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Rate effects of fiber-reinforced concrete specimens in impact regime

Carlos Zanuy[a]*, Gonzalo S.D. Ulzurrún[a]

[a]*Universidad Politécnica de Madrid, Dept. Continuum Mechanics & Structures, c/ Profesor Aranguren, 3, 28040 Madrid, Spain*

Abstract

A study of the rate sensitivity of prismatic specimens of steel fiber-reinforced concrete (FRC) is carried out in this contribution. Experimental results are analyzed from impact tests carried out with an instrumented drop weight testing machine. FRC mixes with two types of fibers have been studied, namely short straight fibers and long hook-ended fibers. The experiments have included two amounts of fibers (volumetric fractions of 0.5 % and 1.0 %), and also companion unreinforced plain concrete specimens are studied. The analysis has focused on the bending properties of the studied mixes, i.e. bending strength and absorbed energy. The study shows that each particular mix of FRC has different rate sensitivity because the dynamic behavior is a consequence of the rate dependence of the mechanisms governing the interaction between fibers and matrix. For the impact strain-rate domain achieved in the tests (1-10 s^{-1}), it is shown that the study has to be done in terms of the energy absorption capacity of FRC. According to the results, the rate sensitivity decreases as the amount of fibers increases and, furthermore, the rate sensitivity of FRC mixes with hook-ended fibers is smaller than that of FRC mixes with straight fibers.
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Keywords: FRC; impact; strain rate

1. Introduction

Concrete structures like rockfall protection galleries, barriers or buildings are susceptible to suffer accidental or terrorist-induced impacts. In such structures, the brittleness of concrete makes the addition of fibers very attractive. It

* Corresponding author. Tel.: +34 913366700; fax: +34 913366702.
E-mail address: czs@caminos.upm.es

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is known that concrete properties are affected by loading rate. Compressive and tensile strength, modulus of elasticity or fracture energy have shown to increase with strain rate. In spite of the considerable scatter of dynamic experimental results, some formulations exist to consider the rate influence on plain concrete, e.g. those provided by the last version of the Model Code [1]. Nevertheless, no general formulations have been reported for rate effects on fiber-reinforced concrete (FRC), and much research is still to be done. In fact, each particular mix of FRC can potentially have different rate sensitivity as a function of the mechanisms governing the interaction between fibers and matrix. In the present contribution, the attention is paid at the rate effects of FRC prismatic specimens reinforced with two types of steel fibers, namely short straight fibers and long hook-ended fibers. An experimental campaign on prismatic specimens subjected to impact leading to strain rates in the range 1-10 s^{-1} is used to analyze the modification of bending properties with respect to those obtained in quasi-static regime. The experimental results are compared with a theoretical model proposed by the authors for the tensile properties of FRC. It is highlighted that further research is needed to understand the different behavior of FRC in bending and in tension.

Nomenclature

d_f	fiber diameter
f_c	concrete compressive strength
f_{ct}	concrete tensile strength
f_y	fiber yield strength
G_f	fracture energy
l_f	fiber length
v_f	volumetric fraction of fibers

2. Experimental research

2.1. Test description

An experimental study has been carried out at the Laboratory of Structures of the Technical University of Madrid (UPM), Spain. The experiments have consisted of impact tests on prismatic specimens of steel fiber-reinforced concrete (FRC), performed with an instrumented drop weight testing machine. The dimensions of specimens were 600 x 150 x 150 mm, and they were simply supported with a span length of 500 mm, as sketched in Fig. 1(a). The impact was produced on top side of midspan, by dropping a mass weight of 100 kg from heights ranging from 0.5 to 1.75 m, which correspond to loading rates of 3.1 to 5.9 m/s. The striking face of the impacter and the supports had a cylindrical shape with 29 mm radius. The possible uplift of supports was avoided by using steel jokes which fixed the support cross-sections of specimens. In addition to impact tests, companion quasi-static tests were carried out in three-point bending configuration under an imposed displacement rate of 0.1 mm/s. The instrumentation has included the measurement of: (a) support reactions and tup impact force by means of piezo-electric force washers manufactured by HBM, especially suited for dynamic records; (b) acceleration of the specimen at midspan section (Fig. 1a) with a PCB 353B14 quartz accelerometer; (c) strain at one point of the specimen with an electric resistance strain gage (the strain gage was not placed at midspan section because it had failed by the development of the critical crack during the test, see Fig. 1a). The sampling rate was 40,000 Hz, except for strain record which was 9,600 Hz. In quasi-static tests, the midspan deflection was measured with an LVDT.

The research has focused on the impact response of FRC materials. Two types of steel fibers have been studied: short straight fibers (l_f = 10 mm, d_f = 0.16 mm, f_y = 3000 MPa) and long hook-ended fibers (l_f = 60 mm, d_f = 0.75 mm, f_y = 1200 MPa). Two volume fractions were used for the FRC mixes (v_f = 0.5 and 1.0 %). In addition, a companion series of unreinforced specimens (v_f = 0%) was tested. The mixture of the concrete matrix was manufactured with 375 kg/m^3 of cement type I-42.5 and a water/cement ratio of 0.42. The maximum aggregate size was 12.5 mm. The compressive and indirect tensile strength of the unreinforced plain concrete were f_c = 48.5 and f_{ct} = 4.8 MPa, respectively.

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