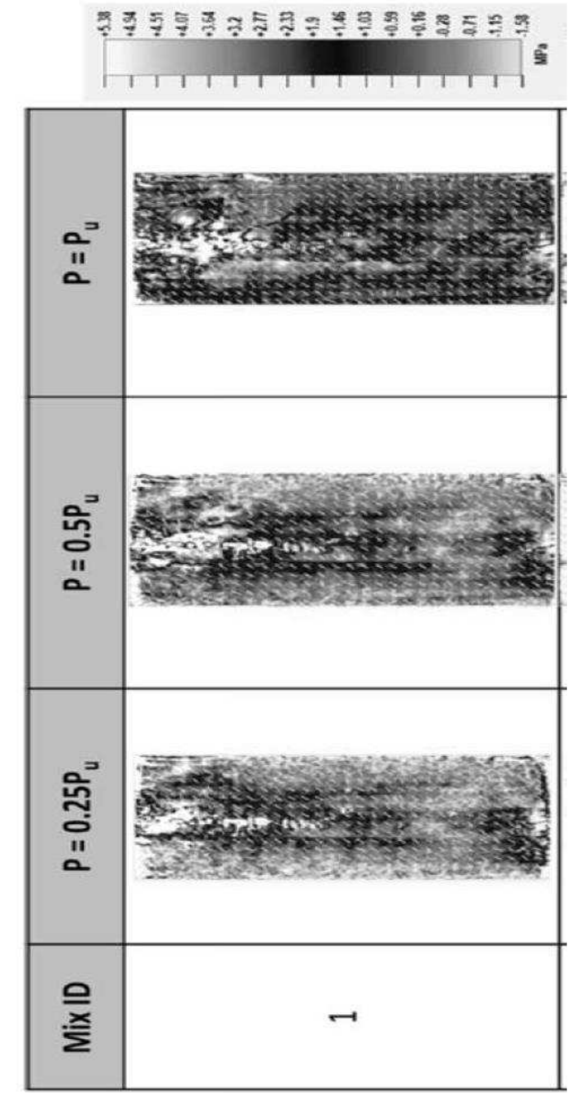

Figure 2: Evolution of maximum shear stress in a typical cylindrical sample-1 subjected to compression under different levels of loading (Pu is the ultimate load).

other studies have shown that, even though the polymer-added concrete composites present some reduction in strength than the control sample, they possess significantly high resistance against sulphate attack [12].

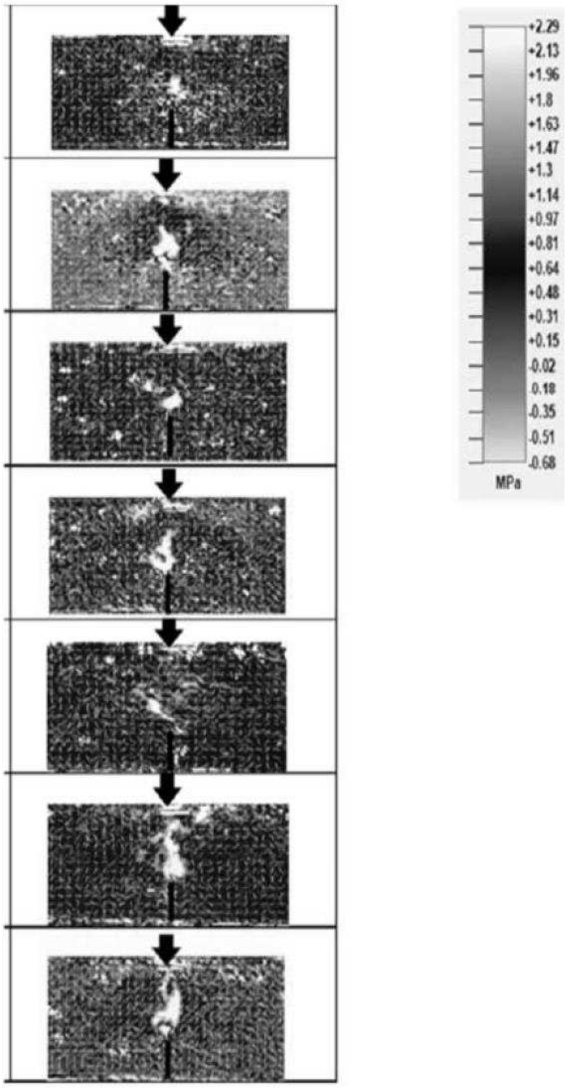

Figure 3: Flame-like distribution of maximum shear stress ahead of the notches on the notched samples 1-7 under the ultimate load (top most sample ID is 1 and bottom most 7 in the ascending order. The notch at the middle is shown in black colour in the plots. The short arrows show the direction of the major principal stress)

Here the focus is on sensing the maximum shear stress distribution on the surface of the samples under mechanical loading and typical plots of them are provided in Figs.2-3. However, such patterns can be also used to characterise the fracture processing zone and fracture toughness of the composite concrete samples [13].

4. Conclusions

The current study demonstrates the usefulness of applying photonic stress analysis for understanding the mechanical properties of composite concretes. This enables us to visualise the whole-field evolution of shear stress (/strain), and their characteristics could be further applied in evaluating the fracture toughness [13] of concrete mixes of different ingredients such as the particulate materials derived from municipal wastes. An improved understanding on both microscale stress (/strain) evolution and macro strength characteristics should in turn help us to develop more realistic theories for describing the strength characteristics of new concrete materials in future. Further detailed studies are ongoing to quantify the effects of particulate inclusions on the stress and strain distribution, and strength characteristics of composite concretes.

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