ACI MATERIALS JOURNAL TECHNICAL PAPER

Title no. 91-M56

Influence of Surface Preparation on Long-Term Bonding of Shotcrete


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Bonding tests were performed to evaluate the capacity of different shotcrete mixes to provide a good and durable joint with concrete surfaces prepared for repair in various ways. A total of 21 slabs (1.2 x 1.2 m) made of ordinary or conventional concrete were covered with a 75- to 100-mm layer of shotcrete. The concrete surfaces to be covered with shotcrete were prepared in different ways: sandblasting, chipping with jackhammers, grinding, or hydrodemolition. Both dry-mix and wet-mix shotcretes were used. Pullout tests, performed after 2 and 6 months, were used to evaluate the strength and durability of the bonding. The results indicate that the type of surface preparation has a strong influence on the strength and durability of the bonding, and that hydrodemolition is probably the best type of surface preparation. The shotcrete mix composition, however, was found to have relatively little influence on bonding durability.

Keywords: bonding; concretes; dry process; **shotcrete**; wet process.

INTRODUCTION

The bonding durability of thin concrete repairs is a very important issue, but little is known regarding the parameters that can influence durability of this bonding, particularly in the case of shotcrete repairs. The repair of concrete structures by applying a thin layer of dry- or wet-mix shotcrete, because of the possible savings involved and quality of the bonding that can be obtained, is now often considered a good alternative to traditional repair methods.[1] Shotcrete was used for the first time in the United States in 1910, and its applications have expanded over the years, with constant improvement of the technique. Shotcrete has, however, had relatively little use in Québec until recently. This study is part of a larger one aimed at improving the quality of shotcrete remedial work in Québec.

There are two different procedures used to apply shotcrete: dry- and wet-mix. In the dry-mix process, water and liquid admixtures are added at the end of the nozzle to the rest of the materials. Air pressure is used to convey the dry mix through the hose to the nozzle, where water is added. The nozzleman determines the amount of water added to the mix at the nozzle. Good shotcrete that will bond strongly to the surface to be repaired is thus highly dependent on nozzleman experience. In the wet-mix process, all materials (including water) are mixed together, as in normal concrete, and the mix is then pumped to the end of the nozzle, where compressed air is used to pneumatically accelerate the shotcrete onto the receiving surface. In this process, the experience of the nozzleman is less important, since he has no control over the mix composition.

This article presents the results of bonding tests performed to evaluate the capacity of different shotcrete mixes to form a good and durable joint with a concrete surface prepared for repair, as well as to evaluate the influence of the type of surface preparation on shotcrete bond. Slabs made of ordinary or conventional concrete were cast, cured, and dried. The surface of these slabs was prepared in different ways, and then covered with a thin layer of shotcrete. Both dry- and wet-mix shotcretes were used. Pullout tests, performed after 2 and 6 months, were used to evaluate the strength and durability of the bonding.

RESEARCH SIGNIFICANCE

Very little information is available concerning the parameters that influence the long-term bonding of shotcrete, particularly the type of preparation of the surface to be repaired. The information on this subject presented in this paper should be useful to all engineers involved in shotcrete repairs of concrete structures.

LITERATURE REVIEW ON BONDING STRENGTH AND DURABILITY

One of the problems encountered in evaluating the results of tests of bonding between two materials is the fact that a variety of different test procedures have been used. This has resulted in different recommendations for minimum bond strengths. ACI Committee 503,[2] for instance, recommends a pullout strength of at least 0.7 MPa (100 psi) for epoxy-based mortars, and describes in an appendix a procedure that can be

ACI Materials Journal, V. 91, No. 6, November-December 1994.
Received Nov. 24, 1992, and reviewed under Institute publication policies. Pertinent discussion will be published in the September-October 1995 *ACI Materials Journal* if received by June 1, 1995.

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used for a direct tensile test of bond strength. This procedure, however, is not directly applicable to shotcrete repairs. In the Canadian National Standard (1990),[3] a direct tensile strength of at least 1.00 MPa is recommended when testing is conducted in accordance with the CAN/CSA A23.2-6B test method.[3] A modified version of this CSA test was used in this study.

Although it is generally agreed that the method used to remove the damaged concrete, as well as the texture, soundness, cleanliness of the surface to be repaired, and the characteristics of the repair materials, can all influence the bonding strength, the conclusions obtained by various investigators are unfortunately often influenced by the specific type of testing procedure used.

In 1956, Felt[4] carried out an important laboratory and field research project on the influence of many different parameters on the strength of concrete to concrete bonding. He studied removal methods, bonding agents, and curing methods. He observed:

> It became apparent that factors influencing bond of new and old concrete were not easily isolated and controlled. The most important factor was the condition of the old surface—its cleanness, roughness and strength or soundness. If the surface was clean, slightly rough and free of weak outer skin, good bond was generally obtained, otherwise relatively poor bond was obtained.

The first step when a repair must be carried out is removal of the damaged concrete. It is very important to select the method most appropriate for the specific field conditions. The usual methods are sandblasting, chipping with jackhammers, and hydrodemolition. It is generally recommended that any method that will weaken sound concrete and create microcracking be avoided. It is also generally recommended that the mass of jackhammers be limited for the same reason. The second step is to insure that the surface is free from dust or broken pieces of old concrete.

Felt[4] concluded that surface texture did not exert a constant influence on bonding. He obtained poor results on sandblasted surfaces, which he attributed to the polishing effect of sandblasting. Saucier and Pigeon,[5,6] however, obtained good results on sawed surfaces.

Hindo[7] performed bonding tests on large surfaces covered with repair concrete. He compared the results obtained with hydrodemolished surfaces (using high-pressure water jets) and jackhammered surfaces, and concluded that a much better bond was obtained with the hydrodemolished surfaces. He observed almost no microcracks on the hydrodemolished surfaces, but found that the jackhammered surfaces were severely damaged. Unfortunately, the same bonding agent was not used in both cases in his studies.

Use of bonding agents with shotcrete has been evaluated in some studies.[8] It was concluded that: "In general, the epoxy-coated panels did not increase the bond strength of shotcrete to old shotcrete or concrete." Felt,[4] Saucier and Pigeon,[5] and Wall, Shrive, and Gamble[9] all reached the same conclusion concerning the bonding of ordinary concrete: the use of a bonding agent reduces the variability of results obtained on an ordinary concrete. According to Judge, Cheriton, and Lambe,[10] this could be due to a reduction of the effects of differential shrinkage and thermal movements.

Prewetting the surface before applying the new concrete layer is also common practice. This practice, however, is subject to controversy. Sasse and Fiebrich[11] reported that the presence of a film of water inhibits formation of a perfect contact between old and new concrete. In dry and hot weather, prewetting is usually considered necessary, because it reduces the surface temperature and potential for curling of the bonded layer. Dhir[12] showed that an important thermal gradient is created when fresh concrete is applied on a slab heated by the sun, and that this gradient reduces the quality of the bond. Saucier and Pigeon,[5] however, found no great differences in the bonding strength obtained between laboratory dry surfaces and prewetted surfaces in tests on concrete.

There is little data in the literature on the influence of concrete materials used for repairs on bond quality. As pointed out by Schrader and Kaden,[13] the accumulation of water at the interface between the old concrete and a particularly impermeable concrete may cause a loss of bond in cold weather. The permeability of the repair concrete should thus ideally be similar to that of the base concrete. With poor quality base concretes, however, this may not be realistic. It should, however, be noted that use of an impermeable material to cover a structure in contact with a humid environment facilitates saturation of the old concrete, which in turn increases its vulnerability to damage from freezing and thawing.

The bond between shotcrete and an old concrete surface is generally very good,[13] probably due to the shotcrete compaction process and the normally low water-cement ratio of this material, particularly for dry-mix shotcretes. Results obtained with dry-mix shotcrete indicate that the force required to break the bond is approximately twice as high as with wet-mix shotcrete (ACI 506R-85). The phenomenon of rebound (the larger particles tend to rebound from the surface) also probably plays a significant role. Parker[14] mentioned that, at the beginning of shotcrete impacting on the receiving surface, only the cement paste bonds to the surface and the other components rebound until a sufficient thickness of paste is obtained. A well-compacted layer of portland cement with a low water-cement ratio is thus formed at the bond interface and acts as a bonding agent.

Very few investigators have analyzed the durability of the bond between a new concrete layer and an old concrete surface. Saucier[6] studied the mechanisms by which this bond can be slowly damaged. He found that the microstructure of the interface was highly influenced by the characteristics of the cement in the new concrete. He also observed that microcracking of the cover layer due to shrinkage was generally the main cause of the reduction of the bonding strength, and that the influence of other effects such as freezing and thawing cycles was less pronounced.

RESEARCH PROGRAM, MIX CHARACTERISTICS, AND OPERATING PROCEDURES

This paper presents part of the results of a research program on the durability of shotcrete repairs. The results of tests performed to analyze the durability of the material itself are reported elsewhere.[15,16] This paper presents the results of tests performed to study the durability of the bonding between shotcrete and an old concrete surface.

A total of 21 slabs (1.2 x 1.2 x 0.1 m) were prepared with ordinary or conventional concrete (Type I cement, 0.45 water-cement ratio, 6 percent air content, and nominal 35 MPa compressive strength). These slabs were wet-cured for 7 days and then placed outside the laboratory for approximately 1 year before their surfaces were prepared for shotcreting. Several methods of surface preparation were used: sandblasting (two slabs), jackhammering (two slabs), jackhammering followed by sandblasting (two slabs), grinding (two slabs), and hydrodemolition (thirteen slabs). Four of the hydrodemolished surfaces were kept wet for 24 hr before shotcreting. All other surfaces were only prewetted immediately before shotcreting.

The choice of the shotcrete mixes was based on results from a previous series of tests, and also on recommendations from the Québec Department of Transportation. Tables 1 and 2 show the composition of the mixes used with dry- and wet-mix shotcretes, respectively. All mixes are identified by a code (described in Fig. 1).

Except for the mix containing latex, all mixes applied by the dry-mix shotcrete process (the process normally used by the Québec Department of Transportation) were air-entrained to obtain a better salt-scaling resistance (Table 1). The air-entraining agent was simply added to the water used for shooting, as explained in a previous publication.[15] Four types of binder were utilized: Type I cement, Type I cement with 10 percent silica fume by mass of cement, Type III cement, and Type lII cement with 10 percent silica fume by mass of cement. Two of the dry-mix shotcretes contained steel fibers (35-mm long deformed fibers). The wet-mix shotcretes (Table 2) were all made with the same Type I cement. One mix contained silica fume, and another contained 35-mm long deformed steel fibers.

The composition and properties of the cements and silica fume used are summarized in Table 3. The coarse aggregate for the dry-mix shotcretes was a l0-mm nominal-size crushed hard dolomite, and that for the wet-mix shotcretes was a 10-mm nominal-size crushed granitic gneiss.

Table 4 gives the amount of air in the fresh dry-mix shotcretes (the mixes were simply shot directly in the airmeter base). Table 5 gives the slump and amount of air for the wet-mix shotcretes (before shooting). All shotcretes were cured with wet burlap for 7 days.

Table 6 shows the results of the compressive strength tests for all shotcrete mixes (except the latex-modified mix). The results represent the average for six specimens (75 mm in diameter by 150 mm in length) taken from additional test panels prepared with the various mixes. These panels were water-cured for 7 days and then left to dry outside. The core specimens were tested at 28 days.

Compressive strengths obtained with the dry-mix process are generally superior to those obtained with the wet-mix process (unless special measures, such as the utilization of superplasticizers and silica fume, are used). This is probably due to a lower water-binder ratio in dry-mix shotcretes. As with ordinary concrete, the compressive strength is typically higher in the mixes made with Type lII cement. The influence of the other parameters on compressive strength is not very clear, particularly for the dry-mix shotcretes. This is probably due to the variability of the air content, and also to the influence that the composition of the mix can have on the amount of water needed to obtain an adequate consistency.

The characteristics of the air-void system of the various mixes, as well as the results of the salt-scaling tests performed, are given in a previous publication.[16]

Table 7 indicates which shotcrete mixes were used with each type of surface preparation. Two mixes were used systematically with each surface preparation: one typical dry-mix shotcrete (D1A40), and one normally expected to give the best bonding, the dry-mix shotcrete containing silica fume and fibers (D1SA40-sf). Only one type of surface preparation (that expected to give the best results, hydrodemolition) was used systematically with all mixes to study the influence of the different mix characteristics.

Pullout tests were performed at 2 months and 6 months after the slabs were covered with shotcrete. Shotcreting was carried out in the months of May (dry-mix shotcrete), and September (wet-mix shotcrete). All test panels were simply left outdoors until testing. The aging process therefore consisted mostly of simple air-drying (plus a few wetting and drying cycles and a few freezing and thawing cycles).

The pullout test that was used (Fig. 2 and 3) is a modified version of the CAN/CSA A23.2-6B test. A core of 95-mm diameter was drilled into the test area. The depth of the test cut extended beyond the bonded interface into the original concrete material to adequately evaluate the interfacial bond strength. A circular steel plate was glued with a fast-setting epoxy to the top of the unbroken core. Then the apparatus with an adjustable loading frame was placed on the test panel and a tensile force was applied until failure occurred. On each shotcrete surface (21 in all), a minimum of six pullout tests (maximum of ten) was performed at 2 months, and the same tests were performed at 6 months.

TEST RESULTS

The results of the pullout tests performed to determine the bonding strength are presented in Table 8. For each condition (mix composition and surface preparation), this table

Table 1—Dry-mix proportions

Mix no.	Binder, percent	Silica fume, percent binder	Sand, percent	Aggregates, percent	Description
D1A40	27.5		47.6	24.9	Type 10, AEA* = 40 ml/l (A40)
D1SA30	27.5	9.7	51.4	21.1	Type 10, silica fume, AEA = 30 ml/l (A30)
D1A30-sf	25.2		48.0	26.8	Type 10, steel fibers = 48 kg/m^3, AEA = 30 ml/l
D1SA40-sf	28.5	9.5	46.0	25.5	Type 10, silica, steel fibers = 48 kg/m^3, AEA = 40 ml/l
D3A30	25.6		49.7	24.7	Type 30, AEA = 30 ml/l
D3SA30	25.0	9.5	44.0	31.0	Type 30, silica fume, AEA = 30 ml/l
D1latex	27.5		47.6	24.9	Type 10, solid latex = 12 percent of binder

* AEA = air -entraining agent.

Table 2—Wet-mix proportions

Mix no.	Cement,* kg/m^3	Silica fume, kg/m^3	Water, kg/m^3	Sand, kg/m^3	Aggregates, kg/m^3	W.R.,† ml/kg	A.E.A., ml/kg	Description
W1	430	0	200	1122	472	1.4	0.35	
W1S	387	45	195	1105	435	0.4	0.35	10 percent silica fume
W1-sf	428	0	199	1109	426	1.4	0.35	Steel fibers = 30 kg/m^3

* Cement Type 10.
† W.R. = water reducer.

Table 3—Properties of cements

	Type I (wet-mix), percent	Type I (dry-mix), percent	Type III (dry-mix), percent	Silica fume, percent
SiO_2	21.0	20.5	21.36	95.2
Al_2O_3	4.2	4.5	4.63	0.02
Fe_2O_3	3.1	2.9	1.92	0.94
CaO	62.2	62.3	62.42	0.17
MgO	2.2	2.1	3.13	0.23
SO_3	3.3	3.0	3.77	0.19
Na_2O, equivalent	0.84	0.82	0.82	0.14
Fineness, m^2/kg	363	356	465	N/A

shows the average failure stress measured at 2 and 6 months, respectively, and the standard deviation.

For the surfaces prepared with hydrodemolition, Table 8 shows the average values for the pullout tests performed on the prewetted surfaces and on the surfaces wetted only immediately prior to shotcreting. Unfortunately, the system used to maintain the surfaces wet for 24 hr did not work as intended. Therefore, no significant conclusions regarding the influence of prewetting can be drawn from these studies, and the average results for both conditions are therefore also presented in the table.

As Table 8 indicates, with the exception of surface preparation G (grinding) and JH (chipping with jackhammers), there seems to be little significant difference between the test results for the various conditions, or between the test results at 2 and 6 months. The results were therefore analyzed using a statistical test based on Student-Fisher's law. This test uses a formula that takes into account, for two series of results, the average value, standard deviation, and number of results used to calculate the average. A number is calculated from these three values, which is then compared to standard statistical values (for a selected confidence level, usually 95 per-

Table 4—Tests on fresh shotcrete, dry-mix

Mix no.	Air content, percent
D1A40	9.5
D1SA30	6.0
D1A30-sf	—
D1SA40-sf	11.0
D3A30	4.2
D3SA30	5.4
D1latex	5.5

Table 5—Tests on fresh shotcrete, wet-mix

Mix no.	Air content before shotcreting, percent	Slump before shotcreting, mm
W1	9.0	130
W1S	9.5	80
W1-sf	11.5	210

Table 6—Tests on hardened shotcrete

Mix no.	Compressive strength, MPa
D1A40	31.3
D1SA30	31.9
D1A30-sf	38.7
D1SA40-sf	51.5
D3A30	53.9
D3SA30	45.0
D1latex	—
W1	32.3
W1S	36.4
W1-sf	31.1

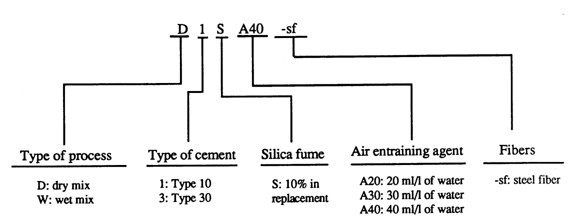

Fig. 1—Identification code

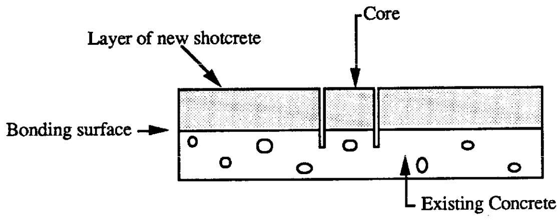

Fig. 2—Bond test preparation

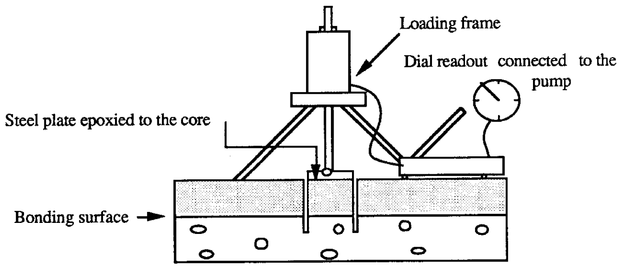

Fig. 3—Bond test apparatus

Table 7—Surface preparation

	Surface preparation					
Mix	HD24	HD	SB	G	JH	JHSB
D1A40	X	X	X	X	X	X
D1SA30	X	X				
D1A30-sf	X	X				
D1SA40-sf	X	X	X	X	X	X
D3A30		X				
D3SA30		X				
D1latex		X				
W1		X				
W1S		X				
W1-sf		X				

Legend:
HD24 = hydrodemolished, predampened 24 hr before shotcreting.
HD = hydrodemolished, predampened before shotcreting.
SB = sandblasted, predampened before shotcreting.
JHSB = jackhammered and sandblasted, predampened before shotcreting.
JH = jackhammered, predampened before shotcreting.
G = ground, predampened before shotcreting.

cent). If the calculated number is not within specified limits, then there is a significant difference between the two series of results.

Influence of mix composition

Apart from the improvement from the combined use of fibers and silica fume, the Student-Fisher law reveals no significant difference between the bonding strength obtained for a given surface preparation. Use of Type 30 cement, and addition of latex, fibers, and silica fume, appeared to have no direct influence on the bonding strength. The statistical test also revealed that the mix composition had no direct influence on the durability (loss of bonding strength with time) of the bonding. However, the fracture mode (i.e., failure at the interface, or in the old or new concrete) does seem to be influenced by the mix composition. This is discussed in a subsequent section.

Influence of surface preparation

The results in Table 8, when analyzed using the statistical test described, show that the type of surface preparation had a significant influence on both bonding strength and bonding durability. For surfaces prepared with hydrodemolition or jackhammering followed by sandblasting, there was no significant loss of bonding strength between 2 and 6 months. For all other types of surface preparation, there was a loss of bonding strength with time. The highest bonding strength was obtained with the sandblasted surfaces, but, as mentioned, there was a loss of bonding strength with time in this case. With the exception of results for sandblasted surfaces, the best bonding strengths were obtained with surfaces prepared by hydrodemolition or jackhammering followed by sandblasting. The influence of surface preparation on the fracture mode is discussed in the next section.

Fracture mode

When a pullout test is performed to measure the bonding strength between new and old concrete, there are three basic possible types of fracture: at the bond interface, in the new concrete, or in the old concrete. When the fracture occurs only partially at the bond interface, it is possible to measure approximately the area of the interface exposed by the fracture. Table 9 summarizes, for Mixes D1A40 and D1SA40-sf, observations made concerning the modes of fracture. In this table, a given percentage of adhesion indicates the percentage area of the interface not exposed by the fracture.

The results in Table 9 confirm, as might be expected, that grinding is not a very good type of surface preparation, since fracture always occurs at the interface. These results also confirm that, for the sandblasted surfaces, some aging of the bonding (i.e., change in the failure mode) occurred, since, with Mix D1SA40-sf, fracture always occurred in the old concrete after 2 months and at the interface after 6 months. For the jackhammered surfaces, the fracture mode is variable with Mix D1A40, but almost always at the interface with Mix D1SA40-sf. For the jackhammered-sandblasted surfaces, there are fewer fractures at the interface at 6 months, which of course indicates no aging of the bonding. For the hydrodemolished surfaces, the results also indicate no aging of the bonding. Aging is attributed primarily to drying shrinkage and thermally induced microcracking, which occurs at the bond interface.

DISCUSSION

In this series of tests, considering both the measured values of bonding strength and modes of fracture, hydrodemolition or chipping with jackhammers followed by sandblasting are clearly the two types of surface preparation yielding the best results, i.e., good bonding strength as well as good bonding durability (no loss of bonding strength with time). Hydrodemolition seems to have the advantage of removing the damaged concrete and leaving the surface clean without weakening the surface layer of the old concrete. It is also fast, efficient, and requires less labor. Chipping with jackhammers can potentially weaken the surface, but, in this case, this phenomenon was not very significant, since low-mass hammers (15 kg) were carefully used, and sandblasting further helped clean the surfaces by removing some of the residual fractured concrete particles. According to Hindo,[7] “the number of microcracks and the thickness of the bruised layer depend on the rated capacity of the hammer, concrete quality, and the amount of effort exerted.” On large sites, of

Table 8—Bonding test results, MPa

Mix no.	Surface preparation													
	HD24		HD		HD average		SB		G		JH		JH+SB	
D1A40	1.78	1.69	1.35	1.42	1.57	1.56	2.33	1.72	0.36	0.00	1.01	1.49	1.70	1.66
	0.46	0.26	0.20	0.25	0.33	0.26	0.10	0.54	0.08	0.00	0.53	0.25	0.41	0.33
D1SA30	1.31	1.49	1.67	1.84	1.49	1.67								
	0.30	0.30	0.49	0.30	0.40	0.30								
D1A30-sf			1.71	1.65										
			0.38	0.18										
D1SA40-sf	2.02	1.80	2.13	1.91	2.08	1.86	2.61	2.00	1.44	0.22	1.26	0.87	2.01	1.81
	0.28	0.36	0.23	0.24	0.26	0.30	0.97	0.55	0.37	0.19	0.23	0.18	0.31	0.33
D3A30			1.68	1.68										
			0.24	0.29										
D3SA30			1.89	1.97										
			0.21	0.47										
D1latex			1.50	1.58										
			0.71	0.20										
W1			1.81	1.54										
			0.21	0.29										
W1-sf			1.86	0.99										
			0.67	0.10										
W1S			1.64	1.67										
			0.30	0.22										

Legend:

A	C
B	D

A = average strength at 2 months; B = standard deviation at 2 months; C = average strength at 6 months; D = standard deviation at 6 months.

HD24 = hydrodemolished, predampened 24 hr before shotcreting.
HD = hydrodemolished, predampened before shotcreting.
SB = sandblasted, predampened before shotcreting.
G = ground, predampened before shotcreting.
JH = jackhammered, predampened before shotcreting.
JH+SB = jackhammered and sandblasted, predampened before shotcreting

Table 9—Comparison between fracture modes

Surface preparation	Age	Fracture in new shotcrete		Fracture in base concrete		Fracture at interface with 0 percent adhesion to base concrete		Partial fracture in interface		Notes when fracture occurs at bond interface
		D1A40	D1SA40-sf	D1A40	D1SA40-sf	D1A40	D1SA40-sf	D1A40	D1SA40-sf	
Ground	2 months					6/6*	8/8			
Ground	6 months					6/6	8/8			
Sandblasted	2 months	4/6		2/6	5/5					
Sandblasted	6 months	6/6					6/6			
Jackhammered	2 months	2/7				4/7		1/7	5/10	5-10 percent adhesion
Jackhammered									5/10	50 percent and more
Jackhammered	6 months	4/7				3/7	8/8			
Jackhammered + Sandblasted	2 months	1/8			2/9			7/8	7/9	5-70 percent adhesion
Jackhammered + Sandblasted	6 months	5/6	7/8					1/6	1/8	5-40 percent adhesion
Hydrodemolition	2 months	1/16	3/16			5/16		10/16	13/16	15-95 percent adhesion
Hydrodemolition	6 months	4/15	3/15		2/15			11/15	10/15	20-95 percent adhesion

* x/y = cores broken at a certain place / total number of cores tested.

course, small jackhammers are relatively inefficient, and heavier jackhammers with the potential to cause more surface damage may be used.

In terms of bonding strength, sandblasting seems to represent the best surface preparation because it does not weaken the old concrete surface. Loss of bonding strength with time was, however, observed. Furthermore, the use of sandblasting is of limited value because, unlike hydrodemolition or chipping with jackhammers, it simply cleans the surface and cannot remove a significant layer of damaged concrete. The old concrete surfaces used in these tests were not damaged, so sandblasting only cleaned an already sound surface without weakening it.

The use of jackhammers alone yielded relatively low bonding strengths, probably because the surface was not well cleaned by sandblasting before shotcreting. The improvement of bonding strength with time for Mix D1A40 is not readily explained. It could in part be due to the variability inherent in surface preparation. If a confidence limit of 99 percent instead of 95 percent were used, this improvement would not be considered statistically significant.

Unlike Saucier,[5,6] who obtained very good bonding strengths on sawed and even lapped surfaces, the surfaces that were ground yielded very poor results, particularly at 6 months, indicating a severe deterioration of bonding with time. In Saucier's work, the repair concrete layer was simply cast against the old surface, whereas shotcreting was used for this series of tests. It is clear from Tables 8 and 9 that the best results were obtained with well-cleaned and relatively rough surfaces (prepared by hydrodemolition or by chipping with jackhammers followed by sandblasting). Aging was observed with the relatively smooth sandblasted surfaces and in one mix where the jackhammered surface was probably not adequately cleaned. It can therefore be concluded that aging had less influence on the bonding of shotcrete to rougher surfaces, perhaps because, in such cases, the plane where microcracks can concentrate and easily propagate is not as well defined. Other phenomena related to the shooting process might also play a role. This warrants further investigation.

Little influence of mix composition on bond strength and durability was observed in this series of tests, particularly with the hydrodemolished surfaces. This type of surface seems to always yield a good and durable bond with any good, well-applied shotcrete mix. Generally, the combined use of silica fume and steel fibers enhanced the bonding strength, but, for the sandblasted or simply jackhammered surfaces, fracture more often occurred at the bond interface at 6 months with this type of mix. The influence of fibers on the mode of fracture in relation to the type of surface preparation and aging warrants further investigation.

CONCLUSIONS AND RECOMMENDATIONS

The test results described in this paper indicate that the bonding between good quality shotcrete mixes (with and without steel fibers) and concrete surfaces prepared by hydrodemolition or chipping with light jackhammers followed by sandblasting is generally strong and durable. The other types of surface preparation (grinding, chipping with jackhammers without sandblasting, and sandblasting alone) resulted in either lower bonding strengths or a reduction in bonding strength with time. No significant difference was observed between the bonding strength of dry- or wet-process shotcrete to a hydrodemolished surface. Further research is recommended to analyze the bonding failure mechanisms in relation to the type of surface preparation to more comprehensively explain the influence of the type of surface preparation on the durability of bonding. Such research should also include longer aging times.

ACKNOWLEDGMENTS

The authors would like to express their thanks to Mr. Donald Donavan and Mr. Denis Otis of St-Romuald Construction Inc., Mr. Roger Blanchette and Mr. Daniel Vézina of the Central Laboratory of the Department of Transportation of Québec, Mr. Jean-François Poulin of Matériaux King, Mr. Michel Cliche of Béton Canfarge Inc., Mr. Jacques Bertrand of Béton Mobile du Québec Inc., Mr. Mario Agozzino of Les Cheminées Zedco Inc., Mr. Philippe Garreault of Groupe Structural L&B, and the Department of Transportation of Québec. The financial support of the government of Québec (Fonds FCAR) is also greatly appreciated.

CONVERSION FACTORS

1 MPa	=	145 psi
1 mm	=	0.0394 in.
1 m	=	3.2808 ft
1kg	=	2.204 lb
1 kg/m^3	=	1.6856 lb/yd^3

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