

## **STUDYING THE EFFECT OF FREEZE AND THAW CYCLES ON BOND STRENGTH OF CONCRETE REPAIR MATERIALS**

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### **ABSTRACT**

In this paper the results of an experimental study of the effect of freeze and thaw cycles on the bond between repair materials and concrete substrate is presented. The work was aimed at studying the effect of various factors such as initial curing periods and surface preparation method on bond strength. Old concrete samples were made based on BS6319, Part 4 standard. Smooth as-sawn and acid etching methods were used for preparation of concrete substrate surface. Ordinary concrete with cement type II and concrete containing microsilica were used as repair materials. Repaired samples were subjected to 10 to 100 freeze and thaw cycles based on ASTM C666. The bond between repair materials and concrete substrate was evaluated based on slant shear test method (BS, 1984). The obtained results are tabulated and presented in this paper.

**Keywords:** Freeze and thaw; concrete; repair; bond strength

### **1. INTRODUCTION**

The serviceability of construction materials in general is of significant economic importance. This is especially so with structures and materials which are part of the infrastructure of a modern society. Concrete is a material heavily used in urban development, meeting the requirements of codes of practices by means of strength and durable structures. Reduced service life of concrete members in the sense of lack of durability may be due to a number of different reasons, e.g. planning/capacity (over loading), improper structural or material design, construction practice or inadequate maintenance – or lack of knowledge.

The mechanisms of damage to concrete from repeated cycles of freezing and thawing are not well understood and continue to be intensively studied. Original research was based on the fact that water expands 9 percent when it freezes. Further researches proposed more mechanisms. Hydraulic pressure theory proposes that destructive stresses can develop if water is displaced to accommodate the advancing ice front in concrete. If the pores are critically saturated, water will begin to flow to make room for the increased ice volume. The

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concrete will rupture if the hydraulic pressure exceeds its tensile strength.

Widespread use of de-icing salts in many parts of the world is considered one of the major cause of rapid degradation of concrete structures. Further, the de-icing salt together with repeated freezing and thawing may cause failure of the concrete cover by surface scaling, which combined with steel corrosion may critically reduce the structure's service life. It is very difficult to estimate the direct repair and maintenance costs caused by freeze-thaw damages of concrete structures. However, due to its still unrevealed secrets concerning deterioration mechanisms, freeze-thaw resistance has received significant attention for several decades.

The mechanisms of damage to concrete from repeated cycles of freezing and thawing are not well understood and continue to be intensively studied. Original research was based on the fact that water expands 9 percent when it freezes. Thus, the term "critical saturation" was coined to describe the point at which the concrete pores were 91.7 percent saturated and, therefore, assumed to be susceptible to damage due to freezing and thawing. Further investigation determined that deterioration due to freezing and thawing can affect concrete with lower degrees of saturation [1].

Four theories have gained wide acceptance in describing the mechanisms of frost action. Although most of these theories were originally used to describe the frost action in cement paste, they are also applicable to concrete [2]. The first was the hydraulic pressure theory Powers proposed in 1945. This was followed by the diffusion and growth of capillary ice theory constructed by Powers and Helmuth in 1953, the dual mechanism theory by Larson and Cady in 1969, and the desorption theory by Litvan in 1972. Other theories have been proposed, but these four form the basis of most research in the area of frost resistance of concrete.

While these theories disagree as to whether water moves toward or away from the point of ice formation, they agree that the amount of water in the pores and the resistance to movement of that water play a role in the frost resistance of concrete. In the case of concrete, it is generally accepted that the pore system is potentially susceptible to damage from freezing and thawing. Efforts to produce frost-resistant concrete have primarily focused on providing a proper system of entrained air voids. In the case of aggregates, some pore systems do not show susceptibility to damage from freezing and thawing while other pore systems do. In addition to the air-entrainment of concrete as mentioned above, efforts have also focused on identifying the aggregates with acceptable pore systems for use in concrete exposed to freezing and thawing.

The causes of concrete deterioration have always been the object of concern and research. This interest is increasing due to the high cost associated with the repair and maintenance of the concrete structure. Repairs, however, are successful in the long-term if the causes of the original damage have been understood and appropriate repair materials are applied to resist future deterioration. Repair materials should be compatible with old concrete and have good adhesion. In repair of concrete, the bond strength between repair materials and old concrete is of vital importance.

The objective of this study was to investigate the effect of freeze and thaw cycles on bond strength of repair materials. Strength and integrity of the bond depends on not only the physical and chemical characteristics of the repair component, but also other factors such as surface preparation method and environmental conditions. The effects of these factors were

studied in this work.

## 2. EXPERIMENT

Old concrete samples were made based on BS6319 Part 4 standard [3]. It is shown that surface preparation method has significant effect on bond strength [4], therefore, two methods including, smooth as-sawn and acid etching were used in order to prepare the surface of old concrete samples. Ordinary concrete, made with type II portland cement, and concrete containing 15 percent microsilica were used as repair materials. Repaired samples were subjected to 10 to 100 freeze and thaw cycles based on ASTM C666 procedure B. The bond between repair materials and concrete substrate was evaluated based on slant shear test method (BS, 1984).

### 2.1 Mix Proportions

Type II portland cement (ASTM C 150 specification) was used in this research. Crushed stone with a maximum size less than 9.5 mm and sand with a fineness modulus of 2.9 were used for producing concrete. The composition of old concrete mixes (OC mix) was 0.5:1.0:2.35:1.04 (water: cement: sand: gravel) by weight. The uniaxial compressive strength of old concrete samples was 35 MPa. MSOC mix was produced with replacement of 15% of cement in OC mix (by weight) with microsilica in order to investigate the effect of microsilica on bond strength.

### 2.2 Specimen Preparation

Old concrete samples were made based on BS 6319: Part 4 standard, Figure 1. They were cast as 55x100x150 mm prisms and cured in water for 28 days in laboratory. Then cut at 30 deg to the vertical axis using a diamond saw. The acid etching method with use of hydrochloric acid was used to prepare the surface of 1/2 of samples.



Figure 1. Concrete samples prepared based on BS 6319: Part 4

For acid etching, with reference to ACI committee 549 [4], a hydrochloric acid solution was chosen. HCl can primarily react with the  $\text{Ca}(\text{OH})_2$  of the hydrated cement paste to form  $\text{CaCl}_2$ , making the substrate more porous. Because no adequate information concerning the influence of acid consistency on bond strength was available in current literature, hydrochloric acid solutions of 5% were chosen for testing [5]. The etching of surface was carried out in such a way that the hydrochloric acid solution was brushed on the surface of concrete substrate with a soft nylon brush at a rate of 20 times/min. The etched surface was then flushed under flowing tap water for 2 minutes.

### 2.3 Repair and test procedure

Concrete samples were formed in the moulds in which they were cast. The repair material, OC or MSOC mixes, was then applied and hand-compacted. Samples were stripped after 24 hr and placed in curing tank for 7, 14, and 28 days.

To evaluate the effect of freeze and thaw cycles on bond strength of repair materials, concrete samples after curing were subjected to 10 to 100 freeze and thaw cycles based on ASTM C666 Procedure B, Figure 2. The loss of the weight in the concrete specimens were also measured and recorded.



Figure 2. Samples of freeze and thaw test

A wide range of test method has been proposed to evaluate bond properties and performance of repair materials in general. The slant shear test has become the most widely accepted test for evaluating the bond of resinous repair materials to concrete. However, there seems to be no standard test for testing the bond to concrete of cementitious and modified cementitious repair materials. To compare the bond strength of repair materials, slant shear test method was used in this work. This method, which puts the bond interface into a combined state of compression and shear is adopted in BS6319: Part 4 [3], was used as a test method for evaluating bond strength of repair materials, Figure 3.



Figure 3. Slant shear test

### 3. TEST RESULTS AND DISCUSSION

Strength and integrity of the bond depends on not only the physical and chemical characteristics of the repair component, but also other factors such as initial curing periods, surface preparation method and environmental conditions. The effects of these factors were studied in this work. The obtained results are presented and discussed briefly in this section.

The results given in Table 1, shows the effect of initial curing periods on durability of samples subjected to 100 freeze and thaw cycles. Based on the results, the curing period has an important effect on durability of concrete samples subjected to freeze and thaw cycles.

Table 1. The effect of initial curing on durability

Repairing material	OC			MSOC		
	7	14	28	7	14	28
Curing period (day)	7	14	28	7	14	28
Weight loss (%)	3.05	2.25	2.11	2.1	1.64	1.43

As shown in the above table with increase in curing period weight loss decreases. For concrete samples repaired with ordinary concrete, the weight loss has decreased from 3.05% to 2.11% with increase in curing period from 7 to 28 days, respectively, which means 31% increase in durability, or in other words, increase in resistance to freeze and thaw cycles. With increase in strength of repair material, the weight loss of samples is decreased. Based on the obtained results, samples repaired with MSOC material show about 30% more resistance to freeze and thaw cycles than concrete samples repaired with OC material. For

concrete samples repaired with microsilica concrete, the weight loss has decreased from 2.1% to 1.43% with increase in curing period from 7 to 28 days, respectively, which means 32% increase in resistance to freeze and thaw cycles.

To study the effect of freeze and thaw (F&T) cycles on bond strength, samples were cured for 28 days in curing tank and then were subjected to 10 to 100 freeze and thaw cycles based on ASTM C666 Procedure B. Test results are given in Table 2. Based on the obtained results freeze and thaw action decreases the bond strength considerably. With increase in number of F&T cycles bond strength decreases. After 100 cycles of F&T, the bond strength of samples repaired with OC and MSOC materials is reduced by 85.6% and 61.2%, respectively. Moreover, microsilica concrete not only increases the bond strength [6-7], but also increases durability regarding F&T cycles.

Table 2. The effect of F&T cycles on bond strength

Repairing material	OC						MSOC						
	No of F&T cycles	0	10	20	50	70	100	0	10	20	50	70	100
Bond strength (MPa)		21.5	20.4	19.2	17.6	10.3	3.1	24.0	23.3	21.4	19.5	15.1	9.3

In Figure 4, the bond strength of samples subjected to F&T cycles is compared to that of samples which were not subjected to F&T cycles (FT/NFT).

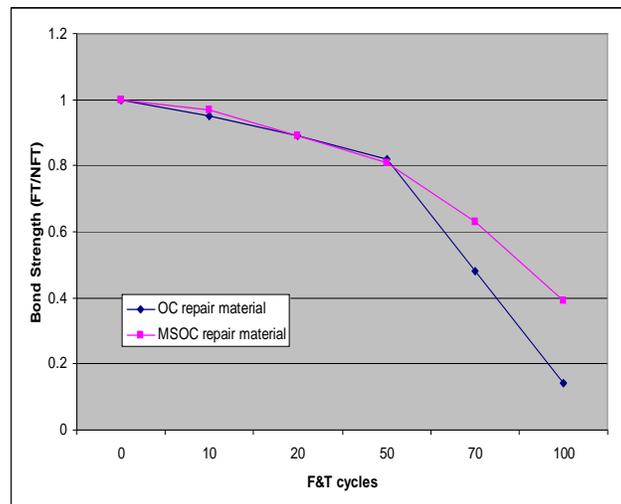


Figure 4. Ratio of bond strength of samples subjected to F&T with that of observation samples

As the above Figure shows, the bond strength of repair materials is not much affected in the first 50 cycles of F&T and reduction is less than 20 percent. However, during the second 50 cycles, the bond strength of repair materials reduces sharply in both OC and MSOC materials. As can be seen, reduction of bond strength in OC repair materials is more than that of MSOC repair material.

Two surface preparation methods, smooth as-sawn (SS) and acid etching (AE) were used to prepare the MSOC samples. After repair, samples were cured for 28 days in curing tank and then were subjected to 70 freeze and thaw cycles. Slant shear test was used for evaluating the bond of MSOC repair materials to concrete. In Table 2, the 28-day bond strength of samples is given.

Table 2. The effect of surface preparation method on durability and bond strength

Surface preparation method	SS			AE		
	50	70	100	50	70	100
Number of F&T cycles	50	70	100	50	70	100
Bond strength (MPa)	19.5	15.1	9.3	22.1	17.5	11.1

Based on the obtained results, the surface preparation method has a considerable effect on bond strength of repair materials subjected to F&T cycles. With use of acid etching method, the bond strength of MSOC repair material is increased by 13%, 16%, and 19% after 50, 70, and 100 F&T cycles, respectively, compare to those of samples prepared by SS method.

#### 4. CONCLUSIONS

In this study the effect of Freeze and thaw cycles on bond strength of cementitious repair material is investigated. The work was aimed at studying the effect of various factors such as initial curing periods and surface preparation method on bond strength. Old concrete samples were made based on BS6319, Part 4 standard. Smooth as-sawn and acid etching methods were used for preparation of concrete substrate surface. Ordinary concrete (OC) with cement type II and concrete containing microsilica (MSOC) were used as repair materials. Repaired samples were subjected to 10 to 100 freeze and thaw cycles based on ASTM C666B. The bond between repair materials and concrete substrate was evaluated based on slant shear test method (BS, 1984). The following conclusions can be drawn from the obtained results:

- 1) the curing period has an important effect on durability of concrete samples subjected to freeze and thaw cycles. With increase in curing period weight loss of samples decreases. In this study, for concrete samples repaired with ordinary concrete, the weight loss has decreased with increase in curing period from 7 to 28 days by 31%.
- 2) freeze and thaw phenomena decreases the bond strength considerably. With

increase in number of F&T cycles bond strength of repair materials decreases. After 100 cycles of F&T, the bond strength of samples repaired with OC and MSOC materials reduced by 85.6% and 61.2%, respectively. Moreover, microsilica concrete not only increases the bond strength but also increases durability regarding F&T cycles.

- 3) with application of an effective surface preparation method one can improve the bond strength of repair material considerably. In this study, with use of acid etching method, the bond strength of MSOC repair material could be increased by 13%, 16%, and 19% after 50, 70, and 100 F&T cycles, respectively, compare to that of samples with smooth as sawn surface.

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