Concrete Removal, Bar Cleaning & Surface Preparation for Concrete Repair

[Extracted from Construction Technology Update No. 24, Published by Institute for Research, National Research Council of Canada, 1998 & http://theconstructor.org/practical-guide/defective-concrete-removal-techniques/5790/]

1.0 Introduction

This article describes detailed procedures for concrete removal; rebar cleaning and proper surface preparation for a durable concrete repair system. Removal of deteriorated, damaged, porous or defective concrete is a must for any repair work but the extent of this removal cannot usually be determined in the planning stage. The decision about how much damaged concrete is to be removed and what level of aging for existing concrete is allowed to remain in place is very tedious. This decision becomes particularly difficult because the change in properties of concrete occurs gradually along the depth of concrete and there is no hard and fast border line. One guideline for the extent of removal in medium and high strength concretes is to continue removing material until aggregate particles are being broken rather than simply removed from the cement matrix. It is not a good practice to remove material only up to the plane of reinforcement and to have a joint between new and old materials right at the same location. Even in those cases where it is decided not to encase the bars fully, it is better to expose about three-fourth of the bars diameter and to expose the corner bars fully.

The depth to which the concrete is removed has a profound effect on the method to be used and the cost of the work. The following classification can be made for removal of concrete (see Fig. 1):

- Surface removal: This is defined as the minimum amount of work needed to remove surface contamination and provide a clean, long-lasting bond between the existing material and the material used to repair or rehabilitate the structure.
- Cover concrete removal: Cover concrete is defined as the concrete that lies outside or above the first layer of reinforcing steel. The removal task does not involve any interaction with the reinforcement and is not hindered by its presence.
- Matrix concrete removal: Matrix concrete is the concrete which lies around and between the steel reinforcement. The removal tasks are severely hindered by the need to work in confined spaces around, below and between individual bars. Contaminated concrete in this zone is thus extremely difficult to remove. The removal of deteriorated concrete is somewhat easier because of fracture planes caused by cracking and delamination. The depth of the zone is defined to extend a small distance (about 25 mm) below the steel to allow for the flow of replacement material into all the voids created.
- Core Concrete Removal: Core concrete forms the core of the structural element and lies between the reinforced zones. The removal task is inhibited by the reinforcing steel that was exposed during the removal of the matrix concrete. Conventional cutting, grinding and sawing techniques cannot be used. The quantity of material in this zone is dictated by the size and shape of the structural element. Thin deck sections contain little core concrete material, while piers and pile caps may contain a fairly substantial quantity. The volume of material to be removed is limited by the extent of chloride contamination.
- Bar Cleaning: Bar cleaning operations are aimed at removing rust and chlorides to provide a fresh surface for bonding with the repair material. The minimum amount of material needed to achieve the required quality must be removed.

2.0 Factors to be considered during concrete removal

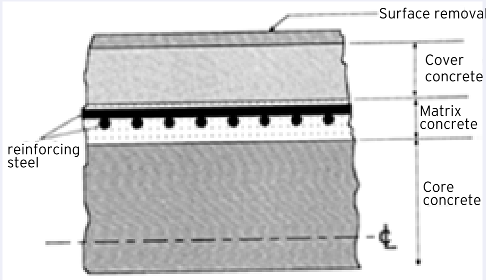

Fig. 1: Depth classification for concrete removal

Removal tasks must be performed selectively on parts of the structure so that only the contaminated or deteriorated concrete and rusted reinforcing steel marked for removal must be removed. It should also ensure that the remaining concrete and reinforcing steel retains its structural integrity. Equipment used to perform the work must not overload the structure. Any impact forces used to remove damaged concrete should be applied in a manner that minimizes cracking in the residual concrete and damage to the bond between the remaining concrete and steel. Methods to remove rust and chlorides from the steel should also minimize damage and loss to the remaining steel.

Blasting of damaged concrete can produce problems in the surrounding concrete and hence its use must be carefully planned. Use of impact tools may also produce small-scale cracking to the surface of the concrete left in place. The debris removal by some primary means is usually followed by using a secondary method such as chipping, sand blasting (impacting sand with high air pressure) or high pressure water jetting to clean the surface. For more precise removal of damaged concrete in small areas, saw cutting may be used but the surfaces obtained must be treated with thin layers of materials to improve the feather edge surface.

When exposing narrow but deep areas for repair along cracks, the cavity is better to be undercut to lock the repair material, for two alternate methods. For large areas, the edges of the area are cut back sharply perpendicular to the face of the existing concrete without any undercut. For large cavities to be filled, the top surface is preferably made slopping towards the interior for easy placement and compaction of the repair material.

The concrete removal techniques used should be effective, safe and economical, and should produce minimum damage to the concrete left in place. Some removal techniques take much longer time than the others but are environment friendly. Some techniques permit a portion of the work to be accomplished without removing the structure from service. A single removal technique may not be the optimum solution for all portions of a given structure. Before removing the damaged concrete, sufficient props should be given to the structural members to relieve the loads and avoid any failure of the structure.

3.0 Methods for Removing Concrete

The removal of cover concrete over a relatively wide area is frequently necessary in structural rehabilitation projects. The work involves removal to a depth less than the cover depth of the steel and thus no work between, around or under the reinforcing mat is included in the task. Scrabbling, planing, sandblasting and shot blasting all can be used in repeated passes to achieve the required depth. This is an inefficient use of these methods, and the only really effective way of doing the work when large areas are involved is by using a concrete milling machine. A milling machine removes concrete by the impact of numerous tungsten-tipped teeth mounted on a rotating drum or mandrel.

It is necessary to remove matrix concrete when contamination, spalling and delamination have progressed into the concrete layer that surrounds and encases the reinforcing mat. The work involved is awkward as it must be performed between, around and under the steel without damaging the steel, cracking the substrate concrete, or destroying the bond between steel and concrete in areas where the concrete is not to be removed. There are basically two methods available: pneumatic breakers and hydrodemolition. Both of these techniques may be used to remove cover and matrix concrete in a single operation or may be used to remove only matrix concrete after a more specialized and high-production method, such as milling, has been used to remove the cover concrete.

Core concrete removal necessitates the removal of concrete at the core of the structural element in a manner which respects the three quality constraints of selectivity, residual damage and bond quality. Pneumatic breakers and hydrodemolition are the only two techniques available if the surrounding mats of reinforcing steel are to be left intact. Both of these methods, however, suffer serious losses in productivity due to the difficulty of reaching the material. There also is no efficient way to remove substantial quantities of core concrete while leaving the reinforcing steel in place. Core concrete material can be more efficiently removed if the reinforcing steel is cut. This will of course require that it be replaced at a later stage but it does permit. The different methods of removal of concrete are discussed in detail in the following sections.

3.1 Cutting methods

Following methods can be used to cut the damaged concrete and the selection of the method basically depends on handling and transportation of the cut pieces.

3.1.1 High-pressure water jet (without abrasives)

A high pressure small water jet is used for producing pressures of 69 to 310 MPa and above to cut the concrete surface.

3.1.2 Saw

Diamond or carbide saws (Fig.2) are available in sizes ranging from very small hand-held saws to very large saws capable of cutting depths of up to 1.3 m. A plane or diamond grinder removes concrete by abrasion. Numerous diamond tipped concrete saw blades are mounted close to one another on a horizontal spindle, which is rotated to cut and remove up to 12 mm of concrete in a single pass. The process requires water to cool the blades and the resulting slurry of concrete particles can be vacuumed up for collection and disposal.

Fig. 2: View of a concrete saw cutting machine

Sawing is a low-cost, versatile technique for performing a number of tasks including: cutting the perimeter of an area (Fig.3) where pneumatic breakers are to be used for removing concrete; cutting to full depth in slabs and decks so that sections may be removed; and cutting joints in new concrete.

Fig. 3: Hand held saw cutting of column surface

3.1.3 Diamond Wire Cutting

A continuous wire having modules impregnated with diamonds is wrapped around the concrete mass to be cut and is connected to a motor to form a revolving loop. The limits of the power source determine the size of the concrete structure that can be cut.

3.1.4 Mechanical Shearing

The mechanical shearing is achieved by hydraulically powered jaws to cut concrete and reinforcing steel for making cuts through slabs, decks, and other thin concrete members. The cuts must be started from free edges or from holes made by hand-held breakers and care must be taken to avoid cutting into other members.

3.1.5 Stitch Drilling

In this method, overlapping bore holes are drilled along the removal perimeter to cut out desired sections of concrete. This method is especially useful for making cutouts through concrete members where access to only one face is possible and the depth of cut is greater.

3.1.6 Thermal Cutting

The powder torch, thermal lance, and powder lance can be used for thermal cutting that use intense heat generated by the reaction between oxygen and powdered metals to melt a part of concrete. These methods are usually slow and the progress depends on the rate at which the resulting slag can flow out of the slot. These devices are best to cut reinforced concrete.

3.2 Impacting Methods

In these methods, repeated striking of concrete surface is done with a high energy tool or a large mass to fracture and spall the concrete. This method may cause micro-cracking in the adjoining concrete particularly if partial depth removal is required. Following equipment are used for this method:

a) Hand-held breakers (Fig. 4)

b) Boom-mounted breakers

c) Scrabblers

Fig. 4: View of hand-held breaker machine

3.2.1 Scrabbling

A scrabbler (Fig. 5) uses pneumatically driven bits to impact the surface to remove concrete to a depth of between 1 mm and 6 mm. Scrabblers vary in size from large, self-propelled machines that can only work on large horizontal surfaces to small, hand-held tools for use in restricted, vertical or irregular surfaces. Vacuum collection systems are frequently used to collect the concrete debris.

Fig. 5: View of scrabbler for concrete removal

3.3 Milling Methods

Milling methods are used to remove a specified amount of concrete from large areas of horizontal or vertical surfaces; having removal depth ranging from 3 mm to approximately 100 mm. These methods usually produce a sound surface free of micro-cracks.

3.3.1 Scarifier

A scarifier (Fig. 6) is generally used as a concrete cutting tool that employs the rotary action and its cutter bits cuts concrete surfaces. This equipment can remove deteriorated and sound concrete in which some of concrete contains form ties and wire mesh, loose concrete from freshly blasted surfaces and concrete that is cracked and weakened by an expansive agent. Scarifiers are available in a wide range of sizes. Depth of cut can be more precisely controlled than with a scabbler. Different styles of interchangeable cutter assemblies can be used for cleaning, grinding and light or heavy milling. Like scabblers, scarifiers are noisy, produce vibrations and generate a great deal of dust, although the latter can be controlled by using a dust collector attachment.

Fig. 6: Concrete scarifier during surface cutting

3.3.2 Grinder

Grinders use diamond-, ceramic- or silica-based abrasives of planetary or rotary types to abrade concrete surfaces. Planetary grinders typically used to abrade surfaces such as concrete for many different applications like profiling concrete in preparation for a coating such as an epoxy or urethane. Rotary grinders are often used for creating a more aggressive profile or removing concrete. Concrete grinders with dust extraction of hand-held and floor models can be used for surface grinding. The use of a dust extraction vacuum with the dust guard and brush rim ensures a clean working environment.

3.4 Hydro-demolition

The majority of hydrodemolition (Fig. 7) work involves the removal of matrix concrete. Extremely high-pressure water jetting of 80 – 240 MPa is used as a primary means for removal of concrete when it is desired to preserve and clean the steel reinforcement for reuse and to minimize damage to the concrete remaining in place. This method has a high efficiency and disintegrates concrete changing it back to sand and gravel-sized pieces.

Fig. 7: Hydrodemolition for concrete removal

The equipment can, however, be calibrated to remove concrete to almost any depth and the nature of the process is such that there is an element of self-adjustment in depth depending on the soundness of the material encountered. Hydrodemolition can be used on inclined, vertical and overhead surfaces but cost effectiveness is reduced by the inordinate cost of the specialized equipment needed to safely direct the jet and contain the debris when working on other than horizontal surfaces. Hydrodemolition is an emerging technology suited to all phases of concrete removal.

3.5 Pre-splitting Methods

Pre-splitting methods use hydraulic splitters, water pressure pulses, or expansive chemicals placed in bore holes drilled along a line to induce a crack plane for the removal of concrete. The direction and extent of the crack planes that propagate depend on pattern, spacing, and depth of the bore holes.

3.6 Abrading Blasting

Abrading blasting removes concrete by propelling an abrasive medium at high velocity against the concrete surface to abrade it. Abrasive blasting is typically used to remove surface contaminants and as a final surface preparation. Commonly used methods include sandblasting (Fig. 8), shot-blasting, and high-pressure water blasting.

Fig. 8: Sand blasting for concrete removal

3.6.1 Sandblasting

This method is the most commonly used technique to clean concrete and reinforcing steel, where common sands, silica sands, or metallic sands is used as the primary abrading tool. Vacuum systems are used to recover the sand and resulting debris. There are following three methods of implementing this method.

a) Dry sandblasting: The concrete surface is bombarded with sand with the help of high-pressure air in the open atmosphere. The sand particles are usually angular and may range in size from passing a 2.12 to a 4.75 mm sieve, larger size particles are used for rougher required surface condition. Compressed air at a minimum pressure of 860 kPa is used in this method. Finer sands are used for removing loose materials and grease from the concrete and reinforcing steel, while coarser sands are commonly used to expose fine and coarse aggregates in the concrete or tightly bonded corrosion products from reinforcing steel. The economical depth up to which sand blasting is effective is about 6 mm from the concrete surface.

b) Wet sandblasting: This method is same as dry sandblasting but the free particles bouncing back from the surface are collected in a circle of water to reduce air pollution.

c) High-pressure wet sandblasting: Sand is projected at the concrete surface or the reinforcing steel with the help of stream of water at high pressures ranging from 10 to 20 MPa. This method is not as effective as dry sandblasting.

3.6.2 Shot-blasting

This method is also similar to sandblasting but here metal pieces are projected at the concrete surface at a high velocity. The shot erodes the concrete from the surface and the removed material is collected by a vacuum chamber in the machine. The shot-blasting process is highly efficient and environment friendly method. A surface cleaning operation is done by using a small-sized shot and setting the machine for maximum travel speed. Removal of as much as 6 mm in a single pass is possible and up to 20 mm thickness can easily be removed. There are three factors that influence the depth of shot-blasting:

- Size of the abrasive (coarse shot etches the surface more deeply);
- Amount of abrasive (an abrasive control valve allows the operator to increase the flow of the abrasive for a deeper etch);
- Speed of the machine (slower speed is needed for a deeper etch). These factors, in addition to the cleaning path width, the desired removal depth, the hardness of the concrete, and the presence of previous coatings, affect production rates. For example, a heavy elastomeric coating on an old floor will cause shots to bounce off the surface rather than to scour it.

3.6.3 High-pressure Water Blasting (with abrasives)

High-pressure water blasting with abrasives uses a stream of water at high pressure of 10 to 35 MPa with an abrasive, such as sand, aluminum oxide. This equipment can remove dirt, grease or other small particles exposing the fine aggregate. The abrasive is removed from the water before it is disposed into a storm or waste water system.

The advantages of high pressure water blasting are as follows:

- There is no dust, and noise is minimal.
- There are no mechanical vibrations that might cause structural damage.
- The machine selectively removes deteriorated concrete and leaves good concrete intact.
- The reinforcing steel is not damaged as it could be by scarifiers or scabblers.
- The removal of deteriorated concrete is faster than by conventional methods such as jackhammers. Removal rates can range from 0.28-0.85 m^3/h and 46.45-74.32 m^2/h when used as a scarifier to remove surface material to a depth of 6 mm.

4.0 Bar Cleaning

Bar cleaning necessitates the removal of rust, chlorides and other unwanted material from the exposed reinforcing steel. The work follows the removal of matrix concrete and is extremely important as all the chloride contaminated rust and cement paste must be removed to stop corrosion from continuing in the backfilled concrete. Three methods such as sand blasting, wire brushing & hydrodemolition are frequently used for rebar cleaning. Chemical rust remover is also used to clean the rebar.

4.1 Wire Brushing

Powered rotary wire bristle brushes (Fig. 9) can be used to clean exposed rebar. Brushes are pneumatically or hydraulically driven and usually mounted on a small utility construction vehicle. Access to hidden and difficult-to-reach surfaces is restricted.

Fig. 9: Rebar cleaning equipment for removal of corrosion products of steel

4.2 Using Chemical Rust Remover

In case of heavy rusting of steel reinforcement, remove the loose rust by wire brushing, chipping, hammering or grinding so that majority of rust scale is removed. Apply any chemical rust remover on affected surface by using cotton waste swab or by brush application. The rusty surface will change its colour to original blackish steel, remove the same with cotton cloth. Then remove the loose rust particles by scrubbing or simple dusting with the brush. Wash the steel surface with water jetty to remove all acidic residue left on the bar, and clean the surface with a cotton cloth.

5.0 Bond Quality

After the removal, the concrete surface is checked by visual inspection and by sounding at the surface, microscopic examination or bond testing for near-surface damage and by taking cores, pulse velocity tests and pulse echo tests for subsurface condition of remaining concrete. All damaged or deteriorated concrete is to be removed and the quantities must be estimated as accurately as possible in the start. The three quality constraints of selectivity, residual damage and bond quality must be met under all conditions. No removal technology can be used if it does not satisfy the constraints.

Removal tasks are only part of the repair process. Any new material needed to patch overlay or replace the damaged material will need to bond effectively with the remaining concrete and steel. Remaining surfaces must be clean and sufficiently textured to provide the required bond. The quality constraints, selectivity, residual damage and bond quality make removal are more demanding and expensive task than demolition. They also preclude the use of much high impact, high-production techniques developed for concrete demolition and limit suitable techniques to those that comply with the constraints.

6.0 Surface Preparation

Surface preparation is a critical factor in the performance of repair materials applied to concrete. The surface preparation of concrete in readiness for the application of a coating or repair material includes all the steps taken after the removal of the deteriorated concrete. Many of the same steps apply when little or no concrete is removed. Proper surface preparation provides a dry, even and level surface free of dirt, dust, oil and grease. Removal of surface contaminants allows primers and repair materials to have direct contact with the substrate, increasing the surface area and roughness of the surface, and providing increased anchorage of the applied material. The optimal condition of the concrete surface, however, depends on the type of repair being undertaken and the condition of the substrate. Also, it is not always possible to determine which material must be removed, because the zones of damaged or deteriorated concrete are sometimes not well defined. Thus, the best approach is to remove material until aggregate particles are being broken rather than simply being pried loose from the matrix. The water blasting can be used during surface preparation application for removing any kind of laitance. Before applying cement-based repair materials, the substrate should be saturated and the surface then dried to prevent the rapid loss of water from the repair material (to the substrate) and subsequent shrinkage and cracking. However, for resin-based materials the concrete surface must be dry for maximum adhesion to be achieved. Prior to the application of coatings, the moisture content of the substrate should be checked by using an electrode-type moisture meter.

It is frequently necessary to remove surface contaminants such as oil, rubber and rust from the work area in order to provide a sound, long-lasting bond between the existing structure and the new materials used to repair or rehabilitate the structure. The objective is to clean rather than to remove material. The following methods are used to clean the surface depending on type of contaminants and nature of the surface:

6.1 Chemical Cleaning

Concrete contaminated with oil, grease or dirt can be cleaned with detergent, trisodium phosphate or various proprietary concrete cleaners. The use of these materials should be followed by vigorous scrubbing and thorough rinsing with water to remove all residues. Solvents should not be used to clean concrete since they will dissolve the contaminate and carry it deeper into the concrete. Muriatic acid is relatively ineffective in removing oil and grease.

6.2 Mechanical Cleaning

Mechanical cleaning devices are of two types, rotary and impact. Rotary equipment includes discs and grinders usually used on low compressive strength concrete substrates that do not have a steel trowelled finish. These devices are not effective on hard dense concrete, which they are likely to polish rather than abrade.

Impact tool devices such as bush hammers (Fig. 10), scabblers and needle guns (Fig. 11) will effectively remove several millimetres of surface concrete. Varying degrees of surface preparation may be achieved, depending on which hammer heads are used. Scabbling operations are dusty and noisy and produce some vibration. Because impact tools pulverize the concrete and can cause fracturing of the concrete substrate, it may be necessary to use water jetting or wet sandblasting for a final surface cleaning. Alternatively, a scarifier can be used which is very much effective on old floors, and will successfully remove old paint, but are relatively expensive and heavy, and require skilled operators.

Fig. 10: View of a Bush hammer used for surface removal of concrete

Fig. 11: View of a needle gun for cleaning concrete surface or rusting of steel

6.3 Blast cleaning

Blast cleaning includes abrasive sand blasting, both wet and dry, shot blasting, and water jet cleaning (Fig.12). All these methods have been discussed in removal of concrete section. But same can also be used during surface preparation of the concrete before application of repair mortar or coating. Additionally, if the existing coating has worn off in spots, the bare concrete will become more deeply etched, producing an irregular surface. When a thick topping is to be applied, the irregular surface will not be a problem, but when a coating is to be used, a uniform surface is needed. If the previous coating is thicker than 3 mm, or has worn off in spots, it should be removed with a scarifier or stripping machine before the surface is shotblasted.

Fig. 12: VHigh-pressure water blasting for concrete cleaning

6.4 Acid Etching

Acid etching removes enough cement paste to provide a roughened surface, which improves the bond between the replacement materials and the substrate. Because of the potential for corrosion, ACI Committee 515 recommends that acid etching only be used when no alternative means of surface preparation is acceptable.

6.5 Flame Cleaning

Flame cleaning is generally used to clean concrete surfaces that are to receive coatings or resinous overlays. This method is particularly useful for oil-stained floors because it permits the application of coatings to the concrete immediately after. A special multi-flame oxy-acetylene blowpipe is passed over the concrete surface at uniform speed. The thickness of the concrete layer removed depends on the speed at which the blowpipe is moved and the properties of the concrete. The most suitable blow pipe speed lies between 0.02 m/s and 0.03 m/s. Concrete and coating removal involves both the spalling and melting off of the surface. The laitance layer is usually removed to a depth of 1 or 2 mm and in a few instances up to 4 mm. The moisture content of the concrete has the greatest effect on concrete removal — completely dry slabs do not produce much spalling, while slabs soaked in water prior to flame cleaning produce uniform concrete removal. Past experiences indicate that flame cleaning does not promote the migration of deep-seated oil to the surface, does not remove the alkalinity of the matrix — the surface gradually attains alkalinity similar to that of new concrete — and does not promote the development of any visible cracks in the surface. The method has proven useful for such applications as the recoating of concrete floors or the removal of defective elastomeric waterproofing membranes from parking decks.

7.0 Safety, Health & Environment

Demolition work involves many of the hazards associated with construction. However, demolition incurs additional hazards due to unknown factors such as deviations from approved plans, unauthorized modifications, hidden materials and weaknesses of construction materials used on the project. The vast majority of hand tool injuries occur when the proper tool is not used for the job. The following health and safety aspects should be taken care:

- All personnel involved in a demolition project must be fully aware of the various hazards, which may be encountered, and the safety precautions that may be taken in order to control the hazards.
- Make sure that wrecking bars or crowbars have a sharp point or keen edge that allows the bar to get a firm hold on the object being moved. Using poor substitutes for these tools, such as pieces of pipe, angle, iron or other building materials can be a serious mistake, since they are more likely to slip or break and cause injury.
- Wire and bolt cutters require the wearing of eye protection at all times. Don't use a cutter too small for the task, or try to gain added leverage by putting a length of pipe over its handle.
- Sledges and hammers require workers to wear eye protection in order to prevent possible blindness from concrete chips and splinters. Inspect equipment prior to use for unacceptable conditions such as mushroomed heads, cracks, looseness and splinters.
- Shovels are often thought of as a relatively safe construction tool, but improper use can cause serious back injuries, as well as injuries to other parts of the body.
- Falling debris is of particular concern in demolition projects, both in terms of the workers actually doing the demolition work, and other workers or bystanders. Make sure the demolition area is clear of all unnecessary personnel prior to work.
- A large part of demolition safety involves proper dress and the use of appropriate safety accessories, especially when using power tools. Ensure the use of PPE equipment such as safety goggles or glasses with side protection, face mask in dusty applications, ear plugs, heavy work gloves and steel-toed shoes.

Effects of the breaker operations must be monitored to ensure minimal impact on the surrounding environment. The primary environmental issues of concern are dust, noise and flying debris created both from the breaker operations and from the subsequent debris removal process. Noise level of such jobs should be within permissible limit. Before taking any kind of repair job necessary barricades and screens should be provided near the repair area. Any statutory permission required from local administrative authority should be taken before the commencement of repair work.

The debris generated from the breaker operations consists of pieces of concrete and aggregate in a variety of sizes. The larger pieces can be removed by hand and loaded into a wheelbarrow or a loader bucket. The small pieces and dust can then be blown away with an air blower. Disposal of the debris generated from breaker operations is generally not a major concern because the debris is readily accepted by most material processing centers which can be used as recycled aggregate after proper cleaning in concrete manufacturing industries.

8.0 Conclusion

One of the biggest problems impacting the long-term performance of concrete repairs and bonded overlays is cracking of the repair material and repair material debonding from the concrete substrate. A prerequisite for monolithic action is long lasting bond between the existing concrete substrate and the repair material which mostly depends on the proper surface preparation.