Engineering Fracture Mechanics 78 (2011) 2957–2965

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Parameters identification of polymer concrete using a fracture mechanics test method and full-field measurements

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ARTICLE INFO

Article history:
Received 21 January 2011
Received in revised form 12 July 2011
Accepted 11 August 2011

Keywords:
Polymer concrete
Parameter identification
Full-field displacement measurements
Fracture mechanics

ABSTRACT

In the present work it is proposed an easy-to-implement alternative procedure to identify not only the fracture properties but also the mean elasticity modulus E and Poisson's ratio v of arbitrary polymer concretes. Only one test using a standard single-edge-cracked three-point bend specimen is necessary. Digital Image Correlation (DIC) method is used to obtain the full-field displacement close to the crack tip. The mean properties (E, v) are determined by fitting analytical expressions for the displacement field to the experimental data. The adequacy of the proposed methodology is checked by comparing the material parameters obtained using the proposed procedure with the ones obtained through standard procedures.

1. Introduction

Polymer concretes are heterogeneous elasto-viscoplastic materials. Nevertheless, they are usually modeled as elastic homogeneous and isotropic materials beyond a certain representative "material volume" and if the loading level is below a given elasticity limit (what normally happens in the most common applications). The adequate identification of the mean elastic properties using the minimum number of tests is still a challenge to designers. Fracture mechanics test methods for concrete are usually adopted to analyze their fracture toughness, loading rate effects, crack propagation, etc. [1]. Nevertheless, such test methods seems to be very interesting as auxiliary tools to identify mean properties of composite materials, like polymer concretes. There are some standard procedures to identify the mean elastic properties of a polymeric concrete (modulus of elasticity E and Poisson's ratio v, using fracture mechanics test methods (see [2], for instance). The most common identification procedure requires at least two kind of testing: (i) the crack mouth opening displacement (CMOD) in a single-edge-cracked three-point bend specimen is measured in order to evaluate the modulus of elasticity and (ii) compressive tests are performed to determine the Poisson's ratio.

In the present work, an easy-to-implement alternative fracture mechanics test method is proposed to estimate the mean elastic properties of this kind of composite material. Only one test using a single-edge-cracked three-point bend specimen is used since a full-field displacement measure technique is necessary. The elastic parameters identification is performed using the experimental displacement field obtained through Digital image correlation method and well-known analytical expressions for the displacement field close to the crack tip.

Digital Image Correlation (DIC) is an optical–numerical full-field surface displacement measurement method [3–5]. It is based on a comparison between two images of a specimen coated by a random speckled pattern in the undeformed and in the deformed states. It is a non-contact measurement technique that requires simple optic setups, no special preparation of

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doi:10.1016/j.engfracmech.2011.08.013

Nomenclature

a, a_0	crack length and initial crack length
B	beam thickness
c_1 and c_2	constants
C_i	initial compliance
E	modulus of elasticity
ε_{ij}^p	plastic strain
F	applied loads
H_0	clip gauge holder thickness
K_I, K_{Ic}	opening mode stress intensity factor and critical stress intensity factor
k, n	positive material constants that account for the rate dependency of σ_y
p	accumulated plastic strain
r	radii (polar coordinates)
r_y	polar distance at which the von Mises criterion is satisfied
S	specimen load span
σ_y	yielding stress obtained in a tensile test
u and v	displacement fields
x and y	Cartesian coordinates
W	beam depth
μ	shear modulus
v	Poisson's ratio
θ	angle (polar coordinates)

specimens and no special illumination. The basic principle of the method is to search for the maximum correlation between small zones (subsets) of the specimen in the undeformed and deformed states. For determining the displacement of each point, a square reference subset of $(2M+1)\times(2M+1)$ pixels from undeformed image is chosen and it is used to find the corresponding target subset at deformed image. From a given image-matching rule, the displacement field at different positions in the analysis region can be computed. The simplest image-matching procedure is the cross-correlation, which provides the in-plane displacement fields $u(x,y)$ and $v(x,y)$ by matching different zones of the two images.

Methodologies to estimate material parameters of different material using full field measurement have yet been proposed [6–8]. Nevertheless, most of the recent works in this field are interested in crack characterization by means of DIC method [9,10], in the determination of the stress intensity factor and in the analysis of crack growth [11–13].

Polymer concretes (PCs) are composites made of inorganic aggregates bonded together by a resin binder. PC is widely used since the middle of the last century to produce building cladding [14]. PC is used very efficiently in precast components especially for industrial flooring, retouching of damaged concrete structures and underground pipes. The composition of a PC is determined by its applications, and its strength is influenced by ratio of aggregate to resin content. The concrete studied in the present paper is a polyester polymer concrete made with foundry sand and unsaturated polyester resin from recycled PET, which substitutes the cement. The proposed methodology for parameter identification is checked by comparing the material parameters identified for this concrete with the ones obtained using a standard procedure, showing a good agreement.

2. Materials and methods

2.1. Polymer concrete

The polymer concrete considered in the present study was obtained by mixing fresh foundry sand and unsaturated polyester resin. The foundry sand is used in the foundry industry and has a homogeneous grain size, employed in a 40–50 design, meaning aggregate with finesses modulus between 4 and 5, with specific gravity of 2.63 g/cm^3. The polyester resin used in this investigation was an unsaturated polyester manufactured by recycled PET. Producing the unsaturated polyester resin was not focused in this research. It was used as a commercial product by Reichhold®. The resin system is pre-accelerated by the manufacturer and the initiator used was methyl ethyl ketone peroxide (2 phr). The resin content was 12% by weight and no filler was added in formulations. Polyester resin is the most used resin to produce polymer concrete due to its high performance, resulting in a high strength and durability against aggressive environments, with low permeability and lower cost when compared to epoxy resins. The resulting behavior is quasi-brittle: the material behaves elastically until a quasi-brutal rupture. Rate-dependent inelastic deformation occurs only at the onset of rupture and is very small in comparison with the elastic deformation. The rupture stress depends very little of the applied strain rate.

Previous studies carried out in [15], considering an extensive experimental program, allowed an optimization of mortar formulations that are now being used in the present work. Optimization of mix design, regarding fracture toughness, was