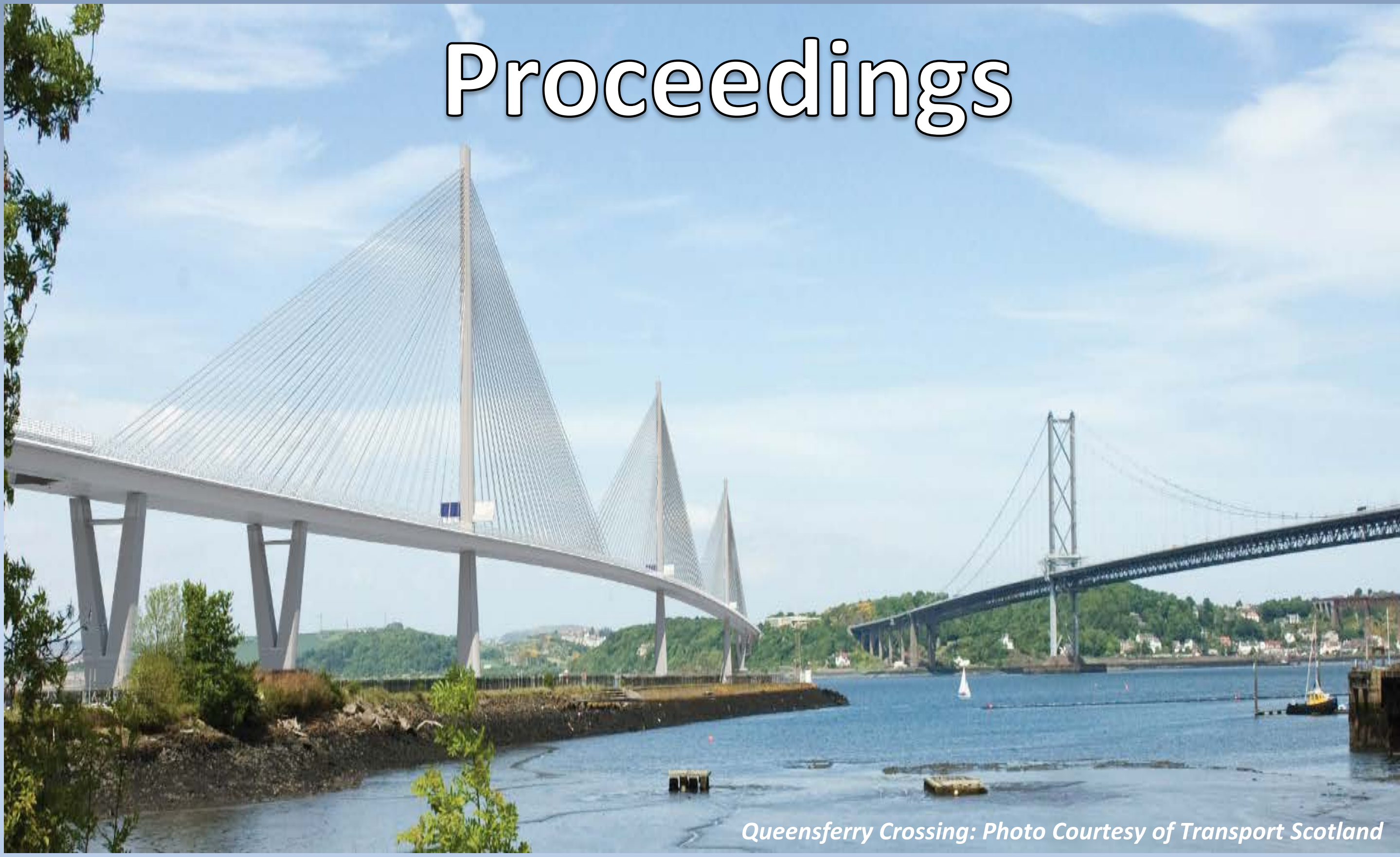
The 9th International Concrete Conference 2016

Environment, Efficiency and Economic Challenges for Concrete

UNIVERSITY OF DUNDEE

Proceedings



Queensferry Crossing: Photo Courtesy of Transport Scotland

Sponsored by

IOM3 The Institute of Materials, Minerals and Mining

RILEM

Dundee & Angus Convention Bureau — Working with you for you

Exhibitors

TA

BASF — We create chemistry

jet materials ltd

Quantachrome UK — Particle Characterisation

Hanson — HeidelbergCement Group

University of Kentucky — Center for Applied Energy Research

Elkem

Surface Measurement Systems — World Leader in Sorption Science

banahCEM — Cement Reimagined

ISBN 9780957326316

9th International Concrete Conference 2016

Environment, Efficiency and Economic Challenges for Concrete

4-6 July 2016
Dundee, Scotland, UK

Edited by

M Roderick Jones
Director, Concrete Technology Unit
University of Dundee

Moray D Newlands
Senior Lecturer, Concrete Technology Unit
University of Dundee

Judith E Halliday
Research/Teaching Fellow, Concrete Technology Unit
University of Dundee

Laszlo J Csetenyi
Research/Teaching Fellow, Concrete Technology Unit
University of Dundee

Li Zheng
Research/Teaching Fellow, Concrete Technology Unit
University of Dundee

Michael J McCarthy
Reader, Concrete Technology Unit
University of Dundee

Thomas D Dyer
Lecturer, Concrete Technology Unit
University of Dundee

ABOUT THE EDITORS

Professor M Roderick Jones is the Director of the Concrete Technology Unit at the University of Dundee. A renowned practitioner in the field of concrete technology, he is a member of numerous national and international technical committees and has published extensively on many aspects of concrete technology, cement science and sustainable construction.

Dr Moray D Newlands is a Senior Lecturer within the Concrete Technology Unit at the University of Dundee. His research focusses on balancing sustainability and durability performance in concrete construction, as well as the use of novel materials and the development of test methods for assessing concrete.

Dr Judith E Halliday is a Research/Teaching Fellow within the Concrete Technology Unit at the University of Dundee. She has been involved in numerous projects relating to sustainable and environmental issues of recycling materials in concrete construction. She has now shifted her focus on the awareness of the depletion of natural resources and the impact of their use in construction as a whole.

Dr Laszlo J Csetenyi is a Research/Teaching Fellow in the Concrete Technology Unit at the University of Dundee. His main areas of interest include cement and concrete science and technology with emphasis on waste stabilisation/solidification and practical use of these materials in construction.

Dr Li Zheng is a Research/Teaching Fellow within the Concrete Technology Unit at the University of Dundee. His current work is concerned with concrete durability, recycling aggregates, foamed concrete, fly ash recovery and beneficiation, cement hydration and temperature rise modelling and mix design/optimisation with novel cement combinations.

Dr Michael J McCarthy is a Reader in the Concrete Technology Unit at the University of Dundee. He has carried out research in the field of concrete technology for the last 20 years. Much of his work has been concerned with the use of fly ash in various construction applications, deterioration of concrete in various exposure conditions and aspects of concrete construction technology. He has been involved in many projects and has published widely on his work.

Dr Thomas D Dyer is a Lecturer in the Concrete Technology Unit at the University of Dundee. His research has primarily involved investigation of interactions of by-products with cement. He is also involved in applying life-cycle assessment techniques to construction. Recently his work has extended to include imprinting of biomimetic microstructures in construction materials, and interactions of brownfield contaminants with fresh concrete.

Cover Photo: Queensferry Crossing, Scotland, Courtesy of Transport Scotland

Details of all publications from the University of Dundee - Concrete Technology Unit are available from:
Concrete Technology Unit, University of Dundee, Dundee, DD1 4HN, UK
Tel: 01382 384498, m.r.jones@dundee.ac.uk

Published by University of Dundee – Concrete Technology Unit, 2016

ISBN 978-0-9573263-1-6

The major themes of this year's conference draw heavily on the need to constantly improve sustainability in the concrete industry. There has been significant progress on issues including, CO_2 and NO_x emissions from raw materials, manufacture, construction, operation and end of use. The industry is developing innovative solutions with low energy cements and by-product materials, and through the use of recycled and secondary aggregates. However, there is still work to be done to balance overall resource efficiency with concrete performance requirements for economic construction.

The demands on concrete are changing emphasis, and beyond the proven engineering advantages other properties are being exploited, for example its high thermal mass, which can help to regulate building temperatures and minimise energy consumption. Off-site prefabricated concrete can offer improved vibration, sound insulation and acoustic performance. At a broader scale, climate change presents a major challenge for infrastructure reliability and resilience and concrete is capable of resisting damage and recovering rapidly from extreme weather events. With increasing traffic, concrete road base/blacktop wearing course composites will be important in achieving road pavement design lives. Energy mixes in most countries are changing from fossil to increasing renewable and low emission production. Wind farm sites have proved popular but are being moved offshore and into deeper waters, and concrete foundations and sub-structures can offer more cost effective solutions for the majority of soils and water depths. New nuclear power stations are being planned and again high performance concrete will be a requirement.

Over the next decade digital design and structural engineering technologies will become de facto and it will be imperative that there is a close working relationship between the research, design, industry and standards communities. Innovative thinking and adoption of practical research and development must be utilised to their full potential for the sector to prosper, which Dundee has championed for many years.

The Concrete Technology Unit organised this Conference to address these challenges, continuing its established series of events, namely, Concrete in the Low Carbon Era, 2012; Concrete: Construction's Sustainable Option, 2008; Global Construction: Ultimate Concrete Opportunities, 2005; Challenges of Concrete Construction, 2002; Creating with Concrete, 1999; Concrete in the Service of Mankind, 1996; Economic and Durable Concrete Construction Through Excellence, 1993 and Protection of Concrete, 1990.

Under the theme of Environment, Efficiency and Economic Challenges for Concrete, the Conference consisted of six Events: *(i) Recycling and Reuse, (ii) Waste Minimisation and Resource Efficiency, (iii) Low Carbon Cements and Concrete, (iv) Novel, Smart and Multi-Functional Concrete, (v) Durability, Serviceability and Reliability, (vi) Advances in Structural Modelling.* In all, over 110 papers were presented from over 40 countries.

The Opening Addresses were given by Professor Sir Peter Downes, Principal and Vice-Chancellor of the University of Dundee, and Professor Rod Jones, Conference Chairman, University of Dundee. The Conference Opening Paper was presented by Professor Tom Robl of the University of Kentucky, USA. The Closing Summary Paper was presented by Professor Peter Hewlett, Visiting Professor at the University of Dundee and Director of Research to the David Ball Group.

The support of International Professional Institutions and Sponsoring Organisations was a major contribution to the success of the Conference. Exhibitors, representing both global and local industry as well as instrument manufacturers and a research centre, formed an integral part of the event. The work of the Conference was an immense undertaking and all of those involved are gratefully acknowledged, in particular, the members of the Organising Committee for managing the event from start to finish; members of the Scientific and Technical Committee for advising on the selection and reviewing of papers; the Authors and the Chairmen of Technical Sessions for their invaluable contributions to the proceedings.

Professor Roderick Jones, Conference Chairman, 4 July 2016

ORGANISING COMMITTEE

Professor M R Jones
Conference Chairman

Dr M D Newlands
Conference Secretary

Dr M J McCarthy

Dr T D Dyer

Dr J E Halliday

Dr L J Csetenyi

Dr L Zheng

Dr L Chernin

Professor P C Hewlett,
David Ball Group, UK

Professor T A Harrison,
Independent Consultant, UK

Professor P Chana
Mineral Products Association, UK

Mr Raman Mangabhai
Mangabhai Consulting, UK

Dr David Dunne
AECOM, UK

SCIENTIFIC AND TECHNICAL COMMITTEE

Prof M Thomas
University New Brunswick, Canada
Prof C Shi
China Building Materials Academy, China, China
Prof J Qian
Chongqing University, China
Dr S Caliskan
Saudi Aramco, Saudi Arabia
Prof S P Singh
NIT Jalandhar, India
Prof M Ganesh
VIT Vellore, India
Prof U Dave
Nirma University, India
Prof M Alexander
UCT, South Africa
Dr E Kearsley
University of Pretoria, South Africa
Prof P Sukontasukkul
King Mongkut University of Technology-North Bangkok, Thailand
Prof M Sugiyama
Hokkai Gakuen University, Japan
Prof B H Oh
Seoul National University, Korea

Prof R I Gilbert
University of New South Wales, Australia
Prof P Helene
Brazilian Concrete Institute, Brazil
Prof K Curtis
Georgia Tech, USA
Prof I Papayianni
Aristotle University of Thessaloniki, Greece
Prof K van Breugel
Delft University of Technology, Netherlands
Mr C Heidrich
ADAA, Australia
Dr C Clear
MPA, UK
Dr K Paine
University of Bath, UK
Dr V Baroghel-Bouny
IFSTTAR, France
Prof F Hunkeler
TFB, Switzerland
Prof S Hanehara
Iwate Universtiy, Japan
Mr C Shaw
independent consultant, UK
Dr A Yerramala
Madanapalle Institute of Technology and Science, India

SPONSORING ORGANISATIONS

The Institute of Concrete Technology, UK

RILEM

The Institute of Materials Minerals and Mining, UK

Dundee and Angus Convention Bureau

University of Dundee

EXHIBITORS

banahCEM

BASF – The Chemical Company

Dundee and Angus Convention Bureau / Dundee City Council

Elkem Silicon Materials

Hanson Cement

Jet Materials Ltd

Quantachrome UK

Surface Measurement Systems UK

TA Instruments

University of Kentucky Center for Applied Energy Research

SUPPORTING INSTITUTIONS

China Civil Engineering Society

Chinese Institute of Engineers (Taiwan)

Concrete Society, UK

Polish Concrete Producers Association

Spanish Precast Concrete Association – ANDECE

Taiwan Concrete Institute

CONTENTS

Please enter page number into your pdf reader page navigator to go to paper

THEME 2 WASTE MINIMISATION AND RESOURCE EFFICIENCY

THEME 3 LOW CARBON CEMENTS AND CONCRETE

THEME 4 NOVEL, SMART AND MULTI-FUNCTIONAL CONCRETE

THEME 5 DURABILITY, SERVICEABILITY AND RELIABILITY

Keynote Paper

ADDITIONAL PAPERS

Keynote Paper

EFFECT OF NANO-SILICA AND AGGREGATE TYPE ON PROPERTIES OF ULTRA HIGH PERFORMANCE CONCRETE

K Janković
IMS Institute

S J Stanković
Vinča Institute of Nuclear Sciences

M Stojanović **D Bojović** **L Antić**
IMS Institute
Serbia

ABSTRACT. The aim of this investigation is to develop ultra high performance concrete (UHPC) for multipurpose - higher mechanical and ionizing radiation protection. The effect of nano-silica replacement (2 or 5%) on the properties of UHPC was compared with the referent concrete by testing compressive and flexural strength. As nano-silica influences cement hydration and modifies the pore structure, qualitative and quantitative analysis of pores was done using a device RapidAir 457. The second objective of this paper is to evaluate the influence of different aggregates on concrete properties. Two types of aggregate were used: quartz and barite. One of the most important characteristics of the concrete for protection against gamma and X radiation is its Total Attenuation Coefficient $(\mu/\rho)_{tot}$.

Key word*:* Nano-silica, UHPC, Barite, Radiation protection.

Ksenija Janković, senior research fellow is Head of Laboratory for Concrete at IMS Institute, Belgrade, Serbia. Her research interests include ultra high performance concrete, utilization of by-products and recycled waste materials in concrete and concrete durability. She has published about 140 papers.

Srboljub J Stanković, MSc EE, research assistant is working in the Department of Radiation and Environmental Protection at Vinča Institute of Nuclear Sciences, University of Belgrade, Serbia. He is a PhD candidate at the School of Electrical Engineering at Belgrade University. He is especially interested in nuclear engineering, physical properties of materials, radiation protection and ionizing radiation.

Marko Stojanović, MSc CE, research assistant is working in the Laboratory for Concrete at IMS Institute. He is a PhD student at the Faculty of Civil Engineering, Subotica at Novi Sad University. His research interests are SCC and ultra high performance concrete.

Dragan Bojović, MSc CE, research assistant is working in the Laboratory for Concrete at IMS Institute. He is a PhD candidate at the Faculty of Technical Sciences at Novi Sad University. His research interests focus on ultra high performance concrete, SCC, concrete fracture and concrete quality control in situ.

Lana Antić, MSc CE is working in the Laboratory for Concrete at IMS Institute.

INTRODUCTION

Modern construction industry required building materials with improved properties. Ultra high performance concrete is one of them. Significant increases in mechanical properties of cementitious materials have been achieved by incorporating nano-silica [1]. By replacing a part of cement content with nano-silica it is possible to produce concrete with high performance and it can also reduce CO_2 emission.

Land and Stephan studied the way different nanoparticles affect cement hydration [2]. The acceleration of cement hydration was dependant on the total surface size of added nano-silica particles [3]. The pore size distribution also showed that nano-silica refined the large capillary pores, due to the combined contribution of the nano-filler effect and the pozzolanic reaction [4]. The fact that pore-size distribution was becoming finer, reduced pore volume and improved physico-mechanical properties of the mortars after the addition of nano-powders could be explained by the filler effect or the amount of hydration products of cement [5].

By adding between 3% and 10% w/w of colloidal silica suspension in the fiber-cement composites, the pullout of the fibers increased significantly [6]. Compressive strength and transport properties of UHPC also increased with the addition of nano-silica. For best performance, the optimum amount of nano-silica for cement replacement in the cement paste was 3 wt.% [7]. The results showed that up to 3% increase in the nano-silica content resulted in the increase in compressive and flexural strength of UHPC, and when the nano-silica content was more than 3% the mechanical properties decreased slightly due to agglomeration of nano-silica particles. The addition of nano-silica accelerated the hydration process. By increasing the nano-silica content the average pore diameter and porosity decreased. The microstructure was more homogenous and dense for nano-silica specimens when compared to the control specimen [8].

By using new nanomaterials higher temperatures will be allowed and hence a more efficient operation of power plants will be achieved, and the development of new energy production systems based on solar, nuclear and renewable sources will be enabled [9]. Ultra high performance concrete can be used in nuclear power plants and defensive facilities due to its dynamical behavior [10].

Barite aggregate is used to produce heavyweight concrete which is used for shielding in nuclear facilities and hospitals. Concrete with barite powder used as sand substitution in range between 0% and 25% decreased the compressive strength at 28 days just by 10% [11]. The grading curve of barite was modified by mixing process at a higher extent than for other aggregates. This influenced the properties of concrete by increasing workability, but decreasing compressive strength and the modulus of elasticity [12]. The basic characteristics of ordinary concrete and heavy-weight concrete with barite were studied for the application in shielding from gamma radiation [13, 14].

Also, one of the goals is the implementation of appropriate numerical calculations for obtaining the total mass attenuation coefficient value in the energy range 10 keV - 150 MeV of gamma and X radiation, depending on the changes in the concrete type in UHPC concrete with specially defined mechanical properties.

EXPERIMENTAL WORK

The design of ultra high performance concrete is different than ordinary concrete. High amount of fine particles is used for UHPC manufacturing. Their properties are shown in Table 1.

Table 1 Properties of powder materials and sand

	CEMENT	SILICA FUME	QUARTZ POWDER	QUARTZ SAND	BARITE SAND
SiO_2, %	20.51	92.52	97.54	97.54	11.13
Al_2O_3, %	6.15	0.64	0.52	0.52	2.24
Fe_2O_3, %	2.80	0.31	0.57	0.57	1.55
CaO, %	63.41	0.38	0	0	0.18
MgO, %	1.85	0.44	0	0	0
Na_2O, %	0.29	0.32	0	0	0.86
K_2O, %	0.79	0.87	0.24	0.24	0.72
SO_3, %	2.69	0.22	0	0	28.05
Ba, %	0	0	0	0	53.15
Cr, %	0	0	0	0	0.4
Sr, %	0	0	0	0	1.72
Specific density, kg/m^3	3100	2200	2695	2695	3770
Bulk density, kg/m^3				1650	2260

Concrete was made with ordinary Portland cement CEM I 42.5 R. Also, silica fume (SF) and nano-silica (nS) with average particle size of 7 nm were pozzolanic materials. Quartz powder (Qp) with average particle size of 50 μm and quartz sand (Qs) or barite sand (B) up to 4 mm were used as aggregate. A modified polycarboxylates based superplasticizer allowed high water reduction. Brass coated steel fibers with 8 mm length and a diameter of 0.15 mm were used (5% by volume). Six types of concrete were made with varying percent of nano-silica (0%, 2% and 5%) and aggregate type (quartz and barite). Composition of concrete mixtures are shown in Table 2.

Table 2 Concrete mixture composition, kg/m^3

	K0f5	K2f5	K5f5	B0f5	B2f5	B5f5
C	950	931	902.5	950	931	902.5
SF	200	200	200	200	200	200
nS	0	19	47.5	0	19	47.5
Qp	350	350	350	335	335	335
Qs	570	570	570	0	0	0
B	0	0	0	810	810	810
Water	230	250	250	230	250	250
Superplasticizer	55	55	55	55	55	55
Fibers	390	390	390	390	390	390

NUMERICAL CALCULATIONS OF TOTAL MASS ATTENUATION COEFFICIENT

Total Mass Attenuation Coefficient $(\mu/\rho)_{tot}$ is one of the most important concrete characteristics for protection against gamma and X radiation.

The definition of Total Mass Attenuation Coefficient for mixture is given by:

$$\left(\frac{\mu}{\rho}\right)_{tot} = \sum_j w_j \cdot \left(\frac{\mu}{\rho}\right)_j \quad (1)$$

where $(\mu/\rho)_j$ and w_j are the weight fraction and mass attenuation coefficient of the constituent element j.

The numerical calculations included two steps: 1. The composition of each type of concrete from Table 2 was determined in accordance with the nomenclature of chemical elements and chemical compounds, 2. Interactive use of the XCOM program [15], where the known composition of individual types of concrete determines the total mass attenuation coefficient depending on the change of energy photon radiation.

XCOM program enables the calculation of interaction coefficients for the following processes: Compton (incoherent) and Rayleigh (coherent) scattering, photoelectric absorption, and pair production in the fields of the atomic nucleus and atomic electrons. The mean free paths between scatterings, between photo-electric absorption events, or between pair production events are the reciprocals of partial interaction coefficients. The total attenuation coefficient is calculated as the sum of the interaction coefficients for the individual processes.

RESULTS AND DISCUSSION

Samples for testing the mechanical properties were prepared in molds 4 cm × 4 cm × 16 cm by the vibration on vibro-table for 60 s. Next day, specimens were demoulded and put into water and cured up to testing.

The results of compressive strength of concrete with quartz were given in Figure 1 and for UHPC with barite aggregate were shown in Figure 2.

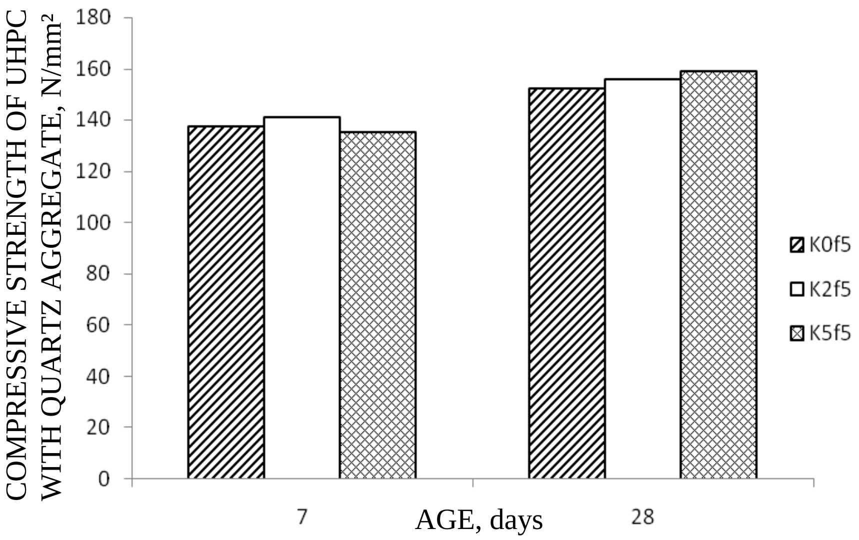


Figure 1 Compressive strength of UHPC with quartz aggregate

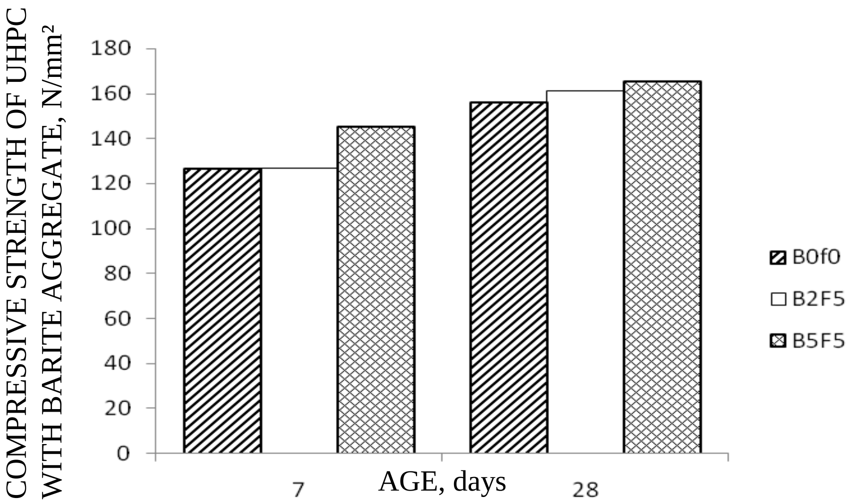


Figure 2 Compressive strength of UHPC with barite aggregate

Obtained values of flexural strength of all concrete types are shown in Table 3.

Table 3 Flexural strength of concrete, N/mm²

	K0f5	K2f5	K5f5	B0f5	B2f5	B5f5
7 days	26.1	29.4	25.0	25.0	34.0	24.8
28 days	28.0	37.4	27.3	31.1	38.9	32.0

By comparing concrete made with different aggregate it can be seen that the concrete made with barite aggregate had better results than concrete made with quartz aggregate. For compressive strength, the difference is about 4% for concrete with nano-silica and 3% for concrete without nano-silica. Flexural strength of concrete with barite sand and 5% of nano-silica is 17% higher, for UHPC without nano-silca is 11% higher, while concrete made with 2% nano-silica had only 4% higher flexural strength when compared to concrete made only with quartz aggregate.

Comparing concrete made with the same type of aggregate we can see that its compressive strength increases with the addition of nano-silica. For barite concrete, the difference is 3% for concrete with 2% nano-silica and 6% for concrete with 5% nano-silica related to UHPC without nano-silica. Concrete with quartz sand and 2% nano-silica had only 2% higher compressive strength and with 5% nano-silica had 4% greater compressive strength comparing to mixture without nano-silica. Influence of 2% nano-silica had positive effect on flexural strength. It increased 34% for quartz concrete and 25% for barite concrete. With 5% nano-silica flexural strength slightly decreased for concrete with quartz aggregate, while it slightly increased for concrete with barite aggregate when compared to UHPC without nano-silica.

Pore-size distribution was tested by RapidAir 457 device. With the increase in the nano-silica content pore-size distribution became finer. Results for concrete with barite sand are given in Table 4.

Table 4 Test results by device RapidAir 457

CONCRETE	B0f5	B2f5	B5f5
Air Content, %	3.35	3.30	2.64
Specific Surface, mm^{-1}	24.14	30.17	68.61
Spacing Factor, mm	0.421	0.278	0.164
Void Frequency, mm^{-1}	0.202	0.400	0.454
Average Chord Length, mm	0.166	0.133	0.058

For a selected value of the nano-silica content (2%) calculations for the mass attenuation coefficients were carried out and their dependence on energy photon radiation is shown in the Figure 3.

Larger values of mass attenuation coefficient for concrete B2 in relation to the K2 concrete due to the presence of barium (Ba) as a component of the aggregate with which the concrete B2 was made (Figure 3). Especially it can be observed the influence of the presence of barium in the concrete type B2 because it significantly increases its capability for absorption of X and gamma rays with energies below 300 keV.

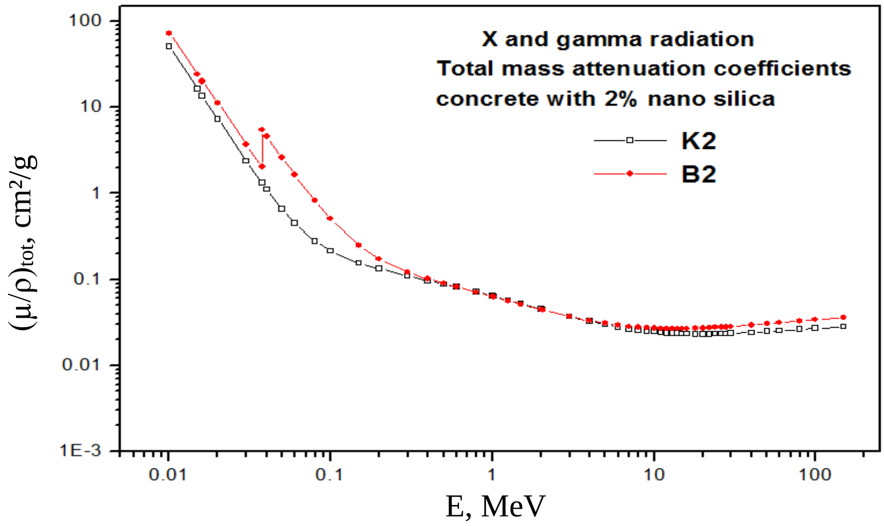


Figure 3 Total mass attenuation coefficients for concrete with 2% nano-silica

CONCLUSIONS

If we compare concrete made with the same type of aggregate, it can be concluded that cement replacement with nano-silica in the amount of 2% has a positive impact on both the compressive and flexural strength. The flexural strength decreased, but the compressive strength increased when the nano-silica content was 5%.

Concrete with barite aggregate had better mechanical properties than concrete with quartz aggregate. Type of used aggregate has a much greater influence on flexural strength than on the compressive strength, e.g. for mixtures with 5% nano-silica content, concrete made with barite sand had 4% greater compressive and 17% greater flexural strength than concrete with quartz sand.

Based on the results of the corresponding graphs for Total Mass Attenuation Coefficient it can be concluded that in the range of energy of gamma and X radiation from 10 keV to 150 MeV, concrete with barite sand has greater protective power than concrete with quartz sand. From the aspect of compressive, flexural strength and radiation protection UHPC with barite sand and 2% cement replacement with nano-silica is optimal.

ACKNOWLEDGEMENTS

The work reported in this paper is a part of the research project TR 36017 supported by the Ministry of Education, Science and Technological Development, Republic of Serbia.

REFERENCES

1. SINGH L.P., KARADE S.R., BHATTACHARYYA S.K., YOUSUF M.M. and AHALAEAT S. Beneficial role of nanosilica in cement based materials – A review, Constr Build Mater, Vol. 47, 2013, pp. 1069–1077.

2. LAND G. and STEPHAN D. Controlling cement hydration with nanoparticles, Cem Concr Comp, Vol. 57, 2015, pp. 64–67.

3. LAND G. and STEPHAN D. The influence of nano-silica on the hydration of ordinary Portland cement, J Mater Sci, Vol. 47, 2012, pp. 1011–1017.

4. DU H., DU S. and LIU X. Durability performances of concrete with nano-silica, Constr Build Mater, Vol. 73, 2014, pp. 705–712.

5. OLTULU M. and SAHIN R. Pore structure analysis of hardened cement mortars containing silica fume and different nano-powders, Constr Build Mater, Vol. 53, 2014, pp. 658–664.

6. SANTOS S.F., De ANCHIETA RODRIGUES J., TONOLI G.H.D., De SOUZA ALMEIDA A.E.F. and SAVASTANO H. Jr. Effect of colloidal silica on the mechanical properties of fiber–cement reinforced with cellulosic fibers, J Mater Sci, Vol. 49, 2014, pp. 7497–7506.

7. GHAFARI E., COSTA H., JULIO E., PORTUGAL A. and DURAES L. The effect of nanosilica addition on flowability, strength and transport properties of ultra high performance concrete, Mater Des, Vol. 59, 2014, pp. 1–9.

8. RONG Z., SUN W., XIAO H. and JIANG G. Effects of nano-SiO_2 particles on the mechanical and microstructural properties of ultra-high performance cementitious composites, Cem Concr Comp, Vol. 56, 2015, pp. 25–31.

9. CHATURVEDI S. and DAVE P.N. Design process for nanomaterials, J Mater Sci, Vol. 48, 2013, pp. 3605–3622.

10. LAI, J, SUN, W. Dynamic behaviour and visco-elastic damage model of ultra-high performance cementitious composite, Cem Concr Res, 39(11), 2009, pp 1044–51

11. SAIDANI K., AJAM L. and OUEZDOU M.B. Barite powder as sand substitution in concrete: Effect on some mechanical properties, Constr Build Mater, Vol. 95, 2015, pp. 287–295.

12. GONZALEZ-ORTEGA M.A., CAVALARO S.H.P. and AGUADO A. Influence of barite aggregate friability on mixing process and mechanical properties of concrete, Constr Build Mater, Vol. 74, 2015, pp. 169–175.

13. AKKURT I., BASYIGIT C., KILINCARSLAN S., MAVI B. and AKKURT A. Radiation shielding of concretes containing different aggregates, Cem Concr Comp, Vol. 28, 2006, pp. 153–157.

14. AKKURT I., BASYIGIT C., KILINCARSLAN S. and MAVI B. The shielding of gamma – rays by concretes produced with barite, Prog Nucl Energy, Vol. 46, No. 1, 2005, pp. 1-11.

15. BERGER M.J., HUBBELL J.H., SELTZER S.M., CHANG J., COURSEY J.S., SUKUMAR R., ZUCKER, D.S. and OLSEN K. XCOM: Photon Cross Section Database (version 3.1). http://www.nist.gov/pml/data/xcom/index.cfm, NBSIR 87-3597. National Institute of Standards and Technology, Gaithersburg, MD, 2010.

ISBN 9780957326316
90000 >
9 780957 326316