# The potential for achieving freeze/thaw protection in concrete through the addition of rubber crumb

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**ABSTRACT**

This paper evaluates the use of recycled rubber tyres in the form of rubber crumb as a freeze/thaw protection agent when used in concrete. Reusing scrap tyres in the form of rubber crumb, in concrete could benefit the environment by reducing landfill and reducing the chemical usage of air entraining agents.

The test procedure involved subjecting concrete to freeze/thaw cycles at 5 days of age. Thawing was conducted in water to ensure full saturation of pores and maximum stress on the concrete samples. Rubber crumb when used at a 0.5% addition by mass provided the optimum freeze/thaw protection whilst maintaining the maximum compressive strength. The practical limitations of the test were time and freezer space so an accelerated test was used, limited to 50 freeze/thaw cycles, which was sufficient for conclusions to be drawn.

This paper contributes to the understanding of the effects of varying doses of rubber crumb in concrete when used as a freeze/thaw protection additive and determines final compressive strength of concrete at normal non freeze/thaw conditions. The compaction of concrete is raised as an area of concern with regard to rubber particle separation within the plastic phase of the concrete's life.

Keywords: Rubber crumb, freeze/thaw protection, sustainability, recycled tyres.

## 1.0 INTRODUCTION

Over one billion tyres are manufactured annually using approximately ten million tonnes of elastomeric materials, including most of the natural rubber produced (Watson Brown 2009). On disposal these tyres produce hazardous waste materials that must be processed and accumulates in large quantities. Re-use of these non-decaying materials will avoid the environmental problems associated with disposal of the material by incorporating it into concrete mixes (Batayeh et al, 2008).

A typical car tyre uses about 40% natural rubber and 60% synthetic rubber (Wasteonline 2009) and needs to be separated from the steel casing and other materials before it can be used as a rubber crumb. Scrap tyres are classified as whole scrap tyres, slit tyres, shredded/chipped, ground and rubber crumb. Rubber crumb particle sizes range between 4.75mm to less than 0.075 mm and are irregularly shaped, torn particles due to the micro-mill process they are subjected to during the manufacturing process (Siddique and Naik 2004).

Benazzouk and Queneudec (2002) and Paine et al (2002) investigated the efficacy of rubber crumb at providing freeze/thaw resistance and they surmised that rubber crumb provides a freeze/thaw protection when added to plain concrete. Concrete can be affected by freeze/thaw damage from the point of placing to being fully cured. This work examines the effects of freeze/thaw cycles starting at 5 days of curing where the concrete has reached about half the design strength. The scarcity of test data identifying the early life performance of concrete with rubber crumb at varying additions was a key factor justifying this research. This paper will examine rubber crumb use at 0.5% and 1.0% addition, by mass (solid density), and compare to contemporary measures for protecting concrete from freeze/thaw damage.

## 2.0 FREEZE THAW PROTECTION FROM RUBBER CRUMB

Air entrainment is currently the most widely adopted method of providing freeze/thaw protection. If it can be shown that rubber crumb in concrete would be as effective as air entrainment in providing freeze/thaw protection, then discarded rubber waste could be utilised in the construction industry as a freeze/thaw protection method with subsequent sustainability credentials. Paine et al (2002) investigated the use of rubber crumb as an alternative to air entrainment using three sizes of crumb from 0.5 to 25 mm and their tests showed that there is potential for using rubber crumb as a freeze thaw resisting agent in concrete.

Recycled particles of sustainable rubber crumb have a low modulus of elasticity (Khaloo et al. 2008). Due to this it is postulated that its inclusion as a constituent of concrete production introduces pressure relief chambers. These chambers alleviate hydrostatic pressure, via a mechanism akin to that afforded by air entrainment, thus promoting freeze/thaw protection. If the rubber crumb does entrain air further concrete protection is afforded. Skripkiunas et al (2007:85) state that, "rubber waste has no influence on capillary porosity of hardened concrete but it does increase the air content … and has a positive effect upon freeze and thawing resistance of concrete". Thus freeze/thaw protection is provided.

The method of freeze/thaw protection has been identified by Khaloo et al, (2008: 5-6) who stated that, "due to the non-polar nature of rubber particles and their tendency to entrap air in their rough surfaces, tyre-rubber concrete specimens contain higher air contents than plain concrete". Furthermore, rubber particles tend to repel water (Khaloo et al, 2008). When tyre particles are substituted for mineral aggregates in the control mixture, the tyre particles attract air; the amount of attraction is dependent on the internal pressure within the mixture.

According to Chatterji 2003, an entrained air bubble system of between 5% and 7% by volume of concrete is required to improve the freeze/thaw performance of concrete. US Patent 669509 (2004) suggests a rubber crumb addition rate per cubic metre for 5% entrained air to be between 5.3 kg/m3 and 9.8 kg/m3. This has informed the dosages used for the purpose of this study as detailed in Section 4.1.2 of this paper.

## 3.0 THE MECHANICAL RESPONSE OF RUBBER CRUMB CONCRETE

Air entrainment when used as a freeze/thaw defence mechanism within concrete produces a compressive strength reduction, and according to Khorami & Ganjian (2007: 274) “rubber filled concrete showed a systematic reduction in strength, while its toughness was enhanced.” Therefore the compressive strength properties of air entrained concrete; with a known protection from freeze/thaw damage may be similar to that of concrete with an addition of ground rubber crumb, and will be investigated in this work.

The properties of concrete with added rubber were outlined by Khorami & Ganjian (2007:274) who state that; “a concrete mixture with tyre chip and crumb rubber aggregates exhibited lower compressive and splitting tensile strengths than regular Portland cement plain concrete. There was approximately 80.5% reduction in compressive strength and 50% reduction in splitting tensile strength when coarse aggregate was fully replaced by coarse crumb rubber chips. However, a reduction of about 60.5% in compressive strength and up to 50% in splitting tensile strength was observed when fine aggregates were fully replaced by fine crumb rubber. Both of these mixtures demonstrated a ductile failure and had the ability to absorb a large amount of energy under compressive and tensile loads,” which may determine the application of rubber concrete use.

Siddique and Naik (2004) compared plain concrete with concrete manufactured with rubber crumb, and determined that on washing the rubber crumb in water, prior to use, an increased compressive strength in the order of 16% may be achieved.

## 4.0 THE LABORATORY INVESTIGATION

This study has incorporated recycled tyre rubber into concrete in the form of rubber crumb. Additions of 0.5% and 1.0% of rubber crumb by mass of concrete are proposed to replicate levels of air entrainment in concrete that will provide freeze/thaw durability. Concrete entrained with 5% air is known to offer a degree of freeze/thaw protection. The addition of 1.0% of rubber crumb by volume of concrete was selected to observe freeze/thaw performance at an upper limit of protection.

The test program presented was developed to compare the compressive strength and weight loss of concrete cubes manufactured from plain and rubber crumb mixes (see section 4.1.2) and. subjected to freeze/thaw cycles, against a similar set of cubes which were not subject to freeze/thaw cycles.

### 4.1 Materials

The materials used were primarily ground rubber crumb from vehicle tyres and virgin aggregates bound with a cement binder containing pulverised fuel ash (PFA) as a Portland cement replacement.

#### *4.1.1 Rubber crumb*

The rubber crumb sourced from vehicle tyres was sieved in accordance with BS 812: Part 103 : 1985 and the results shown in Table 1., and Figure 1., confirm that 94.1% of the sourced rubber crumb particle sizes were between 1.16 and 2.36 mm, with 5% being finer than 1.16 mm and no material passing the 0.43 mm sieve.

The particle size is above the optimum upper limit of air entrainment for freeze/thaw protection as recommended by Harrison et al (2001) being quoted as 300$\mu$m. However no particles were smaller than 0.43 mm which avoided the problem of cement paste disturbance as identified by Neville (1995).

If crumb rubber is used for freeze/thaw protection it has the advantage of being impossible to freeze under normal freeze/thaw conditions and for the purposes of calculating the percentage addition of rubber by volume of concrete the solid density of rubber was taken as 1522 kg/m3 (BS 648:1964).

| Sieve size (mm) | Sieve weight (g) | Sieve and crumb weight (g) | Rubber crumb - weight retained (g) | Percentage of sample passing (%) |
|---|---|---|---|---|
| 2.36 | 482.0 | 482.0 | 0.0 | 100 |
| 1.16 | 443.0 | 443.0 | 473.5 | 5.1 |
| 0.43 | 381.5 | 855.0 | 25.5 | 0 |
| Base Pan | 248.0 | 273.5 | 0 | 0 |
| **Total** | **1554.5** | **2053.5** | **499.0** | **100.0** |

*Table 1. Results of rubber crumb sieve test*

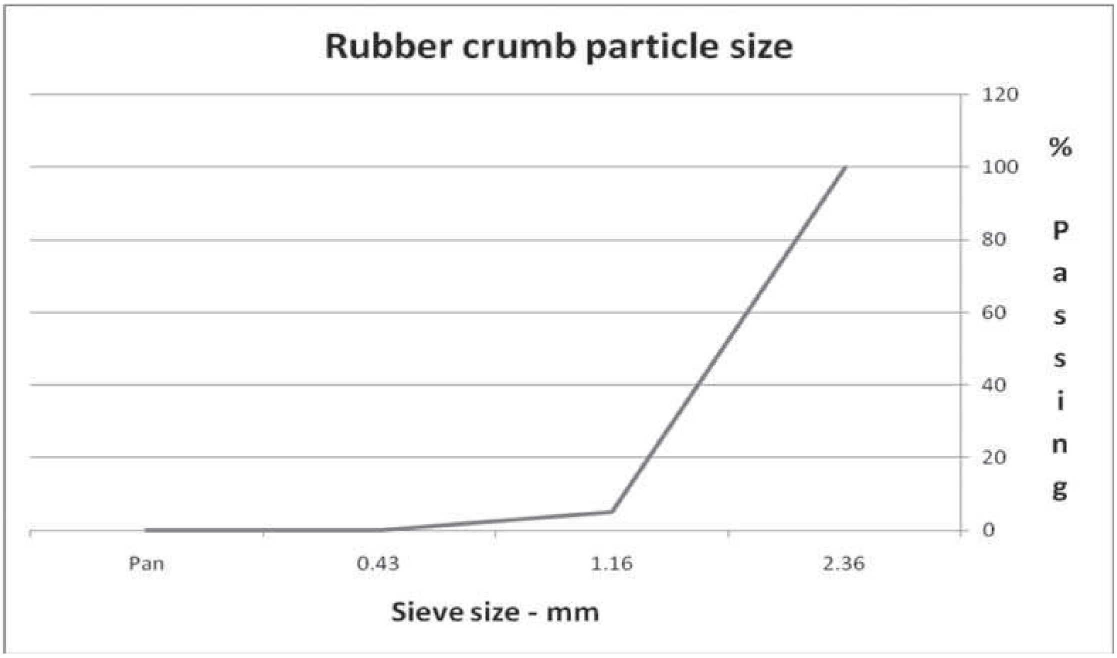


*Figure 1. Rubber crumb grading profile*

### *4.1.2 Design mix*

Four mix designs were utilized in this test program and these were plain, air entrained, 0.5% rubber crumb and 1.0% rubber crumb concrete. The basic mix design used for the plain concrete samples (batch group 1) is shown in Table 2.

| Quantities per m$^3$ of concrete | Material |
|---|---|
| 240 kg | CEM11 cement |
| 731 kg | Coarse sand |
| 1107 kg | 20 mm (max) marine gravel |
| 0.8 | Water cement ratio |

*Table 2: Constituents of the basic mix design – batch group 1*

Batch group 2 was afforded freeze/thaw protection through the addition of rubber crumb at 0.5% volume (7.6 kg/m3) and batch group 3 utilized 1.0% (15.2 kg/m3). Batch group 4 facilitated the comparison of the rubber crumb concretes to those more conventionally protected from freeze/thaw action via the addition of an air entrainment agent at 50 ml per 100 kg of cement dosage. Batayneh et al (2008) and Malek et al. (2007) noted that, the increase of the crumb rubber content in the mix resulted in a decrease in both the slump and the unit weight of the mixtures, and this effect was observed during the mixing process.

The plain concrete mix design proposed for this test was provided by the ready mixed concrete producer Cemex UK. A high water/cement ratio is adopted to produce a weaker concrete exaggerating the effect of freeze thaw damage.

## 4.2 Methodology

The following sections highlight the methods employed during manufacture and testing of the concrete samples.

### *4.2.1 Cube manufacture*

Twelve 100 mm cubes were manufactured of each design mix. Six cubes were subject to freeze/thaw action and the other six remained as control (see Figure 2.). Cube production was controlled with the use of a slump test to BS EN 12350-2:2000 and compaction was carried out with a vibrating table. All compression tests were carried out in accordance with BS EN 12390-3:2002. Care was taken not to over vibrate the cubes, however it was noted the rubber crumb rose to the surface when vibration/compaction took place which is not surprising as the specific gravity for ground rubber may be in the region of 0.48 when compared with concrete which is 2.4.

Producing all twelve cubes at one instance from each mix design batch, ensured all cubes tested were of consistent quality to enable comparisons to be drawn.

### *4.2.2 Cube test program*

From each group of six cubes, two cubes were compression tested at five days after manufacture. This facilitated strength comparisons prior to commencing exposure to the freeze/thaw cycles and highlighted the representivity of the cubes produced from each batch. From here, the testing of the control cubes mirrored those of the freeze/thaw cubes to ensure consistent curing times and aid comparisons to be drawn.

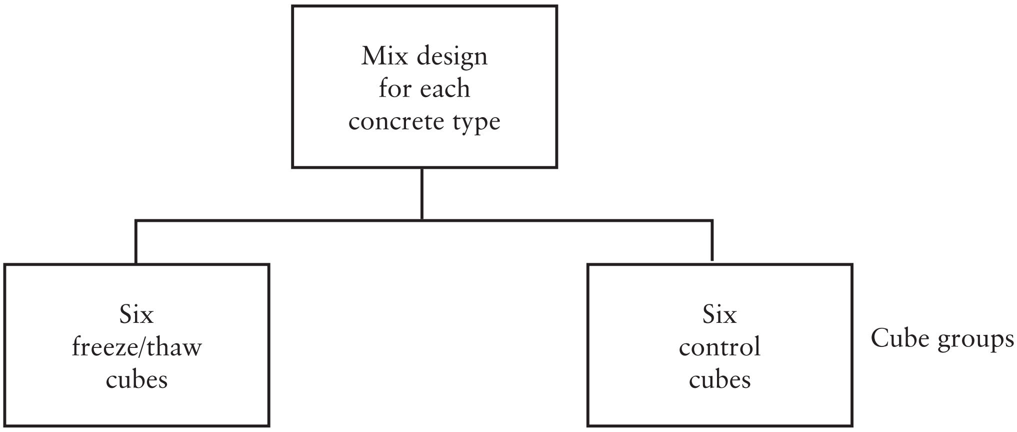


*Figure 2. Batching process*

The freeze/thaw cubes were initially subjected to thirty freeze/thaw cycles and on completion, compression testing was again carried out on the two remaining cubes from this group and the control cubes as shown in Figure 3.

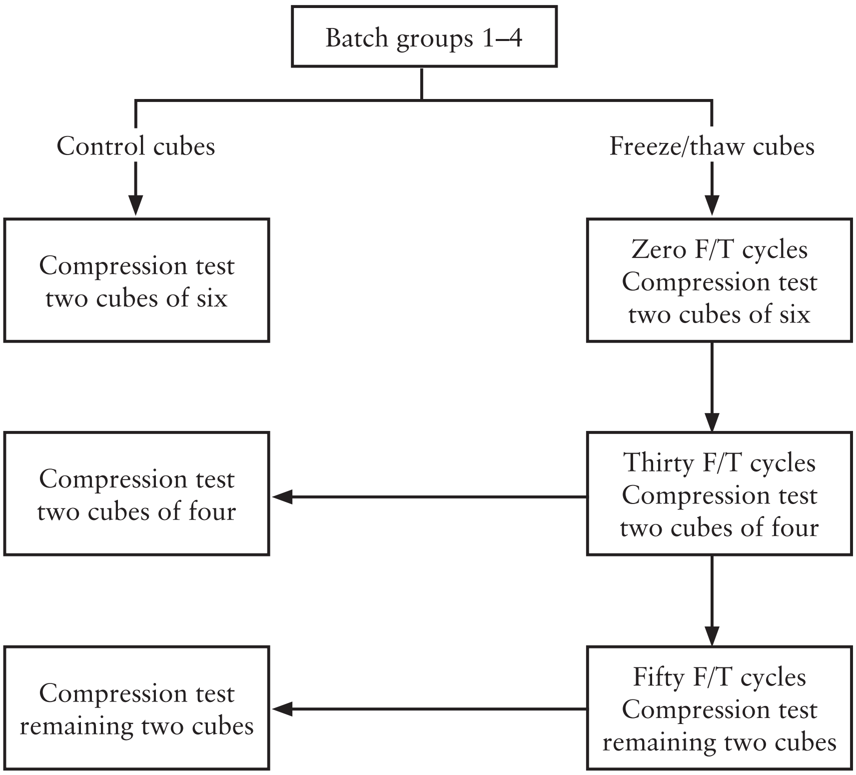


*Figure 3: Staged compressive strength test program*

## 6.0 RESULTS

### 6.1 Batching slump test results

The results of the slump test are shown in Table 3., and the results show that the concrete containing the rubber needed additional water to achieve a slump in keeping with plain or air entrained concrete. This is in accordance with the findings of Malek et al (2007) and Khatib Bayomy (1999) who suggest that rubber particle addition reduces the concrete slump.

| Concrete batch | Initial slump results (mm) | Addition water added (ml) | Subsequent slump results (mm) |
|---|---|---|---|
| Plain | 60 | 0 | 60 |
| Air Entrained | 60 | 0 | 60 |
| 1.0% Rubber | 0 | 300 (+ 3.7%) | 30 |
| 0.5% Rubber | 5 | 100 (+ 1.3%) | 20 |

*Table 3: Slump test results*

### 6.2 Compressive strength and weight loss results from test program

The freeze/thaw test was started after 5 days from batching and the compressive strength of the control cubes prior to any freeze/thaw cycles were 14 and 12.1 N/mm$^2$ which showed a difference of 1.9 N/mm$^2$ providing a mean value of 13 N/mm$^2$ and giving a percentage difference of 7.7% between the cubes from either side of the mean. This was considered within normal batching tolerances. At the end of the test the concrete retained as a control sample had achieved the strength of 26.3 and 24.1 N/mm$^2$ respectively for each cube (2.2 N/mm$^2$ difference) being 4.4% above and below the mean.

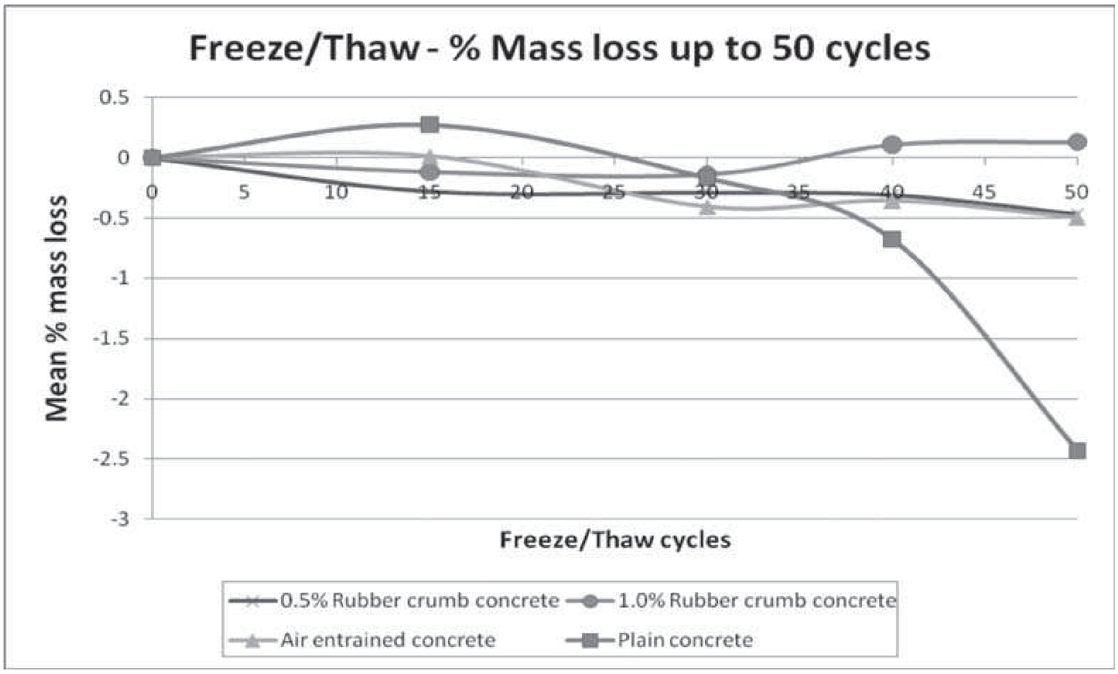


*Figure 4: Freeze/thaw – % mass loss up to 50 cycles (mean value from cubes)*

During the course of the freeze/thaw cycles, the cubes were thawed and weighed in a saturated state and mean values plotted for each six cube group as shown in Figure 4. It is clear the plain concrete cubes lose mass more rapidly than the concrete with air entrainment and rubber crumb. Using the air entrained concrete as a benchmark, the 0.5% rubber crumb performs equally well and the 1.0% rubber crumb concrete performs marginally better.

Figure 5 shows the initial starting mean compressive strengths at 5 days taken from two control cubes. The addition of rubber crumb lowers the compressive strength in accordance with the volume added. Malek et al. (2007) found similar effects with regard to compressive strength although their work dealt with significantly higher doses of rubber crumb (40%) by volume. Bateynah (2008) confirms this characteristic, as substituting the harder dense aggregates with a softer less dense rubber will act as a stress concentrator, causing micro cracking  of the concrete matrix, leading to a loss in strength. The design mix was the same for all of the cubes and the rubber crumb concrete shows signs of strength development despite the freeze/thaw curing conditions. Conversely the plain concrete showed a strength reduction over the 50 cycles and the air entrainment cubes coped well with the freeze/thaw process despite and early fall in strength. The fall in strength of the air entrained concrete between 0 and 30 cycles was thought to be due to potential variations in the concrete batching, which were in line with the initial observations of strength variation prior to the test; rather than an actual strength reduction due to freeze/thaw action.

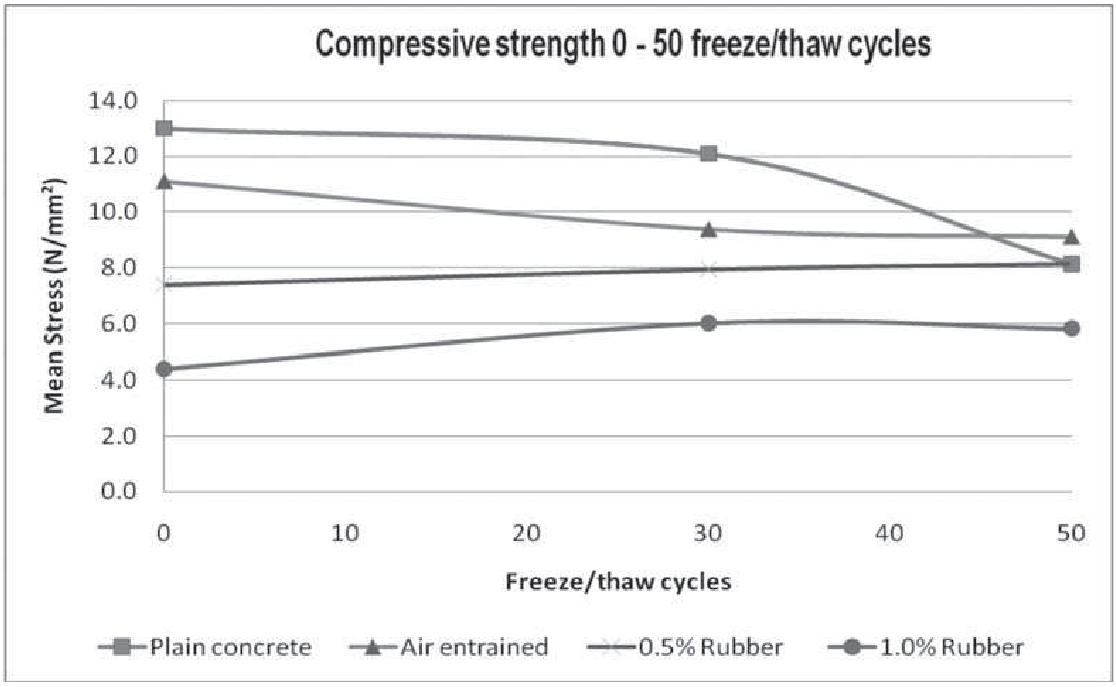


*Figure 5: Freeze/thaw cube compressive strength between 0 and 50 freeze/thaw cycles*

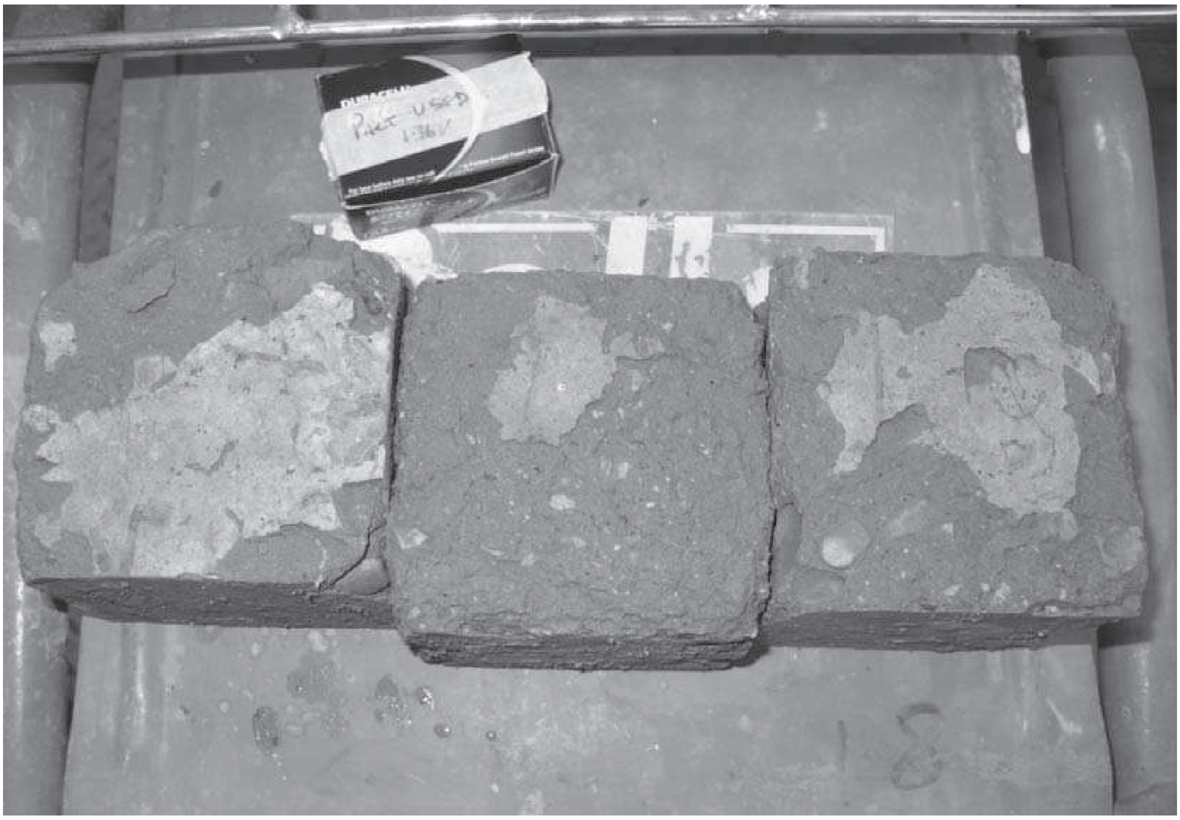

*Plate 1: Plain concrete cubes at 50 freeze/thaw cycles*

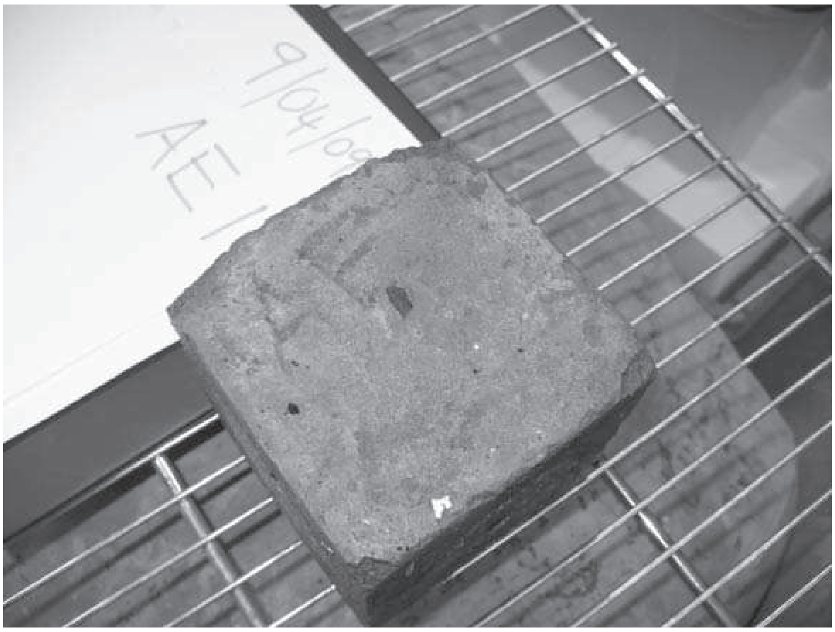

*Plate 2: Air Entrained sample at 50 freeze/thaw cycles*

The plain concrete cubes as Plate 1., showed significant deterioration after 50 cycles, exhibiting severe surface scaling and aggregate pop out, with additional mass being lost from the corners of the cubes.

Plate 2., shows the extent of superficial damage to the air entrained concrete cube, which also suffered concrete loss from the corners, which may have been due to handling.

Plate 3., illustrates minor scaling to concrete with 0.5% rubber crumb after 50 freeze/thaw cycles with all faces being relatively intact.


*Plate 3: 0.5% Rubber sample at 50 freeze/thaw cycles*

Plate 4., shows the 1.0% rubber crumb cube to be relatively intact after 50 freeze/thaw cycles. There is evidence of the rubber crumb separation from the plastic matrix as shown on the surface of the cube in Plate 4, this was due to the compaction method, using a vibrating table. The rubber crumb is exposed due to the loss of surface laitence.

*Plate 4: 10% Rubber sample at 50 freeze/thaw cycles*

The compressive strength of the concrete cubes is shown in Table 4., and Figure 6.

| **Concrete Batch** | Compressive strength 5 days (0 freeze thaw cycles) N/mm² | Compressive strength 35 days (30 freeze thaw cycles) N/mm² | Compressive strength 55 days (50 freeze thaw cycles) N/mm² |
|---|---|---|---|
| Plain | 13.1 | 19.6 | 25.2 |
| 0.5% Rubber | 7.5 | 11.1 | 12.9 |
| 1.0% Rubber | 4.3 | 6.6 | 7.7 |
| Air Entrained | 13.9 | 23.4 | 27.9 |

*Table 4: Compressive strength of control concrete cubes*

The mean compressive strength values taken from Table 4, for the control concrete with rubber crumb additions, show a fall in strength when compared to the plain concrete. The overall mean values measured at 5, 35 and 55 days show that when the 0.5% and 1.0% rubber crumb concretes are compared to the plain batch, there is a respective fall in compressive strength values of 46% and 68%. This strength reduction is an indication of the air void/crumb spacing which affords freeze/thaw protection, hence the effectiveness of the rubber crumb addition with regard to freeze/thaw damage resistance.

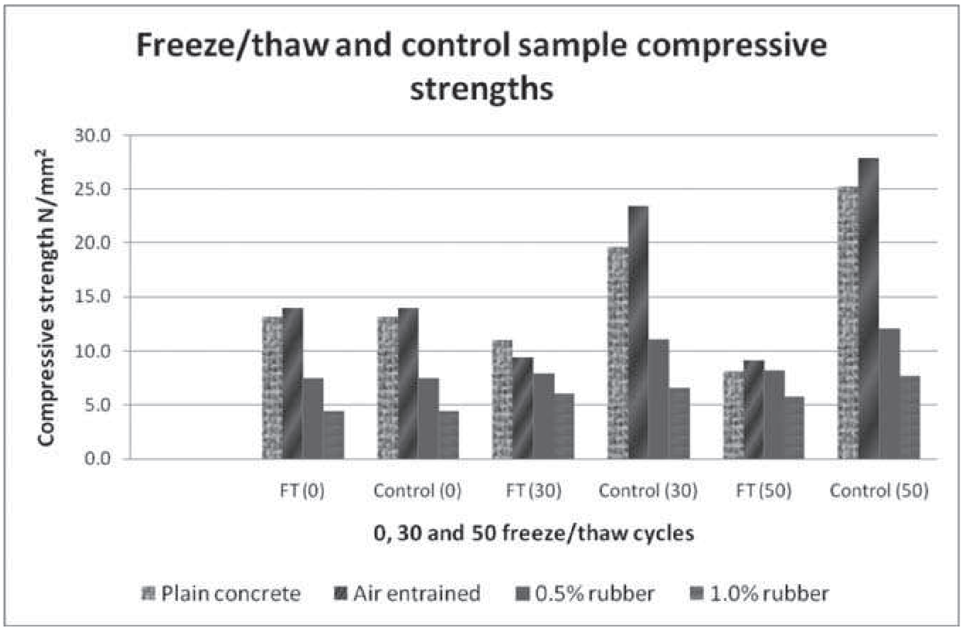


*Figure 6. Freeze/thaw and control sample compressive strengths*

Figure 6., shows the decline in performance of plain concrete between zero and 50 freeze/thaw cycles. The air entrained concrete did not develop strength as the rubber samples, but the comparison of the freeze/thaw and control samples showed a marked difference in strength development. Both rubber concrete samples exhibited lower compressive strength values due to the rubber crumb inclusion and a much lower strength difference after 50 freeze/thaw cycles when comparing the freeze/thaw sample with the control sample.

## 7.0 CONCLUSION

The use of rubber crumb in concrete has shown to be effective in providing freeze/thaw protection. The dosage of 0.5% and 1.0% shows no significant difference in terms of freeze/thaw performance, therefore it is recommended that a 0.5% dose by mass be used to maintain the potential for greater compressive strength development afforded by the 0.5% rubber concrete mix.

The strength reductions of rubber concrete mixes increases with the increasing percentage volume of rubber crumb added to the concrete. To compensate for this aspect of strength reduction, additional cement may be used to bring the design strength back to a plain concrete equivalent. This negates the impact of rubber concrete as a freeze/thaw additive, however air entrainment also promotes concrete strength reductions that must be catered for and air entrainment is widely used in freeze/thaw damage prevention.

An advantage of achieving freeze/thaw protection from rubber concrete mixes is that it facilitates the use of CEM 11 and CEM 111 binders. These cements are cheaper than CEM 1 due to the inclusion of by products such as pulverized fuel ash (PFA) or ground granulated blast furnace slag (GGBS) as partial replacements for cement within their binders. Air entrainment works best using CEM 1, which is a more expensive cement than CEM 11 or CEM 111.

Rubber crumb would be well suited to use with self compacting concrete as no vibration is required to compact and expel air voids with this material. Large volumes of rubber crumb used in concrete would be acceptable where lightweight concrete was required with low compressive strength and elastic properties and maybe considered for use where foamed concrete would be used.

Further testing should be carried out using various rubber crumb additions to find out what the minimum dose of rubber crumb would be for maximum freeze/thaw protection, whilst maintaining maximum compressive strength concrete.

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