Construction and Building Materials 25 (2011) 385–395

Contents lists available at ScienceDirect

Construction and Building Materials

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

Dynamic tensile testing of fabric–cement composites

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ARTICLE INFO

Article history:
Received 5 August 2009
Received in revised form 12 April 2010
Accepted 7 June 2010
Available online 2 July 2010

Keywords:
Dynamic tensile tests
High speed loading
Cement composites
Carbon
AR glass
Textile

ABSTRACT

Dynamic tensile tests were conducted using a high speed servo-hydraulic testing machine on three types of fabric reinforced cement composites. The high speed testing procedure and data processing method are presented. Quasi-static tests were also conducted on the composites. Effects of strain rate on the mechanical properties of fabric–cement composites are noted. A good correlation was found between the properties of the fabrics and the composites, with the carbon fabric exhibiting the highest strength and ductility performance in high speed tensile tests. The differences in tensile behavior of the various composites were correlated with the differences in the role of the fabric materials. Composites tested under high speed loading exhibited different responses as compared to similar composites tested under quasi-static condition.

1. Introduction

Cementitious materials may be subjected to dynamic loading for variety of reasons including: blast explosions, projectiles, earthquakes, fast moving traffic, wind gusts, wind driven objects, and machine vibrations. Due to the inherent brittleness and low tensile strength of most cement-based elements, dynamic loading can cause severe damage and cracking [1,2]. In order to accurately analyze and design structures that are subjected to dynamic loading, it is necessary to utilize the mechanical properties associated with the strain rates to which the structural components are subjected. Testing dynamic properties is a challenge since the results are highly dependent on the loading rate, method of testing, and the geometry of the tested element [3–6].

Fiber reinforcement is undoubtedly one of the most effective means of enhancing the resistance, strength, and energy absorption of cement based materials subjected to dynamic loading [1–6]. To date, dynamic properties of cement composites have been studied mainly for short fiber composites under impact condition. Fabric–cement composites clearly demonstrate a significant improvement in the energy absorption capacity under static loading as compared to plain concrete materials and other fiber cement composites [7–11]. Recent work on their impact behavior clearly showed the potential of such components under high speed loading [12–14]. In spite of recent activity in the study of impact resistance of cement composites, the dynamic tensile behavior is still not well understood.

Characterization of dynamic tensile properties of materials is challenging as the failure process is affected by the mode and manner of testing. Problems appear at high rate loading due to inertial effect, non-uniform loading, and difficulties in measuring reliable mechanical characteristics of the materials. There is a lack of general agreement about the standards and methodology used to conduct dynamic tensile tests [15]. A number of experimental techniques exist to investigate high strain rate material properties: split Hopkinson pressure bar (SHPB), falling weight devices, flywheel facilities, hydraulic machine, etc. [16–19]. The use of servo-hydraulic machines in medium strain rate tensile testing was reported for metals [20,21], plastics [15,22], composite materials [23] and woven fabrics [24,25], but few applications exist in cement based composites.

The importance of specimen geometry and size in dynamic material testing has been recognized by the Society of Automotive Engineers (SAE) which coordinated the standardization of "High Strain Rate Tensile Test Techniques for Automotive Plastics" in order to develop guidelines for dynamic tensile testing at medium strain rates [26,27]. The International Iron and Steel Institute (IISI) also formed a consortium to develop a high strain rate tensile test standard for sheet steel [28], while European researchers have been working on an ISO standard [29]. The SAE [26] and IISI [28] projects provide details of the relationship between specimen size and wave propagation, inertia effect, strain measurement technique, loading, and gripping devices.

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0950-0618/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.conbuildmat.2010.06.014

Research on dynamic tensile strength under high strain rates of fibers and fabrics such as Aramid, Twaron, and Zylon has been reported by several authors [30–34]. Strain rate effects on the mechanical properties of the Kevlar® 49 fibers was studied by Xia and Wang [33] who addressed rate dependence of Young's modulus, failure stress, and failure strain over a strain rate range of 10^{-4} to 1350 s^{-1}. Differences in the behavior of fabrics under high speed loading directly affect the behavior of composites made with the fabrics.

This paper presents the development of a high speed tensile testing system for laminated cement composites reinforced with various fabrics. Three types of fabric were used, i.e., carbon, Alkali Resistant (AR) glass, and polyethylene (PE). The cement based composites reinforced with these three fabrics were tested to obtain the dynamic material properties, including Young's modulus, tensile strength, toughness, and maximum strain. Typical stress–strain curves representing the tensile behavior of individual composites were compared. Crack patterns and failure behavior as well as microstructural features of each composite were observed. Finally, the dynamic response of the composites was compared with their quasi-static response.

2. High speed tensile test methodology

2.1. Dynamic tensile test procedure

The dynamic tensile tests were conducted using a MTS high rate servo-hydraulic testing machine which can operate in closed-loop and open-loop at a maximum speeds of 14 m/s with a load capacity of 25 kN [35]. The development of this test method was addressed in an earlier work [36]. Measurements can be conducted under closed-loop control at testing rates of up to 0.25 m/s and under open-loop control at speed higher than 0.25 m/s. The speed of the actuator is controlled by the opening of the servo-valve of hydraulic supply. By manually setting the level of opening of the servo-valve, the rate of flow of hydraulic fluid and hence the actuator speed can be controlled.

The setup of the dynamic tensile testing is presented in Fig. 1. As the trigger is pushed, the actuator accelerates to reach and maintain the preset speed. During this range of travel, the conical portion of the sliding bar contacts the slack adaptor (hollow tube) which is connected with the actuator and transfers the force to the specimen. The hollow tube travels freely with the actuator at the specified velocity before making contact with the sliding bar. This eliminates the inertia effect of the actuator and the lower grip during the acceleration stage. However, the sudden engagement with the upper portion of the setup generates a high amplitude stress wave, causing oscillations at the system's natural frequency, i.e., system ringing [15]. To reduce the inertia effect, lightweight grips are recommended in dynamic tensile tests [27]. The stainless steel grips are shown in Fig. 2 and weigh approximately 1500 g. A specimen was installed between two steel wedges with serrated faces. Piezoelectric load washers are recommended for dynamic tests [26–29] because conventional load cell has a much lower response frequency. In this study, the load was measured by a Kistler 9041A piezoelectric force link (load washer) with a capacity of 90 kN and rigidity of 7.5 kN/μm and frequency response of 33 kHz. The load signal was amplified through a Kistler 5010B dual mode charge amplifier. A high speed digitizer (up to 10 mega-samples per second) collected the force signal from the piezoelectric force link, and the actuator LVDT signal as the deformation of the specimen. A Phantom v.7 high speed digital camera with sampling rate of 10,000 fps captured the cracking and failure behavior of the different composites. The camera was placed in front of the specimen observing its full size in between the grips.

2.2. Data processing

Processing of the dynamic data is quite cumbersome compared to the quasi-static tests. The signals from the piezoelectric force link and the LVDT of actuator were recorded at a sampling rate of 250 kHz and contained high frequency noise which was filtered using a low-pass filter with cut-off frequency of 3 kHz. An example of the recorded responses of carbon fabric reinforced cement composite generated by the high speed testing setup after applying the low-pass filter is given in Fig. 3 which presents the force and displacement of actuator versus time histories of the entire test. A constant velocity of 1150 mm/s is obtained by linearly fitting the

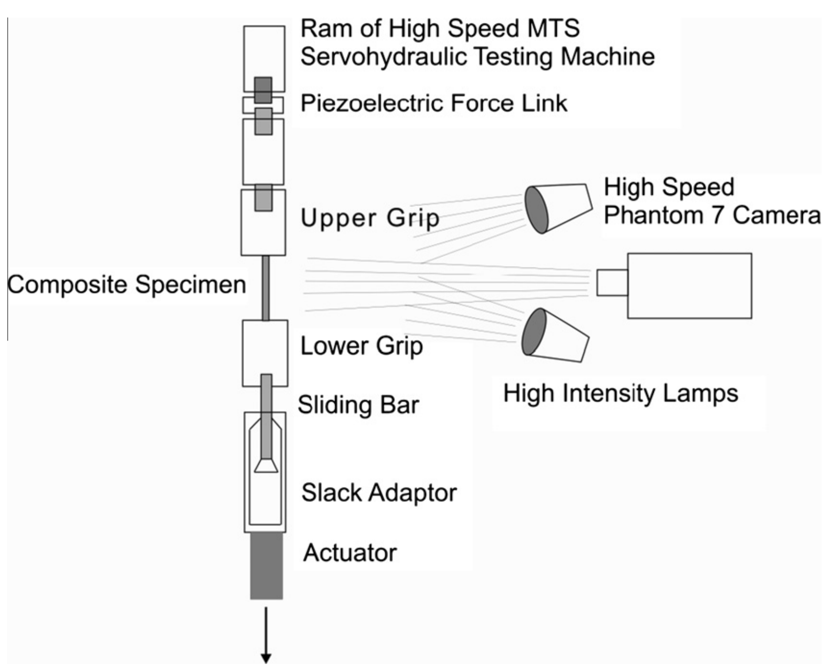

Fig. 1. Schematic diagram of test setup for dynamic tensile testing.