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ScienceDirect
Construction and Building Materials 22 (2008) 277–285
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Aspects of behaviour of CFRP reinforced concrete beams in bending

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Received 13 February 2006; received in revised form 24 July 2006; accepted 30 August 2006
Available online 18 October 2006

Abstract

The corrosion of steel poses a serious problem to the durability of reinforced concrete structures and fibre reinforced polymer (FRP) has emerged as a potential alternative material to the traditional steel. The results of a test series consisting of carbon FRP (CFRP) and steel bars reinforced concrete beams are reported in this paper. The results indicated that the behaviour of CFRP and steel reinforced beams was similar in many aspects. Both type of beams failed in their predicted modes of failure. The strength design method underestimated nominal moment capacity of CFRP reinforced beams. The deflection of CFRP reinforced beams was satisfactory at service load level, corresponding to theoretical load capacity. The deformability factor of CFRP reinforced beams was more than 6 indicating their ductile nature of failure.

Keywords: Fibre reinforced polymer; Carbon FRP; Mode of failure; Concrete beams; Reinforcement; Moment; Deflection; Deformability

1. Introduction

Reinforced concrete (RC) structures have profited from the unrivalled dominance of steel over all other reinforcing materials for more than 100 years. Superior qualities of steel, in terms of strength and compatibility with concrete, make steel an effective concrete reinforcement. Steel is, however, highly susceptible to oxidation when exposed to chlorides. Although, alkaline environment of concrete protects steel from corrosion and makes it very durable it is not always possible to provide an efficient protection. Factors such as insufficient concrete cover, poor design or workmanship, poor concrete mix and aggressive environments can break down the protection layer and may lead to corrosion of the steel rebars. These destructive environments include marine surroundings, use of deicing salts on bridges and parking garages, and the use of salt contaminated aggregates in the concrete mixture. The initial signs of distress are usually cracking and spalling of concrete, which provides access to other environmental agents like moisture to further intensify the oxidisation of steel. As corrosion goes on it causes a reduction in the cross-section of a steel bar, which leads to loss of bond between rebar and concrete. To arrest the rusting of steel remedial work has to be carried out in order to achieve the full potential of the structure. This structural maintenance incurs exorbitant costs annually. Unreliable durability of these structures as a result of corrosion of steel is thus a serious problem. Recent efforts and research have been focussed towards the introduction of innovative non-metallic materials in the construction industry. Fibre reinforcement polymer (FRP) materials have evolved as a result of new developments in the fields of plastics and fibre composites.

A significant amount of research work has been executed to investigate various aspects of the use of FRP bars with concrete. As a result of these efforts, the applications of FRP bars are becoming increasingly common as a reinforcing material. Carbon FRP (CFRP) bars are mostly used in prestressing applications due to their high tensile strength, which is comparable with steel strands. This paper presents the results of tests carried out on concrete beams reinforced with CFRP bars. Testing of these beams

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0950-0618/$ - see front matter
doi:10.1016/j.conbuildmat.2006.08.014

is a part of on-going research on the behaviour of CFRP reinforced concrete beams at room and elevated temperatures at the University of Ulster.

In the first phase of this project a total of four specimen beams were used. Duplicate steel and CFRP reinforced beams were tested at room temperature. The tests results of this series will serve as benchmark to study the performance of similar beams under fire conditions. Steel reinforced beams were tested as control specimens. The study focused on the flexural behaviour of these beams in terms of stress–strain, load–deflection, modes of failure, load-carrying capacity, and cracking pattern. Some of the aspects of behaviour of these beams are discussed hereafter. Long-term behaviour and durability aspects are, however, beyond the scope of this work.

2. Experimental programme

2.1. Test specimens

The overall length of each beam was 2000 mm and the cross-section was 120 × 200 mm. Each of these beams was reinforced with two longitudinal bars on the tension face (CFRP bars for FRP reinforced beams and steel bars for steel reinforced beams). The beams were cast in moulds made of plywood stiffened with aluminium angles to maintain the beam shape under the pressure of newly cast concrete. A 20 mm concrete cover was used all-around the beam. The area and nominal yield strength of the compression steel and nominal concrete strength were kept constant for all beams in this series. Mixing of concrete was done in a rotating mixer. A vibrating table was used for the compaction of concrete inside the mould. The sides of the mould were stripped after 24 h of casting and beams were covered with hessian. Intermittent curing (thrice a day in summer) was carried out for 10 days and then the beams were left air-drying in laboratory conditions until the day of testing. Four 100 mm cubes were cast for each beam. Cubes were cured by keeping them on top of their respective beam. The beams were tested as simply supported beams over a span of 1750 mm under a four-point static load as shown in Fig. 1. The loads were 400 mm apart giving a shear span of 675 mm.

2.2. Materials

2.2.1. Concrete

Four identical concrete mixes of 325 kg/m^3 ordinary Portland cement, 1001 kg/m^3 of graded crushed stone, 853 kg/m^3 of sand and 216 litres/m^3 of water were used. The maximum aggregate size was 10 mm. The exact amount of water varied depending on the moisture contents of aggregates. The slump of concrete ranged from 40 to 50 mm. Cube strength after 28 days was 49.23 MPa, this being the average strength of the four cubes, one from each beam. This is equivalent to 43.31 MPa cylindrical strength [1]. Table 1 shows the equivalent cylindrical strength [1] of the concrete on the day of testing. These strengths were obtained from the average strength of three cubes for each beam. Each beam tested is defined by letters comparing its reinforcing material and temperature conditions. The notation of beams is as: the first letter (B) stands for beam; the second letter indicates the testing temperature as R for room temperature; the third letter represents the type of tension reinforcing bar material such as S for steel and C for CFRP bars. These notations have been consistently followed throughout the rest of the text.

2.2.2. CFRP bars

The FRP bars consisted of 9.5 mm diameter straight CFRP rods, as shown in Fig. 2. The bars were produced by an American manufacturer using the pultrusion process.

Table 1
Strength of concrete on the day of test

Beam	Compressive strength (MPa)
BRS1	46.52
BRS2	44.64
BRC1	42.55
BRC2	41.71

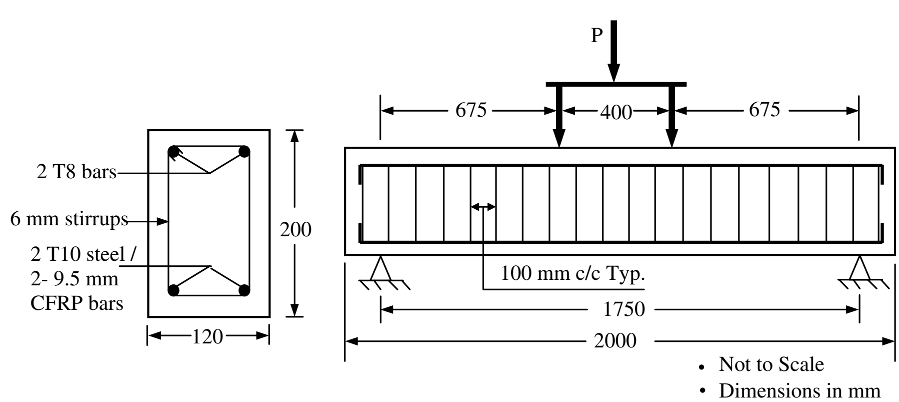

Fig. 1. Details of a typical beam.