APPLICATION OF WATER JET TECHNOLOGY FOR CONCRETE REPAIR

LENKA BODNAROVA[1], LIBOR SITEK[2], JOSEF FOLDYNA[2], TOMAS JAROLIM[1], RUDOLF HELA[1]

[1]Brno University of Technology, Faculty of Civil Engineering, Brno, Czech Republic

[2]Institute of Geonics of the CAS, Ostrava, Czech Republic

DOI: 10.17973/MMSJ.2018_06_201774

e-mail: bodnarova.l@fce.vutbr.cz

This article brings selected knowledge from the long-term cooperation between the Brno University of Technology, the Faculty of Civil Engineering, the Institute of Technology of Building Materials and Components, and the Academy of Sciences of the Czech Republic, v.v.i., Institute of Geonics, Ostrava – Poruba in the field of the interaction of water jets and concrete, especially with regard to the use of water jet technology for the removal of surface layers of concrete during repair of concrete. Attention is paid to monitoring the quality of the concrete surface treated by water jet technology and creating a relief in concrete to achieve good cohesion of concrete with repair mortar. The absence of cracks in the concrete structure after water jet blasting has been proven.

KEYWORDS

Water jet (WJ), concrete, concrete repair, X-ray computer tomography (X-ray CT), micro cracks, tensile strength

1. INTRODUCTION

Deterioration to concrete structures is occurring in all types of construction (bridges, buildings, environmental facilities, road facilities and other structures). Concrete repair is a complex process includes steps from the repair methodology, concrete removal, application of protection systems and maintenance after completion of work. For removal of deteriorated concrete we can use different methods. ACI 555R-01 Removal and Reuse of Hardened Concrete presents various concrete removal systems and methods:

- Hand tools
- Hand-operated power tools
- Vehicle-mounted equipment
- Explosive blasting
- Drills and saws
- Nonexplosive demolition agents
- Mechanical splitters
- Demolition of concrete structures by heat
- Hydrodemolition (water-jet blasting) [ACI COMMITTEE 555 2001].

ACI 546R-14 Guide to Concrete Repair lists these methods for concrete removal:

- Blasting methods
- Cutting methods (includes mechanical sawing, intense heat, or high-pressure water jets)
- Impacting methods (usually done with hand-held chipping hammers or boom-mounted breakers)
- Scarifying
- Hydrodemolition (uses high-pressure water jetting to remove concrete and to clean the steel reinforcement)
- Sandblasting
- Shotblasting (cleaning or removal of concrete with use of metal shot on the concrete surface at a high velocity) [ACI COMMITTEE 546 2014].

Water jet technology is also referred to as a surface preparation method in standards: ASTM D4259 - 88 (2012) Standard Practice for Abrading Concrete, ASTM D4258-5 Practice for Surface Cleaning Concrete for Coating (2012), and EN 1504-10 Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity - Part 10: Site application of products and systems and quality control of the works [ASTM D4259-88 2012], [ASTM D4258-05 2012], [EN 1504-10 2018].

Water jet technology (WJ) is an advanced method used to remove deteriorated concrete and prepare the concrete surface and steel for the repair where the main objective is to selectively remove the layer of broken concrete and keep the healthy concrete [Momber 2005].

The choice of methods and equipment for removing concrete necessarily takes into account the environmental and work safety regulations. Water jet technology meets these demanding requirements. For example, the ACI 555R-01 presents the following benefits of high-speed water jet technology: WJ technology is able to break up solids by transferring energy to an extremely small area, does not engage in mechanical contact with the dismantled material, and destruction is done through erosion [ACI COMMITTEE 555 2001].

The water jet technology is used most often during repairs to remove the layers of concrete damaged by atmospheric influences, the influence of aggressive environment, by common use or because of a change in the usage of the construction work. Concrete of different physical properties is removed [Momber 2005].

Proper application of water jet technology requires knowledge of both water jet technology and knowledge about the disintegration of the material – concrete. When using WJ for concrete disintegration, it is necessary to set the water jet parameters according to the characteristics of the concrete.

It is important to choose the type of water jet and define the water pressure, the rate of breakage of the concrete and the required depth of removal of the damaged layer [Momber 2005], [Hlavac 2012].

The problem of the use of water jets for the removal of degraded concrete is particularly specific to the variability of the concrete as a building material (composition of this composite material, different values of strength characteristics, different effects on the concrete in the structure during its use and other). The properties of concrete and composition of concrete play a very significant role in the resulting effect of WJ and concrete interaction [Momber 1994], [Momber 1996], [Bodnarova 2010].

2. RESEARCH AREA

Concrete of various compositions using dense and light aggregate, with various types of admixtures and dispersed reinforcements and lately also concrete with the addition of carbon nanotubes (CNTs) have been tested during the long-term research, in order to capture the wide range of concrete used for different types of building structures [Foldyna 2016], [Foldyna, 2017]. Different types of water jet have been used to disintegrate concrete – continuous, rotating, flat water jet or the newly developed pulsating jets [Bodnarova 2010], [Sitek 2011], [Hela 2012], [Hlavac 2012], [Foldyna 2016], [Foldyna 2017].

The effect of water jet parameters on the result of disintegration of concrete was monitored. To find out the impact of water jet parameters and the influence of concrete properties on concrete disintegration, it was necessary to define the individual variables that entered the concrete breaking process [Bodnarova 2010], [Foldyna 2016], [Sitek 2011].

On the one hand, this required the definition of water jet parameters (pressure, water flow, water jet type, feed rate, etc.) and, on the other hand, the properties of the degraded concrete.

The effect of water jets was monitored on both "healthy", intact concrete and on concrete exposed to various types of gaseous and liquid corrosive environments as well as high temperatures [Bodnarova 2013].

The properties of the concrete have been described before and after the use of water jets. Particularly, the following properties have been observed: compressive strength of concrete, tensile strength of concrete in surface layers, concrete mass density, type of aggregate, presence of dispersed reinforcement, determination of pH of concrete, eventually monitoring the changes in microstructure, etc. [Sitek 2011], [Hela 2012].

When assessing the state of concrete in the construction, it is necessary to use construction and technical research to determine the extent of structural failure and the prevailing type of degradation of concrete (frost damage, disturbance due to chemicals, the degree of carbonation of the concrete, etc.). The detailed procedure can be found, for example, in the document Technical Conditions for Rehabilitation of Concrete Structures III, Concrete Structure Repair Association [Drochytka 2012].

3. MONITORING THE QUALITY OF THE CONCRETE SURFACE AFTER BLASTING WITH WJ TECHNOLOGY

The often-mentioned advantage of WJ technology for removing damaged layers of concrete is to create a rugged relief of the concrete surface, which will then enable good anchoring of applied repair materials. Therefore, the documentation of the created concrete surface reliefs was carried out.

The experiment was performed on concrete C40/50, SCC C45/55, and C50/60. The siliceous sand (0-4 mm) and crushed granodiorite aggregates (4-8 mm, 8-16 mm) was used. Water cement ratio w was in range 0.39 to 0.47.

Components	C40/50	SCC C45/55	C50/60
Cement CEM I 42.5	330	360	420
Water	170	174	165
Fly ash	--	90	--
Sand 0-4 mm	860	930	800
Crushed aggregate 4-8 mm	--	220	--
Crushed aggregate 8-16 mm	990	550	990
Plasticizer CHRYSO®Plast 760	2.7	--	--
Plasticizer CHRYSO®Fluid Optima 208	--	--	2
Plasticizer CHRYSO®Fluid Premia 320	--	5.6	--
Water/cement ratio w	0.47	0.48	0.39

Table 1. Composition of concrete per 1 m^3

Consistency of concrete C40/50 and C50/60 was Slump S3 [EN 12350-2, 2009], consistency of SCC concrete was VS2, T_{500} 12 s [EN 12350-8, 2010].

The assessment of concrete surfaces blasted by WJ was performed by measuring the depth of cut and the volume of the removed material. The surface quality of the blasted concrete is also evaluated by determining the tensile strength of concrete surface layers [CSN 73 1318 1987].

The concrete layers were removed by the Barracuda rotating cutting head with two pairs of nozzles type OS7. This cutting head is commonly used in practice for the removal of damaged concrete layers during repair works. The water was supplied with a pump URACA KD716, 100 kW, maximum 280 MPa, maximum flow 17 $l.min^{-1}$. A water pressure of 130 and 210 MPa was used. A rotational water jet was used to approximate the real applications of WJ in repair of concrete structures.

The Fig. 1 and Fig. 2 show the results of experiments carried out on concrete samples with granodiorite aggregate, concrete class C40/50.

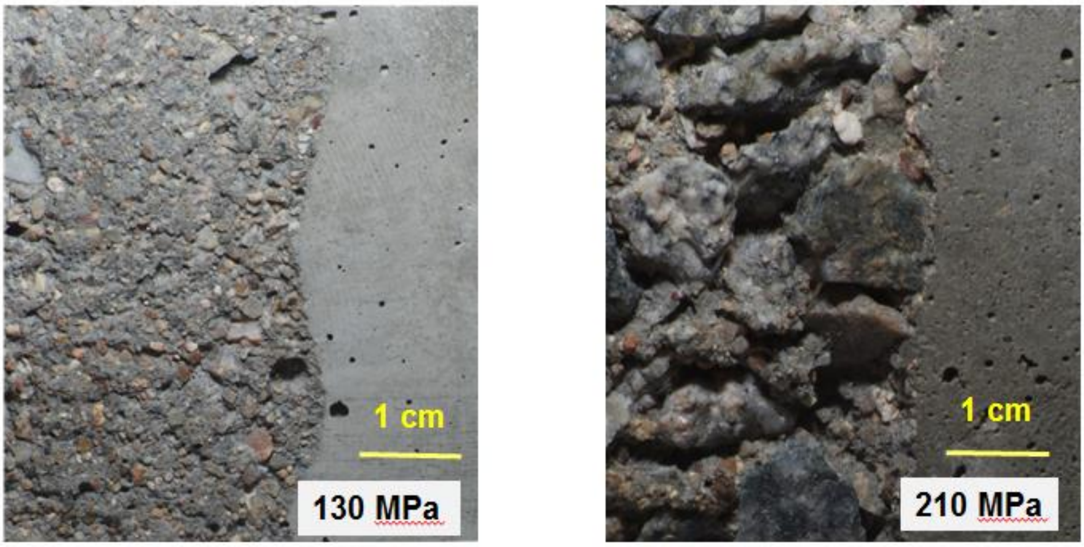

Figure 1. Surface of concrete C40/50 after blasting with rotating WJ, 2 nozzles in rotary head, water pressure 130 MPa and 210 MPa

Figure 2. Reliefs of the concrete surface created by rotating WJ, 2 nozzles in rotary head, water pressure 130 and 210 MPa. Concrete C40/50

The Fig. 1 shows that using a higher water jet pressure (210 MPa) created a more rugged relief of the concrete surface. When using a pressure of 130 MPa, only the surface layer was removed and the aggregate was not exposed. Cutting depth was only 1.4 mm. At a pressure of 210 MPa, a depth cut of 3.5 mm and a more rugged concrete surface were created (see reliefs of the concrete in Fig. 2), which would then allow for better anchoring of mending mortar to concrete during repairs.

This assumption was verified by monitoring the tensile strength of surface layers of concrete by WJ technology, a higher tensile strength of surface layers of concrete was measured than the value determined on the non-blasted smooth surface of the concrete. The following chart shows the results of the tensile strength of surface layers of concrete before blasting with the water jet and after blasting with a rotating water jet at a pressure of 130 and 210 MPa. The tensile strength of surface layers of concrete corresponds to the relief of the cuts (see reliefs in Fig. 2 and tensile strength of surface layers in Fig. 3).

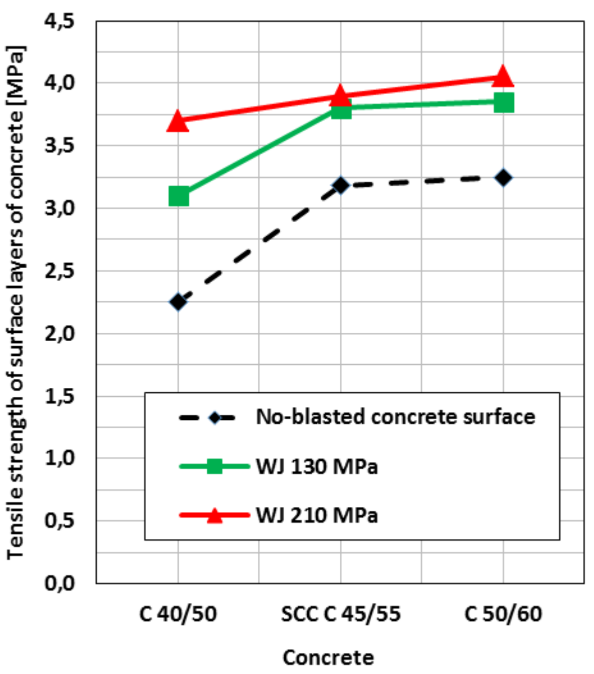

Figure 3. Tensile strength of surface layers of concrete depending on the method of treatment of the concrete surface

4. MONITORING OF THE INFLUENCE OF THE CUT CREATED BY WJ TECHNOLOGY ON THE SURROUNDING AREA, MONITORING OF THE CRACKS IN CONCRETE AFTER BLASTING WITH WJ TECHNOLOGY

One of the significant benefits of WJ technology is the eco-friendliness of this technology towards the repaired structure, as during the removal of the degraded concrete there is no further weakening of the broken structure by undesirable cracks. When using some techniques for disintegration of concrete (especially pneumatic hammers), cracks are generated in the concrete that can further inappropriately weaken and disturb the structure. WJ technology is recommended as a selective method that does not produce cracks in the surrounding concrete, which should be retained intact [ACI COMMITTEE 555 2001].

With the help of modern imaging methods, we could also confirm this often presented the positive side of WJ technology. The surface of the concrete after using WJ technology was first examined visually without enlargement and subsequently with magnification using optical microscopy and X-ray computer tomography and no undesirable cracks were noted (see Fig. 4, Fig. 5 and Fig. 6).

Figure 4. Detail of cut in concrete made by rotating water jet, pressure 210 MPa. Concrete C50/60, CEM 42.5 R, siliceous sand (0-4 mm) and

crushed granodiorite aggregates (4-8 mm, 8-16 mm). No cracks are present in concrete surface after WJ treatment.

Figure 5. Detail of cut in concrete made by rotating water jet, pressure 210 MPa. Concrete C50/60, CEM 42.5 R CEM 42.5 R, siliceous sand (0-4 mm) and crushed granodiorite aggregates (4-8 mm, 8-16 mm). Photo from optical microscope. No cracks are present in concrete structure after WJ treatment.

Further more detailed monitoring of the impact on the area around the cut and possible breakage "inside" of the concrete sample was made possible by the use of X-ray computer tomography [Sitek 2015] (see Fig. 6).

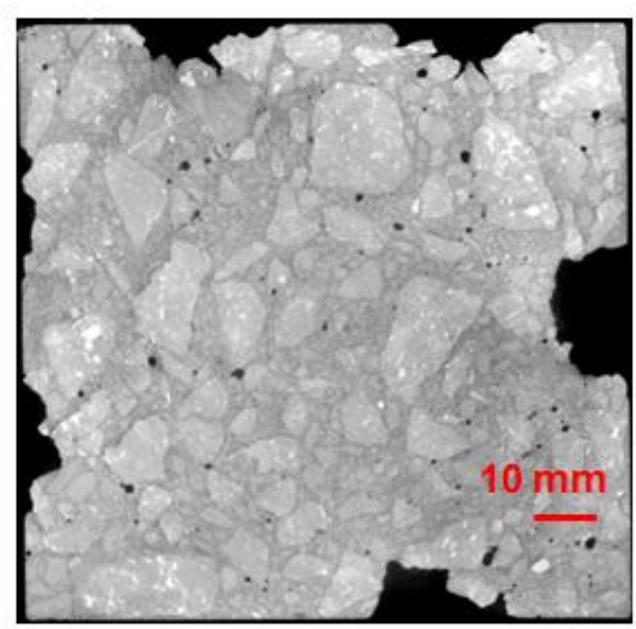

Figure 6. Inner structure of sample of concrete with cuts made by rotating water jet, water pressure 210 MPa. Concrete C50/60, CEM 42.5 R CEM 42.5 R, siliceous sand (0-4 mm) and crushed granodiorite aggregates (4-8 mm, 8-16 mm). Images taken with X-ray computer tomography.

No cracks in the concrete due to WJ technology were detected in concrete or in the immediate vicinity of the cuts created in concrete (see Fig. 4, Fig. 5 and Fig. 6).

5. CONCLUSION

The water jet technology is a highly variable and gentle method that allows the selective removal of the concrete layer according to the defined requirements for the repair of structures. The absence of cracks in the concrete structure after water jet blasting has been proven. An important advantage is the rough surface of the concrete after water jet treatment. Water jet technology can create the relief in concrete surface for better anchoring of mending mortar to concrete during repairs. Increase anchoring was verified by monitoring the tensile strength of surface layers of concrete after using WJ technology. A higher tensile strength of surface layers of concrete after water jet blasting was measured than the value determined on the non-blasted smooth surface of the concrete.

In spite of the above mentioned positives, the conventional methods (pneumatic hammers, milling and blastingare) are still used more than WJ technology. The use of water jet technology in the construction industry is well-founded. From the viewpoint of companies working with the WJ technology as well as the contractors, there is a significant lack of European directives and recommendations for using WJ technology in construction work. The area of promoting greater use of water jet technology through available information sources, making recommendations and directives is a direction deserving attention and further development.

ACKNOWLEDGMENTS

This paper has been worked out under the project GACR P104/15-23219S „Study of methods of nanoparticles dispersion, determination of conditions for preventing their re-agglomeration for application in cement composites", supported by Czech Science Foundation, and under the project No. LO1408 „AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the „National Sustainability Programme I".

REFERENCES

[ACI COMMITTEE 555 2001] ACI Committee 555. ACI 555R-01 Removal and Reuse of Hardened Concrete. American Concrete Institute, 2001. ISBN 978-087-0310-614.

[ACI COMMITTEE 546 2014] ACI Committee 546. ACI 546R-14 Guide to Concrete Repair. American Concrete Institute, 2014. ISBN 9780870319334.

[ASTM D4258-05 2012] ASTM International. ASTM D4258-05(2012), Standard Practice for Surface Cleaning Concrete for Coating, 2012.

[ASTM D4259-88 2012] ASTM International. ASTM D4259-88(2012), Standard Practice for Abrading Concrete, 2012.

[Bodnarova 2010] Bodnarova, L. and Wolf, I. Study of the influence of concrete parameters on the process of HSWJ technology for surface treatment of concrete - Innovation voucher of the South Moravian Region (in Czech: Overení vlivu parametru betonu na proces pouziti technologie VVP pro osetrovani povrchu betonu – Inovacni voucher Jihomoravskeho kraje). Brno: Brno University of Technology, 2010.

[Bodnarova 2013] Bodnarova, L., Valek, J., Sitek, L. and Foldyna, J. Effect of high temperatures on cement composite materials in concrete structures. Acta geodynamica et geomaterialia, 2013, Vol. 10(2), pp. 173 - 180. ISSN 1214-9705.

[CSN 73 1318 1987] Office for standardization and testing. CSN 73 1318 Determination of tensile strength concrete (in Czech: Stanovení pevnosti betonu v tahu), 1987.

[Drochytka Sitek 2011] Drochytka et. al. Technical Conditions for Rehabilitation of Concrete Struct*ures III* (in Czech). Brno: Concrete Structure Repair Association, 2012. ISBN 978-80-260-2210-7.

[EN 1504-10 2018] European Committee for Standardization. EN 1504-10 Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity - Part 10: Site application of products and systems and quality control of the works. 2018.

[EN 12350-2 2009] European Committee for Standardization. EN 12350-2:2009 Testing fresh concrete - Part 2: Slump-test. 2009.

[EN 12350-8 2010] European Committee for Standardization. EN 12350-8:2010 Testing fresh concrete - Part 8: Self-compacting concrete - Slump-flow test. 2010.

[Foldyna 2016] Foldyna et al. Report of the project GACR No. P104/15-23219S Study of methods of nanoparticles dispersion, determination of conditions for preventing their re-agglomeration for application in cement composites. Ostrava: Institute of Geonics of the CAS, 2015, 2016.

[Foldyna 2017] Foldyna, V., Foldyna, J., Klichova, D., Klich, J., Hlavacek, P., Bodnarova, L., Jarolim, T. and Kutlakova, K. M. Effects of continuous and pulsating water jet on CNT/concrete composite. Journal of Mechanical Engineering, 2017, Vol.63, issue 10, pp. 583-589. ISSN 00392480.

[Hela 2012] Hela, R., Bodnarova, L., Novotny, M., Sitek, L., Klich, J., Wolf, I. and Foldyna, J. Comparison of the actual costs during removal of concrete layer by high-speed water jets. Journal of business economics and management, 2012, Vol. 13(4), pp. 763 - 774. ISSN 1611-1699.

[Hlavac 2012] Hlavac, L., Bodnarova, L., Janurova, E. and Sitek, L. Comparison of continuous and pulsing water jets for repair actions on road and bridge concrete. Baltic journal of road and bridge engineering, *2012*, Vol. 7(1), pp. 53 - 59. ISSN 1822-427X.

[Momber 1994] Momber, A. and Louis, H. On the behavior of concrete under water-jet impingement. Materials and structures, April 1994, Vol. 27, No. 167, pp. 153-156. ISSN 1359-5997.

[Momber 1996] Momber, A. and Kovacevic, R. Fracture of brittle multiphase materials by high energy water jets. Journal of materials science, February 1996, Vol. 31, No. 4, pp 1081-1085. ISSN 0022-2461.

[Momber 2005] Momber, A. Hydrodemolition of concrete surfaces and reinforced concrete structures. Oxford: Elsevier, 2005. ISBN 978-185-6174-602.

[Sitek 2011] Sitek, L., Foldyna, J., Martinec, P., Scucka, J., Bodnarova, L. and Hela, R. Use of pulsating water jet technology for removal of concrete on repair of concrete strucutres. Baltic journal of road and bridge engineering, 2011, Vol. 4(6), pp. 235 - 242. ISSN 1822-427X.

[Sitek 2015] Sitek, L., Bodnarova, L., Soucek, K., Stas, L. and Gurkova, L. Analysis of inner structure changes of concretes exposed to high temperatures using micro X-Ray Computed Tomography. Acta Geodynamica Et Geomaterialia, 2015, Vol. 12(1), p. 79-89. ISSN 1214-9705.

CONTACTS:

Assoc. Prof. Ing. Lenka Bodnarova, Ph.D.
Ing. Tomas Jarolim, Ph.D.
Prof. Ing. Rudolf Hela, CSc.
Brno University of Technology, Faculty of Civil Engineering,
Veveri 95, Brno, 602 00, Czech Republic
Tel.: 00420541147509, email: bodnarova.l@fce.vutbr.cz,
Tel.: 00420451147468, email: jarolim.t@fce.vutbr.cz,
Tel.: 00420541147508, email: hela.r@fce.vutbr.cz
www.fce.vutbr.cz

Ing. Libor Sitek, Ph.D.
Ing. Josef Foldyna, Ph.D.
Institute of Geonics of the CAS
Studentska 1768, 708 00 Ostrava, Czech Republic
00420 596 979323,email: libor.sitek@ugn.cas.cz,
00420 596 979328, email: josef.foldyna@ugn.cas.cz,
www.ugn.cas.cz