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A NEW MICROBICIDAL PERVIOUS CONCRETE PAVEMENT FOR HOSPITAL PARKING–LOTS: ASSESSMENT OF THE MODULUS OF ELASTICITY*

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Abstract

In the coronavirus pandemic (COVID-19), it is important to articulate a safeguard against urban contamination originating from hospitals, mainly the tires of vehicles that travel in the hospital parking-lots and contaminating the various parts of the city through traffic on urban roads. With the purpose of disinfecting the pavement of hospital parking-lots to prevent diseases, this research proposes the use of a new pavement composed of pervious concrete with calcium hydroxide ($Ca(OH)_2$) additive, i.e., lime powder. The well-known powder lime becomes a disinfectant with a microbicidal effect which increases the pH of the pavement, being a low cost and an abundant material. Studies have shown that this additive affects the mechanical strength of pervious concrete when added to its mixture. Accordingly, the objective of the study is to find a balance between mechanical strength and the ideal proportion of lime powder additive in the pervious concrete mixture through finite element prototypes subjected to vertical loads of 10,000 N with variation in the modulus of elasticity. The results of the structural simulations indicate the prototype with the best performance ratio is 1:0.8:4 (cement:$Ca(OH)_2$:limestone), compressive strain of 15.70 kg/cm^2, density of 1,971.42 kg/m^3 and modulus of elasticity of 1,480.22 MPa, with demonstrates a satisfactory mechanical performance for the use of this new pavement in hospital parking-lots.

Keywords: calcium hydroxide, elasticity, lime powder, microbicidal pavement, pervious concrete

1. Introduction

The Coronavirus Pandemic (COVID-19) forced the entire planet to revise hygiene and cleaning habits, through the guidelines and protocols of the World Health Organization

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(WHO, 2020) and the concern with disinfecting places became a priority for people and governments around the world, particularly in hospitals, which have high safety protocols for microbicidal and bactericidal disinfection involving products that can affect human skin, according to (Syed et al., 2020). This study aims to contribute to the preparation of health safety protocols in external areas of hospitals, comprising the parking of ambulances and private cars, through the possibility of using pervious concrete modified with calcium hydroxide ($Ca(OH)_2$), also called lime powder, additive as a disinfectant pavement to be use used in these car parks.

Pervious concrete is a porous pavement with environmental and sustainable property, as it allows the recycling of its components. The pervious concrete is formed by the mixture of aggregates of limestone or pebbles, cement and water, according to (Elizondo-Martínez et al., 2020). Studies carried out with comparative porous pavements have recommended for communities the use of pervious concrete for use in the parking-lot pavement, for decontamination of the soil with pollutants originating from nitrogen, often drained by rainwater precipitations (Razzaghmanesh and Borst, 2019). The modified pervious concrete is a new material made by adding $Ca(OH)_2$ to its mixture, an additive that favors carbonation in its internal structure (Aggelakopoulou et al., 2019), and contributes to the sequestration of carbon dioxide (CO_2) in the atmosphere, as report by (Gao et al., 2020) and (de Oliveira et al., 2019).

This environmental benefit is in line with the recommendations and reports of the International Panel Climate Change (IPCC, 2020). In addition to these environmental benefits, the pervious concrete modified has in its porous structure $Ca(OH)_2$, which is a chemical element with disinfectant properties that help to prevent diseases, because when it is spread in external areas with access to domestic animals, it acts in the prevention of diseases such as avian influenza, salmonella and others originated by contaminated animals that pass through this area (Mori et al., 2019). $Ca(OH)_2$ and Calcium Oxide (CaO) are inorganic compounds originated from limestone, used as adsorbents and alkalinizing agents for toxic waste produced by polluting factories (Takayama et al., 2020).

The disinfection properties of CaO and/or $Ca(OH)_2$ are due to the alkaline effect this hydroxide, since a pH $\geq$ 11.5 is a strong microbicide that reduces the cultures of microorganisms during the water purification processes (Grabow et al., 1978). Studies have shown that bioshell calcium oxide (BiSCaO) has a practical application for disinfectant microbicide, favored by the effect of increasing the alkalinity of the environment from CaO (Sato et al., 2019a, 2019b). Research (Takayama et al., 2020) has proven the effectiveness of BiSCaO as a bactericide in the treatment against the bacterium *Pseudomonas aeruginosa*. The microbicidal and bactericidal properties of $Ca(OH)_2$ make it possible to use it as a medicine to fight infections by bacteria such as *Enterococcus faecalis* (Sapra et al., 2017). $Ca(OH)_2$ has practical application in the fight against diseases transmitted by insects such as *Aedes aegypti* and *Culex quinquefasciatus*, as it also has larvicidal properties in contact with water, eliminating the breeding focus of these causing insect endemic diseases such as Dengue and Malaria (Estrada-Aguilar et al., 2012).

All these microbicidal, bactericidal and larvicidal properties provide an effect of practical use for modified pervious concrete as a disinfectant pavement. However, and according to the studies (Esfandiari and Loghmani, 2019), lime powder is added to the pervious concrete mixture it also reduces its ability to resist compression, a phenomenon also proven in conventional concrete with an average reduction of 20% in its mechanical resistance. This phenomenon occurs because the lime powder affects the binding properties of the cement, reducing its mechanical and structural stability. In this way, the more disinfectant the modified pervious concrete, by increasing a higher percentage of $Ca(OH)_2$ additive in its mixture, the lower its structural resistance and stability. Thus, this article proposes to discover the optimal proportion of additive to obtain an effective disinfectant pavement with adequate mechanical resistance in hospital parking-lots.

2. Material and methods

The ANSYS 2019 R1 software was used to develop simulations in 30 pervious concrete prototypes modified with $Ca(OH)_2$ additive. Each digital prototype has the dimensions of 1 m wide, 1 m long and 0.40 m thick. The load used in the simulations was 10,000 N with dynamic variation applied in the center of the prototype, in the vertical direction. The simulations were divided into 2 groups, a G1 group with 15 prototypes that had a progressive increase in the $Ca(OH)_2$ additive, from 0.1 until 1.5%, in the proportion of pervious concrete modified mixture, and another G2 group with 15 prototypes that had progressive increase of cement, from 0.1 until 1.5%, in the proportion of pervious concrete modified mixture. Table 1 indicates the materials and constant and variable proportions used in the 30 prototypes and in the two G1 and G2 groups to perform the deformation calculations using the finite element method.

Table 1. Characteristics of the virtual prototypes of the G1 and G2 groups of modified pervious concrete

Groups	*Prototype number*	*Materials*	*Proportion*[1]	*Type*	*Additive Materials*	*Proportion*[1]
G1	15	Cement Aggregate water/cement	1.0 4.0 0.3	II[2] Limestone[3] Distilled	$Ca(OH)_2$	0.1 to 1.5 %
G2	15	Additive Aggregate water/cement	0.8 4.0 0.3	$Ca(OH)_2$ Limestone[3] Distilled	Cement	0.1 to 1.5 %

[1] Proportion in relation to cement mass. [2]ASTM C150. [3]Granite stone 4.8 to 9.5 mm

Fig. 1 demonstrates photo of the compression and density measurement methodology.

Fig. 1. Compression and density tests: left – rupture of cylindrical specimens; right – weighing of cylindrical specimen submerged in water

Following the indications in Table 1, 30 specimens were prepared, 15 specimens for each G1 and G2 group, to carry out Density Test ASTM C127, and Compressive Strength

Test ASTM C39. The methodology used to calculate Young's modulus or Elasticity modulus used Equation (1):

$$E_c=0.043\cdot w^{1.5}\cdot \sqrt{f_c} \quad (1)$$

Where:

E_c – Young's modulus or Elasticity (MPa);
ω – density of water (kg/m^3);
f_c – compressive strength (kg/cm^2).

After obtaining the data from the different Young's modulus of groups G1 and G2, calculated by Equation (1), the data was entered in the ANSYS 2019 R1 software to calculate the deformations by the finite element method. The Poisson coefficient was defined as 0.22, following recommendation and methodology by (Goed, 2009).

3. Results and discussion

The prototypes were made and submitted to the generation of the finite element mesh to perform the deformation calculations, as shown in Fig. 2.

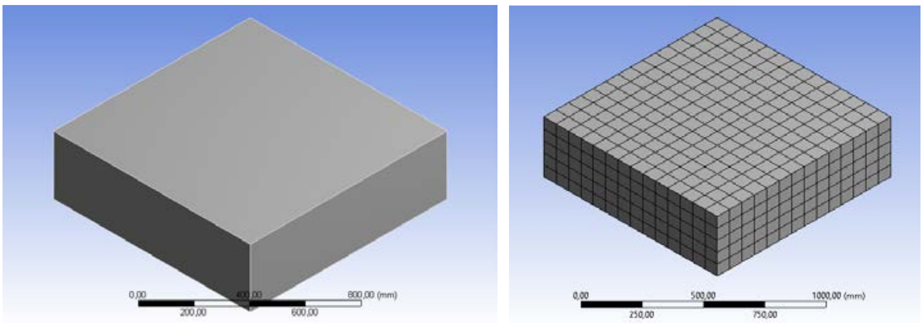

Fig. 2. Elaboration of virtual prototypes for application of 10,000 N dynamic constant load: left – basic prototype; right – prototype after the finite element mesh generation in structure

The results of the density and compression strength and Young's modulus tests for G1 and G2 groups are shown in Tables 2 and 3, respectively.

Table 2. Properties of compressive strength (28 days). Density, Young's modulus and deformation of specimens for G1 group

G1 Specimens	*Compressive strength (kg/cm²)*	*Density, (kg/m³)*	*Young'smodulus (MPa)*	*Deformation × 10⁻⁴(mm)*
1	14.80	2,115.25	1,609.32	1.86
2	12.70	2,196.70	1,577.70	1.90
3	19.40	1,891.62	1,558.18	1.98
4	17.80	1,938.36	1,548.21	2.02
5	15.30	1,988.30	1,491.21	2.08
6	19.90	1,818.62	1,487.68	2.10
7	12.70	2,088.42	1,462.50	2.15
8	12.70	2,081.63	1,455.38	2.21
9	15.80	1,913.23	1,430.37	2.26
10	15.50	1,853.93	1,351.37	2.35
11	18.30	1,735.38	1,329.80	2.40
12	15.30	1,797.67	1,281.98	2.47

13	15.00	1,806.44	1,278.64	2.50
14	11.70	1,911.25	1,228.96	2.53
15	12.90	1,843.77	1,222.71	3.06

Table 3. Properties of compressive strength (28 days). Density, Young's modulus and Deformation of specimens for G2 group

G2 Specimens	*Compressive Strength (kg/cm^2)*	*Density (kg/m^3)*	*Young's modulus (MPa)*	*Deformation $\times 10^{-4}$ (mm)*
1	15.30	1,797.67	1,281.98	2.61
2	18.30	1,735.38	1,329.80	2.58
3	15.50	1,853.93	1,351.37	2.51
4	15.80	1,913.23	1,430.37	2.47
5	12.70	2,081.63	1,455.38	2.35
6	12.70	2,088.42	1,462.50	2.28
7	19.90	1,818.62	1,487.68	2.20
8	15.30	1,988.30	1,491.21	2.20
9	17.80	1,938.36	1,548.21	2.08
10	19.40	1,891.62	1,558.18	2.05
11	12.70	2,196.70	1,577.70	1.98
12	14.80	2,115.25	1,609.32	1.80
13	14.30	2,166.43	1,639.65	1.72
14	13.20	2,270.06	1,689.70	1.65
15	14.80	2,227.54	1,739.15	1.51

Fig. 3 shows the deformations of samples G1and G2 groups.

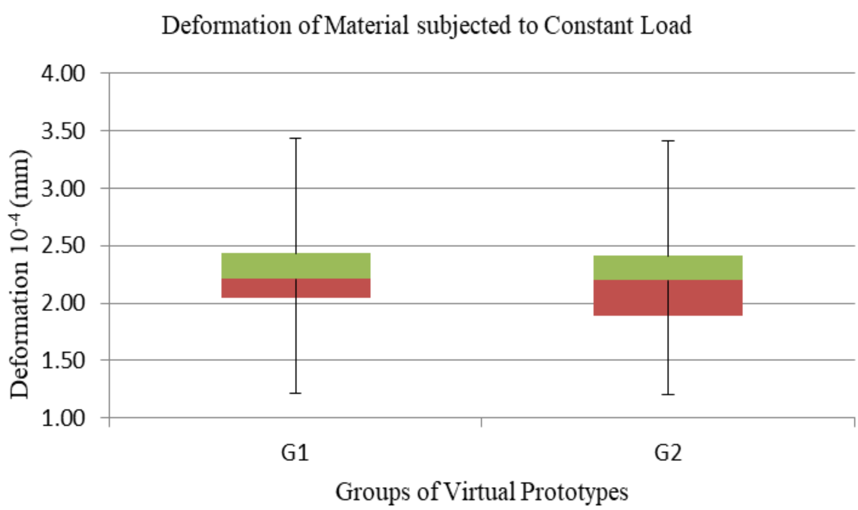

Fig. 3. Deformation of the material with changes in the additive (G1 group) and changes in cement (G2 group)

Fig. 4 shows the deformation of prototype 11 (G1) of pervious concrete modified after loading the dynamic constant force 10,000 N.

In G1 group, as the additive ($Ca(OH)_2$) is added to the pervious concrete mixture, there is an increase in the Young's modulus and a gradual increase in deformation, because the additive impairs the binding property cement, which causes a progressive disruption of the material, until it becomes unstable. In the group G2 the opposite effect occurs because as the cement is added, the material becomes more stable, with a gradual reduction of the elasticity module and a gradual reduction of the deformation, because the cement strengthens the bond between the aggregates, producing a more resistant material.

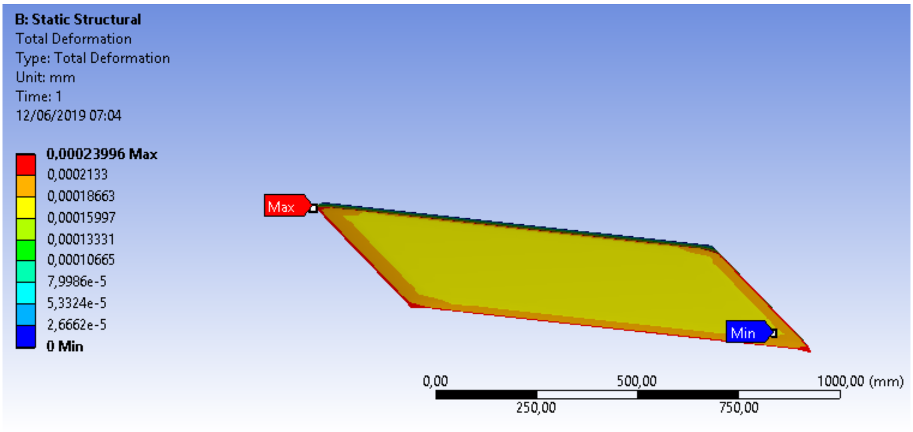

Fig. 4. Deformation of the modified pervious concrete material with loading applied in the center of the prototype

According to (Yu et al., 2019) the pore size of the modified pervious concrete makes the material dependent on cement for binding aggregate particles. For this reason, the interference of the additive when mixing with the cement generates strong destabilization in the internal structure of the modified pervious concrete. The addition of additive interferes with the adhesion of the cement that acts as a binder between the aggregates preventing the cement from acting integrally in the connection between the particles. Porosity is a property that defines pervious concrete itself (Zhang et al., 2019), however the $Ca(OH)_2$ additive fills the voids, the additive impairing this important property, which even affects the possibility of recycling the material (Aliabdo et al., 2018).

For this reason, despite the important advantages of the $Ca(OH)_2$ additive as a larvicide and microbicidal bactericide, which makes it an efficient disinfectant material, it cannot be added in significant percentage in the mixture of the modified pervious concrete, because it may cause complete destabilization of the internal structure material, rendering it useless for structural use, such as pavement for parking vehicles. The solution to the problem is the use of additives within an equilibrium range that encompasses the balance of the properties of G1 and G2 groups, an equilibrium between the $Ca(OH)_2$ additive and the cement used in the mixture of modified pervious concrete. The balance range is the meeting point of two curves with opposite trends.

The G1 curve is ascending, because the more additive is added to the modified pervious concrete mixture, the greater the deformations of the material, tending to a weak and unstable material, the G2 curve is descending, because the more cement is added to the modified pervious concrete mixture, the less the deformation of the material, tending to a resistant material, but with a high financial cost due to the gradual increase in cement.

The meeting point of these two curves, ascending G1 and descending G2, represents the balance range, an optimum point that corresponds to the prototypes with characteristics of compressive strength and percentage of additive coinciding in the two curves, with structural and economic stability properties for the use of modified pervious concrete as a disinfectant pavement in a hospital parking-lot. The balance range contained in the intersection of the curves of the G1 and G2 groups, is shown in Fig. 5, as a solution to the problem of stability of the proposed disinfectant pavement of modified pervious concrete.

Fig. 5 shows the equilibrium range of the modified pervious concrete mixture at the intersection of the ascending curve of the G1 group and the descending curve of the G2 group, considering the deformation in relation to the results found by the finite element method in G1 and G2 groups. The equilibrium range encompasses the properties of the virtual pervious concrete prototype specimens in the range of specimens from 7 to 9, with proportions of 0.7 to 0.9% of $Ca(OH)_2$ additive in the G1 curve and 0.7 to 0.9% cement in the G2 curve. The equilibrium range comprises the values of the compressive strength, density and Young's modulus properties, expressed in Table 4.

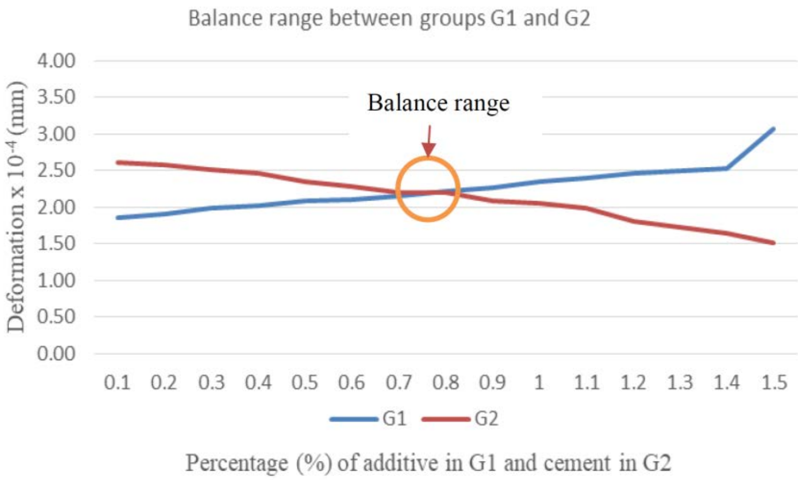

Fig. 5. Balance range between G1 and G2 groups, defined through the intersection point between the deformations of the material in both groups

Table 4. Properties of compressive strength, density, Young's modulus of specimens from balance range

Groups	*Compressive Strength (kg/cm²)*	*Density (kg/m³)*	*Young's modulus (MPa)*
G1	12.70	2,088.42	1,462.50
	12.70	2,081.63	1,455.38
	15.80	1,913.23	1,430.37
G2	19.90	1,818.62	1,487.68
	15.30	1,988.30	1,491.21
	17.80	1,938.36	1,548.21

The average values included in Table 4 were calculated. They reflect the following ratios 1:0.8:4 (cement:$Ca(OH)_2$:limestone), compressive strain of 15.70 kg/cm^2, density of 1,971.42 kg/m^3 and Young's modulus of 1,480.22 MPa, with cement and additive proportions of 0.8%, for obtaining a new modified pervious concrete with disinfectant properties and compatible strength to support vehicle loads up to 10,000 N in hospital parking-lots.

4. Conclusions

The structural simulations in the prototypes of concrete with $Ca(OH)_2$ additive, with finite element modeling, showed results that enabled the drawing of two curves, a curve with a downward trend (G2), relative to the compressive strength in relation to the addition of

$Ca(OH)_2$ in the pervious concrete mixture, and another curve with an increasing trend (G1), relative to the compressive strength in relation to the addition of cement in the mixture of pervious concrete with $Ca(OH)_2$ additive in its mixture. The meeting point between these two curves, one increasing and one decreasing, is the result of the optimization of the best proportion of the microbicidal porous pavement, with a ratio of 1:0.8:4 (cement:$Ca(OH)_2$:limestone), compressive strain of 15.70 kg/cm^2, density of 1,971.42 kg/m^3 and Young's modulus of 1,480.22 MPa, allowing to obtain a material that can be used as a parking floor in hospitals with a balance between the properties of compressive strength and the properties of disinfectant microbicidal pavement. This material can be used in hospital to avoid contamination of vehicle tires and the involuntary transport of pathogenic elements from hospitals to other locations in the city.

Future research should consider tests with specimens of modified pervious concrete installed on the hospital parking pavement to validate the theoretical data obtained during simulations of structural deformation by finite elements, and to further confirm the disinfection properties of the $Ca(OH)_2$ in the mixture of the porous pavement.

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References

Aggelakopoulou E., Bakolas A., Moropoulou A., (2019), Lime putty versus hydrated lime powder: Physicochemical and mechanical characteristics of lime based mortars, *Construction and Building Materials*, **225**, 633-641. DOI: 10.1016/j.conbuildmat.2019.07.218.

Aliabdo A.A., Abd Elmoaty A.E.M., Fawzy A.M., (2018), Experimental investigation on permeability indices and strength of modified pervious concrete with recycled concrete aggregate, *Construction and Building Materials*, **193**, 105-127. DOI: 10.1016/j.conbuildmat.2018.10.182.

Elizondo-Martínez E.-J., Andrés-Valeri V.-C., Jato-Espino D., Rodriguez-Hernandez J., (2020), Review of porous concrete as multifunctional and sustainable pavement, *Journal of Building Engineering*, **27**, 100967. DOI: 10.1016/j.jobe.2019.100967.

Esfandiari J., Loghmani P., (2019), Effect of perlite powder and silica fume on the compressive strength and microstructural characterization of self-compacting concrete with lime-cement binder, *Measurement*, **147**, 106846. DOI: 10.1016/j.measurement.2019.07.074.

Estrada-Aguilar A., Sánchez-Manzano R.M., Martínez-Ibarra J.A., Camacho A.D., Márquez-Navarro A., Nogueda-Torres B., (2012), Larvicidal activity of micronized aqueous suspension of calcium hydroxide against Aedes aegypti and Culex quinquefasciatus (Diptera: Culicidae), *Parasitology Research*, **110**, 1091-1095. DOI: 10.1007/s00436-011-2593-z.

Gao N., Chen K., Quan C., (2020), Development of CaO-based adsorbents loaded on charcoal for CO2 capture at high temperature, *Fuel*, **260**, 116411. DOI: 10.1016/j.fuel.2019.116411.

Goed W.G., (2009), *Pervious concrete: Investigation into structural performance and evaluation of the applicability of existing thickness design methods*, MSc Thesis, University Washington State, Washington, USA.

Grabow W.O., Middendorff I.G., Basson N.C., (1978), Role of lime treatment in the removal of bacteria, enteric viruses, and coliphages in a wastewater reclamation plant., *Applied and Environmental Microbiology*, **35**, 663-669.

IPCC, (2020), Intergovernmental Panel on Climate Change, On line at: https://www.ipcc.ch/.

Mori M., Sakagami Y., Hamazaki Y., Jojima T., (2019), Evaluation of the influence of sprinkling powdered slaked lime on microorganisms for the prevention of domestic animal infectious diseases, *Environmental Technology*, **40**, 3094-3104. DOI: 10.1080/09593330.2018.1465128.

de Oliveira E.A., de Simas Guerreiro M.J.C., Abreu I.M., Dinis M.A.P., (2019), Comparative statistical analysis new urban road pavement versus conventional pavement of pervious concrete, *Procedia Environmental Science, Engineering and Management*, **6**, 473-482.

Razzaghmanesh M., Borst M., (2019), Long-term effects of three types of permeable pavements on nutrient infiltrate concentrations, *Science of The Total Environment*, **670**, 893-901. DOI: 10.1016/j.scitotenv.2019.03.279.

Sapra P., Patil A.C., Bhat K., Kullar A.S., (2017), Comparative evaluation of the antibacterial efficacy of two different formulations of calcium hydroxide as intracanal medicaments against Enterococcus faecalis: an in-vitro study, *Journal of clinical and diagnostic research*, **11**, 26-30. DOI: 10.7860/JCDR/2017/27270.10885.

Sato Y., Ishihara M., Nakamura S., Fukuda K., Takayama T., Hiruma S., Murakami K., Fujita M., Yokoe H., (2019a), Preparation and application of bioshell calcium oxide (BiSCaO) nanoparticle-dispersions with bactericidal activity, *Molecules*, **24**, 3415. DOI: 10.3390/molecules24183415.

Sato Y., Ohata H., Inoue A., Ishihara M., Nakamura S., Fukuda K., Takayama T., Murakami K., Hiruma S., Yokoe H., (2019b), Application of colloidal dispersions of bioshell calcium oxide (BiSCaO) for disinfection, *Polymers*, **11**, 1991. DOI: 10.3390/polym11121991.

Syed S., Liss D.T., Costas C.O., Atkinson J.M., (2020), Diversion principle reduces skin flora contamination rates in a community hospital, *Archives of Pathology and Laboratory Medicine*, Allen Press, **144**, 215-220. DOI: 10.5858/arpa.2018-0524-OA.

Takayama T., Ishihara M., Nakamura S., Sato Y., Hiruma S., Fukuda K., Murakami K., Yokoe H., (2020), Bioshell calcium oxide (BiSCaO) ointment for the disinfection and healing of pseudomonas aeruginosa-infected wounds in hairless rats, *International Journal of Molecular Sciences*, **21**, 4176. DOI: 10.3390/ijms21114176.

WHO, (2020), Country & Technical Guidance - Coronavirus disease (COVID-19), *World Health Organization*, https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance.

Yu F., Sun D., Hu M., Wang J., (2019), Study on the pores characteristics and permeability simulation of pervious concrete based on 2D/3D CT images, *Construction and Building Materials*, **200**, 687-702. DOI: 10.1016/j.conbuildmat.2018.12.135.

Zhang J., Zhang P., Wu J., Feng X., Bian F., Zhang Y., (2019), Time-dependent correlation between micro-structural parameters and gas permeability of concrete in a natural tidal environment, *Construction and Building Materials*, **205**, 475-485. DOI: 10.1016/j.conbuildmat.2019.01.200.