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Shotcrete for Concrete Repairs — Function and Durability

Béton projeté pour les réparations du béton — fonction et résistance

Spritzbeton zur Betonreparatur — Funktion und Beständigkeit

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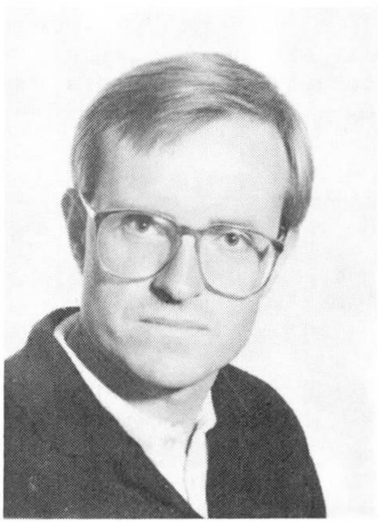

Anders Andalen, born 1955, got his civil engineering degree at Chalmers University of Technology, Gothenburg, Sweden. For three years he worked within an engineering consulting firm. In 1982 he was employed by the National Testing Institute, and is now responsible for the concrete division at the Department of Building Technology.

SUMMARY

The aim of this project, which is to continue until 1990, is to increase knowledge of the function and durability of shotcrete for concrete repair and to develop suitable test methods. Methods for testing bond, salt-frost resistance, strength and shrinkage have been analysed for a number of different qualities of shotcrete. The bond between shotcrete layers and sawn concrete surfaces has been studied for different kinds of surface treatment. The highest bond was obtained when the shotcreting was carried out on dry surfaces.

RÉSUMÉ

L'objet de cette recherche, dont la durée s'étendra jusqu'en 1990, est d'améliorer nos connaissances sur la fonction et sur la résistance des réparations réalisées avec du béton projeté et de développer les méthodes d'essai adéquates. Les essais d'adhésion, la résistance du béton frais vis-à-vis du gel et du sel, la résistance d'échantillons et de retrait sont autant de paramètres déterminés pour différentes qualités de béton projeté. L'adhésion entre les couches de béton et les surfaces sciées a été étudiée pour différents traitements de surfaces. La meilleure adhésion est obtenue lorsque le béton projeté est appliqué sur des surfaces sèches.

ZUSAMMENFASSUNG

Ziel dieses Projektes, das bis 1990 fortgeführt wird, ist es, das Wissen über die Funktion und die Beständigkeit von Spritzbeton bei Betonreparaturen zu erhöhen und passende Testmehoden zu entwickeln. Methoden zur Untersuchung der Haftfähigkeit, der Frostbeständigkeit bei Gegenwart von Salz, der Festigkeit und des Schwunds wurden für einige Spritzbetonsorten unterschiedlicher Qualität analysiert. Die Haftfähigkeit zwischen Spritzbetonschichten und gesägten Betonoberflächen wurde bei verschiedenartiger Oberflächenbehandlung studiert. Die beste Haftung wurde bei Anbringung auf trockenen Oberflächen erzielt.

1. INTRODUCTION

The aim of the present project, which is to continue until 1990, is to increase knowledge of the function and durability of shotcrete for concrete repair and to develop suitable test methods. Of special interest is the rehabilitation of bridges and other structures subjected to frost and deicing agents in aggressive environments.
A shotcrete testing laboratory was established at the National Testing Institute, where it is possible to perform shotcrete in full scale under controlled conditions, see fig 1. All shotcreting necessary for the tests presented in this paper was carried out by contractors, under the supervision of personnel from the Institute.

Fig. 1 Shotcrete gunned towards formwork, with bottoms of sawn concrete surfaces.

As a part of the project the bond between shotcrete layers and sawn concrete surfaces was studied. These surfaces were preparated in six different ways. The shotcrete, both dry mix and wet mix, was gunned into moulds where the bottom consisted of a sawn concrete surface. The shotcrete layers were also used for testing strength, salt-frost resistance and shrinkage. The shotcreting was performed by two contractors with experience in dry mix and wet mix techniques, respectively. According to the contractors experience, the shotcrete composition and the equipment used were expected to give high bond strength and good durability.

2. BOND STRENGTH

2.1 Test method

The shotcrete was sprayed into molds with bottom surface dimensions of 400 x 400 mm. The bottoms consisted of 100 mm thick concrete slabs with sawn surfaces and the walls of steel plates with an inclination of 45 °, see fig 2. After shotcreting the panels were covered with a plastic film and stored in 20±2 °C for one week. The film was then removed and the slabs kept in a laboratory environment at 20±2 °C, RF 50± 10 %. Four cylinders, all with a diameter of 70 mm were drilled out from each of the panels. The cores were sawn to a length of 70 mm, with the adhesion zone in the center of the specimen. When the specimens were 5 weeks old, stiff adapters with screw connectings were glued to the ends of the specimens, and the bond strength was determined in a tensile testing machine.

2.2 Manufacturing of the contrete slabs

To obtain a well-defined surface, it was decided to perform the shotcreting on concrete slabs with sawn surfaces. Two different concrete qualities were used for the slabs: the first with a water cement ratio (w/c) of 0.43 and an air content of 5.5 % and the second with a w/c of 0.57 without any entrained air. One week after casting, the slabs were sawn into two pieces, each with a thickness of about 100 mm and with a sawn surface of 400 x 400 mm. The sawn slabs were stored in water for one further week and then in a climate room, 20±2 °C, RF 50± 5 %, until preparation before shotcreting.

2.3 Preparation of the surfaces

Before shotcreting was carried out, the sawn slabs were adapted to the metal molds. These were then fixed to a rig in the shotcrete testing ground, see fig 2. The surface was subjected to one of the following preparation procedures:

a) in air until the time of shotcreting
b) in water for 48 h before shotcreting
c) in water for 24 h before shotcreting
d) the surface was sprayed with water for 0.5 h before shotcreting
e) the surface was prepared with a bond improving agent before shotcreting
f) the surface was splatterdashed 0.5 h before shotcreting

2.4 Dry mix concrete

The dry mix concrete was delivered by the contractor. It consisted of one part of Portland cement and four parts of aggregates, with a maximum particle size of 8 mm.

2.5 Wet mix concrete

The wet mix concrete was delivered by the contractor in big bags, and consisted of cement, aggregates, silica and a super plasticizing agent. Air-entraining agent was added to the water during mixing, and an accelerating admixture was added to the nozzle when the concrete was sprayed.

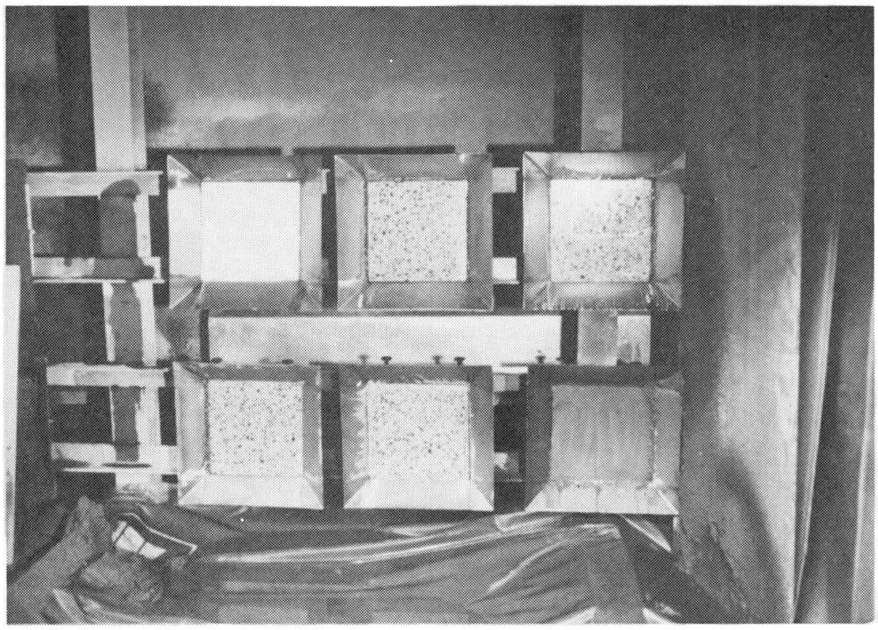

Fig. 2 Six prepared sawn surfaces before shotcreting.

2.6 Test results

The bond strengths for dry mix and wet mix shotcrete are shown in the table below. A complete presentation of all test results can be found in (2). Dry mix A and B are identical, but were used on different occasions. There is no significant difference between the bond due to the two different concrete qualities of the slabs. Bond strength for the wet mix shotcrete was lost during handling of the specimens for all preparations but preparation in air. These low bond strength values are assumed to be equal to zero in table 1. The highest bond strengths were obtained when shotcreting was carried out on dry surfaces. This means that when shotcreting is performed on real structures no water should be sprayed on the surfaces before the spraying of shotcrete.

		Preparation of the surfaces of the slabs before shotcreting					
Shotcrete mix		Air	Water for 48 h	Water for 24 h	Water for 0.5 h	Bond agent	Splatter-dashed
Dry mix A	Mv	1.80	0.17	0.59	0.60	0.75	0.78
	(s)	(0.34)	(0.20)	(0.15)	(0.23)	(0.18)	(0.18)
Dry mix B	Mv	1.37	0.43	0.50	0.53	0.54	0.75
	(s)	(0.67)	(0.33)	(0.14)	(0.16)	(0.13)	(0.24)
Wet mix	Mv	1.74	0	0	0	0	0
	(s)	(0.11)					

Table 1 Bond strength (MPa) for dry mix and wet mix shotcrete. Each value is the mean value of four test results and the values within brackets are standard deviation.

3. Salt-frost resistance

A high salt-frost resistance is of utmost importance for materials used in the repair of bridges and other structures in aggressive environments. Factors affecting the salt-frost resistance are analysed in this project. To begin, a comparison was made of the dry mix and the wet mix shotcrete qualities used for testing the bond strength.

3.1 Test method

Salt-frost resistance was tested according to Swedish standard SS 13 72 44 (1,3). All tests were carried out on the top surface of specimens with a depth of 50 mm and a diameter of 100 mm. All specimens used in this investigation were sawn from drilled cores. The specimens were stored for 7 days after sawing in a climate room with a temperature of 20 ± 2 °C and RH 50 ± 5 %. During this period, rubber cloth was glued to all surfaces of the specimen, with exception of the test surface. When the specimens had been in the climate room for 7 days, tap water was poured on the test surface. The test was started 3 days afterwards. Before the specimens were placed in the freeze chamber, the water on the test surface was replaced by a 3 % NaCl solution and all surfaces except the freeze surface were covered with a thermal insulation layer. Plastic film to protect from evaporation was applied over the salt solution. The specimens were then subjected to repeated freezing and thawing for 56 cycles. Each temperature cycle lasted for 24 hours, and the temperature in the salt solution varied between 20 °C and -18 °C. After 7, 14, 28, 42 and 56 cycles, scaled material from the test surface was collected and dried. The test results examined were the losses of mass per square meter.

3.2 Test results

Mean values of the scaling in the salt-frost resistance test are shown in table 2. A complete presentation of all test results can be found in (2). The highest scaling after 56 cycles for the dry mix shotcrete was 6.9 kg/m²; the lowest was 0.30 kg/m². It is normally assumed for concrete that the spalling for a fair salt-frost resistance should not exceed 1 kg/m². In the present project, this criteria was fulfilled for the wet mix shotcrete, while the results for the dry mix shotcrete were greater than twice this value. It can also be seen that there is a large standard deviation for the dry mix shotcrete. This is probably because it is difficult to maintain a constant w/c-ratio in a dry mix process, as the water content is manually controlled at the nozzle during shotcreting.

Shotcrete mix		Scaling after n cycles (kg/m²) 7	14	28	42	56
Dry mix	Mv	0.28	0.78	1.42	1.80	2.22
	(s)	(0.19)	(0.52)	(1.10)	(1.7)	(2.14)
Wet mix	Mv	0.17	0.32	0.52	0.62	0.71
	(s)	(0.11)	(0.20)	(0.29)	(0.36)	(0.40)

Table 2 Salt-frost resistance for dry mix and wet mix shotcrete. (Mv = mean value, s = standard deviation).

4. Conclusions

The following primary conclusions can be drawn according to the test results of this project:

- The highest bond strength seems to be obtained for both wet mix and dry mix shotcrete when the shotcreting is performed on dry surfaces.
- The bond strength was very poor for the wet mix shotcrete when shotcreting was performed on wet surfaces.
- The quality, i.e. the strength and air content, of the concrete underlayer seems to have very little influence on bond strength.
- Of the two shotcrete qualities tested in this project, wet mix shotcrete demonstrates a better salt-frost resistance than dry mix shotcrete.
- The scattering of the salt-frost resistance is wide for dry mix shotcrete. This is probably because it is difficult to keep the w/c-ratio constant during the dry mix process.
- The methods used in this project for testing bond strength and salt-frost resistance seem to be suitable for evaluating the quality of shotcrete.

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