Limnol. Rev. (2019) 19, 3: 137–145
DOI 10.2478/limre-2019-0012

sciendo

The lethal effect of hydrotechnical concrete on freshwater Bivalvia

Barbara Wojtasik[1,2], Małgorzata Zbawicka[3*], Lucyna Grabarczyk[4], Marzena Kurpińska[4]

[1] Department of Genetics and Biosystematics, Faculty of Biology, University of Gdańsk, Wita Stwosza 59, 80-308 Gdańsk, Poland; 0000-0001-5389-1810

[2] HydroBiolLab, Research and Development Company, Hydrobiological Laboratory, Żeliwna 23a, 81-159 Gdynia, Poland, e-mail: hydrobiollab@wp.pl

[3] Institute of Oceanology, Polish Academy of Sciences, Department of Genetics and Marine Biotechnology, Powstańców Warszawy 55, 81-712 Sopot, Poland, e-mail: mzbawicka@iopan.gda.pl (*corresponding author); 0000-0001-5156-6184

[4] Department of Mechanics of Materials and Structures, Gdańsk University of Technology, Gabriela Narutowicza 11/12, 80-233 Gdańsk, Poland

Abstract: Most hydrotechnical buildings under construction demand the concrete mixture to be set directly under water. The main reason for such a procedure is to limit the washing away of the the concrete binding mixture and to increase the efficiency of organisation of work so as to ensure continuity in concreting. The impact on the aquatic environment of recent developments in concrete technology and the use of new components has not yet been established . Natural pebble aggregate containing portland cement and fugacious siliceous ash as a binder was used to prepare BP concrete samples, while concrete marked LB was composed with lightweight aggregate and portland cement as a binder. The aim of this paper was to answer to the question whether hydrotechnical concrete of different compositions (BP and LB) and the technology of setting in a water habitat have any influence on the life condition of commonly occurring *Dreissena polymorpha* (Mollusca, Bivalvia). The lethal effect of two types of freshly hardening concrete was observed. In the case of LB concrete the lethal outcome for *D. polymorpha* could be the effect of a considerable increase of electrolytic conduction in the test cultivation. In the case of BP the parameters of electrolytic conductivity and pH did not exceed the values appearing in lakes. The possibility of the occurrence of toxic compounds of *D. polymorpha*, arising from the reaction of the aquatic / lake environment or the elution of some components should be taken into account. *D. polymorpha* serves as an indicator of toxicity in the aquatic environment and therefore can be used as a model organism in the analysis of the influence concrete on the natural environment. The results obtained in this study indicate the significant impact of modern chemical composition of concrete on the aquatic environment and the living organisms that cover it. They underline the need for research based on the hydrobiont reaction to the substances used in the natural environment.

Key words: hydrotechnical buildings, concrete admixtures, freshwater reservoirs, *Dreissena polymorpha*, toxic

Introduction

Over recent years there has been intensive development in technologies for the construction of concrete buildings in water. Most hydrotechnical buildings under construction demand the concrete mixture to be set directly under water (underwater concrete, UWC). The main reason for concreting under water is to limit the washing away of the binder of the concrete mixture and to increase the efficient organisation of work, thus ensuring continuity of concreting. In the case of underwater concretes, 375 kg of cement and additives are needed for one cubic metre of concrete. This is justified by the possible loss of binder from washing away (JSCE 1991; Neville 2011). Irrespective of the underwater concreting cements, special chemical additives and admixtures adequate for outside conditions and the size of the concreted element should be used (Horszczaruk et al. 2014; Horszczaruk and Brzozowski 2014). Underwater concreting requires pebbles and broken aggregates. The characteristic feature of the set of modern mixtures used for underwater concretes is the necessity of applying an anti-washout admixture (AWA). The anti-washout admixture (AWA), used in a quantity of less than 5% of cement mass, is designed to prevent the rinsing of firm materials from the concrete mixture and at the same time retain water in the mixture and prevent any occurrence of bleeding (Assaad et al. 2011; Heniegal 2012). The US Army Corps of Engineers Standard (USACE 2006), is a tested method for determining the resistance of freshly mixed concrete to washing out in water. The AWA admixture increases the stickiness of the cement paste and cooperates well with superplasticizers, high-range water-reducing admixtures (HRWR), which help to secure the proper consistency of concrete mixture. The HRWR, used together with AWA, creates underwater concrete of high durability. Sometimes, to avoid difficult underwater concretings, prefabricated concrete elements are made. These can be foundation blocks of a considerable size or light-weight concrete boards used as foundations for houses built on water (Horszczaruk 2016). However,, there are also other factors which should be taken into consideration.

The building process can have a marked influence on life under water. Concrete constructions and the addition of different components to the concrete have an impact on the environment, although to date there is very little research related to this issue. The presence of some substances in concrete can be harmful. This applies to the incorporation of some toxic admixtures to the concrete which may be anti-bacterial, fungicidal or insecticidal (Neville 2011). The rough surface texture of concrete shelters bacteria and surface cleaning is ineffective. However, some additives are known to have a bactericidal effect. Application of silica-titania, a special nanocomposite to the cement mortars has been found to improve the microstructure and has additionally exhibited self-cleaning and bactericidal properties when exposed to UV light (Sikora et al. 2017; Wei et al. 2013). Waste glass has become a global problem in the reduction of waste and energy consumption but it can act as a successful replacement for sand (up to 100%) to produce cement mortars when nanosilica is incorporated. Additionally, waste glass aggregate for bactericidal properties of cement mortars has been observed to have a positive effect (Sikora et al. 2016; Chung et al. 2017).

Cement based products are strongly alkaline due to their lime content, which is a major component. Lime dissolves easily in (water soluble) and drastically changes the pH of water increasing alkalinity (pH 11–13), which in turn makes it toxic to aquatic life. Aquatic organisms are extremely sensitive to pH changes (Lamond and Pielert 2006). Most contractors are aware that concrete slurry or washout can cause burns (just like an acid burn) on fish and kills fish and other aquatic life if it reaches a lake or stream. Concrete waste destroys tree roots and is fatal to other organisms in the soil. There are some special guidelines on how to minimize erosion and sedimentation on construction sites (Fifield 2001, 2004). Fresh concrete should be washed down (water blasted) to remove all particles. Bonacci et al. (2009) observed some negative impacts of grouting on the underground karst environment, in spite of the fact that grouting had been treated as a successful engineering method. Grout curtains, like other anthropogenic structures, should be built with the objective of improving the environment (water regime and the living conditions in the region).

It is not uncommon for ecological components to be overlooked. It is well known that excessive phosphorus can cause the growth of toxic algae in water reservoirs. Studies show that 19% of the phosphorus in lakes (e.g. Lake Mendota, Monona Bay USA) comes from construction site erosion (WDNR 2000).

The zebra mussel (*Dreissena polymorpha*) (Fig. 1), is a small freshwater mussel (*Mollusca*) belonging to the class *Bivalvia* and order *Veneroida* which inhabits fresh and brackish water (low salinity) (Piechocki and Dyduch-Falniowska 1993). *D. polymorpha* are usually about 4 cm in size of. Adult mussels attache themselves to hard surfaces, artificial substrates, industrial flume trials or sewage treatment plants by byssal threads which are secreted from a byssal gland. This is unique among freshwater mussels (Elliott et al. 2008) And it allows them to live even in strong currents of water. Zebra mussels are extremely fertile. Adults live to a depth of 8 meters (above the thermocline) (Stanczykowska and Lewandowski 1993) (Nalepa and Schloesser 1993). The Zebra mussel has a unique physiology which could significantly affect the functioning of the aquatic ecosystems in which it lives. Under natural conditions and stable substrate *D. polymorpha* may occur at a density from a few hundred to several thousand individuals per square meter. In Szczecin Lagoon 114 thousand individuals per square meter were recorded (Wiktor 1969). While in the American Great Lakes up to 700 thousand Zebra mussels have been recorded for every per square meter of the lakebed (Nalepa and Schloesser 1993). They can alter aquatic environments through

Fig. 1. Zebra mussel (*Dreissena polymorpha*,Pallas, 1771)
Photo B. Wojtasik.

their substantial filtration capabilities. Mussels are very tolerant of environmental conditions and accumulate various compounds trapped with filtered water and embed them in their bodies and shells. These include both nutrients (N and P), and heavy metals which are thus temporarily removed from the water cycle. They contribute to increasing water clarity and reducing pollution (Stańczykowska and Lewandowski 1993).

D. polymorpha serves as an indicator of toxicity in the aquatic environment; therefore it was selected for analyses in the present work (Wojtasik et al. 2017)

The aim of the research was answer to the question whether hydrotechnical concrete of different compositions (BP and LB) and the technology of setting in a water habitat has any influence on the life condition of commonly occurring Dreissena polymorpha (Mollusca, Bivalvia). The response to freshly hardening concrete and concrete which remains in the water over a longer period was compared.

Material and methods

Ingredients

Natural pebble aggregate, portland cement and fugacious siliceous ash was used to prepare BP samples, and lightweight aggregate and portland cement was used for samples of concrete marked LB (Table 1). The chemical composition of the aggregate is shown in Table 2. The properties of chemical compounds, such as contents of chlorides, sulphur, organic compounds, cannot be considered to be real rock. Their presence is usually mostly connected with aggregate contamination (chlorides, organic compounds) or with the phenomenon of mineralization of some rock. Perlit is a silicon rock of volcanic origin expanded in stoves at a temperature of 1000–1100°C, at which temperatures mineral raw materials can expand up to 20 times. Thanks to this we can obtain a lightweight, chemically neutral, hygroscopic, volume constant granulate which has no fragrance or colour and is impervious to the development of any fungus or bacteria. Perlit is fine aggregate, soluble in alkaline salt, it is moderately soluble (<10%) in NaOH, slightly soluble (<3%) in mineral acids and indifferently soluble (<1%) in water or indifferent acids. Foam lightweight aggregate is resistant to the effect of all chemical substances. Foam glass is an unlimited material, similar to initial material – ordinary glass in its chemical composition. Moreover, it is not subject to any biological influences, is resistant to disintegration and unaffected by any biological forms; no harmful substances are produced during its use, thus attesting to its high ecological and sanitary safety. The third kind of lightweight aggregate is ash lightweight aggregate, which arises from the granulation and agglomeration of fugacious ash at a temperature of 1000–1350°C. The principal raw material is fugacious ash, a by-product derived from the process of hard coal combustion in power stations and heat and power generating plants. Ash lightweight aggregate is characterized by considerable porosity (62%) and good absorption abilities. A new generation admixture was used as a modifier which significantly reduced the quantity of water and plasticizing. It was applied using the newest technology for hybrid polymers. The new generation superplasticizers allows us to retain the consistency of the concrete mixture and its homogeneity and cohesion for a considerable time. The admixture includes up to 20% of sodium nitrate and is not classified as harmful for the environment. The additive that prevents the spread of the concrete mixture is a white powder with a characteristic smell, pH = 8, soluble in water; it includes formate sodium CL_{50} >1000 mg dm^{-3} (96h).

Table 1. The components used in concretes in the experiment. Component quantities are given in kg per cubic metre

Concrete signature	BP	LB
CEM I 42.5R	320	450
Fugacious siliceous ash	80	–
Natural rinsed sand 0–2 mm	660	–
Natural rinsed gravel 2–16 mm	1140	–
Perlit 0–1 mm	–	15
Foam lightweight aggregate 1–4 mm	–	80
Ash lightweight aggregate 4–12 mm	–	480
Superplasticizers FM	2.72	2.48
Additive to prevent flowing	3.0	–
Water	175	185

Table 2. Chemical composition of concrete components (Component share, weight percentage)

Component	SiO_2	$Al2O_3$	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	Loss of roast
Cement	19.6	5.1	3.1	63.0	1.0	2.9	–	–	–	2.6
Fugacious ash	46.9	26.6	7.2	3.1	2.1	0.9	1.2	1.0	–	–
Natural aggregate	89.9	3.8	1.8	0.6	0.35	0.02	1.4	0.5	–	1.4
Perlit	74.9	12.6	0.7	0.7	0.26	–	4.8	3.4	0.06	–
Ash lightweight aggregate	58.1	22.1	5.9	2.2	1.41	0.3	–	–	–	2.5
Foam aggregate	72.1	–	–	6.3	4.12	–	–	15.5	–	–
AWA additive	1.73	0.17	–	3.83	0.07	0.5	–	0.57	–	50.28

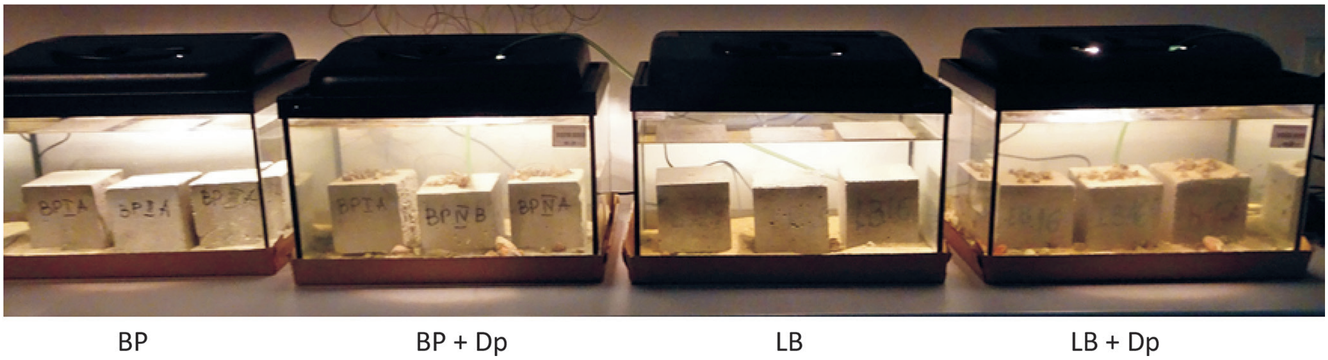

Fig. 2. The aquarium set for experiment 1

Experiment 1 (aquaculture)

The experiment was performed in four 25 litre aquariums (Fig. 2). Three concrete cubes of 10 × 10 × 10 cm dimension were placed in each aquarium. Two kinds of concrete were used: ordinary hydrotechnical, marked with the BP symbol and lightweight concrete marked with the LB symbol (lake water) and 250 individuals of *Dreissena polymorpha* (Fig. 1).

Four aquariums were prepared (Fig. 2): BP – concrete BP without *D. polymorpha*, BP + Dp – concrete BP with *D. polymorpha*, LB – concrete LB without *D. polymorpha*, and LB + Dp – concrete LB with *D. polymorpha*. Additionally one control aquarium containing only *D. polymorpha* was used. The duration of the experiment was one month.

Experiment 2 (natural environment)

Three concrete cubes, BP and LB, were placed in the lake for nine months (from 18.09.2016 to 03.06.2017). Next, the degree to which they had been overgrown with macroscopic organisms (macrobenthos) was assessed. The concrete cubes were then stained with Rose Bengal sodium salt (SIGMA-ALDRICH MERCK 198250) to determine the spread of small aquatic organisms and microorganisms on the samples (Wojtasik 2017).

Experiment 3 (natural environment and aquaculture)

After nine months of immersion in the lake the concrete cubes BP were transferred to the breeding aquarium *D. polymorpha* for a further six months.

Results

Aquaculture experiment

Fifty individuals of *D. polymorpha* were used for one experiment (Hereinafter abbreviation Dp). The measurements of pH and electrolytic conductivity (EC) of water in the tanks were performed during the experiment. The temperature was approximately 20°C. Aquariums were also blown. Concrete cubes were placed in tanks of water from the lake. Basic physical-chemical parameters pH = 7.667 and EC = 251 μS cm^{-1} indicated the first class of water quality according to current standards (MŚ RP 2011).

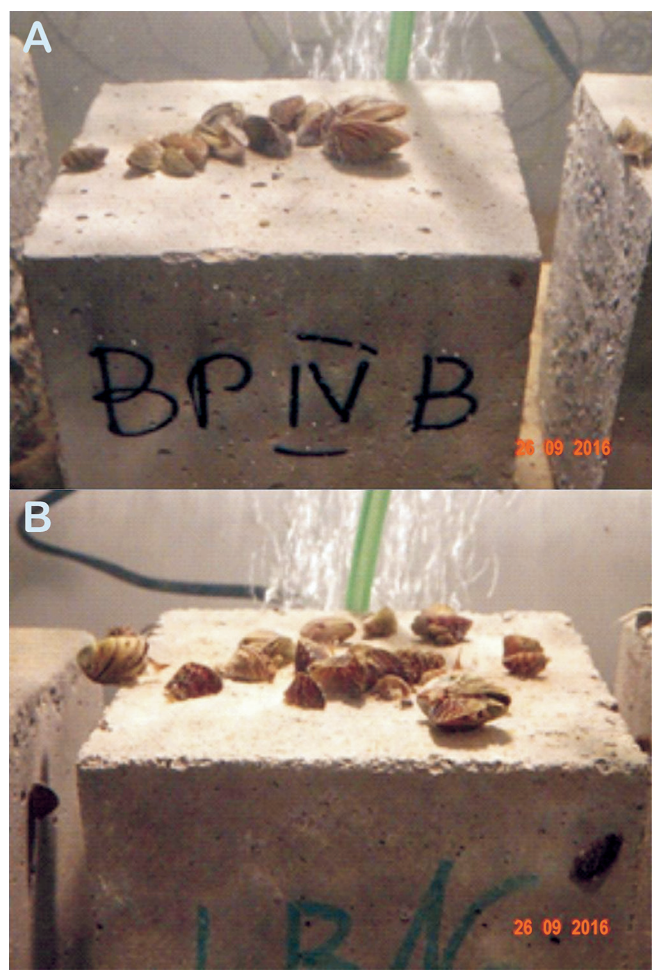

Fig. 3. The result of experiment 1 on the seventh day of its duration A – dead *D. polymorpha* mussels on concrete BP, B – live *D. polymorpha* mussels on concrete LB.

Fig. 4. White solid which separates the BP concrete during experiment 1

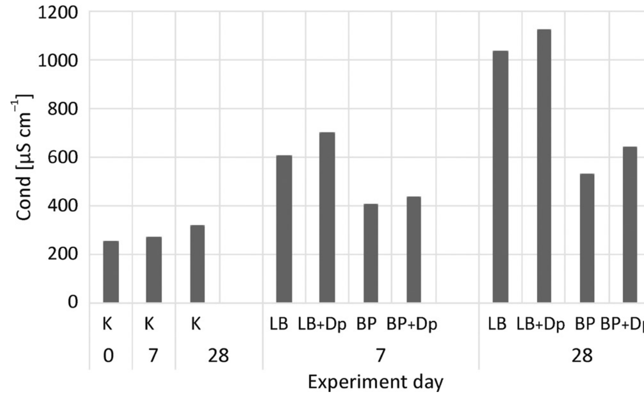

Fig. 6. Change of conductivity over time in experiment 1

Both types of concrete strongly interact with the water of a lake, but another range of variation of electrolytic conductivity and pH was observed. BP concrete was found to be toxic to *D. polymorpha*. Individuals were unable to settle on the BP concrete and all died within a week (Fig. 3). There was no evidence of such high toxicity of LB concrete, although it is likely that due to the increase of electrolytic conductivity associated with the corrosion of concrete, the presence of LB cubes also had lethal effect on *D. polymorpha*. Individuals of *D. polymorpha* settled in actively on the LB concrete, however, after about three weeks of the experiment all of them had died. The appearance of concrete blocks was different in both experiments, independently of the presence of *D. polymorpha*. BP cubes gave off a white solid (Fig. 4). This situation was not observed in the case of LB concrete. All aquacultures had a different range of pH and EC parameters (Fig. 5 and Fig. 6). Electrolytic conductivity increased in the case of the tank with the LB cubes to a value of more than 1 mS cm^{-1}, while in the case of the tank with the BP cubes it was about twofold lower.

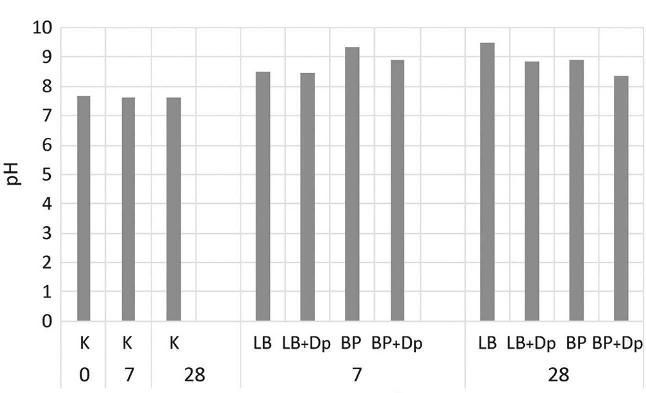

Fig. 5. Change of pH over time in experiment 1

The lethal effect for *D. polymorpha* in the case of LB concrete could be the result of a large rise in electrolytic conductivity in the aquaculture test due to the placement of the LB cubes. In the control culture the tested parameters were lower. By contrast, for the BP concrete, EC and the pH parameters did not exceed the same value in the lakes in which *D. polymorpha* are found. It should be taken into consideration that there is a possibility that compounds toxic for *D. polymorpha*, generated as a reaction to the aquatic environment (white substance that forms on the surface of the concrete). The strength of electrolytic conductivity in the case of the LB blocks led to an increase of EC in the surrounding water, changing its quality from the Ist class to a classless level. In the case of pH for the experiments BP, LB + Dp and LB the received values exceeded those of the first class water quality according to optional norms.

In the case of LB concrete the lethal outcome for *D. polymorpha* could be due to the effect of a high increase of electrolytic conductivity in the test cultivation. This was the result of the presence of perlit, foam glass, ash lightweight aggregate and admixtures. For BP the parameters EC and pH did not exceed the values appearing in the lakes. Thus, one should consider the possibility of the occurrence of compounds that are toxic for *D. polymorpha,* arising as a reaction to the water/lake environment (white substance being produced on the concrete surface).

Natural environment experiment

The BP and LB concrete were overgrown to a similar extent by individuals from *D. polymorpha*, from one to several individuals in one wall (Fig. 7A–B). Differences were found in the number of mollusc eggs. There were few in number on the BP concrete, while on LB they formed dense assemblies (Fig. 7C–D). In addition to *D. polymorpha* individuals, the presence of snails (muddy

Fig. 7. Image of concrete BP and LB cubes after incubation in a lake for nine months (experiment 2)
D. polymorpha growing on the walls: concrete BP (A), and concrete LB (B); packs of mollusc eggs on the side walls: concrete BP (C), concrete LB (D).

ear, pond marshmallow) and leeches was found on both concretes. After staining with Rose Bengal, it was found that colouring had a stronger effect on LB concrete (Fig. 8A–B). In particular, this applied to the bottom wall, which was not subject to rinsing by undulating water in the lake (Fig. 8C–D).

Microscopic images of Rose Bengal stained concrete blocks BP and LB indicate that the alive mollusc eggs developed only on LB concrete, while on concrete BP they were also deposited but died (Fig. 9A–B).

Aquarium test cubes from the lake

After the experiment in the lake concrete BP was transferred to the breeding aquarium *D. polymorpha*. The culture was continued for two months. At that time no lethal effect was observed in *D. polymorpha*. After the next 6 months, a significant increase in C (from 251 to 1570 μS cm^{-1}) was found, pH value increased slightly, while oxygen saturation dropped significantly (from 86.7 to 18.7% of O_2), which had a lethal effect.

Discussion

Concrete is composed of aggregates, cement, water and any other cementitious material or chemical admixture. The most important features of concrete mix should be: workability, consistency, strength, water-cement ratio, durability, density and heat release (Neville 2011). What about the impact on the environment? Recently, there have been increasing changes in concrete technology and the use of new components with an unknown impact on the aquatic environment. Admixtures which may prove toxic should not be used, unless they have been subject to thorough testing. The possible use of some agricultural solid wastes as aggregate in the concrete industry was studied by Shafigh et al. (2014). The

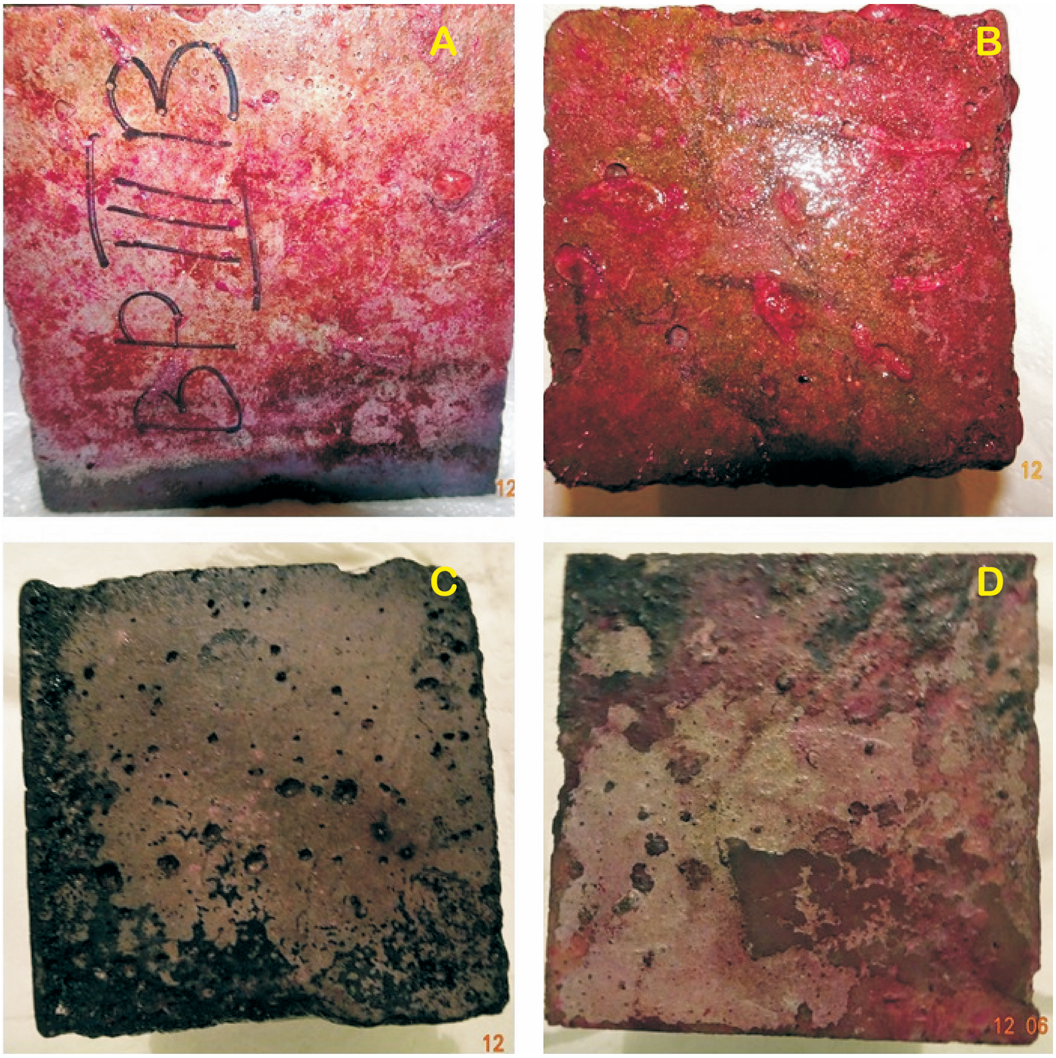

Fig. 8. Image of Rose Bengal stained surface of BP and LB concrete cubes (experiment 2)
Side walls: concrete BP (A), and concrete LB (B); undersides: concrete BP (C), concrete LB (D).

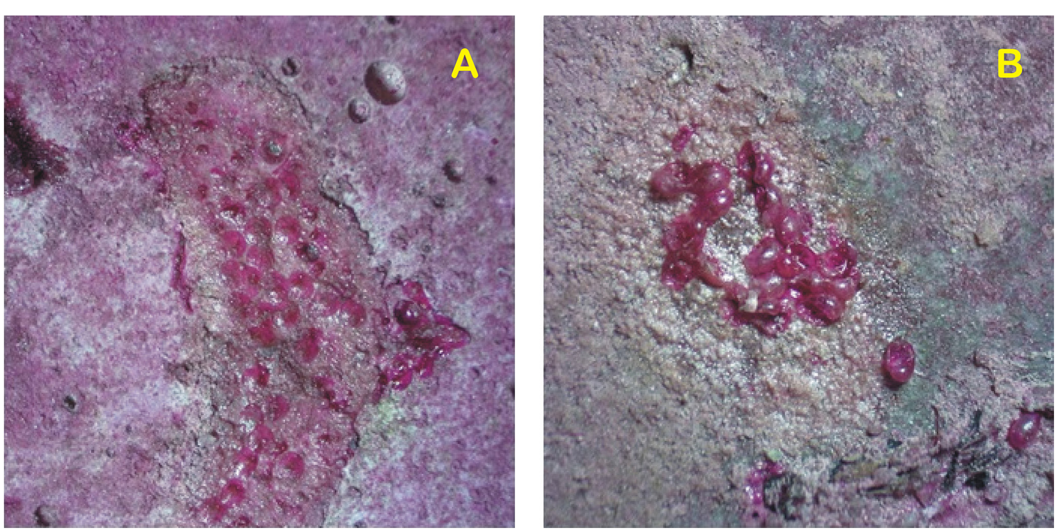

Fig. 9. Microscopic image of BP and LB concrete surfaces after incubation in natural environment (lake) for 9 months and Bengal Rose staining (experiment 2).
Eggs of molluscs on surface of the side walls: death eggs on concrete BP (A), alive eggs on concrete LB (B)

authors used oil palm shell, coconut shell, rice husks, and tobacco waste as aggregate in making concrete. Tobacco waste is toxic due to the presence of alkaloid nicotine, the different percentages of tobacco waste in lightweight concrete containing pumice was tested. Using agricultural wastes as aggregate could make the concrete industry environmentally-friendly. Portland cement clinker is often used for immobilization of hazardous materials, like industrial slurries or shredded tires (Broekmans 2016). These materials remain immobilized in concrete or mortar after hydration and setting of the cement. Laboratory tests seemed to confirm effective mobilization. Lee et al. (2018) tested ultra-high performance concrete UHPC, containing portland type II cement, quartz powder, silica fume, silica sand, steel fibre, superplasticizer, water, and a specific amount of incinerator fly ash (IFA). They evaluated different volumes of IFA and noted that heavy metals, that originated in the IFA, are confined in the UHPC matrix and yield rather low leachability results. This makes them non-hazardous and non-toxic for the environment. However, it should be noted that there is always the possibility of elution of harmful components in unexpected situations, such as a construction disaster or geochemical contamination of urban waters (Walsh et al. 2005; Wright et al. 2011).

A significant development in underwater concrete technology has been achieved in recent years, which seems promising for concrete as a material of the future. Using mixtures of cement with fugacious ashes, slag and microsilica has been shown to be effective in achieving the desired properties of concrete, and it has become a commonly used practise. The use of different admixtures such as AWA, superplasticizers, delayers and inhibitors has made it possible to exercise some control over the properties of both fresh mixture and hardening concrete. The possibility of creating highly-durable concretes with standard aggregates as well as light ones will lead to more effective, much stronger and lighter hydrotechnical constructions, which, should the need arise, will have the ability to float on water. Concretes reinforced with fibres should be characterized by plasticity, resistance to erosion and corrosion. This will allow them to be used in highly aggressive environments, where they will be them impervious to abrasion and damage. There remains the question, however, as to how such huge quantities of concrete will affect the natural water environment. What would happen if the composition of what was believed to be safe material becomes diametrically changed? In recent years, studies on the environmental impact of new concrete components have been carried out. The analysis was based on chemical tests, the possibility of leaching and binding of substances used in concrete technology. However, to date, there are no analyses based on tests indicating the response of aquatic organisms.

The initial results obtained in the presented work indicate that the modern chemical composition of concrete has a significant influence on the water environment and the living organisms that cover it. They show the need for extensive research based on the hydrobiont reaction to the substances used in the natural environment.

Conclusions

Both kinds of concrete have affect lake water, although there is a different range in the lability of the basic examined parameters (electrolytic conductivity and pH).

BP concrete is toxic for *D. polymorpha*. Although hard concrete was used in the research we could expect different results during the concreting if an additive against rinsing the paste from the concrete mixture was used.

LB concrete does not show such high toxicity as BP. This is probably the result of an increase of electrolytic conduction connected with concrete composition. Its presence also had a lethal effect on *D. polymorpha*.

In the lake both BP and LB were successfully colonized by *D. polymorpha,* although eggs were observed mainly on LB.

LB was better colonized by microorganisms.

After the experiment in the lake BP concrete was not toxic in the aquarium for *D. polymorpha*.

The additive including calcium formate in the presence of fugacious ash and the admixture was also toxic for *D. polymorpha*.

Statement

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: This article does not contain any studies with human participants performed by any of the authors. All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

Sampling and field studies: All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities.

References

Assaad J.J., Daou Y., Salman H., 2011, Correlating washout to strength loss of underwater concrete, J. Inst. Civ. Eng. 106(6): 529–536.

Broekmans M.A.T.M., 2016, Safe long-term immobilization of heavy metals: Looking at natural rocks, Am. Mineral. 101(1): 3–4.

Bonacci O., Gottstein S., Roje-Bonacci T., 2009, Negative impacts of grouting on the underground karst environment, Ecohydrology 2: 492–502.

Chung S-Y., Abd Elrahman M., Sikora P., Rucinska T., Horszczaruk E., Stephan D., 2017, Evaluation of the effects of crushed and expanded waste glass aggregates on the material properties of lightweight concrete using image-based approaches, Materials 10(12): 1354.

Elliott P., Aldridge D.C., Moggridge G.D., 2008, Zebra mussel filtration and its potential uses in industrial water treatment, Water Res. 42: 1664–1674.

Fifield J.S., 2001, Field manual on sediment and erosion control best management practices for contractors and inspectors, Forester Press, Huntsville, 150 pp.

Fifield J.S., 2004, Designing for effective sediment and erosion control on construction sites, Forester Press, Huntsville, 302 pp.

Heniegal A.M., 2012, Behavior of underwater self-compacting concrete, J. Eng. Sci. 40(4): 1005–1023.

Horszczaruk E., 2016, Influence of addition of fluidal fly ashes on the mechanical properties of underwater concretes, J. Build. Chem. 1: 27–30.

Horszczaruk E., Brzozowski P., 2014, Bond strength of underwater repair concretes under hydrostatic pressure, Constr. Build. Mater. 72: 167–173.

Horszczaruk E., Brzozowski P., Adamczewski G., Rudnicki T., 2014, Influence of hydrostatic pressure on compressive strength of self-consolidating concrete, J. Civil Eng. Architecture (JCEA) 8(12): 1549–1555.

[JSCE] Japan Society of Civil Engineers, 1991, Recommendations for design and construction in anti-washout underwater concrete, Concr. Libr. JSCE 67 p. 89.

Lamond J.F., Pielert J.H., 2006, Significance of tests and properties of concrete and concrete-making materials. STP 169D, ASTM International, West Conshohocken, 664 pp.

Lee M., Lee M., Su Y., Huang Y., Tung W., 2018, The study of UHPC precast concrete containing incinerator fly ash, J. Test. Eval. 46: 160–167.

[MŚ RP] Ministerstwo Środowiska RP (Ministry of the Environment of the Republic of Poland), 2011, Rozporządzenie Ministra Środowiska z dnia 9 listopada 2011 r. w sprawie sposobu klasyfikacji stanu jednolitych części wód powierzchniowychoraz środowiskowych norm jakości dla substancji priorytetowych (Regulation of the Minister for the Environment of 9 November 2011 on the classification of the status of surface water bodies and environmental quality standards for priority substances), Dz. U. Nr 257, poz. 1545.

Nalepa T.F., Schloesser D.W. (eds), 1993, Zebra mussels: biology, impacts, and control, Lewis Publishers, Boca Raton, 810 pp.

Neville A.M., 2011, Properties of concrete, Pearson Education Limited, Harlow, 872 pp.

Piechocki A., Dyduch-Falniowska A., 1993, Mięczaki (Mollusca), Małże (Bivalvia). Wydaw. Nauk. PWN, Warszawa, 204 pp (in Polish).

Shafigh P., Mahmud H.B., Jumaat M.Z., Zargar M., 2014, Agricultural wastes as aggregate in concrete mixtures – a review, Constr. Build. Mater. 53: 110–117.

Sikora P., Augustyniak A., Cendrowski K., Horszczaruk E., Rucinska T., Nawrotek P., Mijowska E., 2016, Characterization of mechanical and bactericidal properties of cement mortars containing waste glass aggregate and nanomaterials, Materials 9(8): 701.

Sikora P., Cendrowski K., Markowska-Szczupak A., Horszczaruk A., Mijowska E., 2017, The effects of silica/titania nanocomposite on the mechanical and bactericidal properties of cement mortars, Constr. Build. Mater. 150: 738–746.

Stanczykowska A., Lewandowski K., 1993, Thirty years of studies of *Dreissena polymorpha* in Mazurian Lakes of northeastern Poland, [in:] Nalepa T.F., Schloesser D.W. (eds), Zebra mussels: Biology impacts and control, Lewis Publishers, Boca Raton:. 3–33.

[USACE] US Army Corps of Engineers Standards, 2006, CRD-C 661-06 Specification for antiwashout admixtures for concrete, US Government Printing Office, Washington, 15 pp.

Walsh C., Roy A., Feminella J., Cottingham P., Groffman P., Morgan R., 2005, The urban stream syndrome: current knowledge and the search for a cure, J. N. Am. Benthol. Soc. 24: 706–723.

Wei S., Jiang Z., Liu H., Zhou D., Sanchez-Silva M., 2013, Microbiologically induced deterioration of concrete – a review, Braz. J. Microbiol. 44(4): 1001–1007.

Wiktor J., 1969, Biologia Dreissena polymorpha (Pall.) i jej ekologiczne znaczenie w Zalewie Szczecińskim (Biology of Dreissena polymorph (Pall.) and its ecological significance in the Szczecin Lagoon), Stud. Mater. MIR A5: 1–88 (in Polish).

[WDNR] Wisconsin Department of Natural Resources, 2000, Nonpoint source control plan for the Lake Mendota Priority Watershed. Vol. 2, Department of Natural Resources, Mendota.

Wojtasik B., 2017, A method of assessing the biological corrosion of porous structures, including concrete, in particular hydrotechnical concrete, Polish Patent Office, Application Number P.421947.

Wojtasik B., Zbawicka M., Kupiec J., 2017, Molluscs D. polymorpha and L. stagnalis for use in assessing the ecological status of water reservoirs and rivers (waters and bottom sediments) and the effectiveness of probiotic substances, Authorized Mikronatura Środowisko Sp. z o.o, Polish Patent Office, application number P.422659.

Wright I.A., Davies P.J., Findlay S.J., Jonasson O.J., 2011, A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters, Mar. Freshwater Res. 62: 1355–1361.