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Influence of fibres on the mechanical behaviour of fibre reinforced concrete matrixes

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HIGHLIGHTS

- Three types of fibre reinforced concrete matrixes (FRCM) were produced.
- The compressive strength of the FRCM increase with the increase of fibres addition.
- Increasing the fibre tensile strength leads to an increase of the FRCM maximum load.
- The toughness indexes increase for polypropylene (PO) and steel (ST) FRCM.
- FRCM shows ductile behaviour for PO and ST fibres and fragile for glass (GL) fibres.

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ABSTRACT

An experimental analysis focused on the mechanical behaviour of fibre reinforced concrete matrixes (FRCM) is presented using a total of three hundred and twelve specimens. A reference plain mixture was first defined and then three types of fibres were chosen to reinforce it (polypropylene, glass and steel fibres). Within each type of reinforcement, four volumetric proportions were adopted, ranging from 0.5% to 2% in 0.5% increments. The influence of each type of fibre and dosage on the properties of the FRCM, including compressive strength, bending behaviour, cracking and maximum loads and ductility was analysed. In summary, it was observed that the compressive strength generally grows with the reinforcement dosage, and that this growth is greatly affected by the properties of the fibre, namely by its tensile strength. The load-displacement curves are also highly affected by the type of reinforcement. Steel and polypropylene fibres provide the composite material a better capacity to withstand high deformations. Glass fibres have a reduced effect on this regard, due to their brittle behaviour. For each type of fibre, by increasing the fibres percentage, an increase in the load capacity is also observed, with a maximum of 160% for an addition of 2.0% of steel fibres. The cracking loads are consistently lower than that of the reference mixture, due to the loss of homogeneity and increased porosity caused by fibre addition, in spite of the favourable influence associated to the mechanical properties of the fibres. For polypropylene FRCM the cracking loads were approximately 35% lower than that of the reference mixture. For steel and polypropylene fibres the toughness indexes (I5, I10 and I20) were defined, being observed that for 1.5% volume fraction of steel fibres the I5 and I20 are respectively 6.80 and 35.08, whereas for the polypropylene fibres those indexes are respectively of 3.61 and 15.75 for the same fraction.

1. Introduction

Fibres have been consistently used in construction since the beginnings of 20th century. During the 1960s and 1970s, the use of asbestos fibres decreased with the awareness of the health problems caused by long-term heavy exposure to these airborne fibres [1]. Since then, fibres have been produced using different

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materials, such as steel, polypropylene, and glass, among others, that gradually widespread to different applications, in particular to the production of fibre reinforced concrete (FRC) [2].

Concrete is considered a construction material with strong heterogeneous behaviour, with a good compressive strength and a low tensile strength typically around 5–8% of the compressive strength [3]. Moreover, concrete has a low strain capacity and is brittle in fracture. The use of fibre reinforced concrete is currently of particular interest, especially in structures with high standards of performance and durability. The behaviour of these concretes is mainly conditioned by the binding matrix properties and by its interaction with the reinforcing fibres. The most common fibres capable of improving the properties of plain concrete are made of steel, glass or polypropylene. Table 1 show the properties of fibres used to reinforce concrete. To choose the type of reinforcement fibres, the behaviour of the several FRC must be known with a high certain level. Therefore, it is important to understand the influence of each fibre parameters on the general behaviour of the structural composite material. Many parameters can be analysed, being length, diameter, shape and type of material the most important. The geometry and type of material have great influence over the behaviour of fibre reinforced concrete [4,5]. Even the distribution of fibres is affected by the diameter, length and proportion of fibres, as well as by the flowability of the concrete matrix, the placement method and formwork [6]. Obviously, the behaviour of FRC with different fibres will be also significantly different. So, the choice of fibre type, and its properties must be made carefully and should satisfy the structural requirements.

Polypropylene and glass fibres are commonly used in industrial pavements and when its required a concrete with shrinkage cracking control [7]. Many studies refer that the flexural strength of glass FRC seems to increase 15–20% compared with plain concrete mixtures, showing also an improved toughness [9–14]. Most those studies [9–13] also reported an increase in the compressive strength ranging from 20 to 25%, although other publications [14] pointed out only a marginal decrease of this parameter.

For polypropylene FRC, some studies [15–17] mention the compressive strength of polypropylene FRC to be nearly unchanged by adding fibres, whereas others [18,19] show an increase up to 20%. In terms of flexural strength, some authors [15,16] report no impact on this material property, whereas others [17,18,20] state an increase of 10% maximum, or even a decrease on this property [21]. Furthermore, some authors [15,18,20,21] report increased flexural toughness and ductility relatively to plain concrete, for both lower and higher dosages, increasing with the percentage of reinforcement.

Most research about FRC has been focused on steel fibres. This type of fibres is typically used in industrial pavements [22], precast industry [23] and tunnel linings [24]. Studies highlight that the failure mode of steel FRC changes from fragile to ductile and that the post-cracking response is significantly improved [25,26]. Many studies refer to the enhanced toughness, ductility and flexural strength of the steel FRC, the latter reaching values ranging from 30 to 125% when compared to plain concrete and depending of concrete strength and fibres dosage [4,25–29]. However, even for these fibres there are still contradictory results concerning the prediction of material properties. For example, some authors suggest the compressive strength of steel FRC [25,27] to increase up to 10% when compared to plain concrete, whereas other studies claim this change to be only marginal or not even related with the introduction of fibres [26,28].

The great majority of studies found in the literature on FRC, some of them above mentioned, are essentially focused on a single type of fibre and corresponding mechanical behaviour. When new types of fibres are provided by the market, e.g., carbon and, more recently, basalt, the natural tendency of researchers is to redirect their studies to these. However, there are significant differences in FRC mixes produced with current fibres, namely steel, polypropylene and glass, that for some reason have not yet been fully addressed. These are quite difficult to be determined from published studies (on single fibres), due to the large variation in mixes and tests. Having this into consideration, this work aims at presenting an extensive comparative experimental study on three different types of fibres (polypropylene, glass and steel) with the same binding matrix. The purpose was to assess the influence of the type of fibre adopted in the mechanical properties of FRCM. The following specific aims were defined:

- access the FRCM compressive strength evolution with the introduction and proportion of fibres;
- characterise the bending behaviour of FRCM depending on the type of reinforcement fibres;
- determine the FRCM cracking and maximum loads and identify the influence of fibres type on those values;
- define some ductility parameters that show the influence of each type of fibre on the post-peak behaviour of FRCM.

2. Experimental programme

The experimental programme was outlined according to the different aims set in the previous section. In the following, the geometry and number of specimens, FRCM mixtures and test setup for the characterisation of mechanical properties, are described.

2.1. Material properties and specimens production

A reference self-compacting cementitious plain matrix (without fibres) was first selected, which was the basis for comparing the effect of three types of fibres: polypropylene, glass and steel respectively. The choice for a self-compacting mixture aimed compensating the workability reduction caused by fibres addition. For this purpose, four dosages were defined for the reinforced mixtures, ranging from 0.5% up to 2%, considering increments of 0.5%.

The number of fibres present in the polypropylene and glass FRCM is obviously very high when compared to steel FRCM, due to the reduced cross-sectional area of the first (Table 2). Although

Table 1
Typical properties of fibres [7,8].

Fibre	Specific density	Young's modulus (GPa)	Tensile strength (GPa)	Elongation at failure (%)
Steel	7.84	200	0.5–2.0	0.5–3.5
E-glass	2.55	72.4	3.45	4.7
S-glass	2.5	86.9	4.71	5.2
Crocidolite (asbesto)	3.4	196	3.5	2.0–3.0
Chrysolite (asbesto)	2.6	164	3.1	2.0–3.0
Polypropylene	0.90–0.95	3.5–10.0	0.45–0.76	15–25
Polyethylene	0.92–0.96	5	0.08–0.60	3–100
Carbon (high strength)	1.5	230	5.7	2.0
Carbon (high modulus)	1.5	640	1.9	0.36