**Performance of fibre concrete with regard to temperature.**

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When Richardson started his PhD looking at the use of synthetic fibres in concrete with regard to durability, he had a feeling that temperature my play a part in the fibre performance. This was based on reading work by Bakis et al (1998). According to Bakis et al. (1998) there is a linear relationship between temperature and pull out force, tested between the values –20 ºC and 60 ºC and this research has influenced parameters of this series of tests. Sixteen years later we seem to have managed to find time to look at the effects of temperature on fibre concrete. What took so long? Well it might have been the other 100 publications he has managed to accrue. This highlights the fascinating nature of concrete research and how diverse it can be

**1.0 Introduction**

This paper has investigated the effect that temperature variation has on the properties of concrete with steel and synthetic fibre additions. 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.

In many countries across the world, large fluctuations in temperature may be encountered. In countries such as 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 conditions. The temperature parameters used in the research represent the effect of real world temperatures, such as those recorded in the Middle-East and Canada (DeRosa, 2012).

**2.0 Materials**

**2.1 Concrete Specification**

The concrete used within this research is specified within BS EN 1992-1-1:2004+A1:2014 as strength class C28/35.

**2.2 Fibre specification**

Synthetic fibre specification is detailed in BS EN 14889-2: 2006 and the steel fibre classification is covered in BS EN14889-1.

The adopted steel fibres had a hooked end profile, which provide additional bond strength (Richardson *et al,* 2010) and overall fibre dimensions were 50 x 1mm. The amount of steel fibres added to the concrete mix was 40kg/m3 and the tensile strength of the steel fibres was 1050 N/mm2.

For the purpose of this research, Type 2 synthetic fibres, had nominal dimensions of 40 x 0.95mm and were incorporated into the mix design at a dose of 4kg/m3. Previous research shows that these fibres are generally more effective in supplying an increase in residual strength (Richardson *et al*., 2010) when compared to similar synthetic fibres used commercially. The fibre type used was 90% polypropylene and 10% polyethylene mix with known high performance values (Richardson, 2005). The fibre is referred within the text as simply polypropylene.

**3.0 Methodology**

The test methodology was designed to determine how the mechanical properties of plain and fibre reinforced concrete vary with respect to temperature change, 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. To ensure the temperature change was minimised during the test, bubble wrap was used to insulate the test specimens during the test period.

Flexural and bond strength of concrete with the addition of steel and synthetic fibre types were established using test methods BS EN 12390-: 2009 and BS EN 1542: 1999 for three point flexural and bond strength respectively. Each beam testedwas subject to a central loading mechanism which extended at a speed of 2.2mm/min and the span between the rollers was 300mm.

##### The energy absorption capacities of both steel and synthetic fibre reinforced was established using BS EN 14651:2005+A1: 2007 at four crack mouth openings.

Figure 1 displays the test methodology - outlining the range of materials to be tested and the test type at different temperatures.

**Figure 1 – Test programme**

**4.0 Results**

The results obtained were, flexural strength, pull out force and toughness.

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| --- | --- |
| **Concrete Type** | **Average Flexural Strength (N/mm2)** |
| **-20**°C | **Ambient** | **60**°C |
| Plain | 11.628 | 5.84 | 3.778 |
| Synthetic fibre | 11.466 | 4.584 | 4.014 |
| Steel fibre | 11.736 | 6.292 | 3.846 |

Table 1 - The average flexural strength for each beam classification and temperature.

The results show that Type 2 synthetic fibres reduce the flexural strength of concrete beams at ambient temperature compared to plain concrete beams. This is a characteristic of Type 2 fibres which has been well research by Richardson *et al.* (2010).

All beams suffered from a strength reduction when comparing ambient to 60°C flexural strength tests. The plain beam showed an average 35% reduction, the polypropylene fibre beam showed an average a 12% reduction and the steel fibre beam showed an average a 49% reduction.

However, at temperatures of 60°C a lesser decrease in flexural strength can be observed when polypropylene fibres are used and compared to plain concrete, which could suggest that polypropylene fibre concrete can be beneficial in providing improved performance within concrete that experiences elevated temperatures. They also have other advantages in protecting the concrete from high curing temperatures as detailed in Richardson et al (2011).

All beams tested at -20°C displayed a significant increase in flexural strength when compared to the same beam tested at ambient temperatures.

The plain beam showed an average 99% increase in flexural strength, the polypropylene fibre beam showed an average a 150% increase in flexural strength and the steel fibre beam showed an average a 79% increase in flexural strength.

*Synthetic ~~Polypropylene~~ fibre concrete displayed the most improved performance at higher and lower temperatures.*

The beams which featured steel fibres showed improvements across the entire tested temperature range when compared to plain concrete beams. This observation was expected as steel fibres have been proven to supply increased concrete strength (Lau *et al*, 2006). The flexural strength tests also show that steel fibre concrete supplied a slightly greater strength at temperatures of 60°C when compared to plain concrete. This is backed up by Lau *et al* (2006) and, who state that steel fibre reinforced concrete continues to be beneficial to concrete after exposure to high temperatures.

The most notable trend observed from the results of the flexural strength test are that beams stored at temperatures of -20°C had the ability to withstand much larger loads before failure occurred, leading to a significant increase in flexural strength with a subsequent decrease in temperature, for all concrete types. This outcome concurs with Mirzazadeh *et al* (2016) who found an increase in strength of concrete specimens tested at -25°C. A large increase in flexural strength is believed to be due to the formation of ice within the pores of the concrete (Neville, 2006 and DeRosa, 2012).

Table 2 displays the results from the pull out tests for both polypropylene and steel fibres. The results show that as temperature decreases from 60°C to -20°C, there is a 50% increase in force required to pull out or snap the polypropylene fibres. This could be due to the fact that as concrete is cooled; it shrinks around the fibres, causing an increase in bond strength between concrete and polypropylene fibre. The synthetic fibres clearly have an improved performance at lower temperatures.

|  |  |
| --- | --- |
| **Type of Fibre** | **Average Pull Out Force (N)** |
| **-20**°C | **60**°C |
| ~~Polypropylene~~ Synthetic | 196.6 | 131 |
| Steel | 768.9 | 841.4 |

Table 2 - The average pull out force of each fibre type

As temperature decreases, the force required to pull out the steel fibres saw a decrease by 8.6%. This value is negligible within the interpretation of these results.

Figures 2 and 3 display the average flexural toughness of each fibre type at each temperature tested. They show the spread of flexural strength values at each measurement of CMOD and LOP. The figures represent the ability each beam classification to withstand load after failure and an initial crack opening has occurred.

Figure 2 – Comparison of polypropylene fibre reinforced concrete at varying temperatures, in terms of flexural strength at various CMOD

Figure 2 displays a clear difference between the performance of the fibres following the initial rupture of the concrete, the effect of temperature has a clear effect upon the fibre cement matrix bond. Colder fibres create a stronger bond and warmer fibres display lower bond characteristics. The results are in keeping with the earlier tests undertaken. The ambient and cold beams meet the requirements of the BS, whereas the elevated temperature test fails to meet the minimum requirements of post crack load transfer.

Figure 3 – Comparison of steel fibre reinforced concrete at varying temperatures, in terms of flexural strength at various CMOD

Figure 3 shows a significant drop in flexural strength between the LOP and a crack mouth opening of 0.5mm at -20⁰C, and this drop is a common property across all of the tested temperatures. In both steel fibre reinforced concrete and polypropylene fibre reinforced concrete, it is observed that after failure has occurred, there is a large drop in flexural strength. However, the flexural strength still remains higher at -20°C than at warmer temperatures, as the crack widens. While steel fibre reinforced concrete has higher toughness values, it appears that polypropylene fibre reinforced concrete will retain a constant flexural strength from CMOD1 to CMOD4.

**Conclusion**

This research was carried out in order to determine the effects that temperature has on various types of fibre reinforced concrete. The study has illustrated that temperature does affect the properties of fibre reinforced concrete. Both steel and synthetic fibre reinforcement were tested extensively in order to draw comparisons between the various fibre reinforced concrete types as well as plain concrete.

The conclusion that decreasing temperature, increases the toughness of fibre reinforced concrete has to be drawn.

The deterioration in mechanical properties of fibre reinforced concrete, which this research observed at temperatures of 60°C, is a potential cause for concern as world temperatures continue to rise. Recommendations for future research would be to investigate the performance of structures which feature fibre reinforced concrete elements at 60°C and beyond in order to determine whether the loss in performance may harm the fibre concrete structures within the built environment.

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