

# Sustainable Concrete Materials & Structures

International Conference  
Malta 2018

Edited by

Ruben Paul Borg

Petr Hajek

David Fernandez Ordonez



L-Università  
ta' Malta



# **Sustainable Concrete Materials and Structures**

Proceedings of the International Conference

Valletta, Malta – 10<sup>th</sup> April 2018

Organized by the

*fib*

International Federation for Structural Concrete

and the

Faculty for the Built Environment  
University of Malta



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# Sustainable Concrete: Materials and Structures

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Edited by Ruben Paul Borg, Petr Hajek, David Fernandez Ordonez

Cover Photo: Degradation of Reinforced Concrete (R.P.Borg)

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# Sustainable Concrete: Materials and Structures

International Conference organized by



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## Preface

### *fib* International Conference Sustainable Concrete: Materials and Structures

Dr. Ruben Paul Borg

The *fib* International Conference, Sustainable Concrete: Materials and Structures, is being organised on the occasion of the first *fib* (The International Federation for Structural Concrete) event in Malta, the *fib* Commission 7 meeting on Sustainability of Concrete and Concrete Structures; an important meeting focused on new developments in the sustainable use of materials and on the next generation of standards for reinforced concrete structures.

It is a first *fib* event in the Maltese Islands coinciding, after years of activity, with closer collaboration in this leading International organisation. It is being organised this year, 2018, in the UNESCO World Heritage City of Valletta, as the European Capital of Culture; and it is being organised at a time of intense activity in the construction industry and in particular in the concrete industry.

More than ever before there is the need to ensure greater quality in our buildings and infrastructure, particularly for stronger but also more durable concrete, necessary to reach the objectives for improved performance throughout the life cycle of structures and towards greater resilience in the built environment. Economic activity is leading to growing demands on the construction industry, with greater regard to economic considerations in materials and structures, larger sensitivities to societal needs and demands and increase in environmental awareness.

Whilst we must admit, that the concrete industry is often associated with heavy impacts on society and the environment, we need to acknowledge that precisely because of the significant effect of the industry, advances in materials and improvements in construction technology can lead to direct benefits.

This necessitates a leap forward in the way we conceive our structures, which can only be achieved through improved collaboration and knowledge transfer between the scientific and research community and industry; *fib* The International Federation for Structural Concrete reinforces this, serving as a bridge between Research and Practice.

The conference is an opportunity in this regard to bring together the industry stakeholders to share latest innovation in what we cannot but regard as a basic and yet extremely complex building material: concrete. This offers us the opportunity to discuss the challenges faced by the industry and possibilities for development in the concrete industry towards the requirements for sustainable use of materials; environmental protection and resource efficiency, societal demands for better built environment, safe buildings and infrastructure throughout their life cycle and economic considerations.

Therefore the scientific conference is an opportunity;

- for *fib* Commission 7 colleagues, as experts in respective fields to share their knowledge in advances in materials and structures,
- for colleagues and collaborators in concrete to share our research and industrial activities and results,
- for research students at the University of Malta and other research institutions to present their work and get peer review and valuable suggestions and criticism,



- for academics and the scientific community and for industry to meet, agree and disagree but surely discuss the challenges faced by the industry and the potential for development,
- for the commencement of new activity within *fib* Commission 7 through the new Task Force addressing sustainable use of materials through the exploitation of waste materials and industrial by-products towards improved performance of concrete,
- and finally, but most important, to start a sincere discussion on quality concrete and quality in construction, addressing gaps in our legislation and quality frameworks for the execution of our building and infrastructure projects.

The conference is based on 28 high quality presentations from international key experts in the field. There was indeed a larger feedback than anticipated which exceeded expectations when the call for papers was first issued. Furthermore papers have been double peer reviewed with the support of the International Scientific Committee who I gratefully acknowledge. Accepted papers are being published, through an International Publisher, in *Material Science and Engineering*, which is indexed in Scopus and Web of Science. This achievement indeed adds great value to this scientific conference and promises well for future academic activities.

I wish to thank all those who have supported this event from when I first suggested this scientific gathering to Commission colleagues, to coincide with the occasion of the *fib* Commission 7 meeting in Malta; the Chairman of *fib* Commission 7 Prof. Petr Hajek and the Secretary General of *fib* Dr. David Fernandez-Ordóñez.

I thank Philip A Tabone and BASF, who agreed to support this key event and for the effort to ensure a successful conference with the objective of bringing together the academic community and industry partners. I must here recall a similar conference I had the opportunity to organise on concrete in 2012 with Philip A Tabone and BASF. These collaborations between academia and industry demonstrate a genuine continuous drive towards promotion of better quality and greater awareness on advances in cement and concrete.

I also thank all organisations supporting *fib* and the University of Malta in this conference, who agreed to collaborate and be associated with this event and to contribute in the discussions and debates organised in this conference: the Planning and the Property Market Secretariat, Ministry for Transport, Infrastructure and Capital Projects, the Building Industry Consultative Council of the Government of Malta, the Kamra tal-Periti (Malta Chamber of Architects and Civil Engineers), The Malta Developers Association, The Malta Group of Professional Engineering Institutions (Institution of Civil Engineers, UK), Sustainable Built Environment Malta, The International Initiative for a Sustainable Built Environment (iiSBE) and Concrete Plant International CPI-Worldwide.

However, if I may use the analogy of concrete, as a composite based on diverse yet important constituents which may be insignificant as separate materials but which contribute in the whole, even this conference would not have been possible without the contribution of many, who I gratefully acknowledge.

Finally, and most important on a personal note, as a person deeply involved in cement based materials and concrete quality and resource and waste management in civil engineering, both in academia and in the construction industry, living the daily challenges in the concrete industry; I shall continue seeking concrete opportunities to promote advances in concrete - I definitely hope that this gathering sets the scene for continuous dialogue towards a framework for improved quality in concrete in the Maltese Islands.

# Introduction

## Sustainable Concrete: Materials and Structures

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Sustainability of Concrete materials and Structures refers to materials and structures which not only have sufficient strength and durability but which meet these requirements throughout their intended life time in intended applications. The term sustainability, indeed *durable* in French, reflects the need to address environmental, societal and economic priorities. Cement and Concrete have a significant large impact on the environment with 1 ton of CO<sub>2</sub> resulting for every ton of cement produced and with the cement production industry contributing to a significant quantity of the global carbon emissions.

Economic development puts significant larger demands on the exploitation of natural resources. Indeed the construction industry relies particularly on concrete for new buildings and infrastructure to address these growing demands, with large quantities of natural resources required to address these needs. Sustainable construction promotes effective use of resource and waste, therefore exploiting the potential for waste material and industrial by-products not only to reduce demands on natural resources but also exploiting the recycling of materials therefore reducing the volume of waste disposal. The exploitation of waste and industrial by-products present an opportunity in the concrete industry. Industrial by-products have the potential for cement replacement, to improve the properties of the materials even contributing to durability. These measures directly promote sustainable use of the materials through environmental friendly practices, which become even more effective when considering the large quantities of concrete produced.

The innovative use of materials together with the development of new materials and innovation in cement based materials and composites, for more challenging applications in Civil and Structural Engineering, also lead to more durable concrete and reinforced concrete structures with better performance throughout their intended life-time. Advanced materials help achieve more economic structures when considering the whole life cycle; with increased safety of structures during their service life with lower demands for repair and maintenance leading to significant economic advantages.

Quality concrete is key for the sustainable use of materials. Concrete is a very complex composite which can be engineered to address specific performance requirements and which relies on a variety of constituent materials including locally available materials in a specific region. Quality assurance systems are necessary to ensure the adequate use of constituents, mix proportions and production processes and application.

Sustainable use of concrete is not only achieved through innovation in materials and structural systems but also through an appreciation of the optimum use of materials for an intended application. This can be achieved equally through innovation in research and developments in industry, therefore working through effective research and development frameworks as indeed promoted by *fib*, The International Federation for Structural Concretes. Academic and industry collaboration is key towards effective solutions to the demands for greater efficiency and economy, safety of structures and environmental protection.

In this direction, the conference Sustainable Concrete: Materials and Structures, which is the first *fib* conference in Malta is being organised by *fib* The International Federation for Structural Concrete and the University of Malta as the higher academic institution in Malta, with the support of Industrial partners BASF and Philip A. Tabone Ltd, in association with the leading Construction Industry organisations and entities in the Maltese Islands; the Planning and the Property Market Secretariat, Ministry for Transport, Infrastructure and Capital Projects, the Building Industry Consultative Council of the Government of Malta, the Kamra tal-Periti (Malta Chamber of Architects and Civil Engineers), The Malta Developers Association, The Malta Group of Professional Engineering Institutions (Institution of Civil Engineers, UK), Sustainable Built Environment Malta, the International Initiative for a Sustainable Built Environment (iiSBE). The Conference is also organised in association with Concrete Plant International CPI-Worldwide.

The papers presented in the first Malta *fib* Conference being organised at the Valletta Campus of the University of Malta cover a range of advances in cement and concrete. Yet there is a unifying element and a focus which is evident; the promotion of the sustainable use of concrete materials with regards to environmental protection and resource efficiency, addressing societal needs and economic demands, while achieving safe reinforced concrete structures which perform effectively throughout their lifetime.

# Sustainable Construction Materials for Concrete: A Question of Responsible Use

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This paper has been inspired by the principal author's life-time research at the cutting edge of the concrete industry and is propelled by recent research undertaken with his co-authors, which is referenced fully in this paper. In the main, this work has been created to show that the use of sustainable construction materials, in making concrete, should be carefully evaluated for their rheological, engineering and long-term durability effects, in the relevant exposure classes, as well as environment impacts, in the form of leaching, as a material and whilst in use. Failure to do so, can, in the long-term prove to be disappointingly counterproductive in achieving the estimated sustainability benefits from the use of such materials in concrete, and may even prove disastrous.

# Sorptivity of Self-Compacting Concrete with High Volume Fly Ash and Its Eco-Mechanical-Durability Performance

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The durability of concrete is governed by the ability of the concrete to resist the penetration of aggressive agents from the environment. The capillary pores of concrete play an important role in the absorption of water, through which aggressive agents may enter into the body of concrete. The rate and amount of absorbed water can be measured by the sorptivity test. It is also recognised that the composition of concrete itself influences the pore structure of the concrete. Hence, in a non-conventional concrete with a very different mixture such as self-compacting concrete (SCC) incorporating a high volume of fly ash, the sorptivity can be expected to be diverse than that of the concrete. This paper aims to determine the influence of high volume fly ash contents on the sorptivity of SCCs, as measured by the method of ASTM C1858. The balanced performance of the concrete – in term of ecological, mechanical, and durability performance – is assessed using the eco-mechanical-durability index (*EMDI*). The index is developed as a combined value of eco-mechanical index (*EMI*) and eco-durability index (*EDI*). The sorptivity is adopted as the durability parameter in developing the *EDI*. The results confirm that an optimum value of sorptivity at an early age is obtained when about 55% of the cement is replaced with fly ash. At a later age, however, the optimum value is changed to the 65% replacement level. A higher volume of fly ash tends to decrease the *EMI* but increase the *EDI*. Consequently, the effect of fly ash content on *EMDI* depends on the relative importance between *EMI* and *EDI*. Where *EMI* and *EDI* are considered to be equally important, the effect of fly ash content on *EMDI* is controlled by the greater sensitivity of the *EDI* to the fly ash. Thus, it is shown in this particular case that at later age i.e. when the effect of fly ash is maximal, the highest *EMDI* is found in the SCC with 70% of the cement replaced by fly ash.

# Quarry Limestone Dust as Fine Aggregate for Concrete

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In quarrying activities, rock is extracted and transformed into aggregate of various sizes for civil engineering applications. In this process waste, fine aggregates is generated. The disposal of this type of waste is a further cost in the extraction process, but also a possible cause of environmental degradation and pollution (e.g. leaching into water reserves, atmospheric pollution as a result of small particles causing respiratory diseases or deposited on plants disrupting photosynthesis, affecting aquatic habitats, etc.). A strategy for the effective recycling of quarry dust, not only reduces waste generation and disposal but also addressed protection of the environment. The Italian quarrying industry covers a relevant portion of global mineral extraction resulting in a significant production of fine waste. In some cases quarries are located close to ecological sensitive and protected areas and to the coast, with higher risks for biodiversity (an example is the limestone extraction industry in Trapani, Sicily). In this context, the paper reviews the strategies proposed in the use of limestone fine waste, especially for concrete, and discusses an experimental program intended to assess the mechanical properties of concrete made with the fine limestone waste produced in the area of Trapani, as a partial substitute of fine aggregate (sand).

# Utilization of Granite Waste Dust in Ultra-Light Weight Concrete

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In the article the possibility to utilize granite dust in production of ultra-light weight concrete ( $\leq 800 \text{ kg/m}^3$ ) is researched. Granite dust is a by-product of crushed granite, has very fine particles and high surface area. Due to very fine particles and high surface area, applicability of granite dust in concrete is limited. Mainly because granite dust increases W/C ratios and thus mechanical and durability properties tends to decrease. Ultra-light weight concrete, usually has very high W/C ratios, therefore in this type of concrete utilization of granite dust has favourable opportunity. In the research ultra-light weight concrete based on aluminium powder was created. Main mechanical and microstructure properties were researched and thermal conductivity coefficient was calculated. During experiment ultra-light weight concrete with  $700 \text{ kg/m}^3$  and up to  $3.33 \text{ MPa}$  was created. According to the experiment results, waste of granite dust can be properly utilised in production of ultra-light weight concrete blocks suited for one or two storages individual houses.



# Characterization of Libyan Metakaolin and its effects on the Mechanical Properties of Mortar

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Environmental concerns, stemming from high energy demands and CO<sub>2</sub> emission associated with cement manufacture, have brought about pressures to reduce cement consumption through the use of supplementary cementitious materials (SCMs). Besides addressing environmental concerns, the incorporation of SCMs in cement bound materials and concrete can modify and improve specific concrete properties. Metakaolin (MK) is an important SCM which can enhance the performance of cementitious composites through its high pozzolanic reactivity. This study was carried out to characterise the materials and to assess the effect of Libyan metakaolin (LMK) on the mechanical properties including the compressive strength of cement mortar. LMK was produced by calcining kaolinite clay at 700°C for 2 h. X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Differential Thermal Analysis / Thermo-Gravimetric analysis (DTA/TG) and Fourier Transform Infrared Spectroscopy (FTIR) were performed on the raw and calcined kaolinite powders. Seven mixes were prepared with different LMK replacement percentages (0 to 30%), by weight of cement, and a constant water binder ratio (w/b) of 0.5. The specimens were cured for 3, 7, 28, 56 and 90 days. At the end of each curing period, the specimens were tested for compressive strength. The results confirm the transformation of kaolinite clay into metakaolin and the pozzolanic reactivity of the produced LMK and conform to ASTM requirements in this respect. The study confirms that LMK could be effectively used in reducing cement content by up to 30% by weight without compromising compressive strength of the cement mortar.

# Self-Compacting Concrete produced with Limestone Waste

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The aim of the research was to design powder type self-compacting concrete containing a high amount of limestone quarry waste as aggregate and fines. The light coloured aggregate mixed with white cement resulted in esthetical surfaces of exposed concrete for architectural purposes. Large amount waste originated from the limestone mining process requires deposition with further treatment. In our study we tried to replace also the limestone powder fines by the slurry produced during the cut of limestone blocks. Seven recipes were examined during the research: three mixtures of quartz aggregate with different particle size distributions were used as reference mixtures, three mixtures composed of crushed limestone aggregate and one with mixed quartz-limestone composition, respectively. In the recipe of mixed limestone-quartz aggregate dried quarry waste slurry was successfully applied instead of direct ground limestone powder. In the research different test methods were used to determine the fresh properties as well as the hardened properties of concrete.

# Self-healing Cement Based Materials: An Asset for a Sustainable Construction Industry

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Worldwide increasing consciousness for sustainable use of natural resources has made “overcoming the apparent contradictory requirements of cost and performance effectiveness a challenging task” as well as a major concern. Self-healing cement based materials, by controlling and repairing cracks, could prevent “permeation of driving factors for deterioration”, thus extending the structure service life, and even provide partial recovery of the engineering properties relevant to the application. This paper will outline the current state of art on self-healing cement based materials and experimental methods for the assessment of the self-healing capacity. Moreover, it will also critically analyse the current hindrances which challenge the engineering community in paving the way towards the reliable and consistent incorporation of self-healing concepts and effects into a durability-based design framework for buildings and structures made of or retrofitted with self- healing concrete and cementitious composites.

# A New Era and Future Perspectives in Maintenance and Repair of Existing Reinforced Concrete Structures

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Today, over 50 years from the widespread availability of concrete in the construction industry, always more frequently buildings are characterized by severe degradation and instability, especially in marine environments where the corrosion of steel bars and the spalling of concrete cover are exasperated. The present paper shows the main innovations on products and systems for the protection and repair of existing concrete structures. In particular, the article deals with restoration mortars and concretes based on both traditional and Portland-free alternative binders. In particular, attention is given to the mechanisms that regulate the expansion of compensated shrinkage mortars and the dimensional stability over time of mixtures based on calcium sulfoaluminate cement – ordinary Portland cement – gypsum. Furthermore, the latest findings in the field of migrating corrosion inhibitors for Cl<sup>-</sup>-rich environments and surface treatment systems are discussed. Finally, the case history of a reinforced concrete structure successfully repaired in the mid-1980s and recently under survey is presented.

# A Multi-Criteria Decision-Making Based Approach to Assess the Sustainability of Concrete Structures

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The use of sustainability assessment tools is gaining importance in the construction sector. There exist several methods with different approaches and scopes; however, there is still no consensus about which method should be used to deal with the sustainability assessment of concrete structures. Among these, the multi-criteria decision-making based approach called MIVES seems to be a suitable and flexible model that allows taking into account all those indicators and parameters (of economic, social and environmental nature) involved in the sustainability assessment of concrete structures. The objective of this research document is two-fold: (1) to expose the basis and concepts related with the MIVES model as a sustainability assessment tool and (2) to present 3 real study cases (wind precast concrete towers; steel fibre reinforced precast concrete tunnel linings and reinforced concrete pile-supported slabs) in which this model has been used to make decisions. The authors of this research consider that similar approaches should be included in future national and international structural concrete guidelines (as the Spanish Structural Concrete Code does) to perform sustainability analysis of new designed concrete structure.

# Life Cycle Assessment Optimization of a Shotcrete Tunnel Lining

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The proposed contribution describes the formulation of the optimization design of a utility tunnel lining. The objective function is defined as a multi-criterial problem and includes economic and environmental aspects associated not only with concrete member production but also with maintenance during utilization (life cycle assessment). The constraining conditions expressed by relations derived from equations of equilibrium (the solution of optimization calculations for a structure with a Winkler foundation using the Finite Element Method), the reliability conditions of a reinforced concrete structure and the continuity of deformations define the range of allowable solutions from the mathematical viewpoint. The thickness of the tunnel lining and areas of the top and bottom reinforcement in cross-sections are optimized. A method (algorithm) for obtaining a serviceable reinforcement design (via the implementation of reinforcement types) from an optimal solution is described. The obtained results are compared and analysed.

# LCA-Based Comparison of the Environmental Impact of Different Structural Systems

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Construction is one of the most impactful industrial sector because of the high consequences it generates on the society, the environment and the economy. The study presented herein aims to define a methodological framework that can be used for construction community stakeholders in order to conduct environmental sustainability comparisons among building systems at the design stage. An application of the methodology is performed by comparing structures having different building materials. Three alternative material options have been investigated: RC, steel, and wood. Each option has been designed to fulfil predefined structural, functional, and architectural requirements. Later, the environmental impacts of the structures have been assessed according to the four steps of the life-cycle assessment procedure (ISO 14040) and considering the four phases of a building life: extraction and processing of raw materials; construction; operation; end of life. LCA study is conducted for the three alternative structures with the help of SimaPro software, using both IMPACT2002+ and EPD2008 methodologies to quantify environmental impacts.



# Eco-Mechanical Indexes for Sustainability Assessment of AAC Blocks

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This paper aims to provide a proper set of eco-mechanical indexes to evaluate both the mechanical performances and the environmental features of autoclaved aerated concrete blocks. To this purpose, a detailed review of existing sustainability indexes – originally developed for concrete – is first presented, and subsequently different possible eco-mechanical indexes are specifically developed for autoclaved aerated concrete masonry blocks, also in order to compare their performances with those of lightweight aggregate concrete blocks. The obtained results highlight that, based on currently available information, only few parameters appear to be effective in defining the overall sustainability performances of AAC blocks. While several researches were indeed carried out in these last years regarding material structural properties, there is still a lack of environmental data, which should be necessarily deepened in future research work to obtain more reliable results.

# The CARES Sustainable Construction Steel Certification Scheme for Steel Reinforcement in Concrete

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The expectations of stakeholders across the construction industry value chain have evolved significantly in recent years. Driven by scientific trends, a greater understanding of sustainability impacts and new legislation, construction clients are demanding transparent, reliable data and comparable sustainability information about competing construction materials, management of their production and performance trends. Standard setting organisations and building rating systems are maturing in their requirements and third-party certification bodies have responded with improved certification options that enable the provision of data collection, auditing and reporting to meet construction client demands. The CARES Sustainable Constructional Steels (SCS) scheme is one option that applies to reinforcing carbon steel, reinforcing stainless steel, structural steel and hot rolled flat steel. Frequently specified as part of structural concrete building systems, the accredited scheme has been developed with the inputs of a wide range of stakeholders. It is based on foundations of technical specifications, traceability, product quality and the sustainability principles of inclusivity, integrity, stewardship and transparency. SCS Certification provides confidence to specifiers, designers and wider stakeholders that the sustainability impacts of constructional steel products throughout their supply chain are being actively managed and continually improved.

# Sustainability and Concrete in a climate of urgency

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The concrete industry alone accounts for 5% of the global carbon emissions; Concrete is an important materials and is required for the construction of essential public infrastructure. Because of the significant impact of the concrete industry towards carbon emissions, there is a great responsibility with regards the environment. The main actors in the industry need to towards reductions in carbon emissions. There are solutions for mitigating the effects of the concrete industry on green-house gases but there are significant barriers for their effective implementation.

The paper attempts to present a holistic framework for CO2 reduction in the concrete industry. The paper delves into the following important considerations:

- Address three main disciplines that could be better connected; materials and technology, structural engineering and the execution of concrete structures.
- Identify key elements that need urgent action to address the impact of concrete.
- Identify and expose the barriers to advancement in technologies,
- Propose a low cost action project that is intended to attract early career researchers towards an industry that is highly technological.

Reference is made to experience with refractory concrete. The sustainability of concrete structures can be achieved through a plan that is intended to benefit society, the environment and which addresses economic aspects. Innovation in science and technology are the essentials tools to reach these urgent objectives.

# Contribution of Concrete Structures to Sustainability: Challenges for the Future

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New situations in the natural and socio-economic environment require new technical solutions for construction of new and reconstruction and modernization of existing structures. Structures and all the built environment should be better prepared for the new conditions – they should be sustainable and resilient. Concrete gradually becomes a building material with high potential for new technical solutions resulting in needed environmental impact reduction and consequent social and economic improvement. The paper presents the potential contribution of concrete and concrete structures towards the solution of the Sustainability Development Goals specified in the UN 2030 Agenda for Sustainable Development and brings basic principles of implementation of sustainability approach into the *fib* Model Code 2020.

# The Utilization of Recycled Materials for Concrete and Cement Production: A Review

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The utilization of recycled materials is one of the seven principles of sustainable construction. These principles based on the efficient use of resources were defined by the International Council of Building in 1994. Recycled materials such as recycled concrete aggregate or recycled brick aggregate from construction and demolition waste, waste glass from municipal waste or recycled waste gypsum from gypsum boards are able to use as replacement of primary raw materials in cement and concrete production. Concrete and cement production totally depends on the natural resources. The world production of concrete has been twelve times increased during last six decades. Nowadays, nearly one ton of concrete is produced each year for every human being in the world on average. On one hand, the use of recycled materials in cement and concrete production helps to reduce raw materials and urban land occupation. However, on the other hand, the recycled materials used as partial replacement of raw materials influence properties of final product. This paper reviews the different uses of recycled materials in cement and concrete production and the effect of the properties of these materials to the cement and concrete quality.

# The Influence of Sulphur Slime on the Properties of Alkali Binding Material from Biomass Bottom Ashes

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Alkali-activated materials are potential alternatives for Portland cement. Their use leads to reductions in CO<sub>2</sub> emissions and recycling of various industry by-products. These new alternative binders have a wide range of uses and high technological properties. In the research presented in this paper, the influence of additional sulphur slime powder (as accelerator) was investigated. The biomass bottom ash (BBA) was used as raw material and sodium hydroxide was used as the alkaline activator. The sulphur slime is a by-product in a fertilizer production plant. The samples were prepared with different amounts of sulphur slime; the levels of sulphur slime additive were 0%, 0.5%, 1.0%, 3.0% and 5.0% by weight in the raw material mixtures. Alkali activated binders were mixed and conditioned at a temperature of 60 °C for 48 h, followed by curing at room temperature for 26 days. . The microstructure of the material was analysed through scanning electron microscopy (SEM) and the composition of the materials was analysed using X-ray diffraction (XRD) and X-ray fluorescence (XRF) spectroscopy. The compressive strength of hardened alkali activated paste was measured after 28 days. In the all cases investigated, the compressive strength of hardened cement paste samples increases with the presence of Sulphur slime powder. It was found that during the hardening process sulphur reacts with sodium hydroxide forming Na<sub>2</sub>SO<sub>4</sub> which acts as an accelerator. According to some researchers Na<sub>2</sub>SO<sub>4</sub> has shown a significant accelerating influence in the alkali activated binder systems. The optimal amount of sulphur slime in raw materials mixtures was also evaluated.

# The Role of Third Generation Superplasticizers in the Future of Durable and Sustainable Tall Buildings

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This article focuses on the use of 3<sup>rd</sup> generation acrylic-based superplasticizer for concrete which, replacing the outdated naphthalenesulphonate and melamine-based water reducers, allow the construction of very complex reinforced concrete structures, even tall buildings. The use of high range water-reducing admixtures determines a sharp reduction of the mixing water (and therefore of the cement factor), strongly limiting the problems related to the massive foundations which, due to the temperature gradient between the core and the external surface, are very prone to cracks and, consequently, easily affected by degradation. Furthermore, the elevation bearing structures of tall buildings can be realized with ultra-high performance concrete (UHPC). This material, manufactured by using Portland cement, silica fume, limestone powder, 3<sup>rd</sup> generation superplasticizer and fibres, provides high mechanical strength and very low porosity. Moreover, UHPC has considerable advantages in terms of low creep and very high ductility, two fundamental design parameters for tall buildings, respect to ordinary concrete. Therefore, the use of UHPC allows the design of thin sections, reducing the seismic mass and the stresses deriving from earthquakes achieving long last durable structural elements in very severe environmental conditions.



# The application of Natural Organic Additives in Concrete: *Opuntia ficus-indica*

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The use of synthetic additives as setting retarders and plasticisers has over the past years become a standard practice in mortar mixtures, despite their potential adverse environmental effects. Since antiquity, man has used organic additives ranging from plant and animal-derived extracts, to improve the setting properties of mortars. These practices are slowly being revived and investigated scientifically to promote the use of materials with lower impacts on the environment. Amongst the many different types of plant-derived extracts that have been used as mortar and concrete additives, the prickly pear (*Opuntia ficus-indica*) mucilage extract, is popular in Meso- and South-America. The scientific basis of these additives lies in the hydrating properties of the mucilage polysaccharide complex. The purpose of this research was to produce *Opuntia ficus-indica* (OFI) extracts in different forms and incorporate them in cement pastes and mortar mixtures by either replacing the water in the mixture with OFI mucilage or by replacing the cement in the mixture with OFI lyophilised powder. The research findings show that the inclusion of *Opuntia ficus-indica* additives in cement-based mortars increased their performance in terms of strength for both water and powder replacements. Results in cement pastes showed a reduction in workability and an increase in setting time. Results also showed that *Opuntia ficus-indica* additives weakened the cement paste samples in terms of strength in both water and power replacements.

# The effects of the Water Cement Ratio and Chemical Admixtures on the Workability of Concrete

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Concrete chemical admixtures are used to improve the fresh and hardened properties of mortar or concrete in different applications. Their addition can allow for the reduction of the water to cement ratio (w/c), without affecting the workability of the mixture. By reducing the amount of water, the cement paste will have higher density. However, the reduction of the water content in a concrete mixture should be done in such a way that complete cement hydration take place and sufficient workability is achieved. In order to maintain the workability of the concrete mix, the dosage of the admixture must be carefully calculated and must be taken into account in the calculation of the w/c ratio. In the present study, three types of chemical admixtures; Type A water-reducing, Type D water-reducing and retarding and Type F high range, water-reducing admixtures conforming to ASTM C 494/C 494M – 04 standards, were used to optimize the percentage of the admixture with respect to the w/c ratio. The suitable time for the addition of the admixture is also investigated. Results show that using 1.5 % of Type A admixture with 0.45 w/c gives 45.6 MPa, 28 day compressive strength with an associated slump of 110 mm, compared to 0.0 mm slump achieved without admixture. 1.0 % Type A admixture with 0.52 w/c gives 33 MPa, 28 day compressive strength with an associated slump of 95 mm, compared to 35 mm slump achieved without admixture. For Type D admixture, using 1.5 % with 0.5 w/c the slump was 190 mm with 47 MPa, 28 day compressive strength, compared to 15 mm slump achieved without admixture. 1.0% of Type F admixture with 0.35 w/c and 0.45 w/c gave slumps of 25 mm, 225 mm and strength of 63.5MPa and 55.3MPa respectively. For all mixes, the best slump results were achieved when the admixtures were added during the initial mixing process, while maximum compressive strengths were achieved for different times of inclusion of the admixtures.

# Calculation of the Plastic Viscosity of Concrete Mixtures Using the Modified Empirical Formula

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Nowadays various types of viscometers are being designed to measure the rheological properties of cement paste and fresh concrete. Most of them are very expensive and require specific knowledge about their usage. Then in practice usually the empirical formulas are used to calculate the main rheological properties – yield stress (Pa) and plastic viscosity (Pa·s). Therefore, in literature, there are some formulas which can't be used to calculate analytically plastic viscosity of concrete mixture, e.g. it cannot estimate the influence of different chemical admixture on plastic viscosity of concrete. The paper focuses on the modification of the empirical formula to calculate the plastic viscosity of fresh concrete mixtures. In this paper the modification of the viscosity formula is described. For an empirical formula modification the coefficients which describe the influence of different chemical admixture on plastic viscosity of concrete mixture were used. The coefficients  $K_{calc.}$  were calculated as ratios between different viscosity values of cement pastes obtained without and with certain chemical admixtures. The viscosity of cement paste was obtained by using the rotational viscometer Rheotest RN4. The coefficients describe the change in viscosity of the cement pastes when different types (superplasticizer, viscosity modifying agent, air-entraining agent and air voids removing agent) and amounts of chemical admixtures are added.

# Research Activities towards Sustainability Design Systems

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The world is dramatically changing. It means that the concrete and construction industries have to consider what actions are required. We have accumulated the concrete and construction technologies and systems for several decades to make our society more efficient and comfortable, in which we did not have to consider seriously the issues such as CO<sub>2</sub> and natural resources' depletion. However, human beings realized the importance of sustainable development and came to the stage that the sustainable development targets were set in the United Nations. More than half of the targets are directly and indirectly related to construction industry. Under such circumstances, *fib* The International Federation for Structural Concrete has recognized the importance of sustainability, introduced partially "sustainability" in Model Code 2010 and discussed the full framework of sustainability for Model Code 2020 which meets the requirements from our society. The direction is quite clear because there is no other option. In addition, "sustainability thoughts" will be the most powerful innovation "tool." On the premise that the sustainability design framework is introduced in *fib* Model Code 2020, what do we have to pursue in research activities? In the presentation, the essence of sustainability in concrete and construction industries and future research to be accomplished will be discussed.

# Matching Safety and Sustainability: The SAFESUST Approach

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The construction industry, as a main energy consumer and a foremost contributor to greenhouse gas emissions, has been undergoing a “green revolution” in the recent years. Sustainability has become a prominent issue, and environmental methods such as footprint schemes and Life Cycle Analysis approaches are being considered in the design and in the rehabilitation of buildings. However, all environmental assessment methods are applied at a later design stage, to provide a final indication of the life cycle environmental performance. A more effective way would be to consider the environmental issues in the early design stage, along with structural reliability and safety, and the global performance indicator should be expressed in economic terms. The need for an integrated design approach, to tackle safety and sustainability together has been the object of a recent workshop, in which the acronym SAFESUST was introduced. SAFESUST is an acronym to mean SAFETY and SUSTAINABILITY. It also identifies a research work-package on impact of sustainability and energy efficiency requirements on building design and retrofit, being conducted by the European Commission - Joint Research Centre, as a part of the project Safe and Cleaner Technologies for Construction and Buildings. The SAFESUST approach has been implemented into a Sustainable Structural Design (SSD) method, which considers both environmental and structural parameters in a life cycle perspective. The integration of environmental data in the structural performance is the focus of the method. Structural performances are considered in a probabilistic approach, through the introduction of a simplified Performance Based Assessment method.

# Chloride Ion Detection through the Voltage Response of a Galvanic Pair

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Chloride ion ingress into reinforced concrete structures is one of the primary causes of concrete degradation. Real-time monitoring of concrete structures for the ingress of chloride ions is therefore of paramount importance towards the achievement of durable and sustainable structures. It is therefore important that the chloride ion detection method used must be accurate and reliable. This paper will endeavour to show how embedded 316L stainless steel and EN3b mild steel galvanic electrode pairs will react to chloride ions present in the concrete pore solution. Through practical experimentation the correlation between the chloride ion concentration in the pore solution and galvanic voltage measurements between the electrode pairs was explored. An experimental setup was proposed, based on concrete samples with in-built fluid containment vessels holding sodium chloride solution which was allowed to permeate through the pore structure of the concrete over a defined period of time. At particular time intervals core samples were taken at different depths in concrete samples, and the chloride ion content was determined with depth of penetration through titration on the extracted material. The chloride ion content results from titration tests were compared to the measured galvanic voltages. Within certain limits there was good correlation between the chloride ion concentration and the measured voltage readings across the galvanic electrode pair. Galvanic voltage measurement provide a relevant technique for the detection of chloride ions in concrete and in the design of a chloride ion sensory system.

# Sustainable Structural Rehabilitation of a Concrete Bridge “*Ponte delle Grazie*” in Faenza, Italy

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The “*Ponte delle Grazie*” is a three span bridge, with a total length of 72 meters, built between 1948 and 1952 in Faenza, Italy. The reinforced concrete main beams of the deck have undergone a strong deterioration over the years. In detail atmospheric agents and chemical aggressions caused a strong deterioration of the concrete, up to the point of making the structure not accessible and at risk of collapse. In fact, the five main beams were heavily damaged, as well as the concrete bearings were strongly compromised. So, an urgent intervention was necessary to save the structure of this historic bridge. A delicate restoration has allowed to remove the deteriorated concrete and to restore the resistant sections with new materials compatible with the old remaining structures. In particular, a specific rehabilitation procedure was studied using fibre-reinforced cement mortar with low elastic modulus that is shrinkage compensated, in combination with composite materials reinforcements. Without modifying the structural behaviour of the bridge, the deteriorated concrete was restored and reinforced, in a sustainable way, in order to make the structure safe and usable again.

# Concrete Composite – Sustainable Material for Floating Islands

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The aim of the paper is presenting of a nature-friendly achievement of an artificial floating island made from concrete composite with dispersed reinforcement (fibre reinforced concrete). Fibre reinforced concrete is referred to as a material contributing to sustainable construction, as utilisation of fibre reinforced composites enhances durability and resiliency of structures and structural elements. The paper describes the floating island design, its shape and manufacturing process. The focus is also on the composition of fibre reinforced concrete and testing of its material characteristics. The successful application of fibre reinforced concrete in the floating island approved efficiency of fibre reinforced concrete as a material with high potential to meet demands of sustainable building.



# Effects of Climate Change on Structures: Analysis of Carbonation-Induced Corrosion in Reinforced Concrete Structures in Malta

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The various elements that are affecting the Earth's climate have brought climate change to the top of the priority list amongst scientists and policy-makers. Expected changes to local climatic conditions impact directly on the surrounding environment and potentially lead to changes in the degradation processes of building materials, affecting the durability and service life of infrastructures. The aim of this paper is to investigate the effects of future climate projections on concrete structures in Malta, in particular on carbonation-induced corrosion resulting from increasing temperatures and CO<sub>2</sub> concentrations. Thirteen reinforced concrete structures in Malta were chosen for a retrospective analysis in order to validate two carbonation depth prediction models. The validated prediction models were subsequently used to evaluate the varying climate change scenarios in order to determine the effects on concrete carbonation depth for several concrete grades. The age of the structures used for the retrospective analysis ranged from 10 to 60 years. The field data verified the validity of both prediction models for structures with carbonation depths less than 50mm. Although both models proved valid for the retrospective analysis, a difference was noted between the models with regards to the predicted carbonation depth in relation to different climatic scenarios. An increase in carbonation depth of up to 40% is being predicted, by 2070, when considering the worst case climatic scenario. The findings prove that climate change plays a major role on the carbonation depth of concrete, which in turn reduces the service life of concrete structures.

# An Holistic Approach to a Sustainable Future in Concrete Construction

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The main challenge for concrete industry is to serve the two major needs of human society, the protection of the environment, on one hand, and - on the other - the requirements of buildings and infrastructures by the world growing population. In the past, concrete industry has satisfied these needs well. However, for a variety of reasons the situation has changed dramatically in the last years. First of all, the concrete industry is the largest consumer of natural resources. Secondly, Portland cement, the binder of modern concrete mixtures, is not as environmentally friendly. The world's cement production, in fact, contributes to the earth's atmosphere about 7% of the total CO<sub>2</sub> emissions, CO<sub>2</sub> being one of the primary greenhouse gases responsible for global warming and climate change. As a consequence, concrete industry in the future has to face two antithetically needs. In other words, how the concrete industry can feed the growing population needs being – at the same time - sustainable?

Sustainability in construction industry can be achieved through three different main routes based on the “3R – Green Strategy”: Reduction in consumption of gross energy for construction materials production, Reduction in polluting emissions and Reduction in the consumption of non-renewable natural resources.





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