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Monotonic and cyclic behaviour of lightweight concrete beams with and without steel fiber reinforcement

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HIGHLIGHTS

- Experimental tests on lightweight concrete beams with and without steel fiber reinforcement are developed.
- The cement was partially substituted by ashes coming from the combustion of Municipal Solid Waste.
- Both monotonic and cyclic loads are applied.
- The results show the effectiveness of fiber reinforcement in improving the element performance.

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ABSTRACT

Experimental tests on four lightweight concrete beams with and without steel fiber reinforcement, subjected to monotonic and reverse cyclic loads, were set-up in order to investigate the influence of the fiber reinforcement on the strength, ductility and energy dissipation. The tests were performed on beams with 200 × 300 mm cross section and clear span of 3000 mm. Furthermore, in the framework of the definition of sustainable materials, the cement of the concrete matrix was partially substituted by ashes coming from the combustion of Municipal Solid Waste (MSW), with pozzolanic reaction. The obtained results are presented, discussed and compared.

1. Introduction

The use of Fiber Reinforced Concrete (FRC) is continuously growing, particularly in pavements, shotcrete and precast industry [5,22,17]. In some applications, such as precast tunnel segments, the possibility of totally or partially replace the traditional reinforcement with FRC allows several advantages not only in terms of cost reduction but also related to an increase of the quality and structural performance [32,26,9,15,10,29].

With reference to the structural aspects, the fiber reinforcement improves the performance of the material under tensile actions, remarkably increasing the toughness and enhancing the cracking control [34,36]. Furthermore, the presence of fibers in the concrete matrix has important effects in increasing the fatigue and the impact resistance [16,7]. Guidelines and codes for FRC structures have been developed in different Countries [13,11] and the fib Model Code 2010 includes specific indications on FRC structural design [25]. Nevertheless, there is a clear gap in the literature on the application of steel fiber reinforced concrete (SFRC) to enhance the seismic -and thus cyclic – response of a structure and to assess the potential ductility and energy absorption capacity of such composites. Indeed under reverse cyclic loading, concrete is subjected to more severe damage and the presence of fibers can reduce the strain magnitude and control the crack openings [14,33]. Very few papers are nowadays available on the cyclic behaviour of fiber reinforced elements, and mainly beam. Monotonic and cyclic experimental tests on small steel FRC beams (150 × 150 × 500 mm) were made by Campione and Mangiavillano [8]. Several advantages given by the fibers under cyclic action were observed, such as a reduced cover spalling process, a significant increase in shear strength due to the bridging actions of the fibers across the principal cracks, fewer pinching effects.

Twelve two-span beam specimens (150 × 200 × 1000 mm) were tested by Kotsovos et al. [27] using different reinforcement diameters and concrete grades, with or without steel fibers in the mix, with the aim of studying the effect of fibers on the behaviour of reinforced-concrete (RC) structures designed in accordance with Eurocode 8 [19]. Both monotonic and cyclic loading were considered. Based on the experimental results, the authors concluded

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Table 1
Concretes mix design and density (amount in kg/m^3).

	L-MSW	L-FRC-MSW
Cement	472	460
MSW ashes (40% in slurry)	140	133
Sand (0–4 mm)	922	1113
Coarse Aggregate (2–16 mm)	165	–
Expanded clay (0–15 mm)	344	295
Water (total)	170	162
Plasticizers	38	48
Shrinkage reducer agent	32	32
Steel Fibers	–	30
Measured density	2064	2156

that for the specimens without fibers, under cyclic loading, designing to current code provisions does not safeguard against a premature brittle failure. On the contrary, specimens with fibers satisfied the performance requirements of Eurocode 8 for strength and ductility, for concrete strength up to 60 MPa. For higher values of concrete strength, in spite of the significant improvement in performance, the code requirements were not fulfilled in terms of ductility.

Schumach [35] found that in some circumstances the introduction of fibers for the enhancement of a particular structural behaviour (e.g., shear, impact resistance, behaviour at service load, crack control, etc.) can limit the ductility under flexure. This situation occurred in particular conditions, mainly when both steel rebars with a low hardening ratio and a FRC having a high toughness are adopted. The combination of these two aspects was found to be particularly detrimental with regard to the overall ductility. In those circumstances, an increase in the rebar bond leads to a localization of deformations at a crack. Similar conclusions were found by Meda et al. [30].

The lack of works dealing with the influence of the fiber reinforcement on the cyclic behaviour of full-scale beams, and the emerging contrasting views, clearly show the need to provide more experimental data and models.

Recently, a comprehensive research on the adoption of fiber reinforced concretes, with different mix designs, both in beam and slab elements [31] has been developed at University of Rome Tor Vergata. The use of innovative concrete in RC structures is receiving widespread attention, with particular reference to the idea of reducing the environmental impact of new concrete structures [24]. In this context, the possibility of partially replacing the cement with the product of incineration of the Municipal Solid Waste (MSW) can be of great interest [23,6,12,28,1,3]. A research on innovative lightweight concrete with cement partially replaced with ashes coming from the burning of MSW, having pozzolanic properties, has been developed by the authors, and its possible application in combination with steel fiber reinforcement is here proposed for beams subjected to cyclic loads. At this aim,

Table 2
Concretes compressive mechanical properties.

	Mean concrete cubic strength Rc [MPa]	
Time (days)	L-MSW	L-FRC-MSW
3	33.55	34.33
7	47.50	42.50
14	51.14	47.27
28	58.56	52.77
160	65.60	65.00

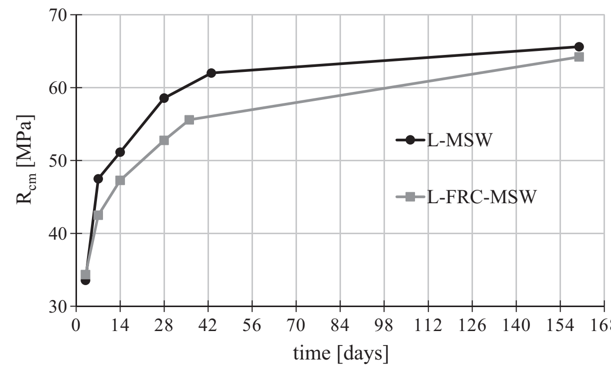

Fig. 2. Mean compressive strength at different curing times.

experimental tests have been carried out on beams with two concrete mixes, also in presence of lightweight aggregates, with and without fiber reinforcement. The full-scale specimens are subjected to cyclic loads and the effectiveness of the FRC material solutions is remarked.

2. Material properties and characterization

Four beams were cast with a lightweight concrete (with clay aggregate) and with a partial replacement of the cement with ashes coming from the burning of Municipal Solid Waste. In two specimens, steel fiber reinforcement was added also. The specimens were subjected to monotonic and cyclic loads.

2.1. Concrete mixes

Two concrete mixes were cast and adopted in the present research:

- Lightweight concrete with ash from Municipal Solid Waste (L-MSW);
- Lightweight fiber-reinforced concrete with ashes from Municipal Solid Waste (L-FRC-MSW).

The fiber reinforced concrete is characterized by the addition of 30 kg/m^3 of hooked steel fibers with length (l) equal to 30 mm and diameter (d) of 0.30 mm (aspect ratio l/d equal to 100). The steel wire strength is higher than 2000 MPa.

The mix design for the concretes used in the experimental program is shown in Table 1.

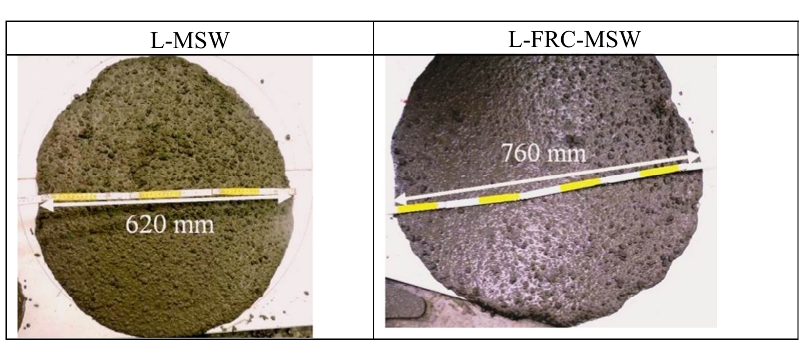

Fig. 1. Slump flow test results.