Composites Part B 92 (2016) 142–150

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Dynamic behaviour of cement mortars reinforced with glass and basalt fibres

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ARTICLE INFO

Article history:
Received 16 October 2014
Received in revised form
11 February 2016
Accepted 16 February 2016
Available online 24 February 2016

Keywords:
A. Glass fibres
B. Impact behaviour
B. Fracture toughness
Glass and basalt fibres

ABSTRACT

In this paper, the dynamic behaviour of cement mortars reinforced with both glass and basalt fibres is studied. The influence of the addition of both types of fibre on energy absorption and tensile strength at high strain-rate was investigated, and the performance of the two types of fibre-reinforced mortar was compared. For this aim, basalt and glass fibres with same diameter and length were used. Static tests in compression, in tension and in bending were first performed. Dynamic tests by means of a Modified Hopkinson Bar were then carried out in order to investigate how glass and basalt fibres affected energy absorption and tensile strength of the fibre reinforced mortar at high strain-rate. The Dynamic Increase Factor (DIF) was finally evaluated. The experimental results show that DIF is not significantly affected by the addition of basalt and glass fibres, while energy absorption at high strain rate is significantly increased by the addition of glass fibres and only slightly increased by the addition of basalt fibres.

1. Introduction

Even if the use of glass fibres to reinforce concrete was first proposed in Russia before the 2nd World War, the industrial use of Glass Fibre Reinforced Concrete (GFRC) dates back to the 1970s, after the development by Pilkington Corporation in 1967 of a suitable formulation to produce Alkali-Resistant glass fibres containing zirconia [1].

Nowadays glass fibres with improved alkali resistance allow a structural use of GFRC [2,3], otherwise limited by the embrittlement of glass fibres caused by the alkaline environment of the Portland cement paste.

Therefore, GFRC was extensively used in the industrial production of prefabricated elements, especially precast façade panels.

While many articles describe the static behaviour of GFRC, its dynamic behaviour has been much less studied. A reference study on toughness and impact tests on GFRC panels was carried out by Mobasher and Shah [4].

Glinicki et al. [5] studied the impact on GFRC plate specimens through the drop weight instrumented test device that allowed to detect the maximum impact load, the energy absorbed up to the maximum load, and the energy absorbed up to total failure, thus obtaining an impact-to-static energy absorption ratio falling within the range 1.7–1.8 for the GFRC plate elements considered.

The impact behaviour of facade panels made of GFRC was investigated by Enfedaque et al. [6] by shooting steel spheres with high velocity on square samples of different GFRC panels, and by then calculating energy absorption as the kinetic energy difference of the projectile before and after impact.

Yldirim et al. [7] studied the impact behaviour of different Fibre Reinforced Concretes (FRC) including GFRC. Using practically the same drop-weight method of ACI 544 2R-89 [8], impact tests were performed time after time on cubical FRC samples with side 100 mm until failure occurred. Glass fibres were shown to be as effective as steel fibres and more effective than polypropylene fibres to prevent first cracking. Samples reinforced with steel fibres needed a much higher number of impact tests until failure occurred with respect to samples reinforced with glass and polypropylene fibres, that both needed almost the same number of impacts to reach failure. Adding glass fibres to steel fibres was very effective to delay failure, better than adding polypropylene fibres.

Sangeetha [9] studied the favourable effect of additives such as superplasticizer, air retaining agent and retarder on impact strength of GFRC plates.

Comparison of the characteristics of glass and basalt fibres has been done in few articles. Wei et al. [10] studied their differences in

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http://dx.doi.org/10.1016/j.compositesb.2016.02.035
1359-8368/

terms of environmental resistance and mechanical performance, finding that basalt fibres are in general suitable for being used in both acid and alkali environments, but acid resistance of glass fibres is much less than that of basalt fibres.

Basalt fibres are suitably used to reinforce concrete panels and domes. Monolithic domes made of concrete reinforced with basalt fibres have been successfully built using a technology developed by the Monolithic Dome Institut [11]. The use of basalt fibres is suitable in concrete structures subjected to fire (i.e. to reinforce concrete segments for tunnelling) because of the high melt-point of basalt (see Table 1). In fact, a common use of basalt fibres is in the fire protection sector. Ipbüker et al. [12] studied cement–basalt mixtures for their radiation shielding properties, finding that basalt fibre has good potential as an addition to heavyweight concrete because, while improving its mechanical properties in terms of strength and toughness, does not reduce shielding against gamma and neutron radiation for long-term applications in nuclear energy industry.

Concrete beams and panels, as well as industrial and road pavements reinforced with basalt rebar have been recently realized [13]. Since it does not rust, it is particularly suitable for environments where corrosion is a continuous concern. Moreover, it is 89% percent lighter than steel, that is an important feature for developing its use in civil engineering: for instance, one man can easily lift a 150 m coil of basalt rebar 10 mm in diameter.

Static behaviour of Basalt Fibre Reinforced Concrete (BFRC) is less known than that of GFRC. A reference study was carried out by Felicetti et al. [14]. Sim et al. [15] and Jiang et al. [16] investigated basalt fibre as a strengthening material for concrete structures and observed that, besides increasing tensile strength and toughness of concrete, have good resistance to chemical attack, even if Sim et al. [14] observed that also basalt fibres are sensitive to alkali attack, although less sensitive than glass fibres. Also, Kabay [17] studied the use of basalt fibres in increasing tensile strength and fracture energy of concrete, together with resistance to abrasion, also finding that the addition of basalt fibres resulted in reduction in the compressive strength. Ayub et al. [18] studied the use of basalt fibres together with silica fume or met kaolin in preparing High Performance Fibre Reinforced Concrete HPFRC. Santarelli et al. [19] proposed lime-based mortars reinforced with basalt fibres as a possible bio-based material for ancient masonry restoration.

While noting that not only glass but also basalt fibres are sensible to alkali attack, Lipatov et al. [20] studied basalt fibres produced with appropriate zirconia content (using $ZrSiO_4$ as a zirconium source) to improve their resistance to alkali attack, thus improving also in the long-term the mechanical properties of BFRC through highly reducing fibre corrosion in the cementitious matrix.

Moreover, very few articles on the dynamic behaviour of BFRC can be mentioned. Lai and Sun [21] studied the dynamic behaviour of Ultra-High Performance Cementitious Composites (UHPCC) reinforced by only steel fibres and by hybrid fibres, the latter consisting of basalt fibres or polyvinyl alcohol (PVA) fibres added to steel fibres. The addition of basalt fibres showed to be effective on improving impact strength of UHPCC, but less effective than the addition of the same percentage of PVA fibres.

Strain-rate behaviour of a basalt fibre reinforced mortar was investigated by Asprone et al. [22] by means of dynamic tests at medium (0.5–3.0 s^{-1}) and high strain rate (50–90 s^{-1}) carried out, respectively, through a Hydro-Pneumatic Machine and a Modified Tensile Hopkinson Bar device. Fracture energy obtained from dynamic tests was shown to be higher than that obtained from quasi-static tests, and the Dynamic Increase Factor (DIF) for tensile strength was shown to be increased by increasing values of strain rate.

Lai et al. [23] showed that resistance to repeated penetration and different depth explosion in Ultra High Performance Concrete (UHPC) is improved significantly by hybrid reinforcement of steel and basalt fibres.

In this paper the different performances under dynamic loading of mortars reinforced with glass and basalt fibres were compared. The dynamic behaviour in tension of both types of fibre reinforced mortar was investigated. Dynamic tensile tests at high strain rate were performed by means of a Modified Tensile Hopkinson Bar device. Since the specimen diameter was 20 mm (depending on the size of the heads of the Modified Tensile Hopkinson Bar device), fine aggregates were used, thus suggesting to carry out the experimental study on mortar specimens and not on concrete specimens.

Also, reference static tests to evaluate flexural, compressive, and tensile strength (the latter to be compared with dynamic tensile strength through the Dynamic Increase Factor) were carried out on both types of mortar.

To allow to compare the performance in reinforcing mortar of the two types of fibre, specimens reinforced with straight glass and basalt fibres were prepared using fibres with same size (in both diameter and length) and same fibre content (in weight).

Not straight fibres (for instance spiral) could be more effective in dissipating impact energy and in increasing tensile strength, especially under dynamic loading conditions at high strain rates [24]. Unfortunately, it is impossible to achieve not straight glass and basalt fibres with same shape, so that their performance comparison would be affected by their different shape. Hence, for this reason, in this study straight glass and basalt fibres with same diameter and length were chosen.

2. Experimental procedure

2.1. Materials and specimen preparation

Both types of specimen (reinforced with glass and basalt fibres) were prepared using Standard Portland cement (CEM I, 52.5 R as prescribed by EN 197-1 [25]) and standard sand, in accordance with EN 196-1 [25]. From this cementitious mixture, a reference cement mortar without fibres (binder to aggregate ratio = 0.5, water over cement ratio w/c = 0.5, cement content 635 kg/m^3, sand content 1270 kg/m^3) was first prepared. The fibre reinforced specimens were then prepared by adding a given fibre content (in weight) of glass and basalt fibres to the cementitious mixture. The water/cement ratio of 0.5 was kept constant for all the investigated compositions.

To better compare the respective performance in reinforcing concrete under dynamic loading conditions, glass and basalt fibres with same size (12 mm in length and 14 μm in diameter) were chosen. For the same reason, both types of specimen were prepared with same fibre content (3% and 5% in weight). Four different types

Table 1
Size, physical and mechanical properties of glass and basalt fibres as provided by the manufacturer.

	Length [mm]	Diameter [μm]	Specific gravity [g/cm^3]	Softening point [°C]	Tensile strength [N/mm^2]	Elastic modulus [kN/mm^2]
Glass fibres	12	14	2.60	860	1000–1700	72
Basalt fibres	12	14	2.60–2.63	1050	3800–4000	89–93