Proceedings
PRO 121

SynerCrete '18

24-26 October 2018, Funchal, Portugal

Interdisciplinary Approaches for Cement-based Materials and Structural Concrete: Synergizing Expertise and Bridging Scales of Space and Time

Final Conference of COST Action TU1404

Electronic Version of Proceedings: Volume 1&2

Edited by Miguel Azenha, Dirk Schlicke, Farid Benboudjema, Agnieszka Jędrzejewska

RILEM Publications S.A.R.L.

SynerCrete'18: Interdisciplinary Approaches for Cement-based Materials and Structural Concrete: Synergizing Expertise and Bridging Scales of Space and Time Vol. 1 & 2

This is an electronic version of the proceedings of SynerCrete'18. It keeps the same
page numbering of the two printed volumes, whereas the blank pages
in the printed volumes are omitted.

Published by RILEM Publications S.A.R.L.
4 avenue du Recteur Poincaré 75016 Paris - France
Tel : + 33 1 42 24 64 46 Fax : + 33 9 70 29 51 20
http://www.rilem.net E-mail: dg@rilem.net

ISBN Vol. 1:978-2-35158-211-4 ISBN Vol. 2: 978-2-35158-212-1
ISBN Vol. 1&2: 978-2-35158-202-2 e-ISBN Vol. 1&2: 978-2-35158-203-9
DOI: 10.5281/zenodo.1405563
Printed by Canto Redondo / VASP DPS http://www.cantoredondo.eu
Cover design by: Boutik Studio http://boutik.pt/

RILEM, The International Union of Laboratories and Experts in Construction Materials, Systems and Structures, is a non-profit-making, non-governmental technical association whose vocation is to contribute to progress in the construction sciences, techniques and industries, essentially by means of the communication it fosters between research and practice. RILEM's activity therefore aims at developing the knowledge of properties of materials and performance of structures, at defining the means for their assessment in laboratory and service conditions and at unifying measurement and testing methods used with this objective.

RILEM was founded in 1947, and has a membership of over 900 in some 70 countries. It forms an institutional framework for co-operation by experts to:
- optimise and harmonise test methods for measuring properties and performance of building and civil engineering materials and structures under laboratory and service environments,
- prepare technical recommendations for testing methods,
- prepare state-of-the-art reports to identify further research needs,
- collaborate with national or international associations in realising these objectives.

RILEM members include the leading building research and testing laboratories around the world, industrial research, manufacturing and contracting interests, as well as a significant number of individual members from industry and universities. RILEM's focus is on construction materials and their use in building and civil engineering structures, covering all phases of the building process from manufacture to use and recycling of materials.

RILEM meets these objectives through the work of its technical committees. Symposia, workshops and seminars are organised to facilitate the exchange of information and dissemination of knowledge. RILEM's primary output consists of technical recommendations. RILEM also publishes the journal *Materials and Structures* which provides a further avenue for reporting the work of its committees. Many other publications, in the form of reports, monographs, symposia and workshop proceedings are produced.

SynerCrete'18:
Interdisciplinary Approaches for Cement-based Materials and Structural Concrete: Synergizing Expertise and Bridging Scales of Space and Time
Vol. 1 & 2

Funchal, Madeira, Portugal
24-26 October 2018

Edited by
Miguel Azenha
Dirk Schlicke
Farid Benboudjema
Agnieszka Jędrzejewska

RILEM Publications S.A.R.L.

National Support (Portugal)

International Support

Sponsors

RILEM Publications

The following list is presenting the global offer of RILEM Publications, sorted by series. Each publication is available in printed version and/or in online version.

RILEM PROCEEDINGS (PRO)

PRO 1: Durability of High Performance Concrete (ISBN: 2-912143-03-9); *Ed. H. Sommer*

PRO 2: Chloride Penetration into Concrete (ISBN: 2-912143-00-04); *Eds. L.-O. Nilsson and J.-P. Ollivier*

PRO 3: Evaluation and Strengthening of Existing Masonry Structures (ISBN: 2-912143-02-0); *Eds. L. Binda and C. Modena*

PRO 4: Concrete: From Material to Structure (ISBN: 2-912143-04-7); *Eds. J.-P. Bournazel and Y. Malier*

PRO 5: The Role of Admixtures in High Performance Concrete (ISBN: 2-912143-05-5); *Eds. J. G. Cabrera and R. Rivera-Villarreal*

PRO 6: High Performance Fiber Reinforced Cement Composites - HPFRCC 3 (ISBN: 2-912143-06-3); *Eds. H. W. Reinhardt and A. E. Naaman*

PRO 7: 1st International RILEM Symposium on Self-Compacting Concrete (ISBN: 2-912143-09-8); *Eds. Å. Skarendahl and Ö. Petersson*

PRO 8: International RILEM Symposium on Timber Engineering (ISBN: 2-912143-10-1); *Ed. L. Boström*

PRO 9: 2nd International RILEM Symposium on Adhesion between Polymers and Concrete ISAP '99 (ISBN: 2-912143-11-X); *Eds. Y. Ohama and M. Puterman*

PRO 10: 3rd International RILEM Symposium on Durability of Building and Construction Sealants (ISBN: 2-912143-13-6); *Eds. A. T. Wolf*

PRO 11: 4th International RILEM Conference on Reflective Cracking in Pavements (ISBN: 2-912143-14-4); *Eds. A. O. Abd El Halim, D. A. Taylor and El H. H. Mohamed*

PRO 12: International RILEM Workshop on Historic Mortars: Characteristics and Tests (ISBN: 2-912143-15-2); *Eds. P. Bartos, C. Groot and J. J. Hughes*

PRO 13: 2nd International RILEM Symposium on Hydration and Setting (ISBN: 2-912143-16-0); *Ed. A. Nonat*

PRO 14: Integrated Life-Cycle Design of Materials and Structures - ILCDES 2000 (ISBN: 951-758-408-3); (ISSN: 0356-9403); *Ed. S. Sarja*

PRO 15: Fifth RILEM Symposium on Fibre-Reinforced Concretes (FRC) - BEFIB'2000 (ISBN: 2-912143-18-7); *Eds. P. Rossi and G. Chanvillard*

PRO 16: Life Prediction and Management of Concrete Structures (ISBN: 2-912143-19-5); *Ed. D. Naus*

PRO 17: Shrinkage of Concrete – Shrinkage 2000 (ISBN: 2-912143-20-9); *Eds. V. Baroghel-Bouny and P.-C. Aïtcin*

PRO 18: Measurement and Interpretation of the On-Site Corrosion Rate (ISBN: 2-912143-21-7); *Eds. C. Andrade, C. Alonso, J. Fullea, J. Polimon and J. Rodriguez*

PRO 19: Testing and Modelling the Chloride Ingress into Concrete (ISBN: 2-912143-22-5); *Eds. C. Andrade and J. Kropp*

PRO 20: 1st International RILEM Workshop on Microbial Impacts on Building Materials (CD 02) (e-ISBN 978-2-35158-013-4); *Ed. M. Ribas Silva*

PRO 21: International RILEM Symposium on Connections between Steel and Concrete (ISBN: 2-912143-25-X); *Ed. R. Eligehausen*

PRO 22: International RILEM Symposium on Joints in Timber Structures (ISBN: 2-912143-28-4); *Eds. S. Aicher and H.-W. Reinhardt*

PRO 23: International RILEM Conference on Early Age Cracking in Cementitious Systems (ISBN: 2-912143-29-2); *Eds. K. Kovler and A. Bentur*

PRO 24: 2nd International RILEM Workshop on Frost Resistance of Concrete (ISBN: 2-912143-30-6); *Eds. M. J. Setzer, R. Auberg and H.-J. Keck*

PRO 25: International RILEM Workshop on Frost Damage in Concrete (ISBN: 2-912143-31-4); *Eds. D. J. Janssen, M. J. Setzer and M. B. Snyder*

PRO 26: International RILEM Workshop on On-Site Control and Evaluation of Masonry Structures (ISBN: 2-912143-34-9); *Eds. L. Binda and R. C. de Vekey*

PRO 27: International RILEM Symposium on Building Joint Sealants (CD03); *Ed. A. T. Wolf*

PRO 28: 6th International RILEM Symposium on Performance Testing and Evaluation of Bituminous Materials - PTEBM'03 (ISBN: 2-912143-35-7; e-ISBN: 978-2-912143-77-8); *Ed. M. N. Partl*

PRO 29: 2nd International RILEM Workshop on Life Prediction and Ageing Management of Concrete Structures (ISBN: 2-912143-36-5); *Ed. D. J. Naus*

PRO 30: 4th International RILEM Workshop on High Performance Fiber Reinforced Cement Composites - HPFRCC 4 (ISBN: 2-912143-37-3); *Eds. A. E. Naaman and H. W. Reinhardt*

PRO 31: International RILEM Workshop on Test and Design Methods for Steel Fibre Reinforced Concrete: Background and Experiences (ISBN: 2-912143-38-1); *Eds. B. Schnütgen and L. Vandewalle*

PRO 32: International Conference on Advances in Concrete and Structures 2 vol. (ISBN (set): 2-912143-41-1); *Eds. Ying-shu Yuan, Surendra P. Shah and Heng-lin Lü*

PRO 33: 3rd International Symposium on Self-Compacting Concrete (ISBN: 2-912143-42-X); *Eds. Ó. Wallevik and I. Níelsson*

PRO 34: International RILEM Conference on Microbial Impact on Building Materials (ISBN: 2-912143-43-8); *Ed. M. Ribas Silva*

PRO 35: International RILEM TC 186-ISA on Internal Sulfate Attack and Delayed Ettringite Formation (ISBN: 2-912143-44-6); *Eds. K. Scrivener and J. Skalny*

PRO 36: International RILEM Symposium on Concrete Science and Engineering – A Tribute to Arnon Bentur (ISBN: 2-912143-46-2); *Eds. K. Kovler, J. Marchand, S. Mindess and J. Weiss*

PRO 37: 5th International RILEM Conference on Cracking in Pavements – Mitigation, Risk Assessment and Prevention (ISBN: 2-912143-47-0); *Eds. C. Petit, I. Al-Qadi and A. Millien*

PRO 38: 3rd International RILEM Workshop on Testing and Modelling the Chloride Ingress into Concrete (ISBN: 2-912143-48-9); *Eds. C. Andrade and J. Kropp*

PRO 39: 6th International RILEM Symposium on Fibre-Reinforced Concretes - BEFIB 2004 (ISBN: 2-912143-51-9); *Eds. M. Di Prisco, R. Felicetti and G. A. Plizzari*

PRO 40: International RILEM Conference on the Use of Recycled Materials in Buildings and Structures (ISBN: 2-912143-52-7); *Eds. E. Vázquez, Ch. F. Hendriks and G. M. T. Janssen*

PRO 41: RILEM International Symposium on Environment-Conscious Materials and Systems for Sustainable Development (ISBN: 2-912143-55-1); *Eds. N. Kashino and Y. Ohama*

PRO 42: SCC'2005 - China: 1st International Symposium on Design, Performance and Use of Self-Consolidating Concrete (ISBN: 2-912143-61-6); *Eds. Zhiwu Yu, Caijun Shi, Kamal Henri Khayat and Youjun Xie*

PRO 43: International RILEM Workshop on Bonded Concrete Overlays (e-ISBN: 2-912143-83-7); *Eds. J. L. Granju and J. Silfwerbrand*

PRO 44: 2nd International RILEM Workshop on Microbial Impacts on Building Materials (CD11) (e-ISBN: 2-912143-84-5); *Ed. M. Ribas Silva*

PRO 45: 2nd International Symposium on Nanotechnology in Construction, Bilbao (ISBN: 2-912143-87-X); *Eds. Peter J. M. Bartos, Yolanda de Miguel and Antonio Porro*

PRO 46: ConcreteLife'06 - International RILEM-JCI Seminar on Concrete Durability and Service Life Planning: Curing, Crack Control, Performance in Harsh Environments (ISBN: 2-912143-89-6); *Ed. K. Kovler*

PRO 47: International RILEM Workshop on Performance Based Evaluation and Indicators for Concrete Durability (ISBN: 978-2-912143-95-2); *Eds. V. Baroghel-Bouny, C. Andrade, R. Torrent and K. Scrivener*

PRO 48: 1st International RILEM Symposium on Advances in Concrete through Science and Engineering (e-ISBN: 2-912143-92-6); *Eds. J. Weiss, K. Kovler, J. Marchand, and S. Mindess*

PRO 49: International RILEM Workshop on High Performance Fiber Reinforced Cementitious Composites in Structural Applications (ISBN: 2-912143-93-4); *Eds. G. Fischer and V.C. Li*

PRO 50: 1st International RILEM Symposium on Textile Reinforced Concrete (ISBN: 2-912143-97-7); *Eds. Josef Hegger, Wolfgang Brameshuber and Norbert Will*

PRO 51: 2nd International Symposium on Advances in Concrete through Science and Engineering (ISBN: 2-35158-003-6; e-ISBN: 2-35158-002-8); *Eds. J. Marchand, B. Bissonnette, R. Gagné, M. Jolin and F. Paradis*

PRO 52: Volume Changes of Hardening Concrete: Testing and Mitigation (ISBN: 2-35158-004-4; e-ISBN: 2-35158-005-2); *Eds. O. M. Jensen, P. Lura and K. Kovler*

PRO 53: High Performance Fiber Reinforced Cement Composites - HPFRCC5 (ISBN: 978-2-35158-046-2); *Eds. H. W. Reinhardt and A. E. Naaman*

PRO 54: 5th International RILEM Symposium on Self-Compacting Concrete (ISBN: 978-2-35158-047-9); *Eds. G. De Schutter and V. Boel*

PRO 55: International RILEM Symposium Photocatalysis, Environment and Construction Materials (ISBN: 978-2-35158-056-1); *Eds. P. Baglioni and L. Cassar*

PRO56: International RILEM Workshop on Integral Service Life Modelling of Concrete Structures (ISBN 978-2-35158-058-5); *Eds. R. M. Ferreira, J. Gulikers and C. Andrade*

PRO57: RILEM Workshop on Performance of cement-based materials in aggressive aqueous environments (e-ISBN: 978-2-35158-059-2); *Ed. N. De Belie*

PRO58: International RILEM Symposium on Concrete Modelling - CONMOD'08 (ISBN: 978-2-35158-060-8); *Eds. E. Schlangen and G. De Schutter*

PRO 59: International RILEM Conference on On Site Assessment of Concrete, Masonry and Timber Structures - SACoMaTiS 2008 (ISBN set: 978-2-35158-061-5); *Eds. L. Binda, M. di Prisco and R. Felicetti*

PRO 60: Seventh RILEM International Symposium on Fibre Reinforced Concrete: Design and Applications - BEFIB 2008 (ISBN: 978-2-35158-064-6); *Ed. R. Gettu*

PRO 61: 1st International Conference on Microstructure Related Durability of Cementitious Composites 2 vol., (ISBN: 978-2-35158-065-3); *Eds. W. Sun, K. van Breugel, C. Miao, G. Ye and H. Chen*

PRO 62: NSF/ RILEM Workshop: In-situ Evaluation of Historic Wood and Masonry Structures (e-ISBN: 978-2-35158-068-4); *Eds. B. Kasal, R. Anthony and M. Drdácký*

PRO 63: Concrete in Aggressive Aqueous Environments: Performance, Testing and Modelling, 2 vol., (ISBN: 978-2-35158-071-4); *Eds. M. G. Alexander and A. Bertron*

PRO 64: Long Term Performance of Cementitious Barriers and Reinforced Concrete in Nuclear Power Plants and Waste Management - NUCPERF 2009 (ISBN: 978-2-35158-072-1); *Eds. V. L'Hostis, R. Gens, C. Gallé*

PRO 65: Design Performance and Use of Self-consolidating Concrete - SCC'2009 (ISBN: 978-2-35158-073-8); *Eds. C. Shi, Z. Yu, K. H. Khayat and P. Yan*

PRO 66: 2nd International RILEM Workshop on Concrete Durability and Service Life Planning - ConcreteLife'09 (ISBN: 978-2-35158-074-5); *Ed. K. Kovler*

PRO 67: Repairs Mortars for Historic Masonry (e-ISBN: 978-2-35158-083-7); *Ed. C. Groot*

PRO 68: Proceedings of the 3rd International RILEM Symposium on 'Rheology of Cement Suspensions such as Fresh Concrete (ISBN 978-2-35158-091-2); *Eds. O. H. Wallevik, S. Kubens and S. Oesterheld*

PRO 69: 3rd International PhD Student Workshop on 'Modelling the Durability of Reinforced Concrete (ISBN: 978-2-35158-095-0); *Eds. R. M. Ferreira, J. Gulikers and C. Andrade*

PRO 70: 2nd International Conference on 'Service Life Design for Infrastructure' (ISBN set: 978-2-35158-096-7, e-ISBN: 978-2-35158-097-4); *Ed. K. van Breugel, G. Ye and Y. Yuan*

PRO 71: Advances in Civil Engineering Materials - The 50-year Teaching Anniversary of Prof. Sun Wei' (ISBN: 978-2-35158-098-1; e-ISBN: 978-2-35158-099-8); *Eds. C. Miao, G. Ye, and H. Chen*

PRO 72: First International Conference on 'Advances in Chemically-Activated Materials – CAM'2010' (2010), 264 pp, ISBN: 978-2-35158-101-8; e-ISBN: 978-2-35158-115-5, *Eds. Caijun Shi and Xiaodong Shen*

PRO 73: 2nd International Conference on 'Waste Engineering and Management - ICWEM 2010' (2010), 894 pp, ISBN: 978-2-35158-102-5; e-ISBN: 978-2-35158-103-2, *Eds. J. Zh. Xiao, Y. Zhang, M. S. Cheung and R. Chu*

PRO 74: International RILEM Conference on 'Use of Superabsorsorbent Polymers and Other New Addditives in Concrete' (2010) 374 pp., ISBN: 978-2-35158-104-9; e-ISBN: 978-2-35158-105-6;
Eds. O.M. Jensen, M.T. Hasholt, and S. Laustsen

PRO 75: International Conference on 'Material Science - 2nd ICTRC - Textile Reinforced Concrete - Theme 1' (2010) 436 pp., ISBN: 978-2-35158-106-3; e-ISBN: 978-2-35158-107-0; *Ed. W. Brameshuber*

PRO 76: International Conference on 'Material Science - HetMat - Modelling of Heterogeneous Materials - Theme 2' (2010) 255 pp., ISBN: 978-2-35158-108-7; e-ISBN: 978-2-35158-109-4; *Ed. W. Brameshuber*

PRO 77: International Conference on 'Material Science - AdIPoC - Additions Improving Properties of Concrete - Theme 3' (2010) 459 pp., ISBN: 978-2-35158-110-0; e-ISBN: 978-2-35158-111-7; *Ed. W. Brameshuber*

PRO 78: 2nd Historic Mortars Conference and RILEM TC 203-RHM Final Workshop – HMC2010 (2010) 1416 pp., e-ISBN: 978-2-35158-112-4; *Eds J. Válek, C. Groot, and J. J. Hughes*

PRO 79: International RILEM Conference on Advances in Construction Materials Through Science and Engineering (2011) 213 pp., e-ISBN: 978-2-35158-117-9; *Eds Christopher Leung and K.T. Wan*

PRO 80: 2nd International RILEM Conference on Concrete Spalling due to Fire Exposure (2011) 453 pp., ISBN: 978-2-35158-118-6, e-ISBN: 978-2-35158-119-3; *Eds E.A.B. Koenders and F. Dehn*

PRO 81: 2nd International RILEM Conference on Strain Hardening Cementitious Composites (SHCC2-Rio) (2011) 451 pp., ISBN: 978-2-35158-120-9, e-ISBN: 978-2-35158-121-6; *Eds R.D. Toledo Filho, F.A. Silva, E.A.B. Koenders and E.M.R. Fairbairn*

PRO 82: 2nd International RILEM Conference on Progress of Recycling in the Built Environment (2011) 507 pp., e-ISBN: 978-2-35158-122-3; *Eds V.M. John, E. Vazquez, S.C. Angulo and C. Ulsen*

PRO 83: 2nd International Conference on Microstructural-related Durability of Cementitious Composites (2012) 250 pp., ISBN: 978-2-35158-129-2; e-ISBN: 978-2-35158-123-0; *Eds G. Ye, K. van Breugel, W. Sun and C. Miao*

PRO 85: RILEM-JCI International Workshop on Crack Control of Mass Concrete and Related issues concerning Early-Age of Concrete Structures – ConCrack 3 – Control of Cracking in Concrete Structures 3 (2012) 237 pp., ISBN: 978-2-35158-125-4; e-ISBN: 978-2-35158-126-1; *Eds F. Toutlemonde and J.-M. Torrenti*

PRO 86: International Symposium on Life Cycle Assessment and Construction (2012) 414 pp., ISBN: 978-2-35158-127-8, e-ISBN: 978-2-35158-128-5; *Eds A. Ventura and C. de la Roche*

PRO 87: UHPFRC 2013 – RILEM-fib-AFGC International Symposium on Ultra-High Performance Fibre-Reinforced Concrete (2013), ISBN: 978-2-35158-130-8, e-ISBN: 978-2-35158-131-5; *Eds F. Toutlemonde*

PRO 88: 8th RILEM International Symposium on Fibre Reinforced Concrete (2012) 344 pp., ISBN: 978-2-35158-132-2, e-ISBN: 978-2-35158-133-9; *Eds Joaquim A.O. Barros*

PRO 89: RILEM International workshop on performance-based specification and control of concrete durability (2014) 678 pp, ISBN: 978-2-35158-135-3, e-ISBN: 978-2-35158-136-0; *Eds. D. Bjegović, H. Beushausen and M. Serdar*

PRO 90: 7th RILEM International Conference on Self-Compacting Concrete and of the 1st RILEM International Conference on Rheology and Processing of Construction Materials (2013) 396 pp, ISBN: 978-2-35158-137-7, e-ISBN: 978-2-35158-138-4; *Eds. Nicolas Roussel and Hela Bessaies-Bey*

PRO 91: CONMOD 2014 - RILEM International Symposium on Concrete Modelling (2014), ISBN: 978-2-35158-139-1; e-ISBN: 978-2-35158-140-7; *Eds. Kefei Li, Peiyu Yan and Rongwei Yang*

PRO 92: CAM 2014 - 2nd International Conference on advances in chemically-activated materials (2014) 392 pp., ISBN: 978-2-35158-141-4; e-ISBN: 978-2-35158-142-1; *Eds. Caijun Shi and Xiadong Shen*

PRO 93: SCC 2014 - 3rd International Symposium on Design, Performance and Use of Self-Consolidating Concrete (2014) 438 pp., ISBN: 978-2-35158-143-8; e-ISBN: 978-2-35158-144-5; *Eds. Caijun Shi, Zhihua Ou, Kamal H. Khayat*

PRO 94 (online version): HPFRCC-7 - 7th RILEM conference on High performance fiber reinforced cement composites (2015), e-ISBN: 978-2-35158-146-9; *Eds. H.W. Reinhardt, G.J. Parra-Montesinos, H. Garrecht*

PRO 95: International RILEM Conference on Application of superabsorbent polymers and other new admixtures in concrete construction (2014), ISBN: 978-2-35158-147-6; e-ISBN: 978-2-35158-148-3; *Eds. Viktor Mechtcherine, Christof Schroefl*

PRO 96 (online version): XIII DBMC: XIII International Conference on Durability of Building Materials and Components (2015), e-ISBN: 978-2-35158-149-0; *Eds. M. Quattrone, V.M. John*

PRO 97: SHCC3 – 3rd International RILEM Conference on Strain Hardening Cementitious Composites (2014), ISBN: 978-2-35158-150-6; e-ISBN: 978-2-35158-151-3; *Eds. E. Schlangen, M.G. Sierra Beltran, M. Lukovic, G. Ye*

PRO 98: FERRO-11 – 11th International Symposium on Ferrocement and 3rd ICTRC - International Conference on Textile Reinforced Concrete (2015), ISBN: 978-2-35158-152-0; e-ISBN: 978-2-35158-153-7; *Ed. W. Brameshuber*

PRO 99 (online version): ICBBM 2015 - 1st International Conference on Bio-Based Building Materials (2015), e-ISBN: 978-2-35158-154-4; *Eds. S. Amziane, M. Sonebi*

PRO 100: SCC16 - RILEM Self-Consolidating Concrete Conference (2016), ISBN: 978-2-35158-156-8; e-ISBN: 978-2-35158-157-5

PRO 101 (online version): III Progress of Recycling in the Built Environment (2015), e-ISBN: 978-2-35158-158-2; *Eds I. Martins, C. Ulsen and S. C. Angulo*

PRO 102 (online version): RILEM Conference on Microorganisms-Cementitious Materials Interactions (2016), e-ISBN: 978-2-35158-160-5; *Eds. Alexandra Bertron, Henk Jonkers, Virginie Wiktor*

PRO 103 (online version): ACESC'16 - Advances in Civil Engineering and Sustainable Construction (2016), e-ISBN: 978-2-35158-161-2

PRO 104 (online version): SSCS'2015 - Numerical Modeling - Strategies for Sustainable Concrete Structures (2015), e-ISBN: 978-2-35158-162-9

PRO 105: 1st International Conference on UHPC Materials and Structures (2016), ISBN: 978-2-35158-164-3, e-ISBN: 978-2-35158-165-0

PRO 106: AFGC-ACI-fib-RILEM International Conference on Ultra-High-Performance Fibre-Reinforced Concrete – UHPFRC 2017 (2017), ISBN: 978-2-35158-166-7, e-ISBN: 978-2-35158-167-4; *Eds. François Toutlemonde & Jacques Resplendino*

PRO 107 (online version): XIV DBMC – 14th International Conference on Durability of Building Materials and Components (2017), e-ISBN: 978-2-35158-159-9; *Eds. Geert De Schutter, Nele De Belie, Arnold Janssens, Nathan Van Den Bossche*

PRO 108: MSSCE 2016 - Innovation of Teaching in Materials and Structures (2016), ISBN: 978-2-35158-178-0, e-ISBN: 978-2-35158-179-7; *Ed. Per Goltermann*

PRO 109 (two volumes): MSSCE 2016 - Service Life of Cement-Based Materials and Structures (2016), ISBN Vol. 1: 978-2-35158-170-4, Vol. 2: 978-2-35158-171-4, Set Vol. 1&2: 978-2-35158-172-8, e-ISBN : 978-2-35158-173-5; *Eds. Miguel Azenha, Ivan Gabrijel, Dirk Schlicke, Terje Kanstad and Ole Mejlhede Jensen*

PRO 110: MSSCE 2016 - Historical Masonry (2016), ISBN: 978-2-35158-178-0, e-ISBN: 978-2-35158-179-7; *Eds. Inge Rörig-Dalgaard and Ioannis Ioannou*

PRO 111: MSSCE 2016 - Electrochemistry in Civil Engineering (2016), ISBN: 978-2-35158-176-6, e-ISBN: 978-2-35158-177-3; *Ed. Lisbeth M. Ottosen*

PRO 112: MSSCE 2016 - Moisture in Materials and Structures (2016), ISBN: 978-2-35158-178-0, e-ISBN: 978-2-35158-179-7; *Eds. Kurt Kielsgaard Hansen, Carsten Rode and Lars-Olof Nilsson*

PRO 113: MSSCE 2016 - Concrete with Supplementary Cementitious Materials (2016), ISBN: 978-2-35158-178-0, e-ISBN: 978-2-35158-179-7; *Eds. Ole Mejlhede Jensen, Konstantin Kovler and Nele De Belie*

PRO 114: MSSCE 2016 - Frost Action in Concrete (2016), ISBN: 978-2-35158-182-7, e-ISBN: 978-2-35158-183-4; *Eds. Marianne Tange Hasholt, Katja Fridh and R. Doug Hooton*

PRO 115: MSSCE 2016 - Fresh Concrete (2016), ISBN: 978-2-35158-184-1, e-ISBN: 978-2-35158-185-8; *Eds. Lars N. Thrane, Claus Pade, Oldrich Svec and Nicolas Roussel*

PRO 116: BEFIB 2016 – 9th RILEM International Symposium on Fiber Reinforced Concrete (2016), ISBN: 978-2-35158-187-2, e-ISBN: 978-2-35158-186-5;

PRO 117: 3rd International RILEM Conference on Microstructure Related Durability of Cementitious Composites (2016), ISBN: 978-2-35158-188-9, e-ISBN: 978-2-35158-189-6; *Eds. Changwen Miao, Wei Sun, Jiaping Liu, Huisu Chen, Guang Ye and Klaas van Breugel*

PRO 118 (4 volumes): International Conference on Advances in Construction Materials and Systems (2017), ISBN Set: 978-2-35158-190-2, Vol. 1: 978-2-35158-193-3, Vol. 2: 978-2-35158-194-0, Vol. 3: ISBN:978-2-35158-195-7, Vol. 4: ISBN:978-2-35158-196-4, e-ISBN: 978-2-35158-191-9; *Ed. Manu Santhanam*

PRO 119 (online version): ICBBM 2017 - Second International RILEM Conference on Bio-based Building Materials, (2017), e-ISBN: 978-2-35158-192-6; *Ed. Sofiane Amziane*

PRO 120 (2 volumes): EAC-02 - 2nd International RILEM/COST Conference on Early Age Cracking and Serviceability in Cement-based Materials and Structures, (2017), Vol. 1: 978-2-35158-199-5, Vol. 2: 978-2-35158-200-8, Set: 978-2-35158-197-1, e-ISBN: 978-2-35158-198-8; *Eds. Stéphanie Staquet and Dimitrios Aggelis*

RILEM REPORTS (REP)

Report 19: Considerations for Use in Managing the Aging of Nuclear Power Plant Concrete Structures (ISBN: 2-912143-07-1); *Ed. D. J. Naus*

Report 20: Engineering and Transport Properties of the Interfacial Transition Zone in Cementitious Composites (ISBN: 2-912143-08-X); *Eds. M. G. Alexander, G. Arliguie, G. Ballivy, A. Bentur and J. Marchand*

Report 21: Durability of Building Sealants (ISBN: 2-912143-12-8); *Ed. A. T. Wolf*

Report 22: Sustainable Raw Materials - Construction and Demolition Waste (ISBN: 2-912143-17-9); *Eds. C. F. Hendriks and H. S. Pietersen*

Report 23: Self-Compacting Concrete state-of-the-art report (ISBN: 2-912143-23-3); *Eds. Å. Skarendahl and Ö. Petersson*

Report 24: Workability and Rheology of Fresh Concrete: Compendium of Tests (ISBN: 2-912143-32-2); *Eds. P. J. M. Bartos, M. Sonebi and A. K. Tamimi*

Report 25: Early Age Cracking in Cementitious Systems (ISBN: 2-912143-33-0); *Ed. A. Bentur*

Report 26: Towards Sustainable Roofing (Joint Committee CIB/RILEM) (CD 07) (e-ISBN 978-2-912143-65-5); *Eds. Thomas W. Hutchinson and Keith Roberts*

Report 27: Condition Assessment of Roofs (Joint Committee CIB/RILEM) (CD 08) (e-ISBN 978-2-912143-66-2); *Ed. CIB W 83/RILEM TC166-RMS*

Report 28: Final report of RILEM TC 167-COM 'Characterisation of Old Mortars with Respect to Their Repair (ISBN: 978-2-912143-56-3); *Eds. C. Groot, G. Ashall and J. Hughes*

Report 29: Pavement Performance Prediction and Evaluation (PPPE): Interlaboratory Tests (e-ISBN: 2-912143-68-3); *Eds. M. Partl and H. Piber*

Report 30: Final Report of RILEM TC 198-URM 'Use of Recycled Materials' (ISBN: 2-912143-82-9; e-ISBN: 2-912143-69-1); *Eds. Ch. F. Hendriks, G. M. T. Janssen and E. Vázquez*

Report 31: Final Report of RILEM TC 185-ATC 'Advanced testing of cement-based materials during setting and hardening' (ISBN: 2-912143-81-0; e-ISBN: 2-912143-70-5); *Eds. H. W. Reinhardt and C. U. Grosse*

Report 32: Probabilistic Assessment of Existing Structures. A JCSS publication (ISBN 2-912143-24-1); *Ed. D. Diamantidis*

Report 33: State-of-the-Art Report of RILEM Technical Committee TC 184-IFE 'Industrial Floors' (ISBN 2-35158-006-0); *Ed. P. Seidler*

Report 34: Report of RILEM Technical Committee TC 147-FMB 'Fracture mechanics applications to anchorage and bond' Tension of Reinforced Concrete Prisms – Round Robin Analysis and Tests on Bond (e-ISBN 2-912143-91-8); *Eds. L. Elfgren and K. Noghabai*

Report 35: Final Report of RILEM Technical Committee TC 188-CSC 'Casting of Self Compacting Concrete' (ISBN 2-35158-001-X; e-ISBN: 2-912143-98-5); *Eds. Å. Skarendahl and P. Billberg*

Report 36: State-of-the-Art Report of RILEM Technical Committee TC 201-TRC 'Textile Reinforced Concrete' (ISBN 2-912143-99-3); *Ed. W. Brameshuber*

Report 37: State-of-the-Art Report of RILEM Technical Committee TC 192-ECM 'Environment-conscious construction materials and systems' (ISBN: 978-2-35158-053-0); *Eds. N. Kashino, D. Van Gemert and K. Imamoto*

Report 38: State-of-the-Art Report of RILEM Technical Committee TC 205-DSC 'Durability of Self-Compacting Concrete' (ISBN: 978-2-35158-048-6); *Eds. G. De Schutter and K. Audenaert*

Report 39: Final Report of RILEM Technical Committee TC 187-SOC 'Experimental determination of the stress-crack opening curve for concrete in tension' (ISBN 978-2-35158-049-3); *Ed. J. Planas*

Report 40: State-of-the-Art Report of RILEM Technical Committee TC 189-NEC 'Non-Destructive Evaluation of the Penetrability and Thickness of the Concrete Cover' (ISBN 978-2-35158-054-7);
Eds. R. Torrent and L. Fernández Luco

Report 41: State-of-the-Art Report of RILEM Technical Committee TC 196-ICC 'Internal Curing of Concrete' (ISBN 978-2-35158-009-7); *Eds. K. Kovler and O. M. Jensen*

Report 42: 'Acoustic Emission and Related Non-destructive Evaluation Techniques for Crack Detection and Damage Evaluation in Concrete' - Final Report of RILEM Technical Committee 212-ACD (e-ISBN: 978-2-35158-100-1); *Ed. M. Ohtsu*

Report 45: Repair Mortars for Historic Masonry - State-of-the-Art Report of RILEM Technical Committee TC 203-RHM (e-ISBN: 978-2-35158-163-6); *Eds. Paul Maurenbrecher and Caspar Groot*

Report 46: Surface delamination of concrete industrial floors and other durability related aspects guide - Report of RILEM Technical Committee TC 268-SIF (e-ISBN: 978-2-35158-201-5); *Ed. Valérie Pollet*

Conference Chairs

Miguel Azenha, Dirk Schlicke

Scientific Committee Chairs

Farid Benboudjema, Agnieszka Jędrzejewska

National Organizing Committee

Paulo Lobo, José Sena Cruz, Eduardo Júlio, Rui Faria, Manuel Pipa, Romeu Vicente

COST Organizing Committee

Violeta Bokan-Bosiljkov, Laurie Lacarrière, Terje Kanstad, Sreejith Nanukuttan, Emmanuel Rozière, Marijana Serdar, Stéphanie Staquet, François Toutlemonde, Mateusz Wyrzykowski

Scientific Committee

Farid Benboudjema (Chair)
Agnieszka Jędrzejewska (Chair)
Ouali Amiri
Sofiane Amziane
Shingo Asamoto
Miguel Azenha
Nele de Belie
Violeta Bokan Bosiljkov
Alexandra Bourdot
Matthieu Briffaut
Tomo Cerovšek
Özlem Cizer
Gianluca Cusatis
Aveline Darquennes
Szymon Dawczyński
Eduardo Fairbairn
Rui Faria
Ivan Gabrijel
Erez Gal
Dariusz Gawin
Ole Jensen
Joachim Juhart
Terje Kanstad
Eduardus Koenders
Barbara Klemczak
Laurie Lacarrière
Paulo B. Lourenço
Ippei Maruyama
Kyuichi Maruyama
Enrico Masoero
Hadi Mazaheripour
Sreejith Nanukuttan
Małgorzata Pająk
Arnaud Perrot
Bernhard Pichler
Manuel Pipa
John Provis
Vlastimir Radonjanin
Marta Roig
Emmanuel Rozière
Mercedes Sanchez Moreno
Ryoichi Sato
José Sena-Cruz
Dirk Schlicke
Geert De Schutter
Giuseppe Sciumè
Marijana Serdar
Carlos Serra
Ioannis Sfikas
Paulo Silva Lobo
Mohammed Sonebi
Carlos Sousa
Tayfun Altuğ Söylev
Maria Stefanidou
Stéphanie Staquet
Aljoša Šajna
Vít Šmilauer
Luping Tang
Katrin Turner
Jean-Michel Torrenti
François Toutlemonde
Jörg F. Unger
Neven Ukrainczyk
Mateusz Wyrzykowski
Guang Ye
Ismail Yurtdas
Xiangming Zhou
Mariusz Zych

Preface

The focus of the conference is set to communicating, discussing and arousing progress in research, development and application of Cement-based Materials and Structural Concrete, which have been attained through combination of expertise from distinct fields of knowledge. Indeed, in the words of Federico Capasso, a renowned Physicist who was one of the inventors of the quantum cascade laser:

> "*... we must not think of science in a disciplinary way, by making boxes. Nature does not know what physics, chemistry or biology is! It is a question of putting an end to the positivist philosophy of Auguste Comte, fortunately in decline of speed, which classified the disciplines and despised the experimental activity.*"

The intent of this conference was therefore to provide added value through collaboration and by bringing together researchers and practitioners with similar views in regard to interdisciplinary approaches in the fields of Cement-based Materials and Structural Concrete: it is about **Syner**gizing expertise on the ultimate goal of Structural Conc**Crete**, hence the acronym **SynerCrete**, was chosen for the conference. Exciting fields of research such as performance-based design, 3D modelling for analysis/design, Building Information Modelling and even robotics (e.g. digital fabrication or robotics design) were included, while retaining focus on multi-scale approaches at time and spatial levels.

SynerCrete'18 also marks the end of COST Action TU1404 "Towards the next generation of standards for service life of cement-based materials and structures" (www.tu1404.eu), offering a final forum to the discussions raised during the funded period of the Action, that started 4 years ago in 2014. The conference is an opportunity for the 304 COST Action members to deepen their collaboration and to focus on activities that allow the continuation of the networking which was established by the Action. A sense of accomplishment is felt by all the members of the Action, in the view of the important achievements of networking tools that were brought about by the extended Round Robin Testing Programme (RRT+), the Numerical Benchmarking Activities and 24 Short Term Scientific Missions (STSMs). Indeed, a remarkable number of papers that have been published in the two volumes of these Conference Proceedings are directly a result of one of the aforementioned networking tools.

The conference has consisted of 8 key-note speakers and 180 regular papers presented over 3 days. It is also relevant to emphasize the collaboration of another COST Action in SynerCrete: COST Action CA15202 "Self-healing As preventive Repair of COncrete Structures – SARCOS", which has an important contribution to the purposes of COST TU1404.

A further remark in regard to the wide international institutional support that this conference attained, is about the direct support of RILEM, fib, JCI and ACI. Specifically, with regard to the Japanese Concrete Institute, a mention is given to the special session dedicated to the most recent version of "JCI Guidelines for Control of Cracking of Mass Concrete", as it was indeed one of the most inspiring documents that influenced the genesis of COST Action TU1404.

A final word is given in regard to the location of the conference which combines implicit symbolisms. Firstly, this is the only event of COST Action TU1404 taking place in Portugal, which is the home country of the Grant Holder and Chairman of the Action. Secondly, the conference venue is the island of Madeira, therefore not in mainland Portugal, putting attention to one of the remotest regions of Europe, officially classified as one of the eight ultra-peripheral regions of the European Union.

Miguel Azenha **Dirk Schlicke** **Farid Benboudjema** **Agnieszka Jędrzejewska**

October 2018, Funchal, Portugal

Acknowledgements

This publication is based upon work from COST Action TU1404 'Towards the next generation of standards for service life of cement-based materials and structures', supported by COST (European Cooperation in Science and Technology).

COST (European Cooperation in Science and Technology) is a pan-European intergovernmental framework. Its mission is to enable break-through scientific and technological developments leading to new concepts and products and thereby contribute to strengthening Europe's research and innovation capacities. It allows researchers, engineers and scholars to jointly develop their own ideas and take new initiatives across all fields of science and technology, while promoting multi- and interdisciplinary approaches. COST aims at fostering a better integration of less research intensive countries to the knowledge hubs of the European Research Area. The COST Association, an International not-for-profit Association under Belgian Law, integrates all management, governing and administrative functions necessary for the operation of the framework. The COST Association has currently 37 Member Countries.

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union

www.tu1404.eu
www.cost.eu

VOLUME 1

KEYNOTE LECTURES

COST ACTION TU1404 - RRT+, NUMERICAL BENCHMARKING AND RECOMMENDATIONS

CONCRETE TECHNOLOGY AND ADVANCED MATERIAL TESTING

GEOPOLYMERS AND ALKALI-ACTIVATED MATERIALS

BIO-BASED MATERIALS

VOLUME 2

MULTI-PHYSICS SIMULATION AND STRUCTURAL DESIGN

MULTI-SCALE IN TIME AND SPACE MODELLING AND EXPERIMENTS

BIM AND STRUCTURAL CONCRETE

DIGITAL FABRICATION AND ROBOTICS

ON-SITE MONITORING AND STRUCTURAL CONDITION ASSESSMENT

SCIENTIFIC INSIGHTS VS. STANDARDIZATION

FIBRE-REINFORCED CONCRETE AND NON-METALLIC REINFORCEMENT

GAMMA AND X RADIATION ABSORPTION CHARACTERISTICS OF SPECIALLY SELECTED TYPES OF CONCRETE

Srboljub Stankovic [(1)], Ksenija Jankovic [(2)]

(1) Institute of nuclear sciences VINCA, Belgrade, Serbia
(2) IMS Institute, Belgrade, Serbia

Abstract
Medical institutions with linear accelerators, cyclotrons as installations for particles acceleration, nuclear facilities as nuclear power stations and nuclear research reactors using concrete in building construction. In cost-benefit analysis the question is what are the radiation characteristics of different types of concrete, which could be used to protect against gamma and X rays. In this paper, computer code XCOM was used for the calculation of the total mass attenuation coefficients, which is an important factor for determination of the photon attenuation, as well as during research and testing of radiation protection properties for concrete with components of different type materials. Thereby, the basic absorption radiation characteristics of ordinary and barite concretes, as well as specially selected type of concrete with magnetite and steel and concrete UHPC with barite and nanosilica as specific material composition, were considered. The results of this research point to the conclusion that before the concrete production of certain mechanical properties is approached, it is reasonable to apply the appropriate methodology with the numerical calculation of the basic absorption characteristic of the concrete for protection against gamma and X radiation.

1. Introduction

Medical institutions with linear accelerators, cyclotrons as installations for particles acceleration, nuclear facilities as nuclear power stations and nuclear research reactors using concrete in building construction. Barite aggregate is used to produce heavyweight concrete which application concerns radiation shielding in hospitals and nuclear facilities. The basic characteristics of ordinary concrete and heavy-weight concrete with barite were studied for the case of their use for shielding from gamma radiation [1, 5, 6]. In cost-benefit analysis the question is what are the radiation characteristics of different types of concrete, which could be used to protect against gamma and X rays [2, 3, 4]. The energy deposited the transmission factor and the mass attenuation coefficients in ordinary and barite concretes have been calculated with the photon transport Monte Carlo software. The numerical simulations results show that using barite as an aggregate in the concrete is one of the solutions for gamma ray shielding. Thereat, it is shown non-destructive method for determining the gamma radiation absorption characteristics of concrete [9]. In references [10, 11], one of the goals is to implement appropriate numerical calculations for obtaining the value of the total mass attenuation coefficient in the energy range 10 keV - 150 MeV of gamma and X radiation, and their dependence in the content of barite and nano-silica in UHPC concrete with specially defined mechanical properties. Nanosilica has a dominant influence on the improvement of the mechanical properties, and barite has a dominant influence on the characteristics that increase the absorption of ionizing radiation, i.e., improves the characteristics for protection against ionizing radiation. Investigations in these references [10, 11] is designed to, by simultaneously using different portions of the two materials, nano-silica and barite, in the composition of various types of concrete conduct tests on the ability to improve the mechanical properties and properties for the radiation protection of concrete.

In this paper, computer code XCOM [8] was used for the calculation of the total mass attenuation coefficients $(\mu/\rho)_{tot}$, which is an important factor for determination of the photon attenuation, as well as during research and testing of radiation protection properties [1-6] for different content of aggregates in concrete. Computer code XCOM operates on a method of combining the values of the existing database for effective cross section of physical processes accompanying the transport of photons through different materials. This means that there is a possibility to use data bases for coherent and incoherent scattering, photoelectric absorption, and pair production cross-sections for the different chemical structure of materials which enter into the composition of the concrete.

2. Numerical methods

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

Basic relations for engineering calculations the attenuation of exposure dose rate of ionizing radiation, which passes through the wall of concrete, can be displayed as:

$$X = X_0 \cdot \exp\left[-\left(\frac{\mu}{\rho}\right)_{tot} \cdot \rho d\right] \quad (1)$$

where X (C/kg s) and X_0 are intensity exposure rates behind and in front of the wall, where the wall thickness is d (m) and the density is ρ (kg/m^3). This Eq. (1) is consistent with the application of Bouguer-Lambert-Beer law for attenuation of the intensity of mono energetic photon radiation for the cases of penetration of the narrow beam of radiation through a concrete wall as a protective barrier.

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

$$\left(\frac{\mu}{\rho}\right)_{tot} = \sum_j w_j \cdot \left(\frac{\mu}{\rho}\right)_j \tag{2}$$

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

The numerical calculations included two steps: 1. For each type of concrete from Tab. 1 its composition was determined in accordance with the nomenclature of chemical elements and chemical compounds, 2. Interactive use of the program XCOM [8], 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 to calculate interaction coefficients for the following processes: Compton (incoherent) and Rayleigh (coherent) scattering, photoelectric absorption, and pair production in the field of the atomic nucleus and in the field of the 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 equal to the sum of the interaction coefficients for the individual processes.

3. Results and discussion

In our work, computer code XCOM was used for the calculation of the total mass attenuation coefficients for four different concrete types, which is specified in Table 1.

Table 1: Types of concrete for numerical calculations of the total mass attenuation coefficients with software code XCOM [8].

Mark	**Type of concrete**	**Density** (g cm^{-3})	**Material composition data in [reference]**
CB	Concrete, Barite (Type BA)	3.350	[7]
CMS	Concrete, Magnetite and Steel	4.640	[7]
COR	Concrete, Ordinary (NBS 04)	2.350	[7]
B5n	Concrete, UHPC barite nanosilica 5%	2.830	[11]

The dependence of values total mass attenuation coefficients on energy photon radiation is shown in the figure Fig. 1.

On the graphs Fig. 1, one can see, that total mass attenuation coefficients $(\mu/\rho)_{tot}$ has dependence of the photon energy (E): a) in three ranges for concrete types CMS and COR, decreasing sharply at low energies (E<0.15 MeV), decreasing slightly in the middle range (0.15 MeV<E<6 MeV) and increasing slightly at high energies (E>6 MeV); b) in three ranges for concrete types CB and B5n, decreasing sharply in bottom range (10 keV<E<400 keV) with the sharp discontinuity around 30 keV, decreasing slightly in the middle range (0.4 MeV<E<6 MeV) and increasing slightly at high energies (E>6 MeV); c) in the energy range of 400 keV to 6 MeV values for the total mass attenuation coefficients are approximately the same for four different types of concrete. The results, which we have pointed out, are tied to different photon absorption mechanism for different energy range. The sharp discontinuities in energy dependence for total mass absorption coefficient are connected with the processes of the photoelectric absorption.

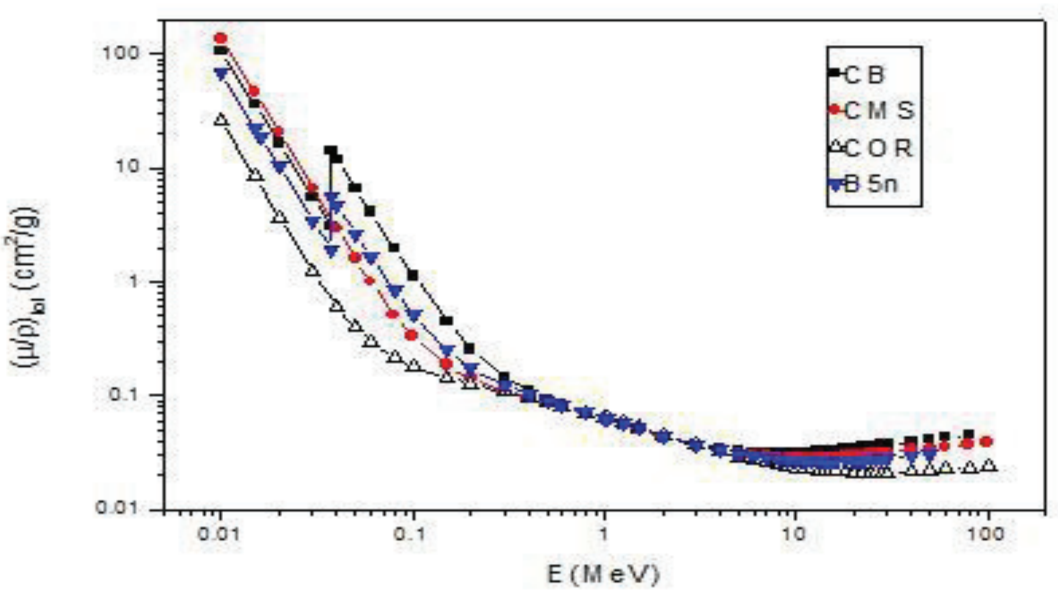

Figure 1: Total mass attenuation coefficients for four different concrete types.

4. Conclusion

In this investigation, based on the results of the corresponding graphs for Total Mass Attenuation Coefficient $(\mu/\rho)_{tot}$ it can be concluded that in the range of energy of gamma and X radiation from 30 keV to 300 keV, concrete types CB and B5n with barite sand has greater protective power than concrete types CMS or COR. Concrete type CMS with magnetite and steel has greater protective power than other three concrete types for the energy of gamma and X radiation E < 30 keV, while the concrete type CB is with better characteristics than other types of concrete for the attenuation of the radiation beam for photon energies greater than 30 keV. The results of this research point to the conclusion that before the concrete production of certain mechanical properties is approached, it is reasonable to apply the appropriate methodology with the numerical calculation of the basic absorption characteristic of the concrete for protection against gamma and X radiation.

Acknowledgements
The work presented in this paper is a part of the investigation conducted within the research projects TR 36017 and III 43009 supported by the Ministry of Education, Science and Technological Development, Republic of Serbia. This support is gratefully acknowledged.

References

[1] Yılmaz, E. et al, Gamma ray and neutron shielding properties of some concrete materials, Annals of Nuclear Energy 38 (2011), 2204–2212
[2] Ling, T.C. et al, X-ray radiation shielding properties of cement mortar prepared with different types of aggregate, Materials and Structures (2013), DOI 10.1617/s11527-012-9959-2
[3] Bashter, I.I. et al, Magnetite ores with steel or basalt for concrete radiation shelding, Jpn. J. Appl. Phys. Vol. 36, Part 1, No.6A (1997), 3692-3696
[4] Sarkawi, M.S. et al, Radiation shielding properties of ferro-boron concrete, IOP Conf. Series: Materials Science and Engineering 298 (2018), doi:10.1088/1757-899X/298/1/012037
[5] Juniora, T.A.A. et al, Mass attenuation coefficients of X-rays in different barite concrete used in radiation protection as shielding against ionizing radiation, Radiation Physics and Chemistry 140 (2017), 349-354
[6] Ouda, A.S., Development of high-performance heavy density concrete using different aggregate for gamma-rey shilding, Progress in Nuclear Energy 79 (2015), 48-55
[7] Shultis J.K. and Faw, R.E., Radiation Shielding, Prentice Hall, Englewood Cliffs, New Jersey, (1996)
[8] Berger, M.J. et al, 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)
[9] Stankovic et al, Gamma Radiation Absorption Charcteristics of Concrete with Components of Different Type Materials, Acta Physica Polonica A, Vol. 117, (2010), 812-816
[10] Jankovic et al, Effect of nano-silica and aggregate type on properties of ultra high performance concrete, Proceedings of the 9th International Concrete Conference 2016 "Environment, Efficiency and Economic Challenges Challenges for Concrete", Dundee, Scotland, UK (2016), 839-846
[11] Jankovic et al, The influence of nano-silica and barite aggregate on properties of ultra high performance concrete, Construction and Building Materials 126 (2016), 147-156