

Guidelines for concrete surface preparation: 10 years research and experience

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Abstract. To repair reinforced concrete infrastructures requests specific preparation operations needed for guaranteeing compatibility between substrate and new materials as well as the development of adhesion properties. These guidelines contain design and construction recommendations for surface preparation of concrete for repair and overlay. The paper illustrates current knowledge, best practices and results of the research concerning the surface preparation of concrete prior to application of repair/overlay materials. This is based on 10 years research activities on this topic through scientific cooperation programs between Wallonia, Quebec and Poland and a document edited by U.S. Bureau of Reclamation (Denver, CO, U.S.A.) entitled *Development of Specifications and Performance Criteria for Surface Preparation Based on Issues Related to Bond Strength*.

1 Introduction

Repair and strengthening of existing concrete structures are among the biggest challenges civil engineers are facing today and will have to face in the years to come. Concerted efforts are needed for improving the durability of concrete repairs. One major critical aspect of durability of concrete repairs and overlays is sufficient interfacial bond between repair material and existing concrete substrate [1]. This has been analysed on the base of 10 years research activities on this topic through scientific cooperation programs between Wallonia, Quebec and Poland and a document edited by U.S. Bureau of Reclamation (Denver, CO, U.S.A.) entitled *Development of Specifications and Performance Criteria for Surface Preparation Based on Issues Related to Bond Strength* [2]. The most significant factors influencing bond in repairs (roughness, degree of saturation and carbonation of the substrate) and its field evaluation (type of loading, device misalignment) are described and recommendations for surface preparation prior to repair are presented [3]. In the present paper, it is focused only cleanliness and humidity of the old concrete material before applying repair product.

2 Situation

The concrete substrates are different, one from the other, in age, quality and service exposure: from the relatively new concrete to the most deteriorated one, exposed to various temperatures, relative humidity, chemically

aggressive interior (inside the concrete substrate) and exterior environments, electrochemical status and mechanical loads.

Published data and information allowed for the following characterization of the concrete substrate to be repaired/overlaid:

- it is physically and chemically very complex;
- such complexity is also very variable from case to case;
- the complexity has to be considered on the basis of scale, which is relevant and dependent on the particular situation;
- practical answers and guidance/performance criteria at the present time, as well as the problem of achieving optimum bond in the repair/overlay composite systems, depend more upon broad judgment and experience than detailed knowledge.

An in-depth literature survey on concrete repair bond issues revealed that many critical details and parameters are still little known [1]. Research is thus needed in order to develop or improve field test characterization methods, in order to enable the identification and field assessment of dependable performance criteria (QA & QC) for practical repair applications.

The process of concrete preparation for repair is the process by which sound, clean, and suitably roughened surfaces are produced on concrete substrates [4]. This process includes the removal of unsound and, if necessary, sound concrete and bond inhibiting foreign materials from the concrete and reinforcement surfaces,

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opening the concrete pore structure, reinforcement damage verification and repair, if necessary [5].

3 Surface conditioning

3.1 General considerations

The preparation of the substrate for repair has to be suitable for the required condition of the substrate and the structural and safety status of the structure to be repaired, so that the realistic requirements of the completed repair, as specified, are satisfied.

In all repair types it is important that the new repair adheres well to the substrate concrete. In this respect, it is important that preparation of the concrete surfaces to receive the repair materials be given careful attention as the adhesion developed is as dependent on good surface preparation as on repair material characteristics [6]. Clearly efforts to obtain good adhesion to a weak surface are futile since failure of the concrete surface is likely to occur. Conversely poor adhesion to a sound surface is possible if the surface is inappropriately prepared.

For a successful repair, the following conditions must be satisfied [7]:

- the concrete must be strong and sound;
- the surface should receive the optimum moisture conditioning;
- the surface should be free of dust, laitance or any other foreign materials;
- the surface should have an open pore system;
- the surface temperature should be within suitable limits to permit proper wetting by the repair materials.

Unless cleaning is carried out immediately prior application of repair materials, the cleaned and otherwise prepared concrete and reinforcement surfaces shall be protected from contamination.

3.2 Surface cleaning

Concrete removal methods may leave the surface to receive the repair material too smooth, too rough, too irregular, and without open pores. In these cases, procedures specifically intended for surface cleaning are necessary.

Microcracking (sometimes referred to as bruising) of the concrete surface is common when impact tools are used to remove concrete [8]. A surface with bruising may weaken the bond between the existing concrete and the repair. In this case, a less aggressive method of surface preparation such as abrasive or water jetting is necessary.

Concrete can be removed by a variety of methods such as chipping hammers, abrasive blasting, and hydrodemolition. Removal subjects the concrete substrate to a wide range of dynamic loads, and the resulting bruising will depend on the method used and

the quality of the concrete. The depth of the bruised layer varies, but is typically on the order of 3.0 mm (1/8 in.). There are no criteria for the degree of bruising that reduces service life.

Pull-off testing of the repair system (surface repair and substrate) can be conducted to determine the bond strength [9]. Excessive bruising may result in low pull-off strength with the failure surface running entirely through the substrate. Bruising is identified conclusively by microscopic examination of the concrete. This examination is typically performed on small samples by a concrete petrographer to identify severity of microcracking. To see bruising, a polished surface needs to be magnified 20 to 100 times, depending on the width of the cracks [8].

Bruising can be minimized by exercising care in the removal process and by avoiding techniques that experience has shown to cause bruising. Techniques to avoid include the use of scabblers, scarifiers, bush hammers, or large pneumatic hammers, especially those equipped with wide chisel tools.

Bruising can be minimized by using methods such as abrasive sand, shotblasting or water jetting. Where the more damaging methods must be used to increase production or reduce costs, the damage can be mitigated somewhat by abrasive sand, shotblasting or water jetting as a final preparation step for the final 0.10 in. Replacing the commonly used sand in abrasive blasting with alternative materials such as sintered slag, flint silicon carbide, or aluminum oxide can reduce damage.

The use of lightweight pneumatic-chipping hammers equipped with sharp, pointed tools can also reduce the magnitude of bruising.

3.2.1 Cleaning stage

First stage cleaning operations shall be commenced in a repair area after all necessary concrete removal has been completed. The remaining concrete surface must have laitance, partially loosened chips of concrete and the bruised concrete layer, removed by blasting.

If in the Engineer's opinion bruising and/or contaminants, or weathered and carbonated concrete surface, which might interfere with bond, are present on the prepared surface, second stage blasting and cleaning must be performed as directed by the Engineer prior to placement of the repair material.

The old weathered and carbonated concrete surface is usually removed during concrete removal operations and following first stage cleaning. However, long periods of time between these operations and repair material placement may result in new carbonation of the exposed surface.

The issue of effect of carbonated surface on bond strength is controversial, as conflicting evidence has been reported in the technical documentation over the years. Theoretical analysis, however, lead to the opinion that carbonation does affect the bond strength since it not only densifies the affected concrete, but also changes the pore structure.

The experiments performed [2] showed that carbonation may have little or no impact on bond strength for an otherwise sound, properly prepared concrete substrate surface. Besides, it confirmed that when some bruising is present within the superficial layer of the concrete surface being treated, carbonation amplifies its detrimental effect upon repair bond. Therefore, a recommendation that the carbonated (existing and/or incipient) surface should be removed is justified.

3.2.2 Cleaning techniques

These techniques consist of removing thin layers of surface concrete using abrasive equipment such as sandblasting, shotblasting, or high-pressure water jetting devices [10]. Abrading techniques remove concrete by propelling an abrasive medium at high velocity against the concrete surface to abrade it as a final step in surface preparation. The process uses common abrasive medium as a primary abrading tool. The process may be executed in one of the following methods.

- Sandblasting – Sand blasting is the most commonly used method of cleaning concrete and reinforcing steel. The process uses common sand, silica sand, metallic sand or slag (also known as Black Beauty) as the primary abrading agent.
- Shotblasting – Shotblasting equipment cleans concrete by projecting metal shot at the concrete surface at a high velocity. This equipment has the capability to remove finite amounts of sound or unsound concrete. The shot erodes the concrete from the surface. The shot rebounds with the pulverized concrete and is vacuumed into the shotblasting machine. The concrete particulates are separated out and deposited into a holding container to be discarded later while the shot is reused. The shotblasting process is a self-contained operation that is highly efficient and environmentally sound.
- Waterblasting – Water is sprayed at pressures between 35-105 MPa (5,000 and 15,000 psi). This technique is suitable for vertical and horizontal surface cleaning. It is the largely the same as hydrodemolition, except that smaller and hand held equipment is typically used.
- Waterblasting (with abrasive) – Water blasting with abrasives is a cleaning system using a stream of water at high pressure with an abrasive such as, aluminum oxide, or garnet introduced into the stream. This equipment has the capability of removing dirt or other foreign particles as well as concrete laitance thereby exposing the fine aggregate.

3.3 Maintenance of repaired surface

After the substrate has been prepared, it should be maintained in a clean condition and protected from damage until the repair/overlay material is placed. Prepared areas should be protected from repair activities in adjacent areas: mud, debris, cement, dust, etc., when deposited on a prepared surface, may act as a bond breaker if not cleaned up.

In hot climates shade should be provided, if practically possible, to keep the substrate cool, thereby reducing rapid hydration or hardening of repair material. In wintertime, necessary steps should be taken to provide sufficient insulation and/or heat to prevent the repair area from being covered with snow, ice, or snowmelt water.

3.4 Moisture content

The moisture condition of the substrate will determine the rate of movement of water from the repair mortar to substrate concrete due to the moisture imbalance between the two layers. Both the surface moisture condition and the moisture distribution inside the substrate are important.

For bonded overlays it is commonly reported and specified that the substrate surface has to be in *SSD* (saturated surface dry, i.e. pre-wetted, but surface-dry) condition prior to overlay application. In such condition, the substrate looks damp but contains no free water on the surface. The surface absorbed all the moisture possible but does not contribute water to the repair material mixture at the time of placement. However, no conclusive evidence is provided in the literature suggesting that this actually improves the quality of the bond. If pre-wetting is done, then it needs to be ensured that the substrate surface has dried out completely before the overlay is applied as any water in the substrate surface pores will prevent mechanical interlock between substrate and overlay.

The results generated in the present study show that optimum moisture saturation levels for repair bond strength of polymer-modified repair mortars would lie somewhere between 55 and 90% (Fig. 1). When acrylic emulsion is used as a bonding layer, the highest saturation levels induce a water film at the interface, which is incompatible with polymeric material and artificially reduces the effectiveness of the adhesion. This means that the moisture condition of the substrate for such repair materials would actually be dryer than *SSD*.

There are indications in the scientific documentation that substrate moisture conditions dryer than *SSD* would also be preferable for cement-based repair and overlay materials. Unfortunately, the reliable user-friendly methodology for relatively easy evaluation of the optimum moisture condition of a given concrete substrate, presently is not available. There clearly is a need for quantitative data in this area to provide more precise guidance.

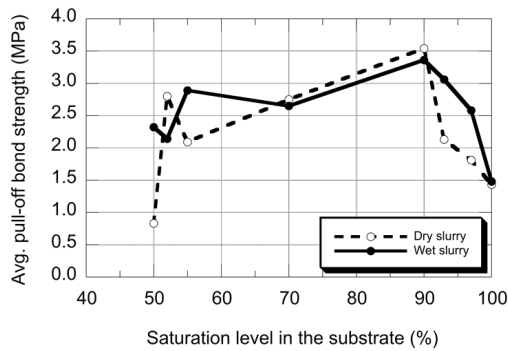


Fig. 1. Relationship between mortar bond strength and the concrete substrate saturation level [11]

In the meantime, the saturated surface dry (*SSD*) condition may not always be the best choice, but when experimental evaluation of the optimum moisture condition is not conducted, is a “safe” compromise. Still, it must be realized that the *SSD* condition itself is a very subjective surface moisture quantity. To what depth must the substrate be actually saturated? This clearly points to the effect of water in the concrete superficial zone and the difficulty of accurately evaluating the saturation level.

The optimum moisture condition will almost inevitably vary from substrate to substrate in otherwise equal conditions because development and performance of the bond depend to some degree on the way the substrate will affect the direction and rate of water movement between phases of the composite repair system.

4 Quality control

The integrity and ultimate performance of repairs and overlays is in large part determined by the quality of the existing concrete surface preparation. It is imperative that care be taken, specifications followed, and surface preparation quality control and related decisions be made by qualified personnel.

Qualified personnel are required for all testing and inspection operations, and shall be performed by the Engineer’s representative, and not by the Contractor performing the surface preparation.

4.1 Evaluation of surface cleanliness

Prior to repair, it is essential to make sure that the concrete surface is free of contaminants, dust, laitance, fragments of concrete, bruised concrete layer, etc. While it may sound simple, there was no unified or systematic approach until recently. In the wake of the newly developed ICRI’s Concrete Surface Repair Technician (CSRT) Certification Program, a reference document [12] provides guidance on how to carry out this evaluation adequately as part of a rigorous QC program for repair works.

4.2 Evaluation of surface moisture content

Investigations concerning the measurement of water saturation levels and their effect on the adhesion of cement and polymer cement concrete repair systems have shown that the Modified Capillary Suction Test (MCST – Fig. 2) gives clearer, more accurate and lower dispersive information than the Initial Surface Absorption Test (ISAT – Fig. 3), with a higher correlation for water content measurement (wet and dry weighing).



Fig. 2. MCST experimental setup [2]

Moreover, there is a very good correlation between the water absorption index and the capillary absorption coefficient determined using the ISAT and MCST tests, respectively [11].

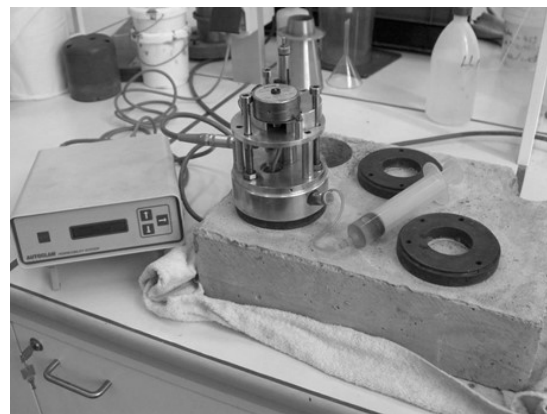


Fig. 3. Autoclam test device (CNS Electronics) used for ISAT testing [2]

MCST requires to core a sample of concrete and to test it in the laboratory. ISAT is an attractive option for performing a quantitative test to evaluate the saturation level of a concrete substrate: it is compact, cost-effective and quick. The higher variation and dispersion of results for ISAT may stem from the difficulty of performing the test with a rough concrete surface (after water jetting). Procedures are influenced by the surface quality, but it is difficult to conclude whether this is due to cracking or roughness.

In situ evaluation of the moisture content of concrete remains a challenge and no definite recommendations can be proposed. A simple method [13] is about to be issued by ACI (final editing stage) to support the newly available ICRI's Concrete Surface Repair Technician (CSRT) Certification Program. The method is solely intended to determine whether the surface is dry using compressed air and cardboard. Besides, on-going research activities at USBR and Laval University notably are devoted to the use of simple electrical R.H. measuring devices to assess the moisture condition of concrete and identify quantitative criteria to be correlated with bond for different repair and overlay materials [14, 15].

5 Perspectives

5.1 Moisture conditioning of the concrete prior to repair

Despite the work accomplished in this project, some fundamental issues remain unresolved with regard to moisture conditioning of the concrete substrate prior to repair. In daily repair practice, inevitably loose specifications and the absence of measuring tools actually result in a wide range of moisture conditions.

In order to develop proper specifications, it is necessary to gain a better understanding of the transport mechanisms between repair materials and concrete substrates and the influence of the moisture state of the substrate upon bond development.

Both the issuing and implementation of such specifications will, in turn, require the development of a test method to evaluate quantitatively the actual moisture condition of concrete in the laboratory, as well as in the field. The envisioned method would allow the determination of optimum conditions for a given concrete substrate, as well as quality control testing. The method needs to be simple and applicable to both laboratory and in situ conditions. In that regard, further investigation should be directed towards measurement techniques already available, such as electrical impedance devices (flooring industry) or superficially encased relative humidity probes.

5.2 Long-term bond

It must be emphasized that this study, as well as other reported work on the subject, is primarily dealing with "short-term" bond strength issues, not with the mechanisms and issues related to long-term bond behavior and durability. The short-term bond strength typically specified and evaluated can be used as an indication of the quality of workmanship (i.e., concrete surface preparation for repair, material selection, application, and curing). Long-term bond strength, however, is usually influenced by various other factors, among them environmental, loading, and fatigue conditions.

Therefore, it is desirable to pursue research efforts on those factors affecting long-term bond strength in concrete repair/overlay systems, notably the surface preparation parameters and characteristics.

5.3 Compatibility issues in repair/overlay systems

When compatibility issues are properly addressed in repair systems, durability of the bond is achieved, as it ensures a lasting coexistence of the repair material and substrate concrete.

Incompatibility issues cause premature debonding and repair failures. Unfortunately, at the present time, much confusion, misconceptions, and misleading guidance exist concerning compatibility of repair materials and the substrate concrete. These issues negatively affect the design, specification, implementation, and, as a result, service life of concrete repairs and overlays.

Development of reliable guidelines addressing compatibility issues – with special emphasis on the factors related to dimensional compatibility issues – is needed for the repair industry to evolve as an engineering discipline.

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