Emerging Trends in Construction Materials: A Perspective on Future Innovations

Dr. Marcus Nguyen[1]
Dr. Aisha Al-Mansouri[2]
Dr. Liam O'Connor[3]

[1]Department of Materials Science and Engineering, University of Melbourne, Australia
[2]Department of Civil Engineering, Qatar University, Doha, Qatar
[3]School of Engineering, Trinity College Dublin, Ireland
***Corresponding Author:** Department of Materials Science and Engineering, University of Melbourne, Australia. Email: m.nguyen@unimelbmaterials.org

Abstract
This paper explores the trajectory of next-generation materials set to shape the future of civil engineering and construction. It reviews significant advancements from recent years while forecasting material technologies that are likely to redefine the built environment. Among the most promising avenues is nanotechnology, which is expected to significantly influence the evolution of advanced construction materials. These innovations are anticipated to take two primary forms: the enhancement of traditional materials and the development of entirely new substances. Environmental sustainability is envisioned as the cornerstone of future material innovation. In addition, these materials must be engineered for longevity, affordability, and efficient spatial utilization—especially in light of increasing urban density and global expansion. The demand for innovative materials is further driven by humanity's ambitions to explore and establish habitats on extraterrestrial bodies such as the Moon and Mars. Furthermore, the resilience of future materials to both natural disasters and human-induced threats will be paramount. Ultimately, the advancement of civil engineering materials must be guided by a commitment to meeting the complex needs of future generations—a mission that lies at the heart of engineering as a discipline.

1 Introduction

Construction materials serve as the fundamental components of civil engineering, playing a pivotal role in the creation of infrastructure such as buildings, transportation networks, water systems, and more. From ancient times to the modern era, materials have continuously evolved to meet the changing needs of society. In early human history, rudimentary shelters were constructed using natural resources like branches and leaves, offering temporary protection from the environment and wildlife. As human civilization advanced—particularly with the rise of agriculture—there emerged a need for more permanent and resilient structures to accommodate people, livestock, and crops. Over time, naturally occurring substances gave way to engineered materials such as stone, timber, bricks, and mortar. This evolution progressed toward stronger innovations like concrete and steel, enabling the development of expansive, multi-storey structures. The pursuit of comfort and functionality led to further advancements in construction, including climate control, lighting, and acoustic design to enhance indoor living conditions. The 20th century, marked by rapid industrialization, brought significant technological achievements in material science. However, it also introduced severe environmental challenges. Civil engineering materials, while transformative, have contributed to pollution and ecological degradation. Materials like concrete, metals, and synthetic polymers, although essential, have raised concerns due to their environmental footprint. As humanity now explores possibilities beyond Earth, such as lunar and planetary colonization, the demand for sustainable, high-performance construction materials becomes more pressing. Future innovations must prioritize environmental responsibility, health safety, and long-term sustainability—ensuring that the built environment serves both current and future generations without compromising ecological balance.

2 FUTURISTIC MATERIALS

2.1 Nanomaterials

Nanotechnology represents a specialized field within materials science that focuses on materials characterized by at least one dimension in the nanometric range, typically around one-billionth of a meter (10^{-9} m). At this ultra-small scale, substances demonstrate properties that deviate significantly from those observed in their micro or macro-scale forms [1]. For instance, copper exhibits extraordinary hardness at the nanoscale, unlike its ductile and malleable behavior at standard sizes [2]. Similarly, gold nanoparticles melt at around 300 °C, substantially lower than the 1064 °C melting point of bulk gold [3,4]. These distinctive features have sparked widespread interest across multiple disciplines, including civil engineering, where researchers have recognized the potential for groundbreaking applications of nanomaterials. In the realm of construction, cement-based materials, including concrete, mortar, and cement paste, are considered foundational [5]. Supplementary cementitious materials (SCMs), often sourced from industrial by-products such as fly ash, silica fume, granulated blast furnace slag, and sugarcane bagasse ash, play a crucial role in enhancing performance. The dual advantage of SCMs lies in their ability to convert waste into usable resources and in their enhancement of concrete's mechanical and durability properties—such as increased strength, better workability, reduced permeability, and enhanced resistance to chemical degradation [5]. Concrete hardens over time through hydration, a series of chemical interactions between water and cement components. The kinetics of this hydration process are strongly influenced by the surface area-to-volume ratio of the reacting particles [6]. Given that nanoparticles possess a significantly higher surface area relative to their volume than microscale particles, they can accelerate hydration reactions and improve both early and long-term strength development [7]. A wealth of research over the last ten years has examined how nanoparticles interact within concrete matrices. Varieties such as carbon nanotubes (CNTs), nanosilica, nanotitania, nanoclays, and even nano-enhanced food additives have been integrated into cement-based materials. Each serves a specific function: CNTs enhance tensile strength and inhibit crack propagation; nanotitania promotes self-cleaning surfaces; nanosilica improves chemical resistance; nanoclays optimize flow properties; and food-based nanomaterials act to reduce the ingress of harmful substances into the porous structure of concrete [8–12]. Nanotechnology is being harnessed in two primary manners: one involves directly adding nanoparticles to traditional building materials such as paints or concrete, and the other involves refining existing substances like cement down to the nanoscale. Nano-cement refers to cement with grain sizes reduced to mere nanometers. The intersection of strength and density remains a focal point in materials research. Although stronger materials often exhibit increased density, thereby raising structural dead loads, nanomaterials offer an attractive alternative due to their ability to deliver high strength while maintaining low weight, a trait especially beneficial for structural engineering applications [13].

Nanotechnology also presents promising advancements in architectural coatings and paints. These products comprise several key components: a base material for body, a vehicle for application, binders for adhesion, thickeners to adjust viscosity, and driers to speed up setting [7]. Paints naturally degrade over time due to environmental exposure. Titanium dioxide, a pigment used in paints since the early 20th century, imparts brightness and opacity [14]. At the nanoscale, titanium dioxide exhibits superior stability and introduces photocatalytic behavior, making it more resilient and long-lasting than its larger counterparts [15]. Paints embedded with nanotitania have demonstrated extended lifespans and self-cleaning capabilities through photoactivation [16]. Concrete structures are vulnerable to chlorides, which compromise long-term durability by penetrating through porous pathways. Once chloride concentrations exceed a critical threshold, they catalyze corrosion of embedded steel reinforcements—a degradation process that results in massive financial losses for the construction industry globally [17–19]. To address this issue, researchers at the National Institute of Standards and Technology (NIST), USA, have developed the Viscosity Enhancers Reducing Diffusion in Concrete Technology (VERDICT) method. This technique involves inserting nano-scale food additives into the concrete pores. These additives raise the viscosity of the pore solution, significantly reducing the mobility of harmful substances [20]. Steel, an alloy primarily composed of iron and carbon, ranks as the second most critical construction material after cement-based composites. While steel is known for its excellent tensile strength, its susceptibility to corrosion and considerable density pose challenges [12]. In contrast, CNTs demonstrate tensile strength nearly 100 times greater than regular steel while maintaining only one-sixth of the density [21]. In the United States, collaborations among the Federal Highway Administration (FHWA), the American Iron and Steel Institute, and the U.S. Navy led to the innovation of a new type of steel enhanced with copper nanoparticles. This advanced steel boasts improved corrosion resistance and weldability [22]. Another notable development is MMFX2 steel, a nanostructured variant characterized by a layered lath structure similar to plywood. MMFX2 exhibits enhanced ductility, impact resistance, and corrosion durability [23].

2.2 Biological Materials

Crack formation is an inherent feature of concrete due to its brittle nature. While microcracks often have negligible impact on load-bearing performance, they increase the permeability of concrete, making the structure vulnerable to moisture and chemical ingress, which can deteriorate its durability over time [24]. This degradation becomes particularly severe in moisture-laden environments [25]. Over prolonged exposure, small cracks can grow, allowing easier passage for aggressive agents and accelerating structural deterioration [26]. If these cracks propagate to reach reinforcing bars, it not only compromises the concrete but also jeopardizes the steel, accelerating corrosion due to exposure to water and oxygen [27]. Traditional methods for sealing such cracks typically involve synthetic polymers, which must be reapplied regularly and often carry environmental drawbacks [28]. In response, newer, eco-conscious solutions have emerged, among which microbial-induced calcium carbonate precipitation has gained traction as a sustainable crack-healing strategy. This method, known as autogenous healing, relies on biological, physical, and chemical mechanisms, but the formation of calcium carbonate is recognized as the principal contributor [26,30]. Certain bacterial species capable of generating calcium carbonate naturally exist in environments such as soil and sand [27]. For application in concrete, spores from these bacteria, along with calcium lactate and nutrients, are embedded into the concrete in protective capsules. These capsules remain inactive until cracks expose them to moisture, which activates the bacteria. Once active, the bacteria convert calcium lactate into limestone, effectively sealing the cracks and obstructing the movement of water through the concrete [31]. One experimental approach embedded a two-part biological healing agent into porous clay granules, partially substituting traditional concrete components. This configuration enabled healing of cracks up to 0.46 mm wide in biologically treated samples, compared to only 0.18 mm in untreated control specimens after immersion in water for 100 days [25]. Another advantage of biological repair methods is their minimal impact on the visual appearance of the treated concrete surface, unlike many conventional repairs [29]. Early concerns about the long-term viability of bacterial spores within hardened concrete have also been addressed. In a study involving Bacillus spores, researchers found that the bacteria remained viable for up to four months. This viability is impacted by the continual reduction in pore size as the concrete sets, which eventually restricts bacterial activity [31]. Furthermore, it was found that higher ambient temperatures enhance the effectiveness of bacterial healing, suggesting environmental conditions play a role in performance outcomes [32]. Concrete's pore solution has an inherently high pH level, typically exceeding 12 [4]. Such alkalinity can significantly suppress bacterial activity [33]. Consequently, researchers proposed using specialized carriers to house the bacteria, protecting them from high pH environments. Among tested carriers, silica gel and polyurethane yielded promising results, with silica gel demonstrating superior performance [34].

Recent studies have increasingly focused on not just the sealing of cracks, but also the restoration of mechanical properties in healed concrete. Evidence indicates that autogenous healing contributes to the structural recovery of concrete. For instance, ultra-high-performance concrete that had suffered damage from freeze-thaw cycles showed improved resonance frequency following biological repair [35]. Ramachandran et al. also reported that calcium carbonate produced by bacterial action enhanced the compressive strength of mortar specimens [36]. In another investigation, mortar samples embedded with biological agents showed marked improvements in compressive strength at 7, 28, and 56 days compared to untreated controls. Post-crack evaluations further confirmed that bio-based healing agents contributed to improved flexural strength and deflection recovery [37]. Beyond mechanical performance, microbial crack repair stands out for its non-polluting nature, offering an environmentally sustainable remedy for structural integrity [38]. In addition to moisture-triggered healing processes, there is also a growing interest in addressing crack formation in dry environments. One method employs hollow natural fibers as reservoirs for healing agents, enabling on-demand delivery when cracks form. Another strategy incorporates water-laden superabsorbent polymers (SAPs) into the concrete matrix. These polymers serve dual roles—initially aiding in cement hydration and later facilitating self-healing when rehydrated during rainfall or water exposure. If the initial hydration consumes all embedded water, environmental moisture can refill the SAPs, thereby perpetuating the self-repair mechanism [37].

2.3 Super Hydrophobic Coatings

Water infiltration and moisture accumulation are persistent issues affecting structural integrity across all types of construction. Moisture is universally recognized as a major threat to buildings, and insufficient protection against it can result in severe structural deterioration. Consequently, waterproofing has become a fundamental strategy to enhance the durability and longevity of concrete infrastructure by mitigating seepage and humidity-related damage [39]. To address this, a range of traditional waterproofing methods have been implemented, including surface impregnation, incorporation of admixtures, use of waterproof paints, polymer-based sealants, and membranes [40,41]. Hydrophobicity, a material's inherent tendency to repel water, is observed in substances such as oils, greases, and alkanes [42]. In contrast, superhydrophobic materials exhibit an exceptional resistance to wetting, with lotus leaves often cited as a natural example due to their remarkable water-repellent properties [43]. Over recent years, numerous superhydrophobic coatings have been developed and evaluated for practical use. These formulations include manganese oxide-polystyrene nanocomposites, zinc oxide-polystyrene nanocomposites, coatings structured with carbon nanotubes (CNTs), nano-silica layers, and precipitated calcium carbonate. These coatings, typically applied using aerosol spray methods, have demonstrated significant durability under testing. Nevertheless, despite their effectiveness, polystyrene-based coatings tend to be expensive [44]. The concept of fabricating highly water-repelling surfaces is seen as a promising solution to counter moisture-related vulnerabilities. Drawing inspiration from the micro-textures of lotus leaves, researchers have successfully engineered water-repellent surfaces by simulating this natural roughness, which facilitates air entrapment beneath water droplets. This unique structural configuration reduces the liquid's contact and adhesion with the surface, ultimately leading to improved hydrophobic performance [45]. Achieving superhydrophobicity involves the synergistic effect of micro/nano-scale surface roughness combined with a hydrophobic chemical layer. Multiple fabrication techniques have been employed to create such surfaces, including plasma treatment, nano-casting, laser etching, and roughening through particle deposition or etching. These processes have enabled the production of roughened textures on materials with inherently low surface energy [46]. Silica nanoparticles, when blended with suitable polymers and hydrophobic agents, have proven especially effective in generating such dual-structured coatings. At Brigham Young University (BYU) in the United States, scientists have developed a new type of superhydrophobic surface by reversing the conventional approach—rather than applying a coating with structure, they incorporated structural elements directly into the coating. Their experiments included two Teflon-based textures: one composed of rib-cavity designs roughly one-tenth the width of a human hair, and another formed by micro-scale posts. In both cases, water droplets maintained a spherical shape and rested atop the surface without spreading [47]. Parallel research at the U.S. Department of Energy’s Brookhaven National Laboratory has proposed nano-cone textures as potential waterproofing materials. These cones, akin to the micro-posts studied at BYU, exhibit the ability to shed water effectively by facilitating droplet roll-off and minimizing surface wetting [48]. Additional geometries like fibers, columns, and other nano-scale features have also been explored to determine their waterproofing capabilities [49]. At the Massachusetts Institute of Technology (MIT), similar outcomes were achieved by introducing ridges into silicon surfaces, creating another form of highly water-repellent structure [50].

2.4 Lunar Materials

Multiple candidates have been evaluated as suitable materials for constructing permanent habitats on the Moon. The use of concrete has been at the center of these discussions. Conventional concrete is typically formulated by combining cement, aggregates such as sand and gravel, and water. For comparative insight, the chemical compositions of ordinary Portland cement, terrestrial fly ash, and lunar regolith have been tabulated in Table 1 [51–53].

Table 1: Chemical Composition of Ordinary Portland Cement, Terrestrial Fly Ash, and Lunar Dust (% by Mass)

Component	Cement	Fly Ash	Lunar Dust
CaO	64.01	0.37–27.68	10
SiO_2	20.13	27.88–59.40	50
Al_2O_3	5.98	5.23–33.99	15
Fe_2O_3	2.35	1.21–29.63	5–15
MgO	1.19	0.42–8.79	10
SO_3	3.53	0.04–8.79	–
Na_2O	0.11	0.2–6.9	–
K_2O	0.77	0.64–6.68	–
TiO_2	0.37	0.24–1.73	5
LOI	1.63	0.21–28.37	–

The chemical composition of lunar dust exhibits substantial similarity to that of terrestrial fly ash. Given that fly ash is widely utilized as a supplementary cementitious component—commonly replacing up to 15% of cement in concrete—lunar dust emerges as a viable alternative material for lunar concrete applications. Investigations have shown that the rocks and regolith present on the moon possess specific gravities exceeding 2.6 [54], suggesting their suitability for conversion into coarse aggregate through mechanical crushing. Similarly, fine aggregates can be produced by sieving lunar soil. However, the primary challenge lies in the binder component—cement. Ordinary Portland cement typically comprises about 65% CaO by mass, while lunar regolith has been reported to contain a maximum of only 19% CaO. This notable discrepancy necessitates exploration into alternative binding systems. Regarding the essential component of water, it may either be transported from Earth or produced in situ by synthesizing it from hydrogen and oxygen, with the latter element extractable from lunar materials [55]. In light of these constraints, research has also explored alternatives to traditional cement and water systems, such as the utilization of sulfur or epoxy resins as binders [56].

The production of sulfur-based concrete involves what is termed "hot technology." In this approach, constituent materials are heated to a temperature range of approximately 140–150°C, which is sufficient to melt the sulfur. Once mixed and subsequently cooled, the re-solidified sulfur acts as the binding agent within the composite. This method has demonstrated promising outcomes, with sulfur concretes achieving compressive strengths ranging from 60 to 115 MPa—an acceptable performance metric for structural use [57]. A notable advantage of this technique is the elimination of water, thereby resolving one of the significant logistical hurdles in lunar construction. Sulfur is the eleventh most abundant element in the average composition of lunar rocks, with a mass percentage ranging from approximately 0.16% to 0.27% [58]. While this concentration is relatively low for extensive infrastructure development, it may be feasible for initial, small-scale construction activities on the lunar surface. With advances in resource extraction technologies, broader utilization of sulfur deposits on the moon could become a practical reality.

2.5 Protective Materials for Security Applications

Nanotechnology has profoundly influenced the development of advanced materials for safeguarding against chemical, biological, explosive, and radiological hazards. Ongoing innovations are pushing the boundaries of nanoscale sensor technologies, offering expansive capabilities for threat detection across these domains [59]. The enhanced efficiency achieved at the nanoscale permits the integration of multiple sensing functions into a single device, enabling simultaneous identification of diverse hazards. While many of these technologies are still undergoing commercialization and scaling, the future implications for security applications are significant [60]. One promising advancement involves the use of nanoscale silver clusters in biological sensing. These clusters exhibit distinct color variations based on their dispersion state in solution. When engineered DNA strands are conjugated with these clusters, the presence of complementary DNA sequences causes aggregation, leading to observable color changes. This colorimetric mechanism offers a sensitive detection system, with reported detection thresholds as low as 500 picomolar for a 24-base single-stranded DNA target and 2.5 nanomolar for double-stranded nucleotides [61,62]. In analytical chemistry, the concept of the limit of detection (LOD) refers to the smallest concentration of a substance that can be reliably differentiated from a zero reading within a specified confidence level [63,64].

Chemical reactions at the nanoscale are central to both technological innovation and the natural processes of life. Engineered nanostructured materials serve as potent catalysts for various reactions due to their tailored surface chemistries, high specific surface areas, and uniquely structured molecular frameworks [65]. Recent technological progress has facilitated the embedding of these nanostructured catalysts within high-porosity carrier networks. These networks typically comprise sintered, interlocked metal fibers of micron-scale diameter, providing an ideal matrix for catalytic processes. Moreover, advancements in computational protein engineering have allowed the redesign of ligand-binding specificities in receptor proteins. These engineered receptors are being developed into robust biosensing platforms that operate via fluorescence, electrochemical signals, or cellular interactions [66]. The overarching aim is to reprogram binding sites to recognize any molecular target within a specific mass range, thereby enabling the rapid creation of durable, reagent-free biosensors for real-time detection of chemical, biological, and explosive threats. The integrated computational and experimental strategies behind this approach offer transformative potential, allowing for the swift development and deployment of new sensors—potentially within just 7 to 10 days from threat identification [67,68].

3 CONCLUSIONS

Reflecting on the evolving landscape of civil engineering materials, one cannot overlook the insightful remark by Nobel Laureate Richard Feynman: “There’s plenty of room at the bottom”. This vision aptly encapsulates the transformative potential of nanotechnology within the construction sector. Emerging nanomaterials are either already in use or in advanced development, introducing groundbreaking innovations to the field. Notable examples include ultra-high-performance concrete and self-cleaning concrete, both made possible due to the enhanced surface area-to-volume ratios of nanoscale particles. These advanced materials offer promising solutions to several limitations of conventional construction materials, addressing key challenges related to sustainability, structural performance, and security. Traditionally grounded in the principles of mathematics, physics, and chemistry, civil engineering is now increasingly embracing biotechnology to design more intelligent and efficient construction materials. In the context of extraterrestrial infrastructure, current research is focused on significantly reducing the dependency on Earth-supplied resources. The continuous exploration and development of advanced construction materials remain a priority for the industry. Clearly, the manipulation of matter at the nanoscale is fostering revolutionary progress, contributing not only to technical advancements but also to notable economic benefits in civil engineering and infrastructure development.

REFERENCES

[1] K. Gopalakrishnan, Nanotechnology in Civil Infrastructure. A Paradigm Shift (Springer, USA, 2011).

[2] B.D. Fahlman, Materials Chemistry (Springer, Germany, 2007).

[3] R. Sardar, A.M. Funston, P. Mulvaney and

R.W. Murray // Langmuir 25 (2009) 13840.

[4] A.M. Neville, Properties of Concrete (Pearson Education, 2011).

[5] A. Khitab, M.T. Arshad, F.M. Awan and I. Khan // International Journal of Sustainable Construction Engineering & Technolog 4 (2013) 33.

[6] M.A.T.M. Broekmans and H. Pöllmann, Applied Mineralogy of Cement and Concrete:Reviews in Mineralogy & Geochemistry 74 (Mineralogical Society of America, 2013).

[7] A. Khitab, Construction Materials: Classical and Novel (Allied Books, Pakistan, 2012).

[8] M.S. Konsta-Gdoutos, Z.S. Metaxa and S.P. Shah // Cement & Concrete Composites 32 (2010) 110.

[9] G. Hüsken, M. Hunger and H.J.H. Brouwers // Building and Environment 44 (2009) 2463.

[10] L.V. Kim, V.V. Potapov, A.N. Kashutin, V.A. Gorbach, K.S. Shalaev and D.S. Gorev, In: Proceedings of the Twenty-third International Offshore and Polar Engineering (Anchorage, Alaska, USA, 2013).

[11] K. Patel // International Journal of Engineering Research and Applications 2 (2012) 1382.

[12] D.P. Bentz, M.A. Peltz, K.A. Snyder and J.M. Davis // Concrete International 31 (2009) 31.

[13] Z. You, J. Mills-Beale, J.M. Folev, S. Roy, G.M. Odegard, O. Dai and S.W. Goh // Construction and Building Materials 25 (2011) 1072.

[14] A. Khitab and M.T. Arshad // Rev Adv. Mater. Sci. 38 (2014) 181.

[15] E. Quagliarini, F. Bondioli, G.B. Goffredo, C. Cordoni and P. Munaf // Construction and Building Materials 37 (2012) 51.

[16] J. Chen and C. Poon // Building and Environment 44 (2009) 1899.

[17] M. Barbesta and D. Schaffer, Concrete that cleans itself and the environment (2009), available at http://txactive.us/images/ concrete_international.pdf.

[18] L. Nilsson, In: Nordic Mini Seminar & fib TG 5.5 meeting (Göteborg, Sweden, 2001).

[19] A. Khitab, Modeling of ionic transport in saturated porous medium (Dissertation, National Institute of Applied Sciences, Toulouse, France, 2005).

[20] N. Silva. Chloride Induced Corrosion of Reinforcement Steel in Concrete (Dissertation, Chalmers University of Technology, Gothenburg, Sweden, 2013).

[21] M.D. Arafa, C. DeFazio and B. Balaguru, In: 2nd International Symposium on Nanotechnology in Construction (Bilbao, Spain, 2005).

[22] W. Zhu, P.J.M. Bartos and A. Porro // Materials and Structures 37 (2004) 649.

[23] A.K. Rana, S.B. Rana, A. Kumari and V. Kiran // Journal of Recent Trends in Engineering 1 (2009) 46.

[24] Ruth W. Chabay and Bruce A. Sherwood, Matter and Interactions, 3rd edition (John Willey & Sons Inc., USA, 2010).

[25] H.M. Jonkers, In: Self Healing Materials (Springer,Netherlands, 2008), p. 195.

[26] V. Wiktor and H.M. Jonkers // Cement and Concrete Composites 33 (2011) 763.

[27] C. Edvardsen // ACI Materials Journal 96 (1999) 448.

[28] V.K. Tittelboom, N. DeBelie, W. DeMuynck and W. Verstraete // Cement and Concrete Research 40 (2010) 157.

[29] S.S. Bang and V. Ramakrishnan, In: Proceedings of the International Symposium on Industrial Application of Microbial Genomes (2001), p. 3.

[30] W. DeMuynck, K. Cox, N.D. Belie and W. Verstraete //Construction and Building Materials 22 (2008) 875.

[31] E. Schlangen and C. Joseph, In: SK, editor. Self-healing materials: fundamentals, design strategies, and applications, ed. by S.K. Gosh (Wiley-VCH verlag GmbH, Weinheim, 2009), p. 141.

[32] H.M. Jonkers, A. Thijssen, G. Muyzer, O. Copuroglu and E. Schlangen // Ecological engineering 36 (2010) 230.

[33] H.W. Reinhardt and M. Jooss // Cement and Concrete Research 37 (2003) 981.

[34] J. Wang, K. Van-Tittelboom, N. De-Belie and W. Verstraete // Construction and Building Materials 26 (2012) 532.

[35] V.C. Li and E.H. Yang, In: Self healing materials (Springer, Netherlands, 2008), p. 161.

[36] S.K. Ramachandran, V. Ramakrishnan and S.S. Bang // ACI Materials journal 98 (2001) 3.

[37] M.G. Sierra-Beltran, H.M. Jonkers and E. Schlangen // Construction and Building Materials 67 (2014) 344.

[38] A. Hosoda, T. Kishi and T. Takakuwa, In: Ist international conference on self-healing materials (Noordwijk, Holland, 2007).

[39] M. Borodicz // Materialy Budowlane 9 (1994) 19.

[40] J. Ślusarek // Electronic Journal of Polish Agricultural Universities 11 (2008) 28.

[41] Z. Scislewski, Protection of reinforced concrete structures (Arkady, Warsaw, 1999).

[42] Behnam Akhavan // ACS Appl. Mater. Interfaces 5 (2013) 8563.

[43] S. Wang and L. Jiang // Advanced Materials 19 (2007) 3423.

[44] L. Jinbin, C. Hongling, F. Ting and Z. Jinlong // Z. Colloids and Surfaces A: Physicochemical and Engineering Aspects 421 (2013) 51.

[45] M. Ma and R.M. Hill // Current Opinion in Colloid & Interface Science 11 (2006) 193.

[46] E. Bengtsson, Creating super hydrophobic surfaces for moisture protection of biobased composites (Master of Science Thesis, Chalmers University of Technology, Sweden, 2013).

[47] Nano-cone textures generate extremely robust, DOE/Brookhaven National Laboratory/releases/2013/10/13 1021 13 1 10 8. htm (2013).

[48] P. Nair, Tribology of Silicon Nano-textured Surfaces Fabricated by Rapid Aluminum-induced Crystallization of Amorphous Silicon (ProQuest, 2007).

[49] C. Antonio, A. Rahman and T.B. Charles // Advanced Materials 26 (2013), DOI:10.1002/ adma.201304006. http://www.techtimes.com/articles/1630/ 20131126/scientists-make-breakthrough-in waterproof - technology.htm.

[51] D. Hesterberg, Chemical Composition, Speciation, and Elemental Associations in Coal Fly Ash Samples Related to the Kingston Ash Spill (Energy Fuels, USA, 2014).

[52] T.D. Lin, In: Space Resources Materials (NASA SP-509, vol. 3, 1992).

[53] D.J. Loftus, E.M. Tranfield, J.C. Rask and C. McCrosssin, The Chemical Reactivity of Lunar Dust Relevant to Human Exploration of the Moon (NASAAmes Research Center, USA, 2008).

[54] T.D. Lin, Concrete for lunar base construction (Construction Technology Laboratories, The Portland Cement Association, Skokie, Illinois, USA, 2006).

[55] F. Ruess, J. Schaenzlin and H. Benaroya // Journal of Aerospace Engineering 19 (2006) 138.

[56] H.A. Omar, Production of Lunar concrete using molten sulfur, Final Research (Report for JoVe NASA Grant NAG8-278, 1993).

[57] N. Ciak and J. Harasymiuk // Technical Sciences 16 (2013) 323.

[58] D. Vaniman, D. Pettit and G. Heiken, Uses of lunar sulfur (Los Aiamos National Laboratory Los Aiamos NM 87545, 1986).

[59 Nanotechnology in the Security Systems, NATO Science for Peace and Security Series C: Environmental Security, ed. by J. Bonca and S. Kruchinin (Springer, 2015).

[60] H. Wohltjen and A.W. Snow // Analytical Chemistry 70 (1998) 2856.

[61] A.W. Snow, H. Wohltjen and N.L. Jarvis, Gold nanocluster vapor sensors (American Chemical Society, 221:324-IEC, Part 1 Apr 1, 2001).

[62] R.A. Reynolds, C. A. Mirkin and R.L. Letsinger // Pure and Applied Chemistry 72 (2000) 229.

[63] R.A. Reynolds, C. A. Mirkin and R.L. Letsinger // J. Am. Chem. Soc. 122 (2000) 3795.

[64] Compendium of Chemical Terminology, 2nd ed. (IUPAC, 1997).

[65] D. MacDougall and B. Warren // Anal. Chem.52 (1980) 2242.

[66] D.R. Cahela and B.J. Tatarchuk // Catalysis Today 69 (2001) 33.

[67] D.K. Harris, D. R. Cahela and B.J. Tatarchuk // Composites: Part A 32 (2001) 1117.

[68] D.E. Benson, A.E. Haddy and H.W. Hellinga // Biochemistry 41 (2002) 3262.

[69] R.P. Feynman, There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics presented at Annual meeting of the American Physical Society (California Institute of Technology, 1959).