BE PREPARED - Is Surface Preparation for Concrete Repairs a Fad?

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Prior to the commencement of concrete repairs, the fundamental thing to consider is surface preparation. The amelioration of damaged concrete structures involves many elements, from engineers, applicators and even legal counsel. This paper details the primary value of surface preparation, for without good bonding no repair system can be expected to perform.

Repair Material to Concrete Substrate – An Alien or a Monolithic Bond:

In European standard (EN1504-10:2003), the term bond refers to the adhesion of the applied material or system to the concrete substrate. Hence, adhesion has an underlying importance in the repair of concrete structures. Surface preparation of the concrete substrate is considered to be the most crucial step in a concrete repair project. A poorly prepared surface will result in the weak association to the repair zone, no matter how proficient the applicator or expensive the repair material might be. The repair material when applied, should not act as 'an alien body' to the host concrete substrate, rather, it should become an integral part of the existing concrete restoring the structure to its original monolithic strength. Lukovic et al., (2012), in their paper "Reliable Concrete Repair – A Critical Review", highlighted that the composite system, by the integration of the repair material with the existing concrete forming a monolithic bond, would allow uniform transfer of stresses in the system.

It is pointless to exert efforts to achieve good adhesion to a weak friable substrate as failure of the concrete surface is imminent in such cases. Similarly, a sound surface might result in poor adhesion if the surface is not properly prepared. The good bonding of repair material to the existing substrate predominantly relies firstly upon, the mechanical bond of a well prepared substrate and secondly, upon the chemical bond amid the repair materials. Several other factors determining the bond strength of the repair system, include exposure conditions, properties of the repair materials and concrete substrate to name a few.

Sawn Edges – Doing It Right the First Time:

Saw cutting is used to delineate the perimeter of the repair zone. A disc type mechanical grinder is used for saw cutting the edges along the perimeter of the repair area. The right angled saw cut to a depth of 10-15mm is recommended to avoid any feather edging and it should not be deeper than the reinforced concrete cover. Saw cut squared edges help contain the repair material. The saw cut edges should be roughened slightly by a needle gun or hacking, as a polished vertical sawed face may result in poor bonding.

The geometry of the repair area should be in simple square or rectangular shapes. Sharp acute angles and re-entrant corners should be avoided (Figure 1). Some concrete repair field installers usually form excessive or tortuous edge conditions as they try to closely follow the geometry of the distressed concrete. Such complex and zigzag edge conditions often result in shrinkage stresses leading to cracking. Where saw cutting is not possible due to smaller areas, chipping tools should be used to remove concrete, ensuring that the edges of the repair area are cut perpendicular to the substrate.

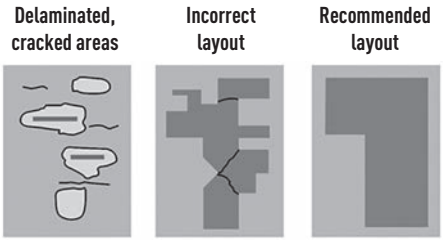
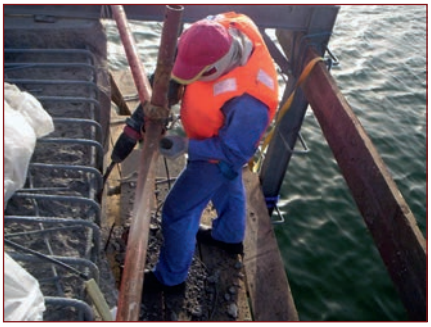


Figure 1: Concrete Repair Geometry. Source: ACI Webinar, 2013

Removal of Spalled Concrete:

Most of the repairs require surface preparation comprising of roughening, exposure of the aggregates and removal of the damaged, delaminated and loose concrete. Regardless of the type of deterioration, all weak, flaky, unsound and disintegrated concrete must be removed. Defective concrete should be broken back to a sound and dense concrete surface. Prior to the removal of any spalled concrete from a load bearing structure, certified shoring must be provided to the structure. The removal of concrete usually starts with saw cutting the repair boundaries. The deteriorated unsound concrete in the centre of the repair area is then removed. Breaking out and the removal of concrete progresses from the centre outwards towards the edges. The next step is to remove the concrete near the edges without damaging the sound concrete at the interface.

The extent of concrete removal depends on the extent of damage. Concrete may be removed by impacting methods using power tools (Figure 2 and 3), or by hydro-demolition such as water blasting and water jetting. The most commonly used concrete removal techniques are impacting methods such as hand held percussive equipment, pneumatic breakers, chipping hammers and scabblers where repeated striking of a concrete surface with a high powered tool to break the concrete is employed. Whenever unsound concrete is removed using impacting methods such as percussive power tools, the surface of the concrete might exhibit micro-cracking or bruising that will form a weak plane acting as a 'bond breaker'. It is recommended that the remaining concrete should therefore receive additional cleaning and preparation using wet sandblasting or water jetting. To avoid any micro-cracking of the concrete substrate, hydro-demolition or abrasive sand, shot or water blasting sometimes become the preferred choice for contractors.



Figures 2 & 3: Impacting Method - Removal of deteriorated concrete by jack hammer.

Figure 4: Concrete substrate is ready to receive repair materials after final surface cleaning.

Figure 5: Steel cleaning and splicing by lapping after removal of concrete.

Concrete Surface Cleaning – Avoid Bond Breakers:

After removal of the deteriorated concrete the exposed concrete substrate must be cleaned with high pressure water washing, oil free compressed air or other appropriate methods. Normal low pressure water washing at 15 MPa or high pressure water washing at 35 MPa can usually be adopted to clean concrete surfaces that have already been prepared by impacting concrete removal methods. Though, some might consider it a redundant step, surface cleaning is crucial to attain the robust bond between the repair material and the substrate. Surface cleanliness is a critical step in surface preparation after the concrete removal process, and prior to the commencement of repair material application, as any dirt, debris or loose particles can act as 'bond breakers'. Surface cleaning facilitates repair materials having direct contact with the host concrete substrate, increasing the surface contact area and roughness of the surface, resulting in enhanced bonding of the applied repair material (Figure 4).

Steel Reinforcement Surface Preparation – Reaching Behind and Between Corroded Rebars:

On steel reinforcement there may be the problem of corrosion. This normally takes the form of rust. Initiation of corrosion and de-passivation of reinforcement is only possible in the presence of water, oxygen and corrosive agents such as chlorides and carbon dioxide. The rust layer is mechanically weak, poorly bonded to the surface and must be removed prior to any application. According to the American Concrete Institute (ACI 546), all weak, spalled, severely cracked, damaged, and easily removable concrete should be chipped away from corroded reinforcement steel. All corroded steel in the repair area should be fully exposed to full circumference and thoroughly cleaned of all loose scale, corrosion deposits and other contaminants. An old rule of thumb is that at least 20- 25mm of clearance around and behind rebar is required to ensure proper cleaning, encasement and bond of repair materials, also complies with the requirements of ACI, AS, EN and other standards.

If the deterioration of concrete has been caused by corrosion of reinforcement, the products of corrosion must be removed prior to the application of the repair material, or else the repair will be short lived. If the structural capacity of the reinforcement is compromised due to chloride contamination, it is essential to remove all rust from the steel before proceeding. Steel reinforcement should be cleaned to achieve a surface preparation equivalent to AS1627 Part 4, Class 2.5 or Part 2, Class 2. The preferred method is abrasive blasting (SSPC-SP 10/NACE No. 2) or water jetting (Vaughn O'Dea, 2011).

Exposed reinforcement in smaller repair sections can be cleaned manually by using hand or mechanical wire brush and emery paper to reach and clean behind and between the rebars. Exposure of steel reinforcement must also continue along its length until non-corroded steel is reached and continued at least 50mm beyond to show sound rust-free steel. If the steel has lost more than 25 percent of its cross-sectional area due to rusting, splicing of reinforcement bars should be carried out by butt welding the bars with backing plates, lapping the affected bars with supplemental reinforcement (Figure 5) or by introducing coupler mechanical joints. The reinforcement bars used in repairs should conform to the requirements of AS4671 and be of the same Grade as the existing steel. An unbroken coat of anti-corrosion zinc rich epoxy primer is normally recommended to protect the steel reinforcement within repair mortars.

Bonding Agents – Bond Aiders or Bond Breakers:

There are number of repair failures recorded when concrete surface preparation prior to repair is neglected due to a false assumption that poor surface preparation can be compensated by using a bonding agent (Bissonnette et al., 2012). Engineers specify bonding agents as a 'belt and braces' measure to enhance the bond at the repair interface, but it should not be considered by any means a replacement of correct surface preparation. Bonding agents provide an additional step and a layer that can create a weak plane if the manufacturer's instructions are not followed. If the bonding agent is allowed to cure prior to the application of the repair mortar, it would rather act as a 'bond breaker' than a 'bond aider', causing failure of the repair. Sprayed repair mortars, in particular, do not require bonding agents as the shotcrete process exhibit excellent bonding characteristics by itself (Figure 6).

Figure 6: Sprayed repair mortar application .

Drunken Concrete – A Safe Compromise:

When repairs are to be carried out using cementitious mortars, the surfaces must be pre-wetted to achieve a Saturated Surface Dry (SSD) condition after cleaning in order to avoid host concrete absorbing the moisture from the repair mortar that is in fact required for its hydration. Although, the term SSD is somewhat subjective, yet many experts consider it a 'safe compromise' for pre-soaking the concrete. If the concrete is dry and 'thirsty', pre-soaking is of utmost importance. The concrete should be thoroughly pre-soaked so that the concrete is 'drunk' with water. If the substrate is not pre-soaked thoroughly, the rate of movement of water from the repair mortar to the host concrete will be high due to the moisture imbalance between the adherent 'substrate' and the adhesive 'repair mortar'. In the SSD condition, the substrate is damp and saturated but does not contain any free water on the surface. Free water at the surface must be avoided as it can impair the bond at the interface due to increased shrinkage leading to lower material strength and reduced bond strength.

Surface Preparation Safety – Be in Control of Potential Hazards:

The effect of the concrete removal on the structural integrity prior to the commencement of removal of existing deteriorated concrete, must be thoroughly assessed. In case of removal of spalled concrete or damaged reinforcement of structural elements, precautionary measures must be employed by providing temporary support. During the concrete breakout and removal process, dust and debris should be contained so as not to pose any hazard to the stakeholders. The areas of repair should be examined to ensure there are no embedded electric conduits, sockets or utility connection lines that might get damaged during concrete removal. All effective measures should be adopted to ensure the safety of the structure and workers are not compromised by repair activities.

Surface Preparation Testing

The tensile pull-off adhesion test of the existing concrete should be conducted as part of the condition evaluation report. To ensure that the surface preparation procedures were followed as per the specifications, the pull-off strength of the prepared surface prior to repair application is measured. ICRI Guideline No. 210.3-2004, "Guide to Using In-Situ Tensile Pull-off Tests to Evaluate Bond of Concrete Surface Materials" is followed by most engineers. In case of a significant deviation of the pull-off strength of the prepared surface from the tensile strength of the existing concrete, the result should be examined by the engineer for additional surface preparation. Such benchmark criteria would allow the engineer to establish and specify the realistic adhesion strength requirements for the on-site repair condition.

To prequalify the quality of a repair, it is vital to evaluate the quality of surface preparation and eventually the durability of bond. This is done by conducting the direct pull off test on a representative sample area for the cured in-situ repair material. This step of surface preparation testing would verify the tensile bond strength of the repair material and the existing host concrete. During the course of the project, surface preparation needs to be periodically validated using tensile pull-off test method, benchmarking the engineer's specifications and the values obtained during prequalification of the reference sample. VicRoads, Standard Specifications, Section 689 suggests that the mean adhesion or pull off strength to concrete substrate at 7 days should not be less than 0.75 MPa, with no individual result less than 0.65 MPa for substrate mode of tensile failure within existing concrete substrate. Bond values for shotcrete and form-and-pour repairs typically exceed 0.75 MPa and, in most cases exceed 1.0 MPa. The ACI 503R and VicRoads Test Method RC 252.02 are commonly used standards for pull-off testing.

Conclusion:

The best of repair materials, despite the best of mixing and application practices, are destined to fail unless the concrete substrate is properly prepared. The intent of this article is to promote precise specifications for surface preparation rather than taking a broad generic approach. The conventional approach of surface preparation for concrete repairs such as to 'clean and sound' should be avoided. This commonly used phrase is too ambivalent to specify the correct level of surface preparation. There is a need to go beyond the boundaries of a 'clean and sound' approach. Field technicians and installers are the cornerstone in any concrete repair project. They must be provided with thorough technical training to enhance their skills. Surface preparation will often be pivotal in determining the overall performance and durability of a repair. A successful repair means that the resulting multi-layer system acts monolithically, ensuring long service life. Proper attention to surface preparation is essential to achieve a robust bond between repair materials and the existing concrete substrate. Only a strong bond will lead to a strong and durable repair. If you want to get the most out of the repair materials, then be prepared to prepare!

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