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# HIGH-SPEED WATER JET (HSWJ) FOR CONCRETE SURFACE TREATMENT – EVALUATION OF CONCRETE SURFACE PROPERTIES AFTER BLASTING USING HSWJ TECHNOLOGY

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Original scientific paper

The article summarizes the results of the interaction of high-speed water jet (HSWJ) and concrete with precisely defined properties. HSWJ technology is inconvertible for renovation of concrete structures, in particular for removing degraded layer of concrete. Concrete structures are exposed to aggressive influences of environment during their lifetime. Concrete can also be damaged by inappropriate use of the structure, overloading or action of fire. When using HSWJ technology to disintegrate concrete surfaces it is necessary to set the jet parameters according to the properties of the concrete. The concrete properties have crucial impact on the interaction of HSWJ and concrete. The properties of tested concretes in fresh and hardened state were described. The results of disintegration of concrete using high-speed water jet were determined after measuring the cut depth. The evaluation of properties of concrete surfaces cured with HSWJ technology includes namely surface tensile strength and observation of the influence of the jet on the surroundings of the cut, possible cracks and the overall appearance of the concrete surface including photographs. These values were compared in relation to the defined concrete properties and the parameters of the jet (water pressure, flow rate and jet type).

***Keywords:*** *high-speed water jet, concrete, surface, depth of cut, reconstruction, relief of blasted concrete surface*

## Uporaba visokobrzinskog vodenog mlaza za obradu površine betona – procjena svojstava površine betona nakon erozije uporabom tehnologije visokobrzinskog vodenog mlaza

Izvorni znanstveni članak

Članak sažima rezultate interakcije visokobrzinskog vodenog mlaza (VBVM) i betona s točno definiranim svojstvima. Tehnologija VBVM je nezamjenjiva za obnovu betonskih konstrukcija, posebice za uklanjanje uništenog sloja betona. Betonske konstrukcije izložene su agresivnim utjecajima okoliša tijekom životnog vijeka. Beton također može biti oštećen neprimjerenom uporabom konstrukcije, preopterećenjem ili djelovanjem vatre. Kada se tehnologija VBVM rabi za razgradnju betonskih površina potrebno je podesiti parametre mlaza prema svojstvima betona. Na svojstva betona presudan utjecaj ima interakcija VBVM i betona. Opisana su svojstva ispitivanog betona u svježem i očvrsnutom stanju. Rezultati razgradnje betona pomoću visokobrzinskog vodenog mlaza određeni su nakon mjerenja dubine reza. Procjena svojstava betonskih površina tretiranih tehnologijom VBVM uključuje naime rasteznu čvrstoću površine i promatranje utjecaja mlaza na okoliš reza, moguće pukotine i ukupan izgled betonske površine uključujući i fotografije. Ove su vrijednosti uspoređene u odnosu na definirana svojstva betona i parametre mlaza vode (tlak, protok i tip).

***Ključne riječi:*** *visokobrzinski vodeni mlaz, beton, površina, dubina rezanja, rekonstrukcija, reljef erodirane betonske površine*

## 1 Introduction

Technology of high-speed water jet (hereinafter referred to as HSWJ) is used in construction industry in particular for treatment of surface before renovation of concrete structures. As for renovation of concrete surface, the most frequent use of HSWJ is removal of concrete damaged by atmospheric corrosion, concrete damaged by aggressive environments, concrete worn down by using or at change of purpose of construction. However, HSWJ can be used for removal of concrete damaged by high temperature of wild fire, too. Removed concrete has various physical properties. To use the technology of HSWJ properly, it is necessary to set parameters of water jet in accordance with the properties of given concrete. Properties of concrete are very important for final effect of the interaction between HSWJ and concrete.

### 1.2 Possibilities of use of HSWJ for structures damaged by fire

One of topical problems, where treatment of concrete surface is important, is renovation of concrete surface damaged by high temperature and fire.

The basic questions of influence of high temperature on concrete involve not only complex identification of changes in cement matrix, but also transport phenomena. Analysis is complicated by the fact that cement based concrete is a composite material consisting (among others) of two considerably different components: mastic cement and aggregate. Moreover, mineralogical composition of various types of aggregate differs. Heated up minerals show various metamorphic changes that are typical for each of the minerals. The sum of the many changes taking place in heated up concrete shows the changes of physical, thermal and mechanical properties.

The temperature of wild fire influences the strength as well as other characteristics of concrete, like elasticity modulus. If concrete is heated up above 100 °C, water (free and partly physically bound water) begins to evaporate, which partly increases strength, however the value of elasticity modulus decreases. In the interval 100 ÷ 200 °C, the value of compressive strength remains practically the same as before heating. Temperatures around 200 ÷ 300 °C do not decrease strength of common concrete even after longer action (maximally 10 hours). Temperatures around 300 °C ÷ 500 °C cause breaking chemically bound water loose (in hydrate of lime) and produce vapour dissociation of bonds. Thus rapidly decrease both strength and elasticity modulus of concrete and this trend continues with temperature increase. Only the strength of fire resistant concrete slightly increases between 800 °C and 1000 °C. Concrete starts to melt at the temperature 1300 °C.

From the macroscopic point of view, high temperatures have the following impact on concrete structures:

- 100 °C ÷ 300 °C → liberation of free water in concrete; common concrete can show surface damage in the form of micro cracks, slight increase of compressive strength (so-called quasi-strengthening), however tensile strength and elasticity modulus slightly decrease.
- 300 °C ÷ 1200 °C → explosive flaking of surface layers of concrete, considerable decrease of strengths and

disturbance of the structure of concrete in the form of cracks, considerable decrease of elasticity modulus (by as much as 50 %), increase of creep.

- Above 1200 °C → total decrease of strengths and dissociation of the concrete structure [1].

Extent of degradation of reinforced concrete structure caused by high temperature depends on several aspects. Basically, two main aspects can be mentioned: parameters of thermal load and parameters of material exposed to high temperature. Concrete structures exposed to high temperatures are damaged in accordance with the above-mentioned principles. Structures damaged in this way usually have to be repaired in the shortest possible time and put into service again, which requires specific renovation action. The general principle of renovation is based on removal of degraded non-coherent material and its replacement with new renovation material. HSWJ represents a fast and economical method of removal of non-coherent material. It is necessary to know basic physico-mechanical parameters of removed material, if the method is to be used effectively and economically [2]. Detailed diagnostics of renovated structure gives required basic information. Diagnostic is more appropriate and accurate if the processes causing damage of the structure are known better. Nowadays, the Technical University in Brno, Faculty of Construction and the Institute of Geonics of the Academy of Sciences solve the project GAČR P104/12/1988 "Study of interactions of components of cementitious composites exposed to high temperatures", which focuses on the study of interactions of components of cement composite materials exposed to high temperatures. Experience gained during resolving of the problems of removal of degraded concrete by means of the technology of HSWJ and knowledge of the process of concrete damage caused by high temperature, help understanding the behaviour of cement composites exposed to high temperatures and application of HSWJ technology for removal of concrete damaged to high temperatures.

## 2 Methods of experimental work

Experimental work focused on the verification of the effect of high-speed water jet on concrete of various classes and quality.

Experimental work followed this frame:

- Properties of tested concrete both fresh and hardened (after 28 days of standardized maturing and at the time of disintegration tests with HSWJ) were described.
- Result of disintegration test with HSWJ technology was determined – depth of cut was measured.
- Properties of concrete surface treated with HSWJ technology were evaluated – tensile strength of surface layers of concrete, effect on area near the cut, cracks, appearance of the treated surface. The values are stated with respect to defined properties of concrete and used parameters of HSWJ – pressure of water, water discharge and type of a water jet.
- Bond strength of renovation mortar to concrete surface treated by HSWJ technology was assessed – renovation plaster was applied to concrete surface treated with HSWJ technology, bond strength of renovation mortar to both treated and untreated concrete surface were evaluated.

### 2.1 Preparation of test specimens for the tests of HSWJ blasting of concrete

**Mix designs of concrete:**

1. Concrete of the class C 20/25, labelling of specimens C20/25
2. Concrete of the class C 45/55, labelling of specimens C45/55
3. Self compacting concrete SCC of the class C 45/55, labelling of specimens SCC
4. Concrete with inappropriate dosage of components, labelling of specimens C45/55 B.

**Manufacture and testing of fresh concrete:**

- Preparation and weighing of components for each of the mix designs. Wetting of mixer with forced circulation. Dosage of powdery components and mixing. Then, 90 % of water content was added. After partial mixing of components, the rest of water with plasticizer was added. Total time of mixing was 4 minutes. Emptying the mixer after mixing.
- Test of consistency of fresh concrete was carried out.
- Concrete was placed in steel formwork with dimension 100×100×400 mm and plastic formwork with dimensions 150×150×150 mm. Testing specimens were made for determination of strength characteristics and volume weight of concrete after 28 days and at the time of disintegration with the HSWJ technology (cubes 150×150×150 mm and beams 100×100×400 mm) as well as testing specimens for the HSWJ disintegration tests (beams 100×100×400 mm).
- Concrete was compacted on vibration table with electromagnetic clamping of forms. Time of compaction was ca 2 minutes in accordance with the character of concrete mix, average acceleration $a$ = 20 m/s, amplitude $A$ = 0,35 mm, frequency $f$ = 50 Hz.
- After compacting of testing specimens, volume weight of fresh concrete was determined.
- After 24 hours, testing specimens were taken out of forms and placed in standardized environment at average temperature $\vartheta$ = 18,3 °C and relative humidity of air 92 %.
- After 28 days, properties of hardened concrete were determined.
- Properties of hardened concrete at the time of tests of

**Table 1** Concrete composition per 1 m$^3$

| Components / Concrete mix | C20/25 | C45/55 | C 45/55 (SCC) | C 45/55 B |
|---|---|---|---|---|
| CEM I 42,5 R Mokrá | 330 kg | 420 kg | 360 kg | 420 kg |
| Water | 170 kg | 165 kg | 174 kg | 175 kg |
| Plasticizer CHRYSO®Plast 760 | 2,6 kg | - | - | - |
| Plasticizer CHRYSO®Fluid Optima 208 | - | 3,65 kg | - | 3,65 kg |
| Plasticizer CHRYSO®Fluid Premia 320 | - | - | 5,5 kg | - |
| Aggregate 0-4 Žabčice (mined) | 860 kg | 790 kg | 930 kg | 760 kg |
| Aggregate 4-8 Žabčice (mined) | - | - | 200 kg | - |
| Aggregate 8-16 Olbramovice (crushed) | 990 kg | 980 kg | 510 kg | 980 kg |
| Fly ash Dětmarovice | - | - | 90 kg | - |
| Water-cement ratio $w$ | 0,47 | 0,39 | 0,48 | 0,42 |

disintegration of concrete with HSWJ technology were determined.

### 2.2 Technical parameters of the device for HSWJ technology

Concrete specimens were blasted with HSWJ at the pressure of 130 MPa and 210 MPa. Blasting of testing specimens was carried out by the company NET spol. s.r.o. Rotating cutting head Baraccuda with four OS7 nozzles diameter 4,25 mm was used. Device URACA KD716 was used, output 100 kW, maximal pressure 280 MPa, maximum water discharge 17 l/min.

### 2.3 Evaluation of treatment of concrete by the HSWJ technology

Following parameters were evaluated on concrete blasted with the HSWJ technology:

- Measurement of depth of the cut.
- Evaluation of properties of concrete surface treated by HSWJ: tensile strength of surface layers before and after HSWJ blasting, evaluation of areas near the cut, presence of cracks, appearance of treated concrete - visual assessment including photographic documentation.
- Bond strength of renovation mortar to concrete surface treated by HSWJ technology was assessed – renovation mortar was applied to concrete surface treated with HSWJ technology, bond strength of renovation mortar to both treated (blasted) and untreated concrete surface were evaluated.

## 3 Results and discussions

### 3.1 Properties of tested concrete

Following properties of fresh and hardened concrete were examined:

1. Consistency of fresh concrete according to EN 12350-2 Testing fresh concrete - Part 2: Slump-test [4], EN 12350-5 Testing fresh concrete - Part 5: Flow table test [5], EN 12350-8 Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test [6].
2. Density of fresh concrete $D$ (kg/m$^3$) according to EN 12350-6 Testing fresh concrete - Part 6: Density [7].
3. Density of hardened concrete $D$ (kg/m$^3$) according to EN 12390-7 Testing hardened concrete - Part 7: Density of hardened concrete [10].
4. Compressive strength of concrete $f_{cc}$ (MPa) according to EN 12390-3 Testing hardened concrete - Part 3: Compressive strength of test specimens [8].
5. Flexural strength of concrete $f_{cf}$ (MPa) according to EN 12390-5 Testing hardened concrete - Part 5: Flexural strength of test specimen [9].
6. Tensile strength of concrete surface layers $R_t$ (MPa) according to CSN 73 1318 Determination of tensile strength of concrete [11].
7. Tensile splitting strength of concrete $f_{ct}$ (MPa) according to EN 12 390-6 Testing hardened concrete - Part 6: Tensile splitting strength of test specimens [12].

**Table 2** Properties of fresh concrete

| Concrete | Consistency | Density of fresh concrete $D$ /kg/m$^3$ |
|---|---|---|
| C 20/25 | S3 | 2390 |
| C 45/55 | S3 | 2470 |
| SCC | SF1, VS2 | 2360 |
| C 45/55 B | F4 | 2370 |

**Table 3** Properties of concrete samples after 28 days of standard hardening

| Concrete | Density $D$ /kg/m$^3$ | Compressive strength $f_{cc}$ /MPa | Flexural strength $f_{cf}$ /MPa | Tensile splitting strength $f_{ct}$ /MPa |
|---|---|---|---|---|
| C 20/25 | 2340 | 52,5 | 7,3 | 2,80 |
| C 45/55 | 2350 | 71,3 | 9,1 | 3,50 |
| SCC | 2340 | 56,6 | 9,1 | 3,70 |
| C 45/55 B | 2350 | 53,6 | 7,1 | 3,65 |

**Table 4** Concrete properties at the time of blasting using HSWJ technology

| Concrete | Density $D$ /kg/m$^3$ | Compressive strength $f_{cc}$ /MPa | Flexural strength $f_{cf}$ /MPa | Tensile splitting strength $f_{ct}$ /MPa |
|---|---|---|---|---|
| C 20/25 | 2 340 | 52,9 | 7,5 | 2,70 |
| C 45/55 | 2 350 | 71,5 | 9,0 | 3,60 |
| SCC | 2 350 | 57,0 | 9,3 | 3,70 |
| C 45/55 B | 2 330 | 54,5 | 7,3 | 3,65 |

### 3.2 Photographical documentation of concrete treated with the HSWJ technology

Blasted concrete surface is shown in Figs. 1 ÷ 4.


**Figure 1** C 20/25 concrete, transition between uncured concrete surface (left) and blasted concrete surface (right), pressure 130 MPa

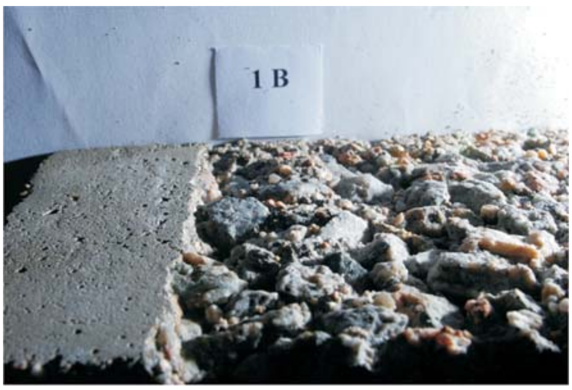


**Figure 2** C 20/25 concrete, transition between uncured concrete surface (left) and blasted concrete surface (right), pressure 210 MPa


**Figure 3** C 45/55 concrete, transition between uncured concrete surface (left) and blasted concrete surface (right), pressure 130 MPa


**Figure 4** C 45/55 concrete, transition between uncured concrete surface (left) and blasted concrete surface (right), pressure 210 MPa

## 3.3 Measurement of the depth of cut by means of optical microscope

Depth of cut was measured by means of optical microscope Nikon with TV camera Sony. The picture was transmitted into PC by means of software equipment LIM Elements (LUCIA). Tested specimen was placed under optical microscope Nikon with digital output. Depth of cut created by the HSWJ technology was read by means of a measuring rule. Depth was read by 5 mm, on the 150 mm long segment, on each corner of treated concrete surface. An average value and standard deviation were calculated from measured values.

Photographical documentation of measurement of the depth of the cut by optical microscope is given in the following pictures. Depth of cut is depicted by yellow measuring rule. Green line shows the height of original surface of concrete beam.

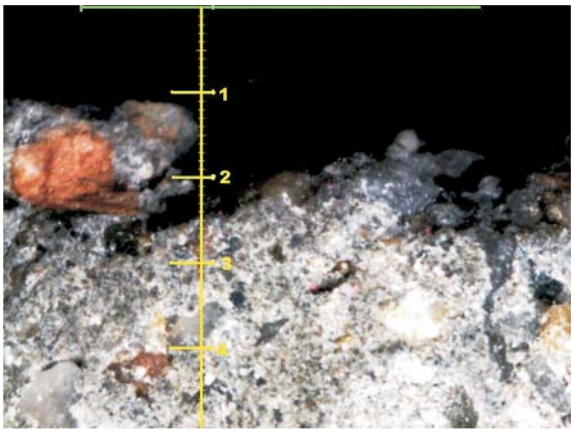


**Figure 5** Measuring the depth of the cut using optical microscope, C 20/25 concrete, pressure 130 MPa, average cut depth 1,21 mm, standard deviation 0,66 mm

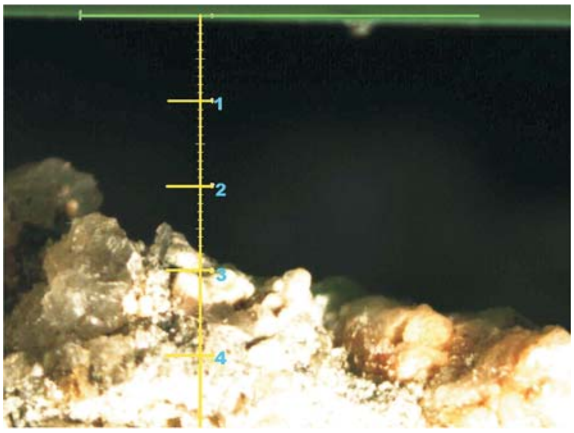


**Figure 6** Measuring the depth of the cut using optical microscope, C 45/55 concrete, pressure 210 MPa, average cut depth 2,26 mm, standard deviation 0,94 mm

**Table 5** Average cut depths in concrete after HSWJ technology curing

| Concrete | Average depth of cut /mm, HSWJ pressure 130 MPa | Standard deviation /mm | Average depth of cut /mm, HSWJ pressure 210 MPa | Standard deviation /mm |
|---|---|---|---|---|
| C 20/25 | 1,58 | 0,66 | 3,64 | 1,85 |
| C 45/55 | 0,95 | 0,71 | 2,26 | 0,94 |
| SCC | 1,19 | 0,70 | 1,98 | 1,07 |
| C 45/55 B | 1,43 | 0,59 | 3,19 | 1,19 |

## 3.4 Evaluation of tensile strength of concrete surface layers before and after blasting with HSWJ

The following testing specimens were used for determination of tensile strength of concrete surface layers:

- Testing specimens at the age of 28 days, concrete surface was not treated with HSWJ blasting.
- Testing specimens with concrete surface blasted with HSWJ technology, pressure 130 MPa and 210 MPa. Steel disks were bonded onto HSWJ blasted surface and near-surface tensile strength of concrete was determined.

**Table 6** Tensile strength of the concrete surface after HSWJ technology curing at different pressures, defined for 100×100×400 mm specimens

| Concrete | Tensile strength of concrete surface layers /MPa | | |
|---|---|---|---|
| | Not blasted* | HSWJ 130 MPa | HSWJ 210 MPa |
| C 20/25 | 2,25 | 3,10 | 3,80 |
| C 45/55 | 3,05 | 3,40 | 4,05 |
| SCC | 3,18 | 4,00 | 4,10 |
| C 45/55 B | 2,00 | 2,80 | 2,80 |

*Not blasted = concrete surface was not treated with HSWJ blasting
HSWJ 130 MPa = concrete surf ace blasted with HSWJ pressure 130 MPa
HSWJ 210 MPa = concrete surface blasted with HSWJ, pressure 210 MPa.

To evaluate the quality of preparation of the surface treated with HSWJ, determination of tensile strength of surface layers was carried out, both before and after HSWJ blasting. After blasting, all four examined specimens showed higher value of surface tensile strength compared to surface tensile strength of the same specimens before HSWJ blasting.

### 3.5. Evaluation of quality of concrete surface treated with HSWJ technology by determination of change of bond strength of repair mortar

For topping up concrete surface treated with HSWJ technology repair mortar Planitop 100 (manufactured by MAPEI) was selected. Renovation material was selected based on the height of surface to be topped up (maximal grain size of the mortar). Renovation material was prepared in accordance with technological process specified by manufacturer. Prepared mix of renovation mortar was applied onto concrete specimens manually with steel float.

Renovation mortar was applied onto three areas of testing specimens (untreated surface, surface blasted at the pressure 130 MPa and surface blasted at the pressure 210 MPa). Before application of renovation material, surface of concrete specimens was thoroughly wetted. Renovation material was applied so that the applied layer of renovation material was as thin as possible, however thick enough to level and cover inequalities of concrete surface produced by treating concrete surface at the mentioned pressures. Thickness of applied layer was always at least 3 mm, on the untreated surface, too. After hardening of repair materials, repaired concrete specimens were placed in maturing chamber with constant value of air humidity 95 ± 5 % and temperature 20 ± 3 °C.

After 28 days of maturing, all repaired surfaces of concrete specimens were subjected to test of bond strength of renovation mortar to the substrate by means of pull-off tests. The tests followed CSN EN 1542 Products and systems for the protection and repair of concrete structures – Test methods – Measurement of bond strength by pull-off [13]. Three metal disks were bonded to repaired surface with Sikadur glue. After hardening of the glue, disks were drilled out with a core drill through the whole layer of renovation mortar to the concrete substrate so that the loaded area was exactly defined. To measure bond strength of renovation mortar and concrete substrate, apparatus DYNA Z 16 with the range 0,0 to 7,5 MPa was used.

Measured values imply that bond strength of renovation mortar to concrete substrate is considerably higher on the surfaces treated by the HSWJ technology. If the influence of pressure of HSWJ applied on the concrete surface on bond strength of renovation mortars on prepared surfaces was compared, no major difference would be found. Failure on repaired surfaces without preparation of concrete substrate surface always occurred at the joint of renovation material and untreated concrete. This fact implies that renovation mortar could not connect with untreated concrete surface well enough to form a suitable repair system. Failure on repaired surfaces treated with HSWJ technology occurred usually in the layer of the repair material itself. Values measured with this type of failure correspond to the values of tensile strength of renovation material itself. If failure occurred at the point of contact of renovation material and concrete substrate, the measured values of bond strength were considerably higher, hence with sufficient parameters.

**Table 7** Determining the adhesion of repair mortar to concrete surfaces, material used for renovation: Planitop 100 MAPEI

| Concrete | Concrete treatment | Adhesion of repair mortar to concrete surfaces /MPa | Change of adhesion /% |
|---|---|---|---|
| C 20/25 | HSWJ 130 MPa | 2,05 | 173,3 |
| | HSWJ 210 MPa | 1,65 | 120,0 |
| | Not blasted | 0,75 | 0,0 |
| C 45/55 | HSWJ 130 MPa | 1,50 | 25,0 |
| | HSWJ210 MPa | 2,15 | 79,2 |
| | Not blasted | 1,20 | 0,0 |
| C 45/55B | HSWJ 130 MPa | 1,25 | 108,3 |
| | HSWJ 210 MPa | 1,65 | 175,0 |
| | Not blasted | 0,60 | 0,0 |
| SCC | HSWJ 130 MPa | 1,35 | 17,3 |
| | HSWJ 210 MPa | 1,45 | 26,1 |
| | Not blasted | 1,15 | 0 |

## 4 Conclusion and remarks

For determination of effects of HSWJ technology used for preparation of concrete surface, testing specimens were prepared from four mix-designs C20/25, C45/55, SCC and C45/55 B with inappropriate dosing of components. Reference specimens were used for verification of design strength class and other physico-mechanical properties.

Testing specimens were treated with the HSWJ technology at the pressures 130 MPa and 210 MPa and surfaces were evaluated by means of measuring the depth of removed material, measuring of tensile strength of near-surface layers, evaluation of effects on the area surrounding the cut, observation of the presence of cracks and photographical documentation. Average depth of removed material and standard deviation were determined for individual mix-designs and pressures of HSWJ. Average depth of removed material for the pressure 130 MPa was between 1,19 and 1,43 mm, for the pressure 210 MPa ware 1,98 ÷ 3,64 mm for all mix designs. After blasting, all four examined specimens showed higher value of near-surface tensile strength compared to the near-surface tensile strength of the same specimens before HSWJ blasting. Bond strength of renovation mortar to concrete substrate is considerably higher on the surfaces treated by the HSWJ technology. Failure on repaired surfaces without preparation of concrete substrate surface always occurred at the joint of renovation material and untreated concrete. This fact implies that renovation mortar could not connect with untreated concrete surface well enough to form suitable repair system.

The acquired knowledge will serve as a basis for further research work focusing on renovation of degraded concrete surface, in particular surface affected by high temperature as a simulation of concrete affected by wild fire.

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## 5
## References

[1] Sičáková, A., et al. New generation cement concretes – Ideas, Design, Technology and Aplications, Košice, 2008, 156 p., ISBN 978-80-553-0040-5.
[2] Foldyna, J., Sitek, L., Švehla, B., Švehla, Š. Utilization of ultrasound to enhance high-speed water jet effects. Ultrasonics Sonochemistry 11 (2004), 2004 Elsevier B.V., p. 131-137.
[3] Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design.
[4] EN 12350-2 Testing fresh concrete - Part 2: Slump-test.
[5] EN 12350-5 Testing fresh concrete - Part 5: Flow table test.
[6] EN 12350-8 Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test.
[7] EN 12350-6 Testing fresh concrete - Part 6: Density.
[8] EN 12390-3 Testing hardened concrete - Part 3: Compressive strength of test specimens.
[9] EN 12390-5 Testing hardened concrete - Part 5: Flexural strength of test specimen.
[10] EN 12390-7 Testing hardened concrete - Part 7: Density of hardened concrete.
[11] CSN 73 1318, Z2 Determination of tensile strength of concrete.
[12] EN 12 390-6 Testing hardened concrete - Part 6: Tensile splitting strength of test specimens.
[13] EN 1542 Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off.

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