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Comparison between polyolefin fibre reinforced vibrated conventional concrete and self-compacting concrete

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HIGHLIGHTS

- The differences in fracture behaviour were clarified by counting fracture surfaces.
- SCC distributes the fibres more homogeneously within the specimen length.
- The mould walls had more influence on the positioning of fibres for VCC specimens.
- Linear relations between residual loads and the number of fibres were established.
- The presence of fibres did not increase the connected porosity network of concrete.

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ABSTRACT

Reinforcing concrete with macro-synthetic structural fibres has become an alternative due to their capacity to comply with standards to substitute steel bars. Compaction and pouring processes influence fibre positioning and orientation and are of key importance for the effectiveness of fibre-reinforcement. This research compares self-compacting concrete with vibrated conventional concrete reinforced with several dosages of polyolefin fibres. The differences between them in fresh and hardened state were assessed and were more noticeable for high-content of fibres. However, fibres were more evenly distributed in the fracture surfaces of self-compacting specimens and wall effects were more evident in the vibrated concrete specimens.

1. Introduction

The main disadvantage that concrete has once hardened is its limited tensile strength and toughness. These characteristics can be enhanced by adding short fibres when mixing, randomly distributed within the bulk material as has been extensively shown in published research [1,2]. The tensile and flexural strength of fibre reinforced concrete (FRC) is commonly superior to that of a conventional concrete and has been highlighted in both the scientific literature and practical uses [3].

In order to regulate the use of FRC, some modifications have been introduced in the design recommendations in several countries [4–7]. If the composite material satisfies certain requirements regarding its residual strength, the contribution of the fibres can be considered in structural design. This enables a reduction or elimination of the steel rebars used in reinforced concrete examples, as shown in the literature [8–10]. Meeting these requirements depends on various factors, such as the type of fibre used, dosage, orientation and distribution of fibres in the fracture section [11,12]. It should be noted that although such recommendations were originally applied to steel fibres, at the time of writing they are being employed to test concrete reinforced with other types of fibres such as micro or macro-plastic. Polyolefin based macro-fibres employed to reinforce concrete, forming polyolefin fibre reinforced concrete (PFRC), are not only chemically stable (which avoids the corrosion problems that steel fibres suffer) but also lighter and with a final lower cost. As they have been proved suitable for structural uses, in some cases they have substituted steel fibres [13–16].

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Table 1
Concrete formulation per m^3.

Concrete formulation	Cement (kg/m^3)	Limestone powder (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Grit (kg/m^3)	Superplasticizer (% cement weight)	Polyolefin fibres (kg/m^3)
SCC	375	200	187.5	918	245	367	1.25	–
VCC	375	100	187.5	916	300	450	0.75	–
SCC3	375	200	187.5	918	245	367	1.25	3
VCC3	375	100	187.5	916	300	450	0.75	3
SCC4.5	375	200	187.5	918	245	367	1.25	4.5
VCC4.5	375	100	187.5	916	300	450	0.75	4.5
SCC10	375	200	187.5	918	245	367	1.25	10
VCC10	375	100	187.5	916	300	450	0.82	10

Table 2
Outlook and properties of the polyolefin fibre.

Density (g/cm^3)	0.910
Length (mm)	60
Eq. diameter. (mm)	0.903
Tensile strength (MPa)	>500
Modulus of elasticity (GPa)	>9

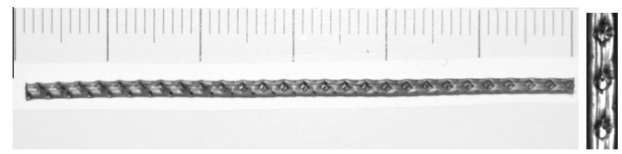

Table 3
Fresh-state tests results.

Parameter	Slump flow test		V funnel	Slump test
	T_{500} (s)	d_f (mm)	T_V (s)	h (cm)
VCC	–	–	–	15.0
SCC	3.5	660	8	–
VCC3	–	–	–	15.0
SCC3	3.5	640	12	–
VCC4.5	–	–	–	15
SCC4.5	4	600	12	–
VCC10	–	–	–	14.5
SCC10	6	570	20	–

Self-compacting concrete (SCC) has been extensively used due to an ease of flow to the parts and chinks of the formwork (and how it passes around the reinforcement), improved mechanical properties and good durability [17]. Since VCC and SCC are the most commonly used types of concrete, the comparison between them was first assessed by means of mechanical testing of steel fibre reinforced concrete (SFRC), with there being significantly higher residual strengths in the case of SCC [18,19]. Furthermore, variations in the pouring method and mould dimensions or shapes imply changes in the distribution of fibres. This has been studied by analysing the position of the fibres and the fracture behaviour of concrete pieces obtained from slabs or specially shaped moulds [11,20]. In addition, it has been assessed by filling standard dimension moulds and using alternative methods [21]. Some studies have explained the results because of the differences in orientation and distribution of the fibres produced by the pouring and compaction procedures of concrete [22,23]. The latter has provided significant information for the structural design of SFRC.

Macro-polymer fibres with improved mechanical properties provide PFRC analogous residual strengths as compared with SFRC although, at the time of writing, there remains hardly any published comparison between SCC and VCC using structural synthetic macro-fibres. Two main factors prevent use of the same assumptions for polyolefin fibres: their remarkably lower density and their flexibility. Thus, this study aims to assess the differences in the behaviour of SCC and VCC reinforced with different dosages of polyolefin fibres by analysing the mechanical and fracture properties of eight concrete mixtures: two reference plain concretes (one VCC and one SCC) and three pairs of VCC and SCC reinforced respectively with 3, 4.5, and 10 kg/m^3 of polyolefin fibres. The behaviour of each concrete was both assessed and justified by analysing the amount and position of fibres in the fracture surfaces generated.

The characterisation of the mechanical properties and the good durability performance (shown by penetration of water under pressure testing), together with the flexural residual strengths and fibre positioning variations, have provided sound conclusions to be considered for the structural design of PFRC. In such a sense, it should be highlighted that the differences of fibre positioning in both types of concrete were more noticeable for the dosage of 10 kg/m^3 which, on another note, amply exceeded the requirements of the standards to consider fibre contribution in structural design. The conclusions have shown that SCC distributed the fibres more homogeneously within the specimen, although the mould walls had more influence on the positioning of fibres for VCC specimens.

2. Concrete production: materials, design and manufacturing

Both VCC and SCC were produced by using the same materials. The changes in the fresh-state behaviour were achieved by minor modifications in the aggregates, proportioning and varying the amount of superplasticizer.

Siliceous crushed aggregates were used with a maximum size of 12.7 mm. The fineness modulus of the gravel was 6.94. The fineness modulus of the grit and sand were 5.83 and 2.66, respectively. A mineral admixture of limestone powder was employed as a micro-aggregate with specific gravity and Blaine surface of 2700 kg/m^3 and 400–450 m^2/kg, respectively. The calcium carbonate content of the limestone powder was higher than 98% and less than 0.05% was retained in the 45 μm sieve. A Portland cement type EN 197-1 CEM I 52.5 R-SR 5 was used. In order to achieve the desired self-compacting properties, an admixture named Sika Viscocrete 5720, which is a polycarboxylate-based superplasticizer with a solid content of 36% and 1090 kg/m^3 density, was employed. All the concretes were manufactured in a planetary mixer with a maximum capacity of 100 l at laboratory temperature.

In order to obtain an SCC mix-design at a competitive cost, some requirements had to be satisfied: the diameter of the patty