ELEVATED TEMPERATURE CONCRETE CURING - USING POLYPROPYLENE FIBRES

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Abstract

This paper examines cement hydration when concrete cures at elevated temperatures with and without the addition of Type 1 polypropylene fibres and addresses some of the ambiguities that have arisen from previous research.

Paired comparison tests were carried out to compare density, strength, pulse velocity, and absorption using plain and fibre concrete at ambient UK indoor temperatures, compared to concrete at elevated temperatures that would be found in The Middle East.

The results show that both plain and fibre concrete were subject to poor internal curing which created an open pore structure that led to high absorption rates. Polypropylene fibres do not have a significant effect in providing optimum curing conditions when subject to elevated temperatures, however they performed better than plain concrete.

Keywords: polypropylene fibres, curing, elevated temperature.

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1.0 INTRODUCTION

When concrete is subjected to elevated curing temperatures there are curing/hydration problems that affect its long term durability. At present there are mechanical cooling methods available to be used however all of these methods come at a cost to the project. This research investigates the possible benefits of using polypropylene fibres as an additive to improve hot weather curing by retaining internal water for satisfactory cement hydration at a lower cost.

1.1 Concrete curing in elevated temperatures.

Concrete subjected to curing at elevated temperatures, may suffer from poor quality and lack of a closed cell pore structure and plastic shrinkage (Basheer and Barbhuiya, 2010). A proportion of the construction carried out world wide will be affected by curing at elevated temperatures, due to latitude and also seasonal variations.

Work by Beddar et al (2008) examined the performance of concrete curing in a hot climate and suggested that while concrete cured at elevated temperatures develops a high early strength, the ultimate strength may be reduced because of evaporation of the mixing water, which may adversely affect cement hydration. Fast evaporation causes irregular shrinkage and thermal stress which results in micro cracking and poor durability of the cement paste. Nadolny (1994) confirms the findings of Takasu and Matsufuji (2010) and Beddar et al (2008) when he suggests that concrete curing in elevated temperatures will have an early stage strength increase, due to the heat acting as a catalyst between the cement particles and the water, promoting an increased rate of reaction. This early stage increase produces more heat of reaction between the cement and water particles which ultimately leads to dehydration of the mix and a reduction in the ultimate strength capacity of the resulting concrete produced. At 28days, the findings of Takasu and Matsufuji (2010) illustrated that the concrete's compressive strength was less than that of concrete curing under 'normal' conditions.

Beddar et al (2008) conclude that wet curing is preferable to dry air cured, but the practicality of realising concrete curing under these conditions in mass construction is not achievable. In their study of temperate climates, Hasimoto et al (2010) illustrate that not only is the climate influential to concrete construction but also the season in which concrete construction occurs; concrete laid in summer has a lower long term residual compressive strength than concrete placed during Spring, Autumn and Winter, due to the inherent fluctuation in the relative humidity of the respective seasons. Consequently, Sanchez et al (2010) communicate their concerns regarding the relevance of concrete research carried out in laboratory conditions maintaining a relative humidity of 100%. The relative humidity of air-cured concrete rarely reaches this level and is therefore cured under less favourable curing conditions, as an adequate closed cell structure can only be achieved at a minimum relative humidity of 65% (Sanchez et al, 2010).

To overcome the problems arising through thermal cracking and shrinkage there are mechanical cooling methods that may be used, such as cooling pipes within the concrete, or surface applied coatings, however all of these methods have adverse cost implications to
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the project. Informed by preliminary work by Dave and Desai (2008) this study has investigated the possible benefits of using polypropylene fibres as an additive to increase concrete durability when concrete is subjected to elevated curing temperatures. The resulting early increase in heat generation promoted by an elevated curing temperature environment can cause differential forces within the concrete and subject the material to early age cracking. Type 1 polypropylene fibres are considered suitable for use to control early age cracking (Clarke 2008).

1.2 Fibre inclusion in concrete

Work by Dave and Desai (2008:353) suggest that the incorporation of Type 1 polypropylene fibres (BS-EN14889) has a beneficial effect when concrete specimens are subject to heating and cooling cycles, observing that “all fibre mixes have exhibited superior performance compared to control mixes” and a “definite improvement in thermal behaviour and cracking characteristics was observed” (Dave and Desai 2008:363). In contrast to the opinions of Dave and Desai (2008), Nabil et al (2010) have suggested that the addition of polypropylene fibres has no effect upon concrete whilst drying and curing, and does not restrain plastic shrinkage. These conflicting observations will be investigated within this work.

1.3 The study

The potential for the addition of polypropylene fibres to restrain early age thermal cracking, and retain bleed water was investigated. It is hypothesised that if this potential is realised, the curing process will be enhanced and greater cement hydration and a closed cell pore structure will be promoted. This study has tested concrete with and without Type One monofilament polypropylene fibres cured within a temperature range of 50°C to 25°C. These are similar temperatures found in Middle Eastern countries (Kuwait Met Office, 2010) and therefore this study is relevant to current construction practices.

2.0 MATERIALS

2.1 Concrete

A range of concrete strength can be used in construction. Structural concrete was represented by the selection of a mix that conformed to exposure class XC/3 and XC/4. A requirement of this class is that the compressive cube strength is $35 N/mm^2$ (BS 8500-1:2006). This characteristic strength is achieved by the use of aggregates, which were tested for grading characteristics to BS 812: Part 103: 1985, and used in the following proportions :1090 kg/m^3 for 20mm marine dredged gravel and 680 kg/m^3 for washed concreting sand. CEM 11 – 42,5 N containing a minimum of 25% fly ash (a by-product of coal fired power stations) was used at a rate of 360 kg/m^3.

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A water cement ratio of 0.5 was adopted to promote SC3 workability which provided sufficient water for cement hydration. The range of permissible slump values for plain concrete that can be achieved lie between 90 and 180 mm (BS 8500-1:2006).

2.1 Fibres

Polypropylene fibres as used in this concrete test are classified in BS EN 14889 as Type 1 (Monofilament < 0.3 mm diameter) and their properties are, 12mm length, flexible, 32 µm diameter and used at a rate of 0.9 kg/m^3. A short fibre length (12 mm) was used to reduce the likelihood of fibre balling when batching the concrete. Previous work by Richardson (2006) used 19mm by 22 µm to batch concrete and a noticeable reduction in slump was observed due to the use of very fine 22 µm diameter fibres. In this study twelve millimetre by 32µm diameter fibres were used to avoid the reduction in slump and the tendency to increase the water demand for an adequate slump found to be the case with 22 µm, thus ensuring workability and a consistent water cement ratio between the batches.

The properties of the fibres used in this test program are shown in Table 1 illustrate a reduced bleed rate for concrete containing fibres over that without fibre inclusion. This may assist in satisfactory curing by retaining water for hydration purposes.

Test	Method	12mm Type 1 fibre concrete	Plain Concrete
Bleed Rate (ml cm^{-2})	ASTM C 232-71	1.20	2.69

Table 1: Type 1 polypropylene fibres @ 0.9kgm/m^3 (Propex, 2009)

3.0 METHODOLOGY

3.1 Introduction

The purpose of this study is to investigate the effect that polypropylene fibres will have on cement hydration and internal pore development when cured with an elevated temperature cycle. Two batches of concrete were tested, half of one batch was heated and the other half cured at an ambient temperature and these individual batches were compared using a significance test to determine whether the room temperature cured concrete and heat cured concrete were from the same population with a significance of 95%. This test was applied to both plain and fibre concrete. The parameters used to assess the internal curing of concrete were the compressive strength test, density, pulse velocity and absorption.

3.2 Establishing the curing temperature

Al-Tayyib et al. (1989), cured concrete at temperatures up to 80°C and Dave and Desai (2008) suggest a lower temperature of 60°C. The temperature used for this test was chosen

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at a lower level of 50°C to facilitate the production of a set of published results which may contribute to a published range of test conditions.

The test methodology was devised to replicate curing temperatures that could reasonably be expected in latitudes such as the Middle East when measured in the shade (Kuwait Met Office, 2010). Thus the drying oven was set to 50°C for a period between 9am and 6pm and then allowed to cool to near the ambient room temperature overnight to 25°C. The ambient curing climate used in this test program was established by quantifying the relative humidity, which was taken with a digital environmental multimeter in the general space of the laboratory, and was between 45and 58% at the time of testing which is within the range that can be expected in the Middle East (Kuwait Meteorological Department, 2010). It was noted the relative humidity is generally higher when taken geographically at coastal locations. The rationale for the test method was to reflect diurnal heating and cooling cycles.

3.3 Sample production and curing

Cubes were manufactured using 100 mm moulds to BS 1881 : Part 108 : 1983. The cube size was constrained by the size of the drying oven as sufficient air space between all of the samples was required to ensure uniform drying of all of the cubes. Two batches of concrete were produced, one plain (Mix A) and one with fibre inclusion (Mix B). Figure 1, illustrates the cube batching and the associated fibre treatment.

After one day of curing the cubes were removed from the moulds and given a reference mark to identify the individual samples. Cubes 1-12 of both Mix A and B were left to air cure for additional 27 days within the laboratory environment. Cubes 13-24 of both Mix A and B were placed within a drying oven for their remaining 27days of curing. To facilitate uniform oven curing, the cubes were re-ordered within the drying oven every seven days. The temperatures shown in Figure 1 are maximum and minimum values for the drying oven and mean values ±3°C for the general laboratory environment.

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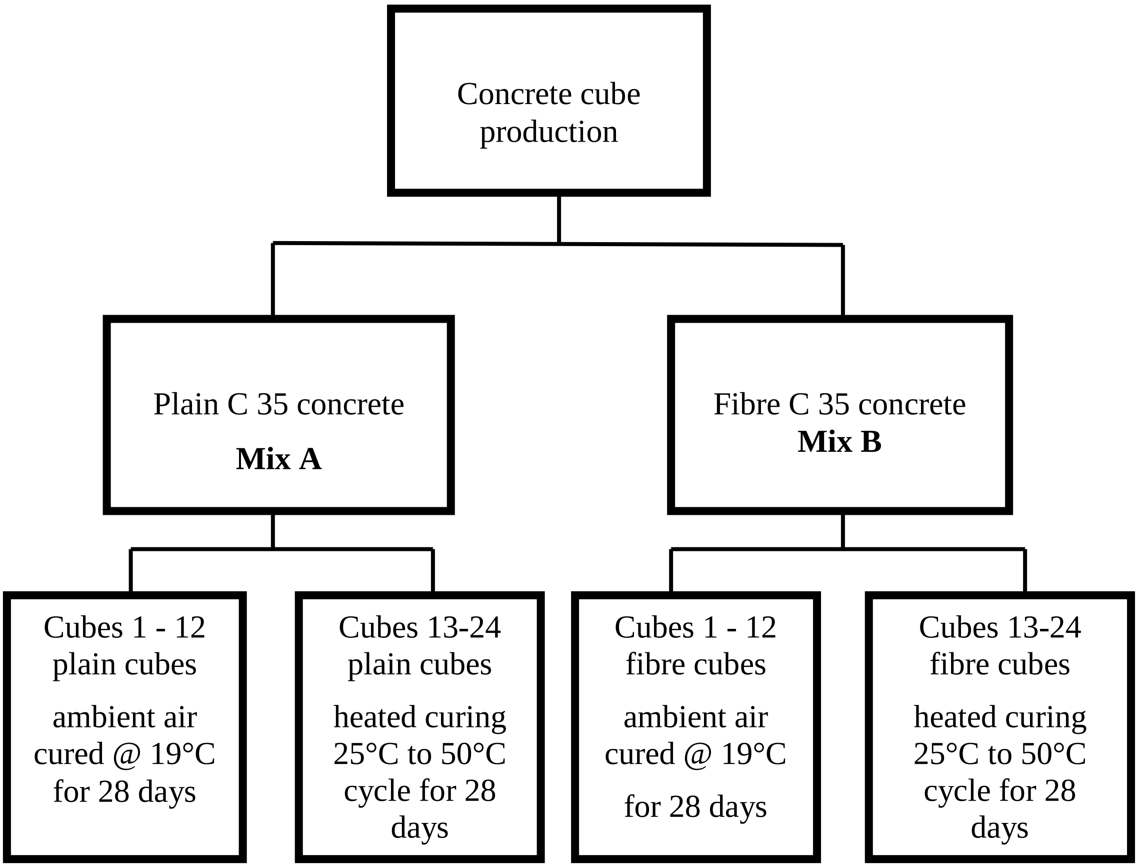

Figure 1: Concrete Cube production

Cubes were tested using non destructive tests for the full amount of samples until the final destructive tests, where three samples were removed for the absorption testing as informed by BS 1881 : Part 122 : 1983 and the remaining cubes tested for compressive strength.

4.0 RESULTS

A slump test recorded true slump with values of 90 mm for both concrete batches and this was within the acceptable limits set. All tests were undertaken 28 days from casting, during a 6 hours test period.

4.1 Non destructive tests

4.1.1 Density

The air cured cubes were weighed on a calibrated electronic scale and the results recorded for mix A of 2259.69 kg/m^3 for ambient cured plain concrete and 2203.14 kg/m^3 for heat

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cured plain concrete. Mix B for ambient cured fibre concrete had a density of 2261.83 kg/m^{3}and 2206.45 kg/m^{3}for heat cured concrete. Both plain and fibre concrete produced a lower density for heat cured concrete with a density reduction of 2.5%, which is not a significant amount. The cube samples exposed to elevated curing temperatures developed a lower density due to lack of available water for cement hydration resulting in larger pores within the mass and poor particle cohesion. The standard deviation was calculated, within each of the four sample sets and the deviation was a normal distribution with little scatter.

4.1.2 Pulse velocity

Pulse velocity was measured to BS EN 1881-203 using a coupling gel to ensure good contact with the plane faces of the cubes. The greater the pulse velocity, the better the internal curing, cement hydration and pore development, conversely a slower pulse velocity indicates poor curing. Mix A had pulse velocities of 3.79 km/s for ambient cured concrete and 3.65 km/s for heat cured concrete. Mix B had pulse velocities of 3.50 km/s for ambient cured fibre concrete and 3.33 km/s for heat cured fibre concrete. Checking the ambient values against the heated concrete, there is a pulse velocity reduction of 3.7% for plain and 5.7% for fibre concrete. Both batches of heated concrete are adversely affected by curing at elevated temperatures and the pulse velocity values for fibre concrete show a slightly higher transit time. This time difference for the fibre concrete could be due to the presence of fibres in the concrete as they present many discontinuities within the cement paste per m^3 which creates a tortuous path for the signal when passing through the matrix.

4.1.3 Absorption Testing

Three cubes were taken from each concrete type and tested for absorption. The cubes were cut in half to provide samples which were labelled “A” and “B”. One face was polished to facilitate pore/void examination. The test method involved weighing the air dried samples and immersing them in a water tank for 30 minutes. After this the samples were removed from the tank wiped with a cloth to remove the surface water off with a cloth before weighing the water absorbed sample to determine the percentage water gain by mass. The test was informed by BS 1881 : Part 122 : 1983, with regard to sample number and immersed time. Part 122 recommends the testing of 75 mm cores but this was not practical using 100 mm cubes.

The average absorption data for Mix A, was 1.25% for plain ambient concrete with a standard deviation of 0.42. The heat cured concrete produced an average absorption value of 2.67% with a standard deviation of 0.21. Fibre concrete as Mix B produced a mean water content of 1.4% for ambient concrete with a standard deviation of 0.24. The fibre concrete subject to heat curing produced a water absorption of 2.6% with a standard deviation of 0.36.

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Standard deviation within this test shows a normal distribution. The plain concrete cubes when cured at elevated temperatures showed a 114% increase in water absorption. This is a significant amount when durability is considered (Dill 2000). The fibre concrete cured at elevated temperatures showed a 77% increase in water absorption. There is a 37% reduction in water absorption when using Type 1 monofilament fibres when comparing both concrete types cured at elevated temperatures. This does not negate the fact that absorption is significantly increased when concrete is cured at higher temperatures, with or without fibre additions. Mix A plain cubes cured under elevated temperatures were found to have larger air pockets within the internal structure, as determined by TR 32, when compared to the other concrete samples. It is suggested that the density reflects the degree of hydration of concrete cured under elevated temperature.

A two tailed "t" test was applied to the concrete sample population to compare the difference in performance between ambient and heated plain concrete, "t" has been calculated using Equation 1:

$$t = \frac{Xp - Xf}{\sqrt{\frac{SD1}{N1} + \frac{SD2}{N2}}}$$ (Equation 1)

t = Test statistic
Xp = Mean mix A (Plain) ambient moisture content (%)
Xf = Mean mix A (Fibre) heated moisture content (%)
SD1 = Standard deviation sample 1
SD2 = Standard deviation sample 2
N1 = Number of test samples in mix A ambient
N2 = Number of test samples in mix A heated.

For Mix A (Plain) the "t" calculation provided a value of 4.38 – this is outside the permitted value of 1.812 for 95% confidence in the results being from the same population and therefore this result shows a significant change between the two test samples of ambient and heat cured concrete.

Using the same Equation 1 and Mix B for fibre concrete, a "t" value of 2.44 was obtained which is outside the value of 1.812 to prove a null hypothesis, therefore the null hypothesis is rejected. The results show there is a significant change in absorption qualities when concrete is cured at elevated temperatures.

4.1.4. Compressive strength

Compressive strength testing of the concrete cubes was carried out an a Dennison compression tester in accordance with BS EN 12390-3:2002. All failure modes were normal with even compressive stress fracture lines. The compressive test results along with

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standard deviation, which is low and this indicates the batching was consistent. The results are as follows: plain concrete Mix A ambient cured, had a compressive strength of 35.7 N/mm^2, and a standard deviation 1.48. Heat cured concrete plain concrete had a compresive strength of 37.2 N/mm^2 with a standard deviation of 0.85. Mix B fibre concrete had an ambient compressive strength of 36.4 N/mm^2 with a standard deviation of 1.93. The heat cured fibre concrete compressive strength of 36.8 N/mm^2 with a standard deviation of 2.25.

The plain concrete showed a small strength increase difference of 4.2% between the ambient and heated cured concrete. The fibre concrete provided a lesser difference of 0.85%. The final compressive strength value for the heated concrete is higher than the concrete left to air cure at an ambient temperature. This was predicted due to the heat of curing. A "t" test was carried out and the strength differences were shown not to be significant.

5.0 CONCLUSION

The density, pulse velocity and compressive strength tests show a slight change in behaviour of the concrete cured at elevated temperatures. When comparing the air cured population to the heat cured population, polypropylene fibres do not have a significant benefit in assisting good cement hydration and closed pore structure under these prescribed test conditions. The most significant test carried out was water absorption, where concrete cured at elevated temperatures showed a significant absorption, both with and without fibres. The fibres did not fully protect the concrete from dehydration as originally thought may be the case, however as suggested by Dave and Desai (2008) the fibre concrete performed 37% better than the plain concrete with regard to absorption when cured at elevated temperatures when comparing the two separate batches (plain and fibre). The significance test was applied to the individual batches only where an obvious change had taken place.

It can be concluded that polypropylene fibres additions alone are not a sufficient measure to avoid unsatisfactory pore development when concrete is cured at elevated temperatures, however the absorption characteristics are such that fibres in concrete may be considered to improve pore development when compared to plain concrete in the same curing circumstances. The cost of fibres is relatively small per cubic metre of concrete and this beneficial improvement shown may be considered worthwhile by designers and specifiers.

6.0 RECOMMENDED FURTHER WORK

The compressive strength test could be performed at several stages possibly 1 day, 3 days, 5 days, 7 days,14 days, 28 days and 56 days to see what effect the polypropylene fibres have in terms of progressive strength development when exposed to elevated temperatures. This could be repeated at various relative humidity values. Direct control of the relative humidity would be of value to understand the nature of pore and cell structure development, which could be measured with compressive strength as well as a mercury

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intrusion porisometry test which would be useful to determine the total volume of pores and the range of pore sizes of the concrete during the curing period and when the curing was complete.

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