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Early Life Freeze/Thaw Durability of Polypropylene Fibre and Ground Granulated Blast Furnace Slag Concrete

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ABSTRACT

This investigation considers the freeze/thaw durability characteristics of concrete produced with the addition of polypropylene fibres and ground granulated blast furnace slag (GGBS).

Previous work [Richardson 2005] has shown monofilament fibres to be instrumental in maintaining the integrity of early life concrete when subject to freeze/thaw cycles. This work expands upon the earlier data collection by introducing a bye product (GGBS) as a partial cement replacement. The test methodology allows comparisons to be drawn between fibre and non fibre concretes with and without GGBS.

Concrete cubes cured to four days were subjected to a maximum of 50 freeze/thaw cycles.

It was found that there was a clear association with the use of monofilament fibres in concrete with regard to enhanced durability qualities, when compared to plain PC concrete and concrete mixes with partial GGBS cement replacement.

INTRODUCTION

The effects of freeze/thaw action on fully matured concrete are well documented [Larsen 1991, Mu et al. 2002, and Pentalla 2006]. However the durability of early life concrete, subjected to freeze/thaw action has hitherto drawn less interest. In the very early life of concrete; either side of the initial set, is a period where concrete is very vulnerable to damage from freezing. This is because concrete has not reached sufficient strength to resist the hydraulic forces placed upon it from the expansion of freezing water within the concrete matrix. In actual field practice the first freezing cycle may occur as soon as the first night after the concrete is placed if proper winter concreting practices are not employed [Norlite 2006].

This test program addresses the freeze/thaw effect upon the compressive strength of concretes that have not fully cured. The concretes under consideration may be classified as plain, plain/fibre concrete, ground granulated blast furnace slag (GGBS) concrete used as a partial replacement for cement, and GGBS/ fibre concrete - the detail of these mixes is presented in Materials and Mix Designs.

CONCRETE SELECTION

Plain concrete will be represented by two mixes of low and medium strength classifications C20 and C30. The specification of these mixes with respect to cement content, has been informed by the work of Pink [1978] who specified that concrete mixes of cement contents lower than 300kg/m^3 should not be adopted if the resulting concrete is to afford freeze/thaw protection. Thus it is anticipated that a tangible difference will be observed in the compressive strength values obtained for these concretes after testing. However, plain concrete is approximately 5% more expensive to manufacture [Woodfine 2009] when compared to concrete manufactured with GGBS and is significant in its cost to the environment [Dean. 2007], therefore the test program has been widened to include more sustainable concretes where cement has been partially substituted.

The use of GGBS as a partial replacement for cement costs less to manufacture and is less harmful to the environment [Dean. 2007] which provides a case for its incorporation into buildings. The manufacture of Portland cement (CEM 1) has embodied energy of 4.6 MJ/kg and a 50% cementitious replacement with GGBS has an embodied energy of 3.01 MJ/kg, providing a saving to the environment of 35% in terms of embodied energy. There is also a 54% CO_2 reduction when GGBS is used as a 50% cementitious replacement [Hammond and Jones 2008]. Binci et al [2007] have already shown that GGBS concretes have the potential to realise higher compressive strengths over plain concrete mixes due to the formation of a more tightly closed cell matrix, over an extended period of curing. Irrespective of this work, the effects of freeze/thaw action on the early life matrix formation of GGBS concretes and how this translates to compressive strength behaviour remains largely unreported.

The lack of documentation concerning the compressive strength characteristics of GGBS concretes mixed with polypropylene fibres - GGBS/fibre concrete – is less surprising given the general limitation in the amount of data associated with plain concretes utilizing Type 2, macro synthetic fibres [Concrete Society, 2007:2]. However, evidence does exist [Snyder and Jansen, 1992; Soh et al, 1997] to support the use of Type 1 synthetic monofilament polypropylene fibres as a freeze/thaw protection agent, while Hannant [1995] has explored the durability of the fibres themselves and found them to be durable over periods in excess of 18 years. The compressive strength of early-life concretes subjected to freeze/thaw for plain/fibre concretes and GGBS/fibre concretes considered within this research will generate further data to facilitate the evaluation of fibre adoption in concretes.

MATERIALS AND MIX DESIGNS

Table1 illustrates the mix design specified for the low strength (C20) and medium strength (C30) concretes. The target strengths for these mixes are 20N/mm^2 and 30N/mm^2 respectively.

Table1: Plain Concrete Mix Designs

Mix constituents	**C20 mix**	**C30 mix**
PC (Cement)	240 kg/m^3	370 kg/m^3
Coarse sand	731 kg/m^3	675 kg/m^3
Dredged gravel	1107 kg/m^3	1008 kg/m^3
Water cement ratio	0.8	0.5

Considering the C20 mix, the high water cement ratio of 0.8 has been adopted to facilitate the production of lower strength concrete of open pore structure with a larger percentage of free water that is subject to freeze/thaw attack. Vondran [1997] suggested that concretes of water cement ratios between 0.4 to 0.5, were “impermeable”. Therefore the medium strength, C30 concrete is at the upper limit of this range where ‘impermeability’ may occur, although this is considered to be unlikely due to the short curing period.

Compression test data on the early life of the plain concrete mixes detailed in Table 1 will be obtained however these mixes will also be used to produce the concrete variants; namely plain/fibre concrete, GGBS concrete and GGBS/ fibre concrete.

The fibres to be used are classified in BS EN 14889 as Type 1 (monofilament < 0.3 mm diameter) and their dimensions are, 19mm length, 22 micron diameter and used at a dosage of 0.9 kg/m^3. The ground granulated blast furnace slag, GGBS, adopted for half of the test cubes as a 50% cement replacement conformed to BS EN 15167-1:2006.

METHODOLOGY

Four batches of six 100 mm cubes were batched to BS 1881 : Part 108 : 1983 using a rotary drum mixer. Each batch was separated into two equal parts and re-mixed, adding fibres into one part, with the other remaining plain; Table 2 illustrates the concrete strength classification relative to the batching reference and corresponding concrete production.

Mixing continued for the fibre concrete, to ensure even fibre distribution within the plastic concrete, and for the plain concrete, to ensure mixing conformity with the fibre concrete. Minimising production variability facilitated the manufacture of comparative mixes. A slump test to BS EN 12350 – 2:2000 was used to determine consistency and achieve mix compatibility between the C20 batches 1 and 2 and the C30 batches 3 and 4 concrete mixes.

Table 2: Concretes Tested

Strength classification	**Batch**	**Concrete Reference**
C20	1	C20plain
		C20plain/fibre
	2	C20 GGBS
		C20GGBS/fibre
C30	3	C30plain
		C30plain/fibre
	4	C30GGBS
		C30GGBS/fibre

Ultimately, four sets of three cubes with fibres, and four sets of three cubes without fibres, were manufactured for testing. Three cubes were considered the minimum group size of test samples that would produce a significant set of results.

Figure1. illustrates the production of the cubes to be compression tested and measured for weight loss.

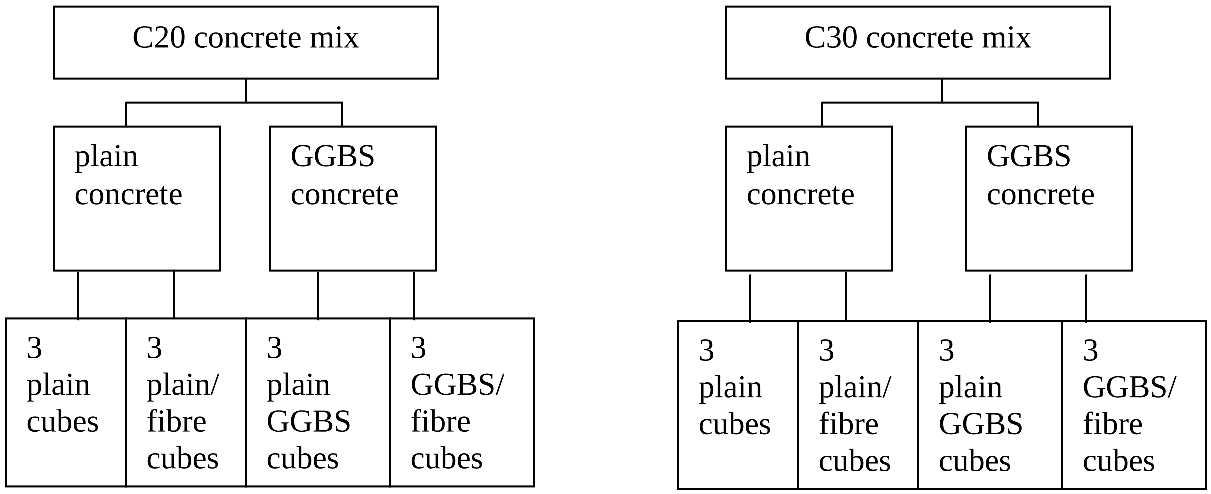

Fig 1: Cube Production

For the development of frost damage it is essential that a high degree of saturation of the capillaries is prevailing [Basheer et al 2001:97], therefore this test procedure has ensured fully saturated cubes by leaving the test cubes to cure in a water-filled tank at 20°C. Curing was restricted to four days to ensure low strength development prior to starting the freeze/thaw cycles. This condition facilitates the striking of the cube mould due to sufficient curing while also ensuring the most onerous condition of hydrostatic pressure within the cube on commencing the freeze-thaw program. After four days curing in the tank, three cubes from each group were then subjected to fifty freeze/thaw cycles adopting a method partially informed by ASTM 666: procedure B. The elements taken from ASTM 666 procedure B are the method of freezing in air and thawing in water to ensure full saturation of the cubes and the weight loss criteria.

Monitoring of the cubes occurred after every 10 cycles in terms of changes to cube weight and surface condition. Under the criteria set by Mu et al [2002], samples exhibiting 5% or more total weight loss were prematurely removed from the freeze/thaw program and compression strength tested to BS EN 12390-3:2002. Cube weighing occurred under thawed, fully saturated, conditions. Figure 2 and Figure 3 illustrates the weight loss results for the cubes relative to their basic concrete strengths of C20 and C30 respectively.

The time period between cube manufacture and compression testing for all cubes completing the freeze/thaw program, totalled 39 days.

WEIGHT LOSS RESULTS

The freeze/thaw weight loss is shown in Figures 2 and 3. When weight loss exceeded 5% the cubes were removed from the freeze/thaw programme as shown in Figure 2 for C20 plain and C20 GGBS plain concrete.

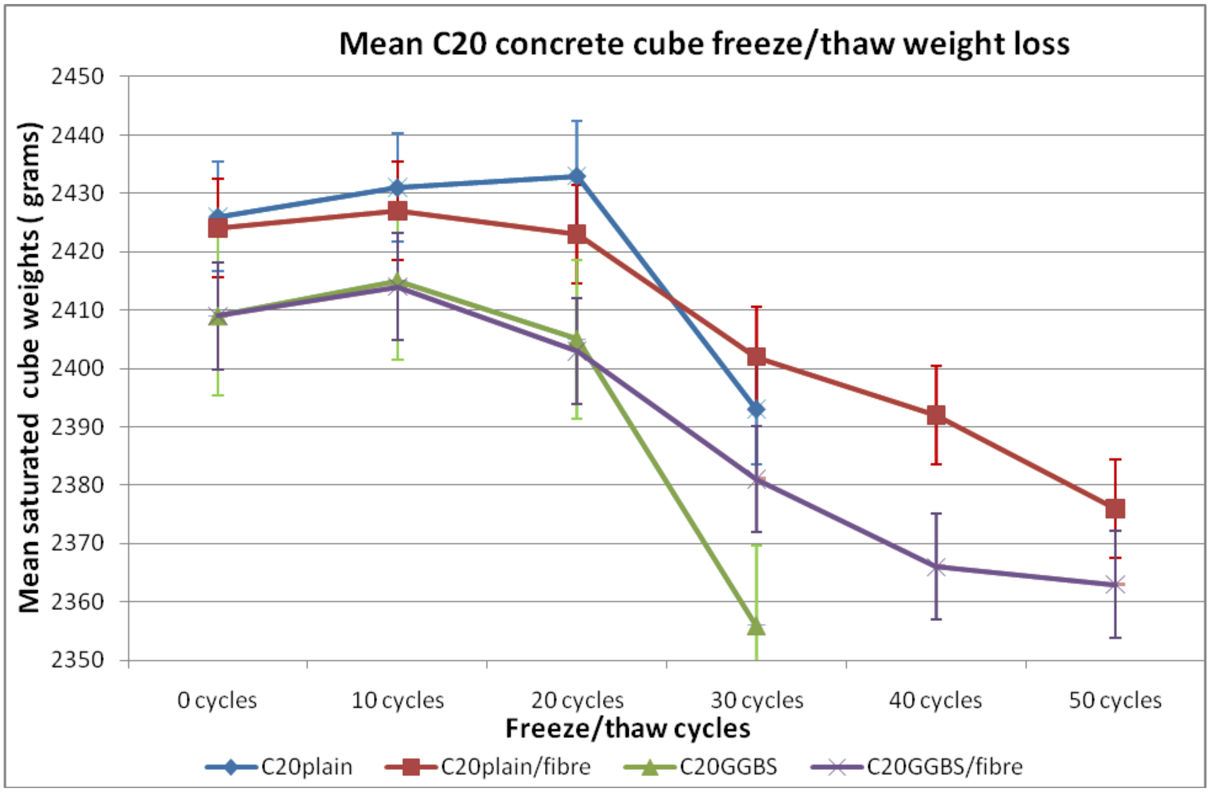

Fig 2: C20 Strength Concrete Weight Loss.

It was observed in Figures 2 and 3 that slight weight gain took place in the early freeze/thaw cycles. This was due to slight micro cracking of the concrete, which allowed water into the freeze/thaw specimens prior to sufficient frozen water being present to cause hydrostatic damage. When the volume of absorbed water became critical at between 20 to 30 freeze/thaw cycles for the C20 concrete and the propogation of cracks significantly developed, hydrostatic damage took place. The C20 concrete suffered significant weight loss between 30 to 40 cycles with regard to all the plain concrete cubes, both PC and GGBS. At this point all of the plain concrete was removed from the testing programme due to weight loss in excess of 5%.

A similar process took place with the C30 concrete except the major damage started at 30 cycles for the plain GGBS concrete and 40 cycles for the remaining C30 cubes. The C30 concrete performed predictably better than the C20 concrete due to the lower water cement ratio and higher compressive strength. The C30 concrete started failure in the 40 to 50 cycle range with five of the six concrete cubes without fibres exhibiting a 25 to 35% weight loss.

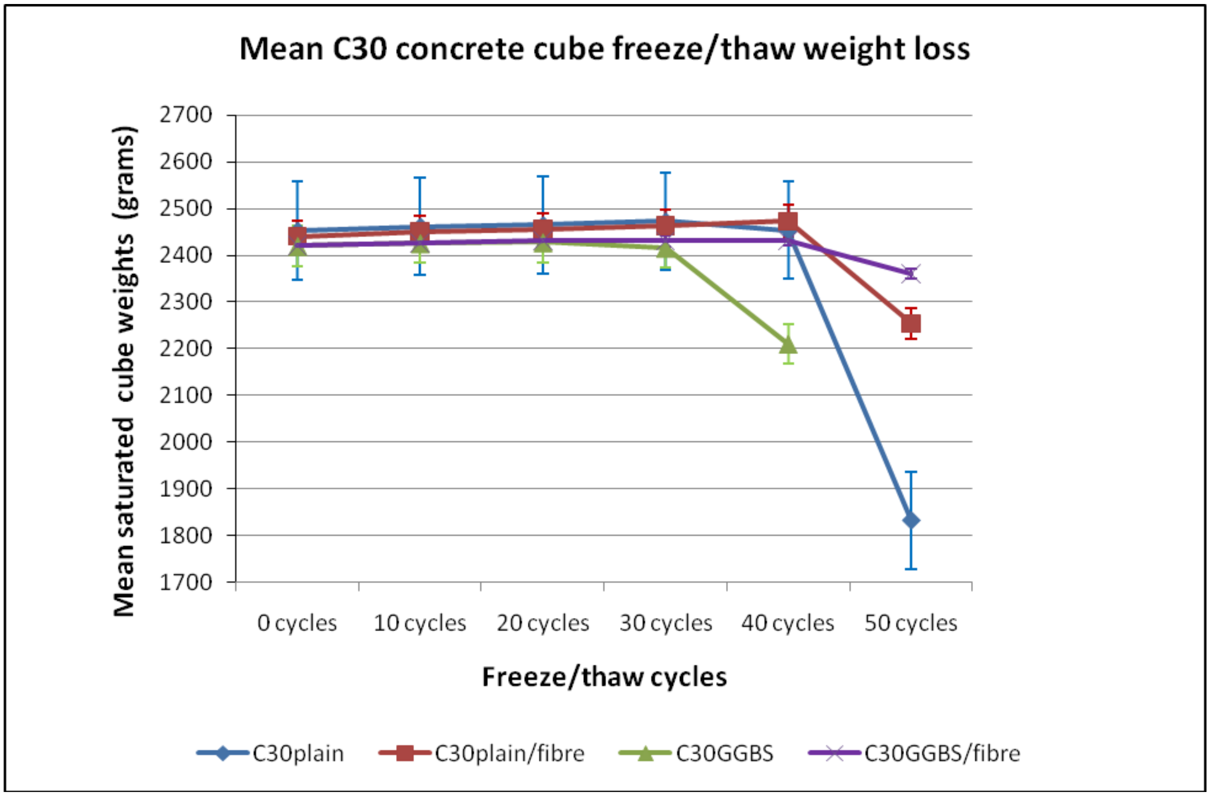

Fig 3: C30 Strength Concrete Weight Loss.

Figure 3 shows GGBS concrete with fibres has a lower weight loss than plain concrete with fibres. This result is possible due to the extended curing time available to enable the GGBS concrete to reach a similar strength to plain concrete using PC.

COMPRESSIVE STRENGTH RESULTS

The mean compressive strength results taken as a mean value of three cubes are shown in Figure 4 between 0 and 50 freeze/thaw cycles which equates to 39 days of curing.

The results show the C20 concrete is more susceptible to freeze/thaw damage than the stronger C30 concrete. Plain and GGBS C20 concrete without fibres failed early in the test and therefore is not shown in Figure 4. The C20 fibre concrete survived in a better condition although the GGBS concrete final strength was lower than the plain cubes. The plain and GGBS concrete C30 cubes had a residual strength although they failed structurally in terms of overall mass lost as shown in Figure 3.

A clear trend was shown with regard to the performance of concrete with and without fibres when subject to freeze/thaw cycles as shown in Figure 4.

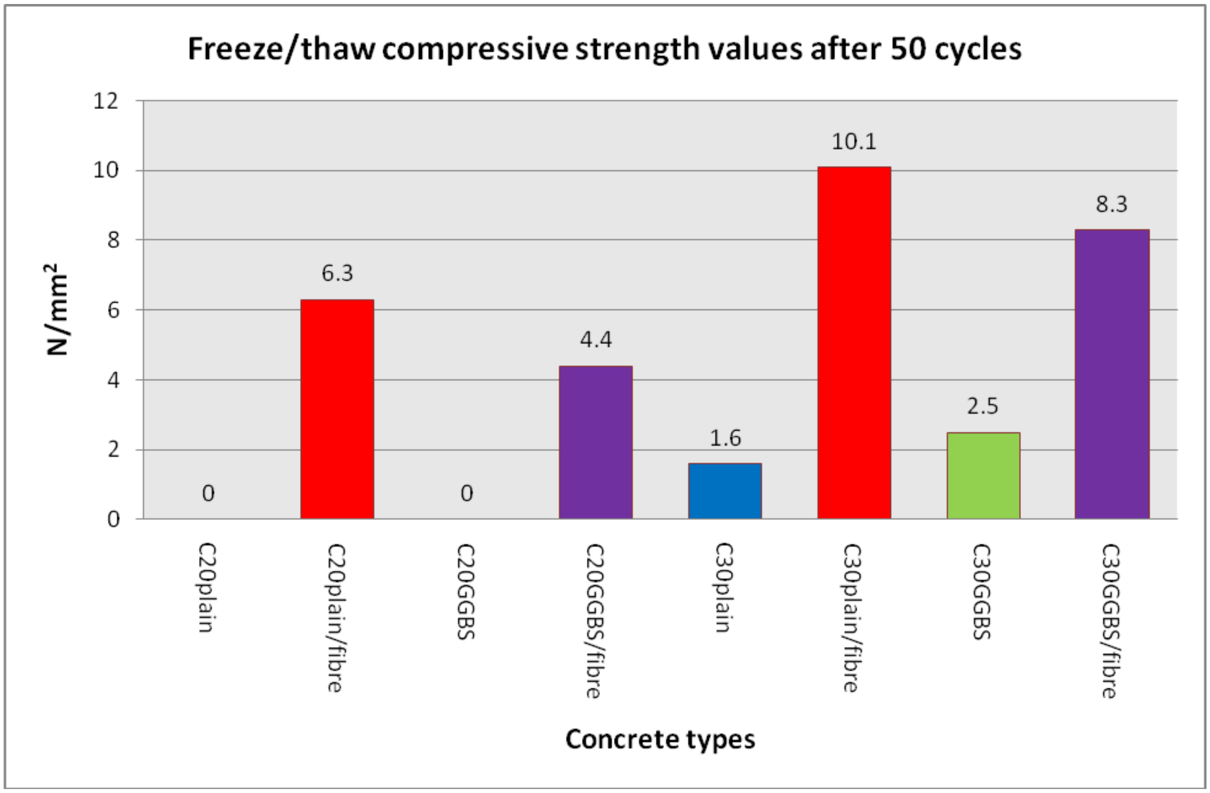

Fig 4: Mean Compressive Strength of Different Batches of Concrete – after 50 Freeze/thaw Cycles.

CONCLUSION

The weight loss results for the C20 mix show that GGBS fibre concrete is slower at strength development when compared to plain PC fibre concrete and suffers more damage as a consequence of this property. The general cube weight loss was less pronounced with the C30 mix during the early freeze/thaw cycles, however weight loss was observed to be increased at 30 – 40 cycles for the GGBS concrete. When both plain and GGBS concrete reached 50 cycles and 39 days of curing; their respective final weight loss was virtually identical. Polypropylene Type 1 monofilament fibres improve the freeze/thaw durability performance of concrete when measured against the plain concrete with regard to weight loss and final compressive strength. This effect occurs in different types of concrete, utilising different binders and of varying concrete mix designs. The improved freeze/thaw performance using Type 1 polypropylene fibres is apparent when compared against plain concrete with and without GGBS additions. This initial work may be used to inform a larger scale study.

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