Removal of a Degraded Concrete Layer with Emphasis on the Surface Optimisation before Application of Repair Material

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Abstract. *The contribution is aimed at destructive effects of a high-velocity water jet, used as a tool removing the corroded and degraded layers of concrete. Application of water jets for preparation of surfaces on the undamaged concrete core during reconstructions is one of the most common and safe destruction actions on structures, in particular when vibrations can induce some fissures in the undamaged parts of concrete. The removing process was studied on artificially prepared degraded concrete layers both theoretically and experimentally. The tests were designed so that the results could be consequently used for applications during repair actions on concrete constructions damaged by gaseous carbon and sulphur oxides, water during its phase changes and after several cycles of chemical defrosting substances application. The most important up-to-date result is the evaluation of a methodology for determination of both degraded and subsequently finished concrete surface.*

Keywords

Concrete, degradation, repair, surface, water jet.

1. Introduction

Reconstruction of corroded and degraded structures, in particular concrete ones [1], [2], [3], is a very important worldwide topic. The first step often includes removing of the eroded and degraded layers. Subsequently, the new material layers are applied on such prepared surfaces to protect the construction and improve its static properties.

Damaged concrete and other material parts can be quickly and efficiently removed using the high-velocity water jet (HVWJ) whose impact on firm brittle material has been described in past [4], [5]. Material surfaces can be repaired even in hard accessible places and under extreme conditions. In some EU countries (for example in Germany) the use of the HVWJ as a tool for removing of corroded and degraded materials on certain types of structures (bridges and roads) is prescribed and classified in the appropriate standards for reconstruction.

Many structures needing reconstruction, especially in civil engineering (stalks, stacks, exhaust towers, dam walls, bridges, etc.), are still treated in an inappropriate way in our country, applying various blasting and drilling devices and machines producing hard vibrations. Using of the HVWJ for heavily loaded constructions (bridges and roads), thin-walled constructions (exhaust towers and stalks) and everywhere, where the large area removal of weathered parts of construction materials is considered, is strongly needed, especially for reducing of the dynamic loading of the structure during removal of a corroded material to the minimum. However, the preparation rate needs to be sufficient for preparation of constructions for application of repair materials. Therefore, the new ways of the HVWJ applications are tested to prepare the more powerful mobile and economically efficient equipment.

2. Concrete Samples

An easiest way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into iConcrete [2], [3] is an artificial construction material created joining filler (solids with appropriate grain size) with an appropriate binding material. The most often used fillers are various natural or artificial inorganic materials (aggregates) and the binder is usually cement. Cement and aggregates are mixed with certain amount of water and subsequently the mixture sets as a concrete.

Concrete has very pressure resistance that is useful for applications in civil engineering. Nevertheless, the tensile strength is quite low, approximately one tenth of the uniaxial compressive strength. Such a brittle material is incapable to resist larger deformation. Its elongation limit is approximately 0,1 % for the simple tensile test and 0,3 % for the bending tensile test, due to the concrete plasticity during this type of loading.

Concrete compressive strength depends on the concrete grade and varies also according to the site of preparation. Concretes prepared at the construction site can have uniaxial compressive strengths up to 33 MPa, those from concrete plants up to 60 MPa and the ones from laboratories up to 120 MPa. Low tensile strength is compensated by steel reinforcements. Regular concretes can stand higher loads than brick masonry, however, they have worse heat and sound isolation characteristics and they are heavier.

Cement is produced from a mixture of calcite, marl and a small amount of some other components in powder form. The powder is clogged into the clinger in a cement furnace and then it is finely ground. Cement is slowly dissolved after mixing with water and aggregates, subsequently it crystallizes creating the artificial stone. After hardening it keeps its stability and strength even under water.

Another component of concrete is aggregate. This is filler composed of grainy inorganic substances with suitable physical and chemical properties. The aggregate strength must be at least 1,5 times higher than the required concrete pressure strength. Aggregate absorption capacity is related to its porosity, and it should not exceed 1,5 %. If the absorption capacity is lower, the aggregate can be considered as freeze-resistant. The grain shape and granulation are very important technological properties of aggregates - the grain shape influences workability of a concrete mixture. Flat grains, width is larger than thickness, and elongated grains, length is larger than thickness, are not very suitable. The granulation needs to be optimised for achievement of the smallest gaps and the smallest specific surface. This minimizes the amount of cement binder necessary for filling of holes and covering of aggregate grains.

2.1. Concrete Degradation

Factors influencing concrete quality [1] can be divided into several groups: aggressive chemicals, liquid or solid substances and freezing temperatures.

Aggressive chemicals can affect both cement and limestone and also dolomite aggregates. The reaction of acids with carbon hydroxide often creates water-soluble limestone compounds that are consequently leached from the concrete. Freezing damage occurs on wet surfaces, where water penetrates to concrete pores and capillaries and increases its volume during transformation to ice and local tensions break the concrete. Liquid substances like acid or lye remove calcium carbonate out of concrete. They can also contain substances creating in reactions with cement binder substances with larger volume. The volume increase inside concrete induce small fractures. Solids in dry state do not break concrete at all, but when hydrated their action is analogous to the action of liquid substances. Therefore, it is very important to focus on the hygroscopic substances occluding atmospheric humidity subsequently reacting inside the concrete and creating components inducing corrosion pressures.

2.2. Analysed Samples

Experimental samples were prepared in the Faculty of Civil Engineering, Brno University of Technology, laboratory from several types of concrete. Samples used in experiments presented in this paper were prepared as the standard concrete of class B30 (corresponding to the Czech standards). Cement is CEM I 42,5, aggregate with the grain size 0-4 mm is from Ledce, the one with the size 8-16 mm is from Olbramovice, the one with the size 11-22 mm is from Lomnicka, plasticiser is Sikament 100. The concrete samples were divided into several groups. The first group is a reference one; the samples are stored in a room away from degradation agents. The second group consists of samples placed in a solution with high concentration of ammonia NH_3 ions in water solution (up to 4% in volume) that simulates aggressive action in chemical plants, waste drains and other objects. The third group was placed to a solution of Na_2SO_4 (the concentration of Na_2SO_4 is 51,2 g/l) simulating situation in chemical plants and influence of aggressive waters rich in sulphates. The fourth group consists of samples stored in special containers with concentration of CO_2 gas around 10 % of volume (checked and filled each day) and relative humidity of 90 % - these conditions simulate carbonation of concrete by CO_2 in combination with atmospheric humidity or simulate the influence of aggressive CO_2 contained in underground waters. The fifth group was placed to a water solution of NaCl (100 g/l) that simulates aggressive action in sewers, water treatment plants or pools with chlorinated water. The sixth group consists of samples that were exposed to several tens of freezing and thawing cycles.

The solutions were changed every two months and their pH was checked every 14 days. Nevertheless, the samples are from heterogeneous materials, therefore their local strength can differ from the presented prescribed values. Furthermore, aggressive media degrade a cement binder faster than aggregate. Therefore, the local depths of water jet penetration into material can differ from values calculated from theoretical equations.

2.3. Concrete Repair

The basis of the concrete repair action is the removing of the corroded and degraded concrete from area that needs to be fixed. The concrete is removed to a required depth where the concrete is supposed to be undamaged. The surface needs to be thoroughly cleaned before application of repair material. The corroded concrete layer can be removed using various mechanical means, like e.g. an air pick, compressed hammer, pick-hammer, cutting machine or another impacting devices. The disadvantage of all these devices is the possibility of fissure formation in the repaired apparently undamaged concrete. In case of hydraulic removal the probability of described problem is substantially reduced [7], but it is necessary to solve the cleaning-up of the wastewater.

3. High-Velocity Water Jet

The areas of the HVWJ [4], [5], [6] use can be divided to several groups. The first type of applied water jet is the continuous one without any additives. It can be used for parting of a low strength non-fragmenting materials, thin layers of plastic and mild metal materials, disintegration of brittle materials (concretes, rocks, scales), removal of rust and paints and surface modification.

Continuous jets with additives can be applied on the basis of used additives:

- liquid polymers increase efficiency and coherency; apart from some exceptions it is not used due to ecology considerations,
- solid additives – abrasives are used for preparation of abrasive water jet (AWJ); AWJ is used for high quality machining of metals, hard-to-machine and laminated materials, glass, rocks, ceramics, etc.

The AWJ is used also for splitting of very thick materials in nuclear power plants, e.g. reinforced concrete girders, pillars and panels, with no special requirements on surface quality, but with very important ecology and economy considerations. Tools producing compound jet movements, rotary, vibration and oscillating, are often used for demolitions.

Another tool type produces flat profile jet (called also “fan jet”) Fig. 1. These jets are used for finishing of material surfaces, especially for removing of degraded rock, concrete or other low resistant and cohesive layers. Higher destruction of materials can be achieved using discontinuous jet. That can be generated either as pulsing ones or modulated ones. Interrupted continuous jets are often low efficient. It was proven experimentally that pulsing and modulated jets after separation into drops are much more efficient in material disintegration than the continuous ones in cleaning, removal of layers, corroded material disintegration, etc.

Comparison of different methods of concrete surface cleaning shown that the most suitable tool for removal of the degraded concrete layers before repair is HVWJ [7]. It is suitable also from the ecological and economical point of view. Using of the HVWJ enables to remove just degraded concrete up to the solid state. There are no significant vibrations and heat or tension stresses inside concrete that could induce its failure. It is also possible to uncover reinforcement and get rid of rust. However, the most important effect of water jet seems to be the creation of the optimal surface for application of repair materials through increasing their adhesion to prepared surface.

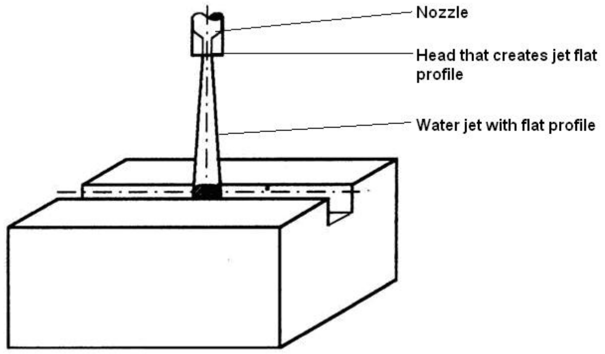

Fig. 1: The application of high-velocity water jet to a concrete surface, groove cutting.

The study at the Missouri-Rolla University [7] concerning reconstruction of concrete constructions and reinforcement proved the ability to prepare surfaces with roughness that was the best for adhesion of the repair materials comparing all tested technologies. However, no sufficiently objective method usable for identification of the surface preparation quality has been prepared so far.

Preparation of concrete for repair actions requires cleaned, sufficiently rough and undamaged surface. All undesirable, weakened or damaged concrete parts need to be removed. Then the appropriate roughness of surface is to be prepared, because shortage in this parameter leads to a lower cohesion of the concrete surface with repair materials. Therefore, the International Concrete Repair Institute (ICRI) has prepared nine plastic models with various degrees of roughness. These samples serve as standards for evaluation of concrete surfaces. However, their use is based on subjective comparison, not objective evaluation.

Nevertheless, according to the ICRI it is necessary to select a treatment method with respect to requirements summarized here:

a) the surface prepared for repair actions must be undamaged,

b) steel concrete reinforcements must be undamaged and its cohesion with concrete must not be weakened,

c) vibration, temperature or any other physical phenomena that occur during surface treatment must not weaken the basic undamaged concrete.

As mentioned before, surface can be prepared applying various different mechanical methods. Using of air pick tools for concrete treatment increased probability of cohesion failure during the tensile test as it was proved by comparison of the sand blasting, jack hammering and HVWJ in [7] – the failure probability in percents was 38 %, 31 % and 7 % respectively. This result is related to the size of the area generated after treatment, as concrete consists of aggregate and cement binder, the aggregate being stronger than the porous cement binder (removal of weakened cement is assumed). So, it can be concluded that the surface with maximized area is the best one.

4. Surface Photographing

Roughness of the surface prepared using the HVWJ can be made better visible when the oblique exposure is used. Generated shadows can be consequently photographed by a camera. To keep minimal distortion of photography the optical axis of camera needs to be perpendicular to the inspected surface. The axis of the light source has been set one by one to the values 0°, 10°, 20°, 30°, 40°, 140°, 150°, 160°, 170° and 180° measured from the plane of the inspected surface. The background light exposure in the laboratory has not exceed value 10 lx.

A groove being the object of inspection has been digitally cut out from the photography. Then the picture has been transferred to the grey one (Fig. 2) and pixels of the computer degree grey scale have been determined and summarized in the histogram (Fig. 3).

Fig. 2: The groove photography transformed into grey scale.

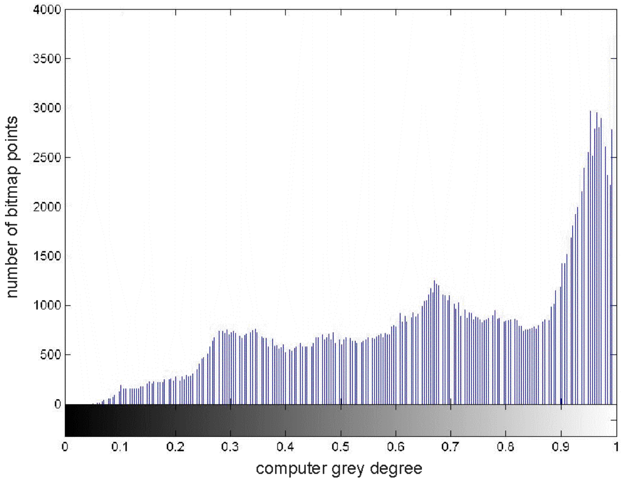

Fig. 3: The histogram of grey scale transformed into interval <0; 1>.

This histogram shows how many pixels belong to individual grey level in the 256 levels computer scale transformed into the span from zero (black) up to one (white). This evaluation can yield information about lighted and shaded parts. The next processing of the histogram performed introducing selected threshold value (Fig. 4) transforms the original photography into black and white one summing the pixels lying in the intervals <0; threshold> and <threshold; 1>. The numbers of pixels lying in the shade and the number of lighted ones are presented in Fig. 5.

Fig. 4: The modified groove photography after use of the threshold.

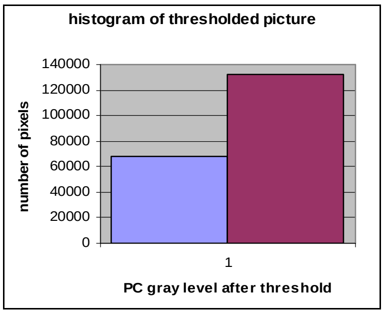

Fig. 5: The groove histogram after summarization of pixels in groups set introducing the threshold.

5. Comparison

The described application of the threshold value for an inspection of the digital photography has been used for analyses of grooves prepared on concrete samples by the HVWJ. The grooves were made on concrete samples described in part 2.2 Analysed Samples at the liquid jet workshop of the Geonics Institute of CAS in Ostrava. Two water jet tools were used for this purpose: fan jet with flat profile produced by nozzle Lechler 1508 and two water jets produced by rotating tool Barracuda™. The traverse speed of both tools was set to 400 mm/min and the pressure generated in the pump was 30 MPa. The distances from the nozzles (tool surfaces) to the sample surface were 40 mm and 50 mm for Lechler nozzle 1508 and Barracuda™ tool respectively. The analysed area size on the photo was 1000 x 200 pixels. The samples were photographed with the light source axis in 30° position.

The inequalities produce shades covering a part of surface. This shaded part yields the information about surface roughness and the size of the actual surface. As proven at the Missouri-Rolla University [7] these surface characteristics strongly influence the cohesion between the repaired concrete and the applied repair substances.

The photographs were transformed into the grey scale and their histograms were divided using threshold value 0,6 in the MATLAB program. Pixels in the black and white areas were summarized to determine the size of the shaded area and the disintegrated volume was also measured. The substance remaining in a flexible state after its polymerisation was used for filling of the groove. After polymerisation, the stiffened filling has been removed from the groove and its volume has been determined. The results are summarized in the Tab. 1.

Tab.1: Measured values on selected samples.

Corrosive medium	**S. No.**	**Black** (zero)	**White** (one)	**Dis. Vol.** (cm^3)	**HVWJ profile**
CHRL 100	B3	68021	131979	30,0	Flat
Frost 100	B14	65608	134392	28,2	Flat
Chlorides	B41	35848	164152	41,3	Rotary
Sulphates	B46	31126	168874	21,3	Rotary
Nitrates	B63	28597	171403	23,8	Rotary

Legend: S. No. – sample number; Dis. Vol. – disintegrated volume; CHRL 100 – one hundred freezing and thawing cycles applied on concrete samples in NaCl based solution simulating corrosive action of winter treatment of roads; Frost 100 – one hundred freezing and thawing cycles applied on wet samples; Chlorides – concrete samples after one year of exposition by NaCl water solution; Sulphates - concrete samples after one year of exposition by Na_2SO_4 water solution; Nitrates - concrete samples after one year of exposition by NH_3 water solution.

6. Discussion of Results

Results presented in Tab. 1 indicate that flat jet from Lechler 1508 nozzle produces higher amount of rough surface than rotating tool Barracuda^{TM} with two nozzles (the higher amount of inequalities on surface treated by flat jet corresponds with higher amount of black after application of threshold). It is apparent that this result is independent on the type of concrete sample corrosion. Small differences between samples fall into the interval of uncertainty determined for such measurement from input conditions, measuring devices and methods. The determined uncertainty interval is approximately ± 10 %.

The evaluated size of photography remained constant in all cases used for comparison, but the real groove sizes were larger. In the case of the rotating jets the grooves were wider, especially on the B41 sample. It can be said that data from measurement on this sample is misleading for a specific evaluation. In order to obtain more exact data it would be necessary to compare results of one type of concrete corroded by one particular effect, and disintegrated using constant values for both types of applied water jet tools. This approach could not be realized due to lack of financial sources and technical problems at workshop applying water jets.

7. Conclusion

The presented work has been aimed at influence of the degrading medium and the disintegration tool on surface preparation of concrete before repair works. The method of surface evaluation has been developed. It is based on surface photography processed in the computer greyscale and transformed through the threshold implementation into the black and white image. The percentage of black was used for characterization of surfaces produced by flat jet and two rotating jets.

The research did not prove any substantial differences regarding the degrading factors. In contrast to the degrading media the tool shape plays a higher importance. The rotating head with two jets creates wider groove than flat jet, but shallower and with lower surface inequalities. Therefore, the flat jets seem to be the more appropriate tools for preparation of concrete surfaces ensuring better fixation of repair materials.

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