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Effects on Freeze-Thaw Durability of Fibers in Concrete

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1. Introduction

The investigation on a construction having such properties as durability, ductility, toughness and strength has boosted interest in materials, such as concrete with fiber and high performance (Otter & Naaman, 1988; Ramakrishnan et al., 1996; P.B. Cachim et al., 2002; Singh & Kaushik, 2003). While improvement of durability of the concrete depends on these conditions, contributory improvements in both chemical and mechanical properties of the concrete are also essential. The fibers improving concrete mechanically are primarily added to minimize cracking or to increase ductility of the concrete and fracture toughness against impact or dynamic loads (Naaman & Reinhardt, 1996; Dias&Thaumaturgo, 2005).

Since short fiber types greatly increase the number of fibers used in the concrete, they are used to decrease cracking and increase durability depending on the properties of the materials used; whereas, long fibers aim more often to increase mechanical properties of the concrete. Addition of hybrid fibers created synergy in the concrete and leaded to similar significant improvements in monofiber reinforced concrete having the higher total fiber content (Qian & Stroeven, 2000).

Studies on durability have emphasized that fiber gains particular importance on increasing freeze-thaw durability. Dramatic falls have been observed in elasticity modulus reaching as many as 300 cycles in the concrete specimens kept both in a 5 % $NaSO_4$ solution and in water, whose rate of w/c was 0.26, 0.32 and 0.44. Concrete including steel fibers do fail in much higher cycles than do plain concrete. Also, the concrete specimens, including fibers with the same rate of w/c, kept in the solution have been shown to have a higher performance in comparison with concrete without fibers kept in water (Singh & Kaushik, 2003).

In some studies, external loads have been exerted upon the concrete kept in a NaCl solution under the influence of effective freeze-thaw cycles. The concrete specimens exposed to NaCl have been shown to lose twice as much weight as those exposed to water. Specimens with steel fibers lose weight maximum at the w/c ratio of 0.44 that becomes obvious after 20-25 cycles. As the rate of the tension of the burdens exerted increased, resistance of the concrete specimens to cycles decreased. Addition of steel fibers in concrete specimens has been shown to cause a delay in a decrease in the performance of the concrete in the advanced cycles in comparison with the concrete without fiber (Sun et al., 2002; Mu et al., 2002; Miao et al., 2002). Morgan (1991) tested dry and wet hybrid shotcretes with sprayed fibers according to ASTM C 666 rapid water freeze-thaw method (A). In the case of air entraining and use of a high amount of steel and polypropylene fibers freeze-thaw durability can be achieved in wet and dry sprayed concrete. However, a rapid fall is observed in durability when there is no air entraining.

According to ASTM C 666 rapid water freeze-thaw method, 300 and 700 freeze-thaw cycles were applied. The results have shown that despite falls in durability and dynamic elasticity modulus, freeze-thaw performance of both concrete have been shown to be perfect. A study by Juska et al. (1999) on thermal effects upon concrete with glass fibers reported interesting results pertaining to durability. Gomez and Casto (1996) conducted the experiment of freeze (-17.8 °C) and thaw (4.4 °C) came in a 2 % NaCl solution upon composites with fibers. Flexural strength of the specimens and some other properties has been reported to suffer substantial loss. Moreover, Myers et al. (2001) reported flexural rigidity and strength in plaques with glass fibers to decrease more than did rigidity and strength in plaques with carbon fibers.

In this study, micro-structured polypropylene and glass fibers were both used separately and in combination with macro-structured steel fibers in the concrete. Experiments were conducted in order to determine weight-loss and durability factor based on ultrasound pulse velocity of 12 different concrete series produced according to ASTM C-666. The separate and combined effects of the fibers used in the concrete in terms of the rapid freeze-thaw period were investigated.

2. Experimental study

2.1 Materials

CEM I 42.5 R cement was used in the study (Yildirim, 2002). As the aggregate, crushed stone dust of 0-0.5 mm, natural sand of 0.5-4 mm, natural coarse aggregate of 4-16 mm and crushed stone of 16-32 mm were used. Densities of the aggregate used were 2.62, 2.65, 2.70, 2.70 gr/cm^3, respectively. The largest dimension of aggregate was 22 mm. Hooked steel fibers (SF), plain glass fiber (GF) and polypropylene fibers (PF) apart from additive materials providing superplasticizer was used. The properties of fibers have been presented in Table 1, while the properties of cement and additive providing super plasticizer have been presented in Table 2.

Properties	SF	PF	GF
Size (mm)	60	20	12
Dimension (mm)	0.75	0.05	0.014
Brittleness	80	400	857
Density (kg/mm^3)	7480	910	2680
Modulus of elasticity (MPa)	200000	3500-3900	72000
Tensile strength (MPa)	1100	320-400	1700
The number of fibers per kilogram	4600	82 Million	200 Million

Table 1. Technical properties of steel, polypropylene and glass fibers.

Concrete including fibers with different percentages were produced within the same main compounds. K represents the control concrete specimen, while S, P and G represent the concrete specimens including steel, polypropylene and glass fibers, respectively. Three series of concrete, including 0.5 (S 0.5), 0.75 (S 0.75) and 1 (S 1) % as volumetric of hooked steel fibers respectively, were produced. Another six series of concrete were produced with the use of polypropylene and glass fibers of 0.1 % (P and G). The symbols of the fiber material used in the mixture fiber specimens have been defined as SP and SG. They were both used separately and in combination with macro-structured steel fibers of 0.5 (SP 0.5 and SG 0.5), 0.75 (SP 0.75 and SG 0.75) and 1 (SP 1 and SG 1)%. Six specimens were produced from all the series so that they would be used in the experiments. Therefore, all of the twelve series of concrete were produced.

Chemical Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl^-	Insoluble Remains	LOI	C	S
Cement	20.03	5.09	3.44	64.5	1.43	1.3	0.19	0.65	0.01	0.42	2.31	-	-
Superplasticizer	90	0.75	1	0.65	1.15	-	0.55	1.05	0.03	-	-	1.90	0.23

Table 2. Chemical properties of cement and superplasticizer.

As to the control concrete compound of 1 m^3, slump was constant as 130 mm. 181.0 kg of water, 281.9 kg of cement and 14.83 kg of silica fume were used, apart from superplasticizer. Water/cement rate was taken as 0.61. Fibers used as volumetric in concrete.

2.2 Experimental method

Freeze-thaw tests in the concrete series were conducted according to ASTM C 666 (Procedure B: rapid freeze-thaw under air conditions). It was applied on standard prismatic specimens at the dimensions of 80x80x360 mm. The experiment was conducted after the specimens had been cured for 28 days. Heat transfer calculations were made in order to determine how long the heat in the specimens would take to reach the optimal heat required for the experiment so that the freeze-thaw test could be made in the deep frost according to ASTM C 666. Therefore, the central heat of the specimens (20 °C) was lowered to -20 °C. The central heat of the specimens left in the water was increased to 5.4 °C. 30 cycles were made altogether, with the central heat adjusted in such a way that it would vary between -20 °C (2 hours and 40 minutes) and 5.4 °C (36 minutes).

Weight loss and ultrasound pulse velocity were measured at the beginning and the end of the cycles applied on concrete specimens. The percentage of dynamic E-modulus determined after freeze-thaw cycles through ultrasound instrument (P) was calculated by dividing the square of the pulse velocity after freeze-thaw cycles by the square of the pulse velocity before freeze-thaw cycles and then multiplying the result by 100. Afterwards, dynamic E-modulus was determined by multiplying a predetermined value (30) by the continuing number of cycles (N). The result was then divided by the final number of cycle (30) (M). After this, durability factor (DF) for the concrete specimens was determined with

DF=P.N/M formula. N and M values were equal for this study (American Society for Testing and Materials [ASTM C 666], 1999).

3. Test results and discussion

As a result of the experiment, surface damages of concrete specimens were determined after 30 freeze-thaw cycles. The specimens were seen that they have a sponge-like surface and broken edge. These damages occurred more intensively between 20 and 25 cycles (Mia et al., 2002).

As seen in Fig. 1, the plain concrete specimens had far less amounts of weight-loss than most of the concrete specimens including fiber. However, there occurred roughness over the surface. In order to obtain a more precise determination of weight-loss, the number of freeze-thaw cycles should be increased. The surface of concrete gets damaged when exposed to low freeze-thaw cycles. A much less amount of weight-loss could have been expected in fiber reinforced concrete if they had been exposed to a larger number of freeze-thaw cycles, considering the capability of fibers to keep matrixes together. Weight-loss was also determined to get affected by some of the parts falling off the corners of the specimens. In particular, the corners of the concrete with steel fibers are weaker and so may cause falling off some parts in the corners by forcing the matrix during the freeze-thaw cycles.

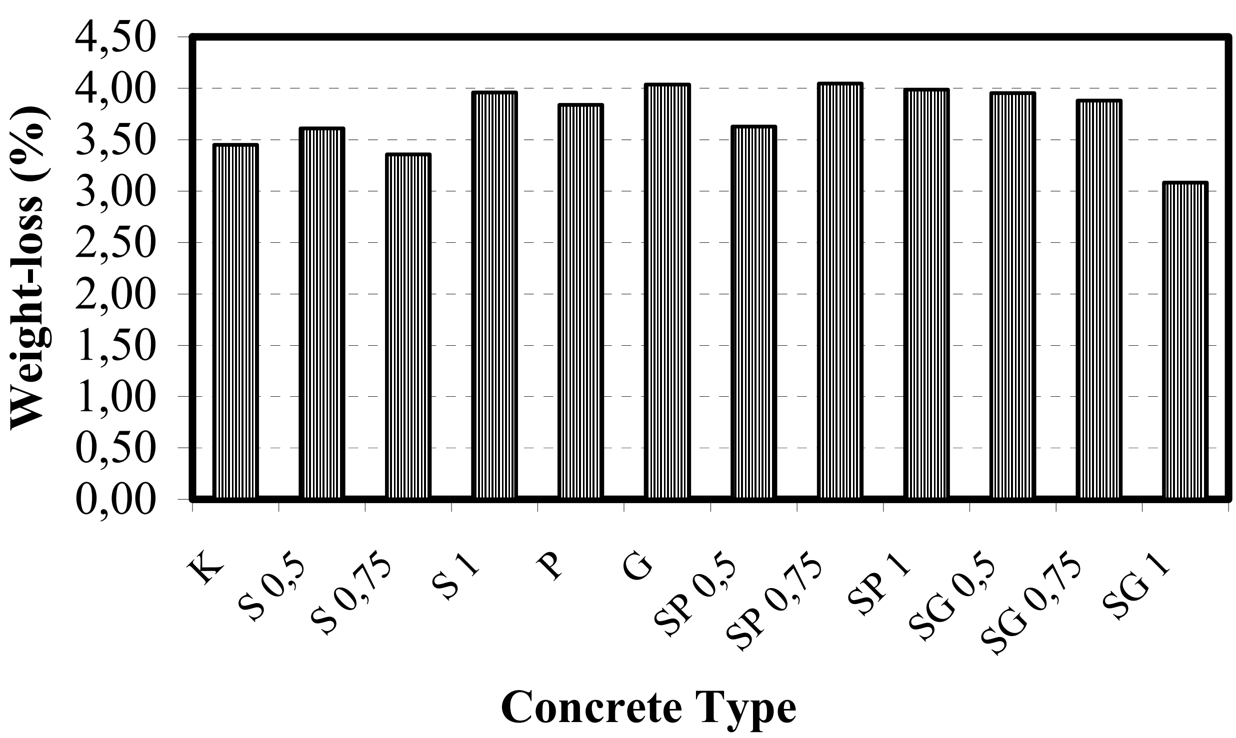

Fig. 1. Weight-loss after freeze-thaw cycles.

As seen in Fig. 2, the decrease in the pulse velocity of the specimens was obvious in contrast to their weight-loss. Polypropylene fibers demonstrated the best performance as a stand-alone and mixed with steel fibers (Morgan, 1991). A similar effect was determined for the mixture fibers. Fibers did affect the concrete specimens in agreement with their own properties. Because of the capability of polypropylene fibers to prevent cracking and to be remarkably safe from corrosion, the pulse velocity value was determined to be low.

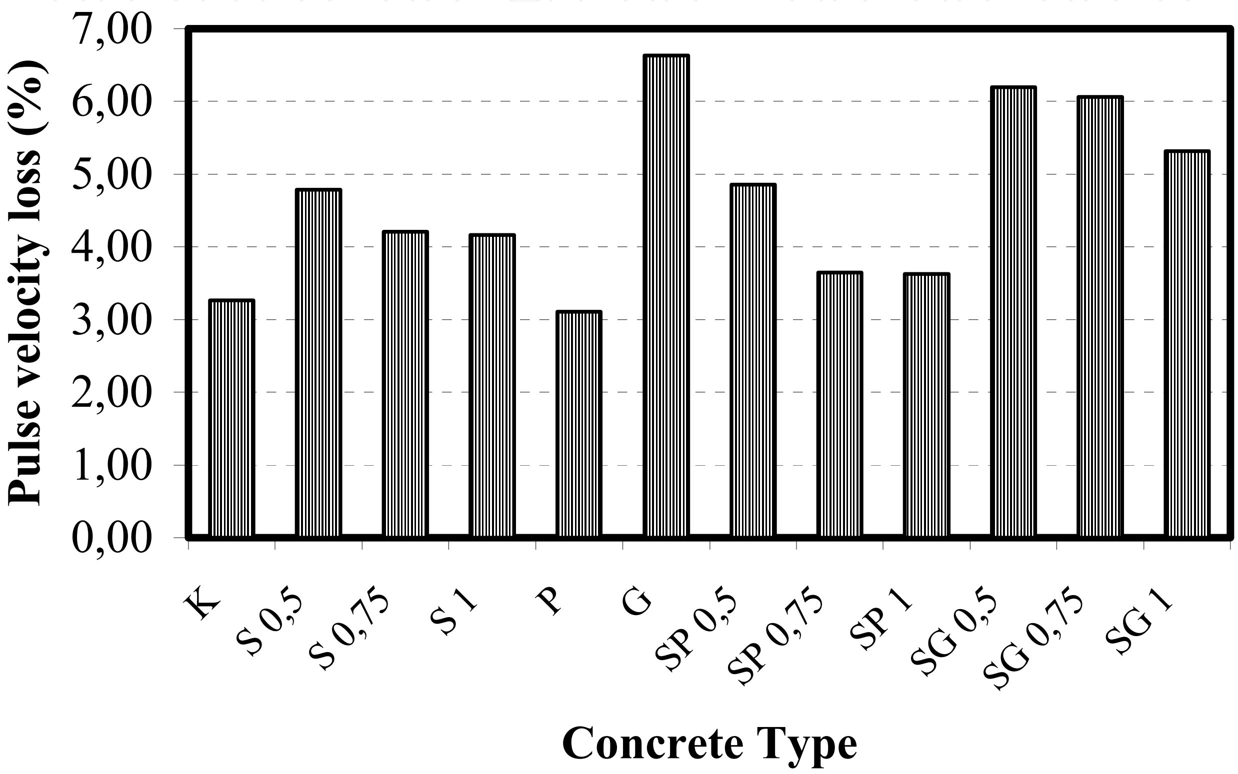

Fig. 2. Decreases in the pulse velocity following freeze-thaw cycles.

Though glass fibers have microstructures like polypropylene fibers, they showed their general weakness and the fibers were observed to have caused voids and to have affected adhesion negatively (Juska,1999). The initial decrease was in the steel fibers were attributed to the voids between the fiber-matrix interfaces. Moreover, due the fact that the ends of the fibers were curved, and that they are more resistant to dilation or contraction, the pulse velocity decreases due to the increase in the amount of fiber. However, it should be emphasized that the following cycles may change this. In other words, it is possible to say that the durability factor may be higher in following cycles (Singh & Kaushik, 2003). In order to ensure this, the number of cycles should over 30. Because the durability factors seen in Fig. 3 are inversely proportional to the decrease in the ultrasound pulse velocity, the low values are seen as high here.

Durability of the concrete series was determined to have been increased by polypropylene fibers, while glass fibers were determined to be highly unsuccessful. No concrete specimens including steel fibers, inclusive of mixture fibers, had higher values than plain concrete specimens.

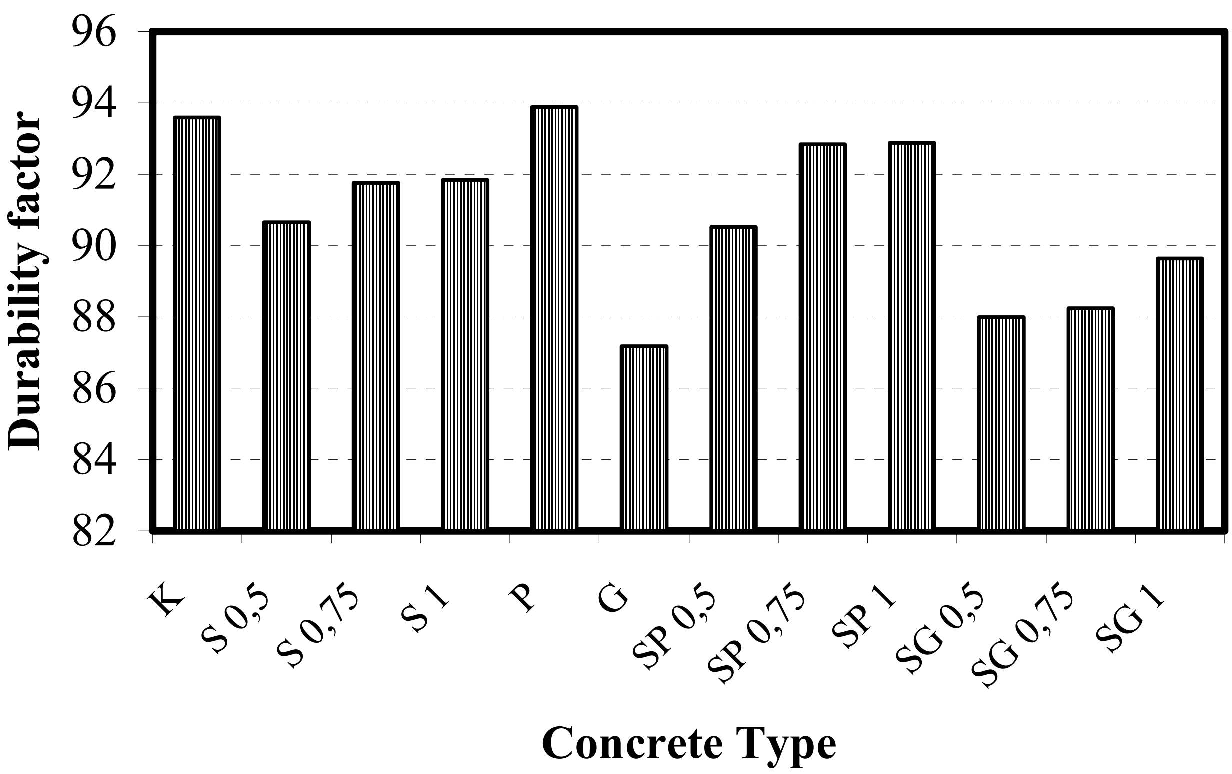

Fig. 3. Durability factors determined after freeze-thaw cycles.

4. Conclusion

20-25 of freeze-thaw cycles in concrete specimens was determined to be highly critical. Though they seem to be enough in number to form an opinion about the durability factor, 30 cycles of the freeze-thaw process seem to be insufficient to determine the precise weight loss of the concrete specimens. It was concluded that increasing the number of cycles could be advantageous to measuring weight, and that steel fibers could provide advantages for durability determination of in the following cycles. Using polypropylene fiber in all the concrete specimens to be reinforced by fibers in consideration of the effects of freeze-thaw cycles will be advantageous. Steel fibers did not cause any difference in terms of freeze-thaw cycles but did cause some negative effects for mixture concrete. Therefore, it is important that glass fibers should not be used in the places exposed to freeze-thaw cycles, or that concrete should be protected against this effect. Base on the study results, it can be suggested that steel fibers, which have different levels of brittleness, those with smaller dimensions in particular, should be investigated for the effects of freeze-thaw cycles.

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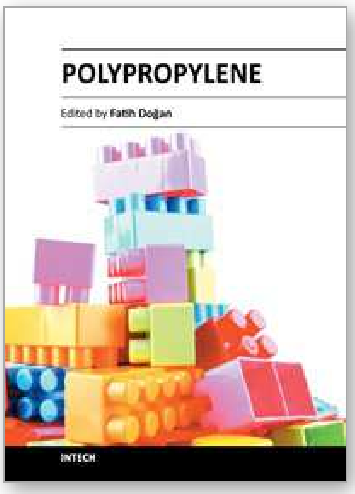

Polypropylene
Edited by Dr. Fatih Dogan

ISBN 978-953-51-0636-4
Hard cover, 500 pages
Publisher InTech
Published online 30, May, 2012
Published in print edition May, 2012

This book aims to bring together researchers and their papers on polypropylene, and to describe and illustrate the developmental stages polypropylene has gone through over the last 70 years. Besides, one can find papers not only on every application and practice of polypropylene but also on the latest polypropylene technologies. It is also intended in this compilation to present information on polypropylene in a medium readily accessible for any reader.

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