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Temperature related steel and synthetic fibre concrete performance

Alan Richardson *, Rhys Ovington

Department of Mechanical and Construction Engineering, Faculty of Engineering and Environment, Northumbria University, Tyne & Wear NE1 8ST, UK

HIGHLIGHTS

- Synthetic and steel fibre performance.
- Temperature performance.
- Fibre pull out performance.
- Cold increase performance.
- Heat decrease in performance.

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ABSTRACT

The effect of temperature variation on concrete properties with steel and synthetic fibre additions was examined. The range of performance characteristics were determined at room temperature (20 °C) and ±40 °C of room temperature. Standard test methods were carried out in order to determine the flexural strength, bond strength and toughness of fibre reinforced concrete at varying temperatures. A significant increase in the performance of concrete was observed at a temperature of −20 °C as well as a minor decrease in performance at temperatures of 60 °C. Steel fibre concrete performed best within the parameters of this test. However synthetic fibres provided the optimal performance based on the flexural strength percentage change when compared to the control and steel fibre samples.

1. Introduction

There are large fluctuations in temperature Worldwide. In Russia, Greenland and Canada, the temperature varies massively over the four seasons. It is therefore crucial to effectively predict the thermal behaviour of building materials in order to properly design structures which are capable of withstanding such extreme variations in temperature. The temperature parameters used in the research represent the effect of real world temperatures, such as those recorded in the Middle-East and Canada [9].

This research examines two fibre types, namely steel and polypropylene Type 2 macro synthetic fibres. Polypropylene has a high resistance to the flow of electrons, leading to a low rate of heat transfer within the material. At ambient to high temperatures, polypropylene is a ductile material and shows qualities of a plastic/elastic nature. At temperatures below freezing, polypropylene tends to become brittle. Hall [10] states that the brittle nature of polypropylene is a serious disadvantage and can become problematic, especially in certain applications when mechanical performance is concerned.

The temperature parameter choice was based upon a benchmark of ambient temperature, assumed to be 20 °C for the UK and an even temperature differential above and below this mark to ensure the same conditions were applied to the samples, thus allowing a fair comparison to be drawn at high and low temperatures. The temperature differential was considered to be marginally above maximum expected hot and cold environment temperatures where concrete would normally be used. The upper test limit was informed by Dave and Desai [8] who suggest a maximum temperature of 60 °C for curing. These are similar temperatures found in Middle Eastern countries [11] and therefore this study is relevant to current construction practices.

Research carried out by Lau et al. [12] investigated the effect that elevated temperature had on steel fibre concrete. The steel fibre concrete was subject to temperatures ranging between 105 °C and 1200 °C. These temperatures are extreme and beyond maximum air temperature, but they do provide an understanding of the performance of steel fibre concrete under high temperatures. Lau et al.'s [12] research reported a decrease in elastic modulus as the temperature increased as well as a small, but not significant,

* Corresponding author.
E-mail address: alan.richardson@northumbria.ac.uk (A. Richardson).

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reduction in strength at temperatures below 400 °C. It was concluded that the use of steel fibres in concrete continues to be beneficial even at temperatures of 1200 °C and that steel fibre concrete can provide a greater resistance to the effects of heating.

Mirzazadeh et al. [13] found that concrete beams tested at -25 °C demonstrated an increase in strength and ductility of 13% and 34% respectively, compared to those tested at room temperature. This may be equally applicable to steel fibre reinforced beams? Neville [14] suggests that, within wet specimens, the compressive strength of cooled/frozen concrete can reach values up to three times the strength at room temperature. This is believed to be due to water freezing within the pores and thus providing the increased strength.

Possibly the most beneficial effect of fibre additions in concrete is the ability to absorb energy [19–21]. This is the main reason for the use of fibre reinforcements within floor slabs. If toughness is reduced with an increase in temperature, this could be considered a major disadvantage when designing structural elements for hot climates, such as the Middle East, where it is not unheard of for air temperatures to rise above to and beyond 40 °C. This research has investigated this physical property further in order to determine whether fibre reinforced concrete should be designed with temperature induced mechanical degradation in mind. According to Bakis et al. [1] there is a linear relationship between temperature and pull out force, tested between the values −20 °C and 60 °C and this research has influenced parameters of this series of tests. Temperature fluctuations between the limits of −20 and 60 °C influence nominal bond strength and this influence was not dominated by changes in elastic properties of the material properties of the fibres tested.

Despite the widespread use of fibre reinforced concrete, there is still debate within the industry as to the benefits they offer. Steel and type 2 synthetic fibres are currently used to good effect in many engineering applications however temperature changes the physical characteristics of the fibres and the composite matrix of fibres and concrete. This paper examines the relationship between fibre performance and temperature.

2. Materials

2.1. Concrete specification

The concrete used for this research is specified within Eurocode 2 as strength class C28/35 at 28 days of curing. The specifications for both synthetic and steel fibres are detailed in BS EN 14889 Parts 1 and 2 (See Fig. 1).

2.2. Fibre specification

Synthetic fibre specification is detailed in BS EN 14889-2: [5] and the steel fibre classification is covered in BS EN14889-1.

The adopted steel fibres have a hooked end profile as shown in Fig. 2, which provide additional bond strength [17] and the overall fibre dimensions were 50mm x 1mm with a tensile strength of 1050 N/mm^2.

Fig. 1. Steel fibre details (http://www.reinforcingmesh.net, accessed 04.07.2017).

Fig. 2. Synthetic macro fibres (https://www.alibaba.com/product-detail/Propex – accessed 04.07.2017).

Steel fibres were added to the concrete mix at 40 kg/m^3. Type 2 synthetic fibres, had nominal dimensions of 40 × 0.95 mm and were incorporated into the mix design. Previous research shows that these fibres are generally more effective in supplying an increase in residual strength [17] when compared to similar synthetic fibres used commercially. The fibre type used was a 90% polypropylene and 10% polyethylene mix with known high performance values [15] and is referred within the text as simply "polypropylene".

Synthetic fibres were added to the concrete mix at a dosage of 4 kg/m^3. The relationship between the fibre dosage of 40 kg/m^3 for steel fibres and 4 kg/m^3 for synthetic fibres provides a very similar level of performance in terms of flexural strength [17].

3. Methodology

The test methodology was designed to determine how the mechanical properties of plain and fibre reinforced concrete vary with respect to temperature changes, at −20 °C and 60 °C. An environmental chamber was used to heat the specimens and a walk in freezer was used for freezing the specimens. The specimens were left in the respective heat and cold appliances for 24 h prior to testing. To ensure the temperature change was minimised during the test, bubble wrap was used to insulate the test specimens during the test period when the specimens were removed from their storage areas. The samples as tested were surface dry at −20 °C and 60 °C, in addition the frozen samples were free from any surface ice.

Compressive strength was determined using BS EN 12390-3 [3], and this was carried out on the plain samples only. The rationale for this decision was based upon an extensive study of the compressive strength of concrete with fibre additions and this study concluded that the addition of synthetic fibres to concrete reduced the density and compressive strength [16]. Steel fibres have a natural affinity with concrete due to very similar thermal coefficients, whereas synthetic fibres do not have the same qualities. It would be impossible to draw comparative conclusions using the compressive strengths of plain, synthetic and steel fibre concrete, therefore the base material for all cubes was established as a common material providing bond strength and encapsulating the fibre types.

Flexural and bond strength of concrete with the addition of steel and synthetic fibre types was established using test methods BS EN 12390-5: [4] and BS EN 1542: [6] for three point flexural and bond strength.

The energy absorption capacities of both steel and synthetic fibre reinforced was established using the area under the load deflection curve and the flexural toughness was further examined using BS EN 14651:2005+A1: [7] at four crack mouth openings.