

Effect of Different Curing Regime and Cementitious Materials on the Bond Strength of Self Compacting Mortars

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Abstract: In order to obtain the desired performance of repair mortars in repairing concrete structures, one of the most important factors is proper bonding between the base concrete and the repair mortars, which in turn results in a monolithic behavior of the repaired element and therefore no failure at the interface is observed. To achieve such behavior the mechanical characteristics of the repair materials, the base concrete and their compatibility as well as the surface condition are of great importance. The repair layer compactness has significant effect on bonding strength since the more the repair layer penetrates into the voids the more mechanical interlock between two layer is obtained. Consequently considering the thickness and volume of concrete casting, one faces difficulty in compacting concrete which results in less bonding between the base concrete and the repair mortars. Therefore selecting self-compacting repair mortars (SCRM) could be a suitable alternative. In this study, bond strength of three different SCRM and one normal mortar mixtures are examined by using friction transfer method, involving different surface conditions and varying curing. In order to measure the adhesion between different layers of repair mortars, their torsional shear strengths are calculated along the failed interface of the layers. Due to the shear nature of these measurements and the fact that in practice the shear stresses induced by expansion and contraction are the main cause of failure of the bonding between the repair material and the base concrete, these results can help to select optimized SCRM mixtures for repairing concrete structures.

Key words: Self-compacting repair mortars, Bond strength, Friction transfer method

INTRODUCTION

In order to obtain the desired performance of repair mortars in repairing concrete structures, one of the most important factors is proper bonding between the base concrete and the repair mortars, which in turn results in a monolithic behavior of the repaired element and therefore no failure at the interface is observed. (American Concrete Institute, 1975) To achieve such behavior the mechanical characteristics of the repair materials, the base concrete and their compatibility as well as the surface condition are of great importance. The repair layer compactness has significant effect on bonding strength since the more the repair layer penetrates into the voids the more mechanical interlock between two layer is obtained. Consequently; considering the thickness and volume of mortar casting, one faces difficulty in compacting mortar which results in less bonding between the base concrete and the repair mortars. Therefore selecting self-compacting repair mortars (SCRM) could be a suitable alternative. Self-compacting repair mortars (SCRM), as new technology products, are especially preferred for the rehabilitation and repair of reinforced concrete structures (Courard *et al.*, 2002) The repair mortar applied to concrete is usually hard to consolidate, and in most cases vibration is not possible. From this point of view, the self-compactability of repair mortars may bring considerable advantages at narrow mould systems Khayat KH, Morin R. (2002). The objective of this study is to evaluate the effects of different admixtures, surface conditions and varying curing in the performance of SCRM mortars bond strength. In this respect three SCRM included different mineral additives and one normal mortar mixtures and five surface conditions and also three different types of mortars curing conditions are examined by using friction transfer method and Pull-off test. As the characteristics of mortars have deep influences on the bond strength between repair layer of mortars and base concrete Allen *et al.*, (1993) hence, three tests included tensile strength test, flexural strength test, and compressive strength test, have been performed at three ages of 7, 14 and 28 days.

The advantages and disadvantages of non-destructive methods are widely known Malhotra, (1976). Non-

destructive methods involve the measurement of some property of the concrete, which can be obtained without the need for destructive forces and these methods can normally be performed quickly and inexpensively Naderi, (2005). In order to measure the adhesion between different layers of repair mortars, their torsional shear strengths are calculated along the failed inter-facial surfaces of the layers and different calibration graphs are used to relate the failure stress or torque, to the material compressive strength. Due to the shear nature of these measurements and the fact that in practice the shear stresses induced by expansion and contraction are the main cause of failure of the bonding between the repair material and the base concrete, these results can help to select optimized SCRM mixtures for repairing concrete structures.

Friction transfer method:

The theory behind the Friction-Transfer method is that the twisting of the metallic gripping device causes the concrete within the partial core to fail in torsion Naderi, (2005). Although random diagonal failures usually means that the failure stress are not pure torsional shear stress, it has been found Naderi, (1998) that the most consistent nominal torsional shear strength can be calculated by using the torque required to cause failure in the maximum torsional shear stress–torque relationships. However, as the quality of concrete and mortar is usually assessed in terms of their cube compressive strengths, it is necessary to introduce some form of calibration to estimate this parameter. The Friction-Transfer test, which is used for assessing the bond strength of repair mortars and base concrete in this study, is one such partially destructive method, which has been providing increasing interest as a result of providing tests undertaken in the laboratory and on site Naderi, (1998). The method involves the drilling of a 50 mm diameter partial core with 25 mm depth on the surface of concrete under test and fixing a specially designed gripping device on top of the partial core by fastening its bolts as shown in Fig. 1. An ordinary torque-meter is then situated on the gripping device and a gradually increasing torque is applied by hand. As the frictional resistance of the gripping device is higher than the torsional resistance of the partial core, the latter will eventually fail. Using the shear stress–torque relationship, the failure torsional shear stress is calculated. This can be used to estimate the concrete's equivalent cube compressive strength by means of a previously prepared calibration graph Naderi, (2005).



Fig. 1: Friction transfer method

Experimental Study:

Material:

An ordinary Type-I Portland cement (CEM I 42.5N) was used in all compositions. In order to enhance the paste content, finely grounded limestone filler from ABHEYK Factory and a C-type fly ash (FA) in conformity with ASTM C 618 (ASTM C 618. 2002) from NAMIKARAN Company were employed. The chemical composition and the physical properties of cement, fly ash, Brick powder (BP) and limestone powder (LP) are given in *Table I* Local well-graded natural sand with a maximum size of 10 mm was used. The superplasticizer (SP) was a “polycarboxylic-acid” type; commercially branded as HS100 “Smart flow” produced by NAMIKARAN Science and Technology Production Corporation, Qazvin, Iran. It is an ASTM C 494 (ASTM C 494. 2002) F-type high-range water reducer. The solid content, pH and specific gravity of admixture were 35.7%, 6.5%, and 1.11%, respectively.

Mixture Properties:

In this study, four mixtures with different mineral additives and chemical admixtures were prepared. Table 2 presents the composition and labeling of the SCRMs prepared. After the preliminary investigations, the water–powder ratio (w/p) was selected as 0.40 and the total powder content was fixed to 650 kg/m³. The control mixture consisted of only PC, sand and water without any chemical admixture and mineral additives.

Ternary mixtures were prepared by utilizing simultaneous use of two mineral additives. As seen in Table II, the mixtures are labeled such that the ingredients are identifiable from their IDs. For example, the mixture SCFL contained FA and LP mineral additives.

Table 1: Properties of Portland cement and mineral additives

Basic compounds (%)	Cement	Fly ash	Limestone filler	Brick powder
CaO	61.94	11.34	52.35	4.65
SiO ₂	19.68	42.14	0.45	63.11
Al ₂ O ₃	5.75	19.38	0.33	15.08
Fe ₂ O ₃	3.00	4.64	0.14	6.66
MgO	0.90	1.78	1.05	1.94
Na ₂ O	0.20	–	0.06	0.78
K ₂ O	0.83	1.13	0.02	2.34
SO ₃	2.78	2.43	–	0.36
Loss on ignition	2.84	1.34	42.50	2.33
Specific surface (m ² /kg)	340	290	538	201
Specific gravity	3.14	2.20	2.65	2.64

Table 2: Composition and labeling of SCRM

Index	Water	Cement	Sand	FA	LP	BP	SP	Spread(mm)	V-funnel time(sec)
SCFL	260	450	1260	100	100	-	9.75	24.5	3.65
SCLB	260	450	1271	-	100	100	9.75	21.5	5.65
SCFB	260	450	1260	100	-	100	9.75	23.2	4.1
PC	260	550	1298	-	-	-	-	-	-

Specimen Preparation and test procedure:

The mixing process for all the SCRM was kept constant. It started by mixing all the powder and sand for 3 minute using a standard mixer described by ASTM C109/C 109M- 01. Then three quarters of the mixing water was added and mixed for an extra minute. Later on, the premixed chemical admixture and remaining water were added and the mortar was mixed for an additional three minutes. After the mixing was completed, tests were conducted on fresh mortar to determine mini slump flow diameter and mini V-funnel flow time. (Fig2) Segregation and bleeding were visually checked during the slump flow test and was not observed. 50-mm and 100 mm cubic specimens were prepared from each mortar mixture. No compaction was applied in any of the mixtures, except for the control mixture. The 50-mm cubes were used for compressive strength. In addition the 210.50.50 samples and briquette samples were cast in conformity with ASTM C 618 for assessing flexural strength and tensile strength.

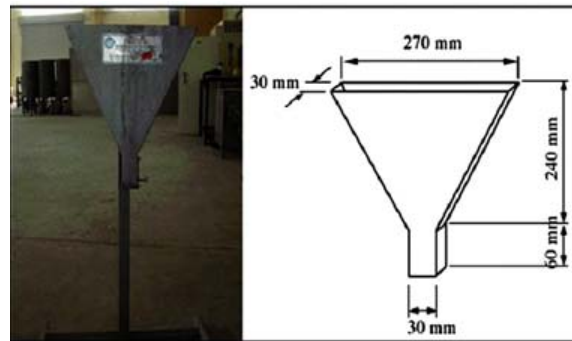


Fig. 2: The v-funnel testing for SCRM

For bond strength assessment, 150 · 150 · 150 mm concrete blocks were cast at the age of 28 days, they were saw cut or split by driving wedges into the predetermined holes, to produce 150 · 150 · 50 mm slabs. In order to study the effect of varying surface condition of sub concrete and also different curing conditions on the bond strength of repair mortars and base concrete ,five different surface conditions and also three curing circumstances were supposed ,these conditions are shown in Table III, IV.

On the saw cut or split/chiseled surfaces of these slabs, a 15 mm thick repair mortar was applied. Those samples that were intended for site investigations were repaired and cured under site conditions until the age of testing and remainder of samples were cured with Wet Jute canvas with nylon and without nylon. At the time of testing, 20 mm deep partial cores were drilled on the repaired surface of each slab, using ordinary diamond tipped drill and both Friction-Transfer and pull-off tests were carried out.

Table 3: Surface conditions

Position	Index	Surface of slabs	slabs
1	SSD	dry	saturate
2	SSW	saturate	saturate
3	SSC	Cement grout	saturate
4	ASW	saturate	dry
5	ASD	dry	dry1

Table 4: Curing conditions

Position	Index	Type of curing
1	A	Open air
2	B	Wet Jute canvas
3	C	Wet Jute canvas with nylon

The depth of the partial cores for assessing the repair strength was 25 mm, while the depth for bond assessment was deep enough to penetrate into the substrate concrete. In order to study the relationships between the results of Friction-Transfer, pull-off for each slab 4 cores were cut. The bond strengths of two cores were assessed by pull-off test and remainder cores were assessed by Friction transfer method. (Fig3)


Fig 3: the specimens for testing by pull-off and friction transfer method

Laboratory Test:

Deformability and viscosity of fresh mortar was evaluated through the measurement of mini slump flow diameter and mini V-funnel flow time. The mini-slump flow test in conformity with EFNARC (2005) standards is conducted to verify the self-compactability of mortars. In this test, the truncated cone mould is placed on a metal plate, filled with mortar and lifted vertically. The spread diameter of the mortar is measured in two perpendicular directions, and the mean is taken (Domone and J. Jin, 1999). The initial diameter of the cone is 100 mm. The mini V-funnel flow test for SCM is also described by EFNARC (2005). In this test, the funnel was filled completely with 1.1 liters of mortars and the bottom outlet is opened, allowing the mortar to flow out. V-funnel flow time of mortar was the elapsed time (t) in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top. The mini-slump flow diameter and V-funnel flow time values of SCRM containing optimum superplasticizer dosages are shown in Table2.

In order to study the effect of physical characteristics of mortars on the bond strength of repair layer of mortars and base concrete, tensile strength test, flexural strength test, and compressive strength test, have been performed at three ages of 7, 14 and 28 days. To reach this purpose the 210.50.50 samples and briquette samples were cast and were examined in conformity with C348 (Domone and J. Jin, 1999) and C349 (ASTM C349, 2002) for assessing flexural strength and tensile strength. [Fig4]


Fig. 4: Physical characteristics of mortars test: (a) flexural test (b) tensile test

The laboratory work involved over 480 Friction-Transfer and Pull-Off tests on the slabs cured under standard conditions and at three ages of 7, 14 and 28 days. In order to measure the bond strength mortars; different calibration graphs are used to relate the failure stress or torque, to the material compressive strength. These graphs have been already obtained during several researches in Imam Khomeini International University Naderi *et al.*, (1986). When measuring the adhesion between two different layers, the only meaningful stress obtained is the maximum torsional shear strength obtained from the maximum shear stress–torque relationships. Although, the distribution of the failure stresses along the interfacial surface maybe different for different layer of repair mortars, the comparison of the adhesional strengths of different systems measured by pull-off and Friction-Transfer methods showed almost perfect linear relationship between the two. [Fig5]. The accuracy of the Friction-Transfer method was found to be better than that of all other currently available partially destructive methods. The reason for this could be the way that the load (torque) was applied and the nature of failure surfaces as well as the destructive stresses involved. For example in pull-off method, a small deficiency or failure around the perimeter of the 50 mm probe area, would initiate a tearing failure and causes eccentricity to the direct pulling force, with consequent effect on the final result.

Although mixed failures (old concrete, repair and bonding surface between the two), were observed in pull-off testing, with Friction-Transfer tests due to the restraining effect of the gripping device, almost all the failures took place along the concrete/repair interface, proving the superiority of the Friction-Transfer method over the pull-off, when studying the bond strengths of different repair systems.

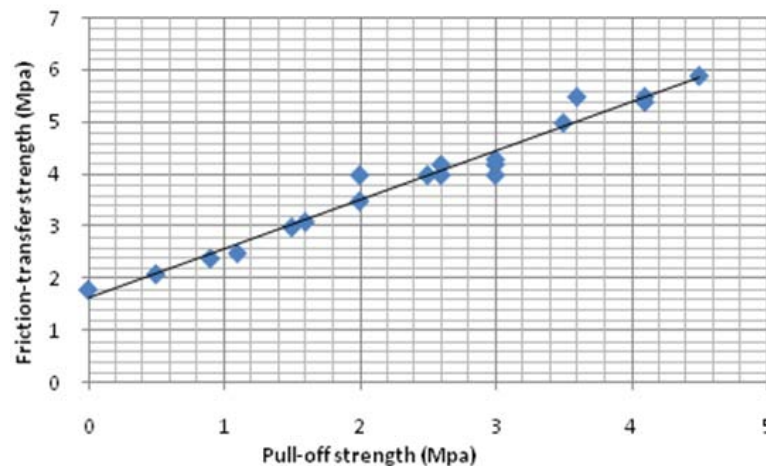


Fig. 5: Typical Friction-Transfer/pull-off correlation

RESULT AND DISCUSSION

Analysis of primary testing:

As seen in Fig 6, achieved results has been expressed that mortar SCFL has the most compressive strength in primary days, and also it can be seen that simultaneous use from LP and BP in mortar SCLB is caused to decrease the compressive strength in it and generally the process of strength obtained in this mortar is accomplished slowly. Fig 9 presents the amounts of bond strength of mortars which are tested by friction transfer method. By comparing Fig 6 and Fig 9 it can be concluded that in initial day there is not systematic connection between compressive strength and bond strength but gradually by growing the mortar age, the direct connection is appeared between compressive strength and bond strength. This connection is obvious completely on 28- day old, as in mortars which are in highly compressive strength, generally they are high bonding strength, too. The results of tensile strength of mortars are shown in Fig 7, as seen in Fig 7 results and by comparing it by Fig 9, we come to conclusion that tension strength has completely direct coherence with bond strength, although in initial year this matter is appeared less. By considering achieved results in Fig 8 and considering Fig 9 it can't be found defined connection between flexural strength increase and bond strength. It should be mentioned that by consideration Fig 6 and 9, contrary expectation mortar SCFL contains very

low bond strength in comparison with other mortars in initial days, Because the high compressive strength is caused modulus of elasticity increasing and the compressive strength of repair mortar should be agreeable as much as possible with compressive strength of base concrete. Low amount of bond strength of 7 – day mortar SCFL can be jointed to the same issue.

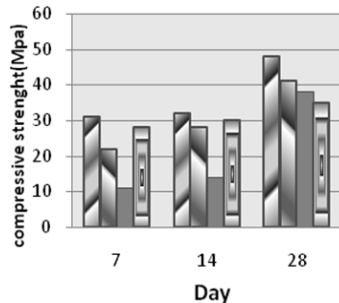


Fig. 6: Compressive strength of mortars

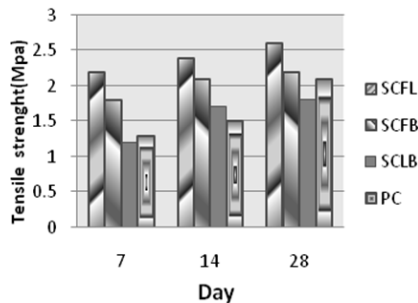


Fig. 7: Tensile strength of mortars

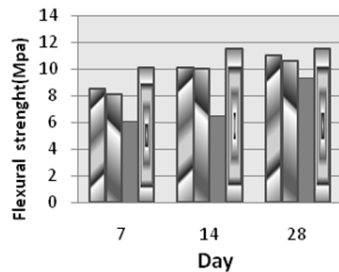


Fig. 8: Fluxeral strength of mortars

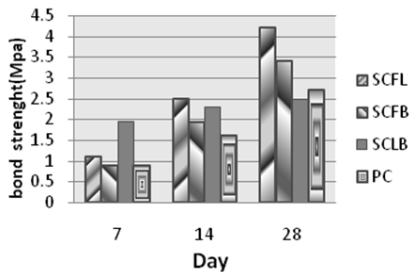


Fig. 9: Bond strength of mortars

Analysis the Effect of Curing and Surface Conditions and Different Mixtures:

The results of bond strength of mortars which are applied on different surface conditions of sub concrete and were tested by friction transfer method at ages of 28 day and under different curing conditions are shown in Fig 10,11,12,13. According to achieve results in this research, and considering following Figures, the most bond strength is related into ASW and SSD surface conditions. SSD condition has been known as the best surface conditions state because base concrete doesn't absorb the repair mortar water (because of being saturation) and on the other hand be dry of surface isn't caused to become disrupted the ratio W/C into repaired mortar. The reason of being low bond strength in the case of saturation with wet surface(SSW) can be knew to raise the ratio water into concrete in repair layer border which the most statistics related into failure are relevant to this state. ACI recommends that one hour before casting the mortar, the concrete surface is wetted completely, but before casting the mortar, the surface should be without any additional water. The Austin's tests results Austin and Robin, (1995) are shown that the most failures are occurred in common level between repair mortars and sub concrete. This is according to this idea that one surface has been very wet (SSW) conditions or one surface has been very dry (ASD) contained lesser strength than SSD and ASW surface states. In SSC surface conditions, cement paste as a gluey layer in short – time, it is caused bond strength, because it is possible that resulted stresses of shrinkage in the early age repaired mortar is caused to separate mortar from base concrete. In this case repaired mortar should be cast before drying the cement grout and when it has the sticky and semi – dry state. If this layer is dried and then repaired mortar is cast, not only it isn't caused to increase the bond strength but also it is caused to decrease the bond strength.

By considering Fig 10 and 11, 12, 13 it can be seen that, different curing conditions caused to create difference in tested results on repaired mortar samples. In practice for achieving into one suitable and strength repair mortar, it should be taken into consideration the suitable curing conditions for mentioned place. According to achieve results in this research, curing with Wet Jute canvas with nylon has been known as the best surface conditions state because this action is keeping wet the surface for carrying out full hydration process. Almost in all curing cases in the open air, repair layer with very low strength is separated from two layers common surface. Although mortar SCLB contains the lowest bond strength than other mortars but the

noticeable point is the highly bond strength of this mortar in A and B curing condition in comparison with other mortar under the same condition.

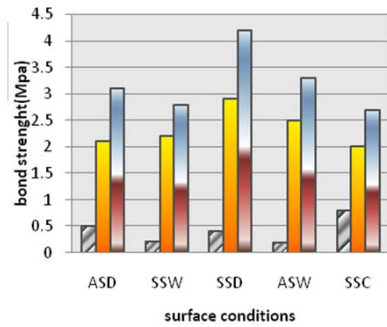


Fig. 10: Bond strength of SCFL mortar

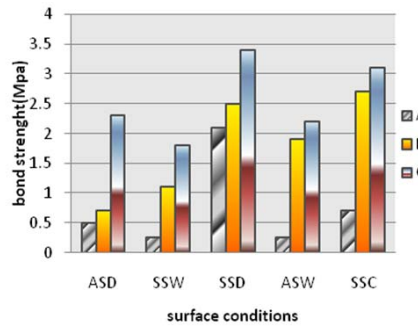


Fig. 11: Bond strength of SCFB mortar

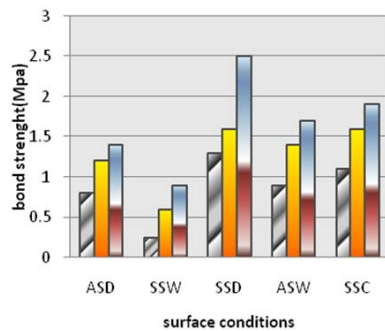


Fig. 12: Bond strength of SCLB mortar

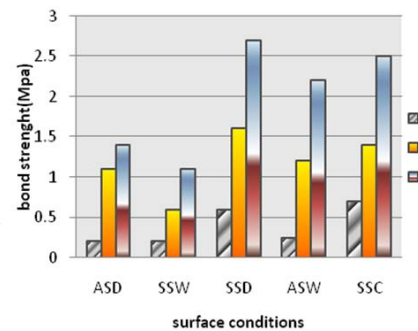


Fig. 13: Bond strength of PC mortar

Summary and conclusion:

As a result of this experimental study, the following conclusions could be drawn:

- Among the mineral additives considered, use of FA and LP simultaneously improved the workability of SCRM. BP and LP, however, could not be used alone as they adversely affect workability.
- Among the ternary mixtures considered in this study, FA–LP mixtures increased the bond strength of repair mortars and sub concrete effectively while LP-BP haven't appropriate performance and these mixtures reduced the bond strength of mortars.
- The direct connection is observed between compressive strength and bond strength. This connection is obvious completely on 28- day old, as in mortars which are in highly compressive strength, generally they are high bond strength, too.
- The results are shown that tension strength has completely direct coherence with bond strength, although in initial year this matter is appeared less.
- By considering achieved results it can't be found defined connection between flexural strength increase and bond strength.
- According to achieve results in this research, curing with Wet Jute canvas with nylon has been known as the best surface conditions state. Almost in all curing cases in the open air, repair layer with very low strength is separated from two layer common surface.
- PC mortar is very lower bond strength in comparison with self compacting repair mortar especially than SCFL and SCFB mortars.
- According to statistic analysis on all the results, it has been found out that the most shares in increasing the bond strength which are in order to relate curing with 46 percent, mortar type with 29 percent, and sub base concrete surface conditions with 29 percent. In the case of elimination curing state in the open air mortar type with 37 percent, curing with 33 percent, and surface conditions with 30 percent have been the most shares in increasing the bond strength, by considering this issue it can be found out that the importance role of each three factors on repair mortar bond strength.

- The Friction-Transfer test can provide accurate and reliable estimates of bond strength of repair materials. This method can be used very successfully to measure the adhesional strengths of different repair, decorative, protective, topping systems with at least 5 mm thickness, used in construction industry. The damage caused by this method is trivial (60 mm diameter with 25 mm depth) and can be repaired by hand, using s/c mortar.
- Tests on different samples prepared and cured under different site conditions, provided us with valuable information about the variables studied, consequently suggesting the Friction-Transfer method as an excellent test method for research and quality control works which need to be carried out under different site conditions e.g. dry and wet; cold and hot; under water or any other environments.

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