EM4SS'21

ENGINEERED MATERIALS FOR SUSTAINABLE STRUCTURES

Modena, 26th - 28th April 2021

BOOK OF ABSTRACTS

EM4SS'21 – Engineered Materials Sustainable Structures

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About

EM4SS’21

The Research Centres EN&TECH and CRICT of the University of Modena and Reggio Emilia, in the framework of the Project IMPReSA, are proud to organise the international workshop “Engineered Materials for Sustainable Structures (EM4SS)”, which provides a unique forum for researchers, companies, and practitioners to exchange ideas on the new frontiers of innovative materials and structures.

Five thematic sessions address the fundamental aspects of the broad spectrum of engineered materials, with the main goal of establishing a meaningful dialogue within the different scientific communities and the business world:

- **Innovative building materials:** sixteen talks explore the recent progress in materials science and technology, with application in the construction field as innovative reinforcements for cementitious materials, sustainable concrete pastes, geopolymers, artificial and natural recycled aggregates. In addition, notable contributions investigate innovative materials for consolidation and preservation of the architectural heritage, functionalized nano-materials, and materials for additive manufacturing in construction.

- **Mechanics of solids and structures:** state-of-the-art and new concepts in mechanics of solids and structures are explored through thirty talks from all over the world. These high-level researches deal with multiscale and asymptotic models, homogenization and instability, nonlinear elasticity, wave propagation and reflection, plasticity, fracture mechanics, metamaterials, and multiphysics modelling.

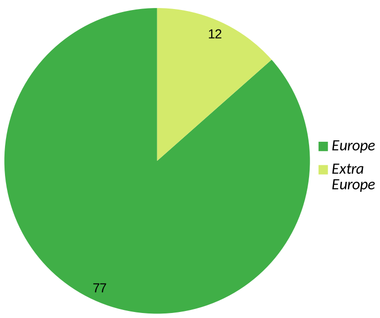
- **Advanced composite materials for structural purposes:** two minisymposia investigate the new frontiers in the field of composite materials, with focus on inorganic and ceramic matrix composites for structural retrofitting and rehabilitation of civil and industrial buildings. Among the topics addressed in the twelve talks here presented, fibre-reinforced polymers (FRP), textile reinforced mortar/fibre-reinforced cementitious mortar (TRM/FRCM), fibre-reinforced concrete (FRC), circular economy in composites, and architectural conceptualisation are the major ones.

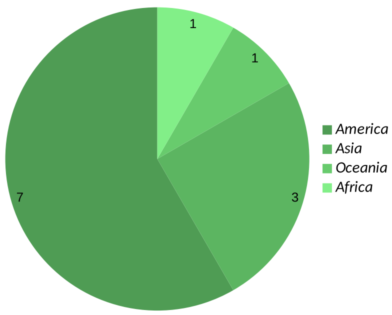
- **Durability and Corrosion:** fifteen contributions discuss the crucial topic of structures durability and steel corrosion in building materials. Spotlight is set on innovative and sustainable materials like (but not restricted to this) new and reinforced concrete, alkali-activated cement or concrete, fly ashes, slags, metakaolin, etc. In addition, corrosion and passivation mechanisms, critical chloride content, long-term corrosion resistance, durability, and monitoring methods are also investigated.

- **Life Cycle Assessment:** sustainability issues of construction materials, also related to the environmental impact, recycled content, legal requirements (CAM, EPD, etc.), are currently taken into serious account by the research community and by the recent guidelines and standards, which strongly endorse the development of "green" materials. In this session, sixteen speakers from academic and industrial communities explore the multifaceted topic of circular economy approach in the construction field, also focussing on the environmental assessment of construction materials, LCA of products, challenges and new perspectives on waste recycling, and relevant cases of study.

The Numbers of EM4SS'21

The first online edition of the EM4SS'21 workshop involves **89 talks**, coming from all the continents. The EM4SS'21 community involves **77 speakers from European countries** (Italy, Spain, Belgium, Cyprus, United Kingdom, Norway, Republic of Ireland, France, Greece, Austria, Poland, Switzerland, and Slovenia), **7 from America** (Canada, United States, and Brazil), **3 speakers from Asia** (China, Vietnam, and India), **1 speaker from Oceania** (Australia) and **1 speaker from Africa** (Nigeria).





Project IMPReSA

IMPReSA is a Project founded by the Emilia Romagna Region, which combines both the scientific knowledge of four Research Centres and the expertise of four important companies located in the Region.
IMPReSA aims at providing novel applications in the civil engineering field, which incorporate plastic debris no longer exploitable for the pristine intended use, by following the Circular Economy principles. The Project, in fact, promotes the use of non-recyclable plastic materials as reinforcing phase within cementitious mortars for structural purposes, by substituting the aggregates of natural origin. The main goals are the study, the design, and the development of innovative "eco-friendly" construction materials, including reinforcing plastic fibers or aggregates, which may contribute to the transition towards a green economy endorsing a sustainable use of resources.

Scientific committee

- Prof. Francesco Ascione – University of Salerno
- Prof. Davide Bigoni – University of Trento
- Prof. Anna Maria Ferrari – University of Modena and Reggio Emilia
- Prof. Roberto Frassine – Polytechnic University of Milan
- Prof. Gennady Mishuris – University of Aberystwyth
- Prof. Cecilia Monticelli – University of Ferrara
- Prof. Natasha Movchan – University of Liverpool
- Prof. Andrea Nobili – University of Modena and Reggio Emilia
- Prof. Enrico Radi – University of Modena and Reggio Emilia
- Prof. Michael Raupach - RWTH Aachen University
- Prof. Giuseppe Saccomandi – University of Perugia
- Prof. Prof. Igor Sevostianov – New Mexico State University
- Dr. Antonella Sola – Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Organizing committee

- Prof. Andrea Balbo – University of Ferrara
- Prof. Andrea Nobili – University of Modena and Reggio Emilia
- Dr. Cesare Signorini – University of Modena and Reggio Emilia
- Prof. Cristina Siligardi – University of Modena and Reggio Emilia
- Dr. Valentina Volpini – University of Modena and Reggio Emilia

Innovative Building Materials

Monday, 26 of April

9:15–9:40	**Opening ceremony**		
Mini-symposium	**Eco-friendly materials for smart structures and infrastructures**		
			Chairperson: *Dr. Antonella Sola*
10:00–10:20		**Nele De Belie** Ghent University, Belgium	Durability, service life prediction and life cycle assessment of self-healing concrete
10:20–10:40		**Sumit Chakraborty** University of Sheffield, UK	Development of cement-less construction materials utilizing waste alumino-silicate precursors by hydrothermal method and alkali activation
10:40–11:00		**Bartolomeo Coppola** Polytechnic University of Turin, Italy	Reuse of carbonatic and alumino-silicate sludges as alkali-activated materials: innovation and sustainability
11:00–11:20	**Virtual coffee break**		
11:20–11:40		**Piyush Chaunsali** IIT Madras, Chennai, India	Beneficial Utilization of Indian Biomass Ash in Eco-friendly Bricks
11:40–12:00		**Diego M. Barbieri** Norwegian University of Science and Technology, Norway	Stabilization of road subsurface layers with organosilane and lignosulfonate
12:00–12:20		**Antroula Georgiou** University of Cyprus	Engineered Cementitious Composites for the conservation of 20th century concrete architectural heritage
12:20–12:40		**Prannoy Suraneni** University of Miami, USA	Feasibility of using ashes glass fibre reinforced polymer materials as a supplementary cementitious material in concrete
12:40–13:00	**Q&A Session**		

Wednesday, 28 of April

		***Chairperson**: Dr. Antonella Sola*
9:40–10:00	**Victor T. Ibeabuchi** Federal University Ndufu Alike, Nigeria	Mechanical properties of high strength concrete incorporating Calcined Ebonyi Shale (CES) at elevated temperature
10:00–10:20	**Matteo Sambucci** Sapienza University of Rome, Italy	Eco-sustainable approach for cementitious mix construction materials: a preliminary comparison between geopolymer and cement-based matrices incorporating Tire recycled rubber
10:20–10:40	**Chiara Moletti** Polytechnic University of Milan, Italy	Microstructural and mechanical characterization of different hempcrete mix design for prefabricated blocks production
10:40–11:00	**Beatrice Malchiodi** University of Modena and Reggio Emilia, Italy	Use of recycled textile fibres for sustainable and thermal insulating Fibre Reinforced Cement
11:00–11:20	**Virginia Barbieri** University of Modena and Reggio Emilia, Italy	Use of modified magnesium oxysulfate (MOS) cement for the production of lightweight hemp concretes
11:20–11:40	**Virtual coffee break**	
11:40–12:00	**Farid Salari** University of Trento, Italy	Parametric analysis of binder-powder interaction in binder jet 3D printing of cement-based materials
12:00–12:20	**Antonella Sola** Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia	Progress of fibre coatings in fabric-reinforced lime-based composites: materials selection and property optimisation
12:20–12:40	**Silvia Barbi** University of Modena and Reggio Emilia, Italy	Materials characterization and thermal analysis of PCM-silica mixtures for backfilling of ground heat exchangers
12:40–13:00	**María Jimena de Hita Fernández** Eduardo Torroja Institute for Construction Sciences, Spain	Cementitious matrixes for nuclear waste management: effect of admixtures on fresh state properties
13:00–13:20	**Q&A Session**	

Mechanics of Solids and Structures

Monday, 26 of April

9:15–9:40	**Opening ceremony**		
			***Chairperson**: Prof. Andrea Nobili*
9:40-10:00		**Victor Eremeyev** University of Cagliari, Italy	Antiplane surface waves in the framework of strongly anisotropic surface elasticity
10:00–10:20		**Matteo Pelliciari** University of Modena and Reggio Emilia, Italy	Snap-through of a bi-stable truss in finite elasticity
10:20–10:40		**Jean-François Barthélémy** Cerema, France	Equivalent particle in conduction homogenization and application to a composite spheroid
10:40–11:00		**Gaetano Napoli** University of Salento, Italy	Temperature-induced textures on nematic shells
11:00–11:20	**Virtual coffee break**		
11:20–11:40		**Yibin Fu** Keele University, UK	Post-buckling of an elastic half-space coated by double layers
11:40–12:00		**Andrea Nobili** University of Modena and Reggio Emilia, Italy	Reduced dimensional models for microstructured plates
12:00–12:20		**Ludmila Prikazchikova** Keele University, UK	Asymptotic methods in nonlocal elasticity
12:20–12:40		**Michael Nieves** Keele University, UK	Asymptotic analysis of vibrations in membranes with clusters of small inclusions
12:40–13:00	**Q&A Session**		

Tuesday, 27 of April

			***Chairperson**: Dr. Valentina Volpini*
11:40–12:00		**Gennady Mishuris** University of Aberystwyth, UK	General framework for evaluation of finite Energy Release Rate in Fracture Mechanics and beyond
12:00–12:20		**Michel Destrade** National University of Ireland, Galway, Ireland	Measuring stress levels in structures directly with ultrasonic waves
12:20–12:40		**Panos A. Gourgiotis** The University of Thessaly, Greece	Some results for surface waves in the framework of gradient theories for microstructured materials
12:40–13:00		**Alexey V. Pichugin** Brunel University of London, UK	Thermoelastic dispersion and dissipation of surface waves in an orthorhombic half-space
13:00–14:00	**Lunch break**		

			***Chairperson**: Prof. Giuseppe Saccomandi*
14:00–14:20		**Davide Bigoni** University of Trento, Italy	Metamaterials and shear bands
14:20–14:40		**Lorenzo Morini** Cardiff University, Wales UK	Effective properties and generalized Floquet-Bloch spectrum of multi-layered renewable energy devices
14:40–15:00		**Massimiliano Gei** University of Trieste, Italy	On generalised canonical axial waveguides
15:00–15:20		**Anar Rakhimzhanova** University of Cagliari, Italy	Solitary waves in a non linear chain
15:20–15:40	**Virtual coffee break**		
15:40–16:00		**Igor Sevostianov** New Mexico State University, US	Characterization of partially disordered microstructures of heterogeneous materials
16:00–16:20		**Giuseppe Saccomandi** University of Perugia, Italy	Waves in nonlinear elastodynamics
16:20–16:40		**Anton Trofimov** Polytechnique Montréal, Canada	A unified methodology for computation of compliance and stiffness contribution tensors of inhomogeneities of arbitrary 2D and 3D shapes–open access software
16:40–17:00		**Andrea Piccolroaz** University of Trento, Italy	Dynamics of prestressed elastic lattices: Homogenization, instabilities, and strain localization
17:00–17:20		**Ada Amendola** University of Salerno, Italy	Tensegrity modeling of the spider dragline silk fiber and biomimetic fibers
17:20–17:40	**Q&A Session**		

Wednesday, 28 of April

			***Chairperson**: Prof. Enrico Radi*
9:40–10:00		**Enrico Radi** University of Modena and Reggio Emilia, Italy	Effect of pore coalescence on the effective conductivity of an isotropic material
10:00–10:20		**Kou Du** GeoRessources, University of Lorraine, France	Effective elastic properties of heterogeneous material with concave pores and transversely isotropic matrix
10:20–10:40		**Lorenzo Bardella** University of Brescia, Italy	An electrochemo-poromechanical theory for actuation and sensing of ionic polymer metal composites
10:40–11:00		**Giovanni Bianchi** University of Modena and Reggio Emilia, Italy	Analytical estimates of the pull-in voltage in MEMS and NEMS
11:00–11:20		**Christian Hellmich** Vienna University of Technology, Austria	The structural mechanics of the Vienna tramway rails: advanced beam theory-assisted 1D/2D FE modelling
11:20–11:40	**Virtual coffee break**		

11:40–12:00		**Francesco Dal Corso** University of Trento, Italy	Elastica catastrophe machine
12:00–12:20		**Frédéric Lebon** Aix-Marseille University, France	On models of imperfect interfaces
12:20–12:40		**Jacopo Ciambella** University of Rome "La Sapienza", Italy	Fiber reorientation in active viscoelastic media
12:40–13:00		**Stefano Sirotti** Fuzhou University, China	Damage-based hysteresis Bouc-Wen model for reinforced concrete elements
13:00–13:20	**Q&A Session**		

Advanced Composite Materials for Structural Purposes

Monday, 26 of April

9:15–9:40	**Opening ceremony**		
			Chairperson: *Dr. Cesare Signorini*
14:00–14:20		**Antonio Nanni** University of Miami, US	Resilience Meets Sustainability in Coastal Construction
14:20–14:40		**Francesco Ascione** University of Salerno, Italy	Modeling SRG interfacial bond behaviour and strength
14:40–15:00		**Sara Fares** "Roma Tre" University, Italy	Tensile and pull-out behaviour of Steel Reinforced Grout connectors
15:00–15:20		**Aloysio Gomes de Souza Filho** Universidade Tecnológica Federal do Paraná, Brazil	Investigation of multi-scale fibre-reinforced cementitious mortar (FRCM), developed using microcrystalline cellulose (MCC) and sisal fibres
15:20–15:40		**Lampros Koutas** University of Thessaly, Greece	Advanced Composites with Alkali-Activated Matrices for Strengthening of Structures: Review Study
15:40–16:00		**Giosué Boscato** IUAV University of Venice, Italy	NFRCM-strengthened masonry, numerical and experimental analysis
16:00–16:20	**Q&A session**		

Tuesday, 27 of April

			Chairperson: *Dr. Tommaso D'Antino*
9:20–9:40		**Lino Antonio Credali**	The Influence of Second Order Transitions (T_g) in the Structural Applications of Composites in Building and Constructions
9:40–10:00		**Tommaso D'Antino** Polytechnic University of Milan, Italy	Determination of the matrix-fiber cohesive material law using FRCM-concrete joints
10:00–10:20		**Gabriele Grana Castagnetti** Kerakoll SpA	Influencing parameters for the failure mechanism of carbon-FRCM (Fibre Reinforced Cementitious Matrix systems)
10:20–10:40		**Cesare Signorini** University of Modena and Reggio Emilia, Italy	Functionalisation techniques for polypropylene fibres in Fibre Reinforced Concrete (FRC): experimental and analytical study of the pull-out mechanisms
10:40–11:00		**Jacopo Donnini** Polytecnic University of Marche, Italy	Mechanical characterization of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) under quasi-static and cyclic loads
11:00–11:20		**Valentina Volpini** University of Modena and Reggio Emilia, Italy	Mechanical properties of cement composites reinforced with fully-recycled plastic fibres

11:20–11:40		**Marco Savoia** University of Bologna, Italy	Retrofitting with FRCM composites: shear and flexural behaviour of strengthened masonry walls
11:40–12:00	**Q&A session**		

Durability and Corrosion

Monday, 26 of April

9:15–9:40	**Opening ceremony**

Tuesday, 27 of April

			Chairperson: *Prof. Andrea Balbo*
9:40–10:00		**María Criado** Eduardo Torroja Institute for Construction Sciences, Spain	Alkali-activated materials: Corrosion of steel reinforcement
10:00–10:20		**Federica Zanotto** University of Ferrara, Italy	Durability of reinforced concretes containing biochar and recycled polymers
10:20–10:40		**Nina Gartner** Slovenian National Building and Civil Engineering Institute (ZAG), Slovenia	Monitoring of steel corrosion in Alkali-Activated Mortars
10:40–11:00		**Giulia Masi** University of Bologna, Italy	Coatings based on light-weight alkali activated mortars as sustainable system for steel corrosion protection
11:00–11:20		**Chinh Van Nguyen** The University of Danang, Vietnam	Effect of locally sourced fly ash and GGBS on the compressive strength and chloride resistance of concrete
11:20–11:40	**Virtual coffee break**		
11:40–12:00		**Sergio Lorenzi** University of Bergamo, Italy	Corrosion behaviour of carbon steel in sulfoaluminate-based binders and blended binders
12:00–12:20		**Matteo Gastaldi** Polytechnic University of Milan, Italy	Preliminary assessment on durability of high performance fiber reinforced concrete with CSA cement
12:20–12:40		**Denny Coffetti** University of Bergamo, Italy	Durability of mortars manufactured with low-carbon binders exposed to calcium chloride-based de-icing salts
12:40–13:00		**Lorenzo Franceschini** University of Parma, Italy	The PARC_CL 2.1 crack model for reinforced concrete elements subjected to corrosion and long-term effects
13:00–14:00	**Lunch break**		
			Chairperson: *Prof. Michael Raupach*
14:00–14:20		**Ueli Angst** ETH Zurich, Switzerland	Ensuring both eco-efficiency and durability of reinforced concrete through scientifically understanding corrosion of steel in carbonated concrete
14:20–14:40		**Fabio Bolzoni** Polytechnic University of Milan, Italy	Evaluation of different preventative methods to prevent corrosion in concrete

14:40–15:00		**Bernhard Elsener** University of Cagliari, Italy	Stainless steels as sustainable solution for concrete reinforcement - from laboratory to practice
15:00–15:20		**David M Bastidas** The University of Akron, US	Corrosion behavior of steel reinforced geopolymer concrete: A pathway towards long-lasting and sustainable structures
15:20–15:40		**Tiziano Bellezze** Polytechnic University of Marche, Italy	Corrosion behaviour of galvanized steel in cement- and geopolymer-based concrete: a review on scientific work at the Polytechnic University of Marche
15:40–16:00		**Edoardo Proverbio** University of Messina, Italy	Increase sustainability of aged prestressed concrete structures by improving knowledge on degradation mechanisms and proper corrosion monitoring systems
16:00–16:20	**Q&A session**		

Life Cycle Assessment (LCA)

Monday, 26 of April

9:15–9:40	**Opening ceremony**		
			Chairperson: *Prof. Anna Maria Ferrari*
14:00–14:20		**Alessandra Bonoli** University of Bologna, Italy	Life Cycle Sustainability Assessment (LCSA) in building and construction as tool supporting the European green transition
14:20–14:40		**Federica Carollo** Polytechnic University of Milan, Italy	Economic evaluation of circular schemes for managing Construction and Demolition waste
14:40–15:00		**Valeria Annibaldi** University of L'Aquila, Italy	Life cycle cost analysis: a useful tool for reaching sustainable objectives in buildings sector
15:00–15:20		**Angela Daniela La Rosa** Norwegian University of Science and Technology, Norway	Benefits and opportunities of reusing waste rotor blades in cementitious materials from a life cycle perspective
15:20–15:40		**Cinzia Salzano** University Parthenope of Naples, Italy	Environmental impact assessment of geopolymeric hydraulic pipeline
15:40–16:00		**Elisa Rambaldi** Centro Ceramico Bologna, Italy	Porcelain stoneware tiles production minimizing the use of imported raw materials
16:00–16:20	**Virtual coffee break**		
16:20–16:40		**Marianna Rotilio** University of L'Aquila, Italy	Recycled materials for circular economy in construction sector. A review
16:40–17:00		**Simona Marinelli** University of Modena and Reggio Emilia, Italy	Circularity performances of the production of a cement mortar reinforced with recycled synthetic fibers
17:00–17:20		**Grazia Maria Cappucci** University of Modena and Reggio Emilia, Italy	Life cycle assessment of a wall made with agro-concrete blocks with wheat husk
17:20–17:40		**Micol Centorrino** University of Modena and Reggio Emilia, Italy	LCA of fiber-reinforced concrete industrial flooring with recycled plastics
17:40–18:00	**Q&A session**		

Tuesday, 27 of April

			Chairperson: *Prof. Bianca Rimini*
14:00–14:20		**Patrizia Ghisellini** University Parthenope of Naples, Italy	The role of product certification in the transition towards the circular economy for construction sector
14:20–14:40		**Marta Rossi** Polytechnic University of Marche, Italy	An environmental sustainability database to support the identification of green construction products
14:40–15:00		**Francesco Carnelli** ICMQ S.p.A., Italy	The EPD as a competitive and transparency tool on the environmental impacts of products and services
15:00–15:20		**Fabrizio Passarini** University of Bologna, Italy	Sustainability in building and construction: LCA of 21 mural paints
15:20–15:40		**Antonello Monsù Scolaro, Sara Corridori** University of Sassari, Italy	Limits and potential innovation to a more circular design approach in public procurement refurbishment works
15:40–16:00		**Francesco Baldoni** Esalex srl, Italy	The environmental sustainability of CBI Europe products through the EPD certification with the aim of implementing circular economy actions
16:00–16:20	**Q&A session**		

List of Abstracts

IT Invited Talk CT Contributed Talk

Innovative Building Materials

Durability, service life prediction and life cycle assessment of self-healing concrete

*N. De Belie**

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By incorporating self-healing agents in concrete, cracks can be healed autonomously upon occurrence. As a result, a significant extension in service life can be achieved and environmental burdens related to maintenance and repair can be avoided to a large extent. For self-healing concrete with macro-encapsulated polyurethane, chloride diffusion results showed that this mechanism was efficient to reduce the chloride penetration. Electrochemical measurements on reinforced concrete specimens subjected to cyclic exposure with a NaCl solution proved that autonomous crack healing could significantly reduce the corrosion propagation [1]. While self-healing by encapsulated polyurethane is complete after one day, bacteria-based products take several weeks to heal a 300 µm crack. In this case, bacterial granules containing denitrifying cultures have the benefit to release nitrite as an intermediate metabolic product which can protect the reinforcement during the crack healing process [2]. A probabilistic prediction model could then be applied to estimate the time to chloride-induced steel depassivation for self-healing and ordinary cracked concrete. A subsequent life cycle assessment showed a substantial environmental benefit which can mainly be attributed to the service life extension possible with self-healing concrete which easily overcomes environmental burdens inherent to the self-healing additions [1].

References

[1] Van Belleghem, B., Van den Heede, P., Van Tittelboom, K., De Belie, N. (2017). Quantification of the service life extension and environmental benefit of chloride exposed self-healing concrete. Materials, 10 (5), 22p.
[2] Erşan, Y.C., Verbruggen, H., De Graeve, I., Verstraete, W., De Belie, N., Boon, N. (2016). Nitrate reducing CaCO3 precipitating bacteria survive in mortar and inhibit steel corrosion. Cement and concrete research, 83, 19-30.

Development of cement-less construction materials utilizing waste alumino-silicate precursors by hydrothermal method and alkali activation

S. Chakraborty*, ***M. Guadagnini, K. Pilakoutas***

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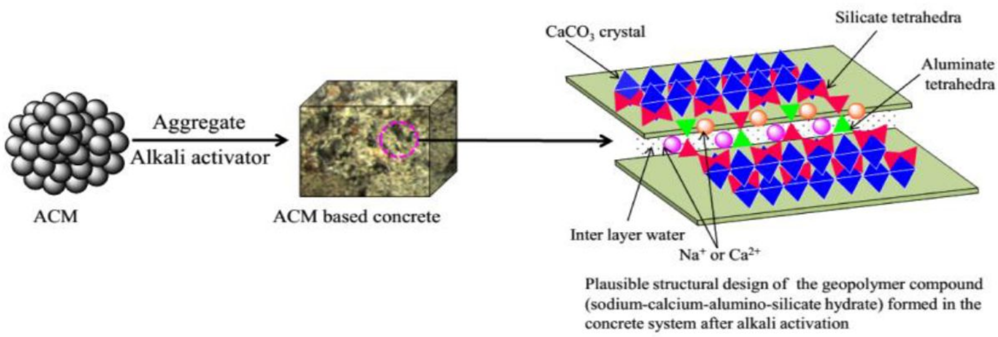
Keeping view of climate emergence and zero-emission strategy, the focus of construction and building materials research has been turned into the development of cement-less materials utilizing recycled materials from several sectors. This study investigated the impact of several methods to produce cement-less construction materials, such as by using 1) silica fume infused with hydrated alumina 2) aqueous-based carbonated lime infused with silica fume and hydrated alumina and 3) use of solid industrial wastes (sewage sludge ash), followed by alkali activation. The cementitious materials produced by the hydrothermal method and using SSA showed similar properties to that of existing cement and achieved adequate mechanical strength $\geq$25 MPa after alkali activation. The mechanical and microstructural properties of these cementitious materials are primarily controlled by the formation of the interpenetrating net structure of geopolymer compounds (Figure) through the reaction of alumino-silicate precursors with alkalis [1, 2]. Based on the cost and environmental impact analysis, it is assessed that the newly developed cementitious materials possessed comparable cost to that of the existing cement and minimised the environmental concerns associated with cement production.



Plausible mechanism for the binding action of cement lees materials composites

References

[1] Chakraborty, S., Jo, B.W., Jo, J.H., Baloch, Z. (2017). Effectiveness of sewage sludge ash combined with waste pozzolanic minerals in developing sustainable construction material: an alternative approach for waste management. J. Clean. Prod. 153, 253-263.

[2] Jo, B.W., Chakraborty, S., Jo, J.H. (2017). Effectiveness of a hydrothermally produced alternative cementitious material on the physical and mechanical performance of concrete. J. Clean. Prod. 142, 3269-3280.

Reuse of carbonatic and alumino-silicate sludges as alkali-activated materials: innovation and sustainability

***B. Coppola**, J. Tulliani, L. Montanaro, P. Palmero**

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Nowadays, the reuse of waste materials for the production of more sustainable binders, compared to OPC, is a trending topic among researchers. Within this context, alkali-activated materials are receiving increasing attention thanks to the possibility to use amorphous or semi-crystalline waste materials as raw powders to be activated with an alkaline solution (generally made of sodium silicate and sodium hydroxide). The novelty of our researches lies in the exploitation of highly crystalline powders, deriving from mining operations, in the production of alkali-activated materials. In particular, two different powders were used: an alumino silicate mud [1], composed of quartz, feldspars, biotite and dolomite; and a carbonatic one [2], composed of calcite and small amounts of dolomite. Both powders were alkali-activated using a solution of NaOH and Na_2SiO_3. Very good mechanical results were obtained in terms of compressive strength (about 30 MPa for the aluminosilicate sludge and up to 45 MPa for the carbonatic one), showing their potential as innovative building products. Indeed, despite their low solubility within the alkaline solution, several parameters (i.e. curing conditions, particle fineness and activating solution molarity) were determined as effective in mechanical properties development as also compared with other literature results [3].

References

[1] Palmero, P., Formia, A., Tulliani, J.M., Antonaci, P. (2017). Valorisation of alumino-silicate stone muds: From wastes to source materials for innovative alkali-activated materials. Cem. Concr. Compos. 83, 251-262.
[2] Coppola, B., Palmero, P., Montanaro, L., Tulliani, J.M. (2020). Alkali-activation of marble sludge: Influence of curing conditions and waste glass addition. J. Eur. Ceram. Soc. 40 3776-3787.
[3] Coppola, B., Tulliani, J.M., Antonaci, P., Palmero, P. (2020). Role of Natural Stone Wastes and Minerals in the Alkali Activation Process: A Review. Materials 13, 2284.

Beneficial Utilization of Indian Biomass Ash in Eco-friendly Bricks

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Agricultural residues offer one of the most promising sectors of growth in renewable energy based on biomass. Current availability of agricultural residues in India is estimated around 500 million tons per year. Many small and medium scale industries in India rely on these agricultural residues to meet their energy requirement. In the process of harnessing energy, there is significant generation of biomass ash which is landfilled due to its high carbon content. This presentation will cover the beneficial utilization of an Indian biomass ash in structural masonry product. Alkali activation of amorphous biomass ash enabled its effective utilization in eco-friendly bricks. The results from lab and field study (Figure) will be discussed with respect to mechanical and durability characteristics.

Prototype wall made of biomass ash bricks

Stabilization of road subsurface layers with organosilane and lignosulfonate

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The Norwegian Public Roads Administration (NPRA) is responsible for the "Ferry-free coastal highway route E39" project, which leads to the construction of an extended tunnel network along the southwestern Norwegian coast; consequently, these operations create a considerable quantity of blasted rocks. These aggregates can be used in the unbound courses of the roads close to the excavation operations, thus providing sustainable road pavement construction materials. Due to the variety of the rocks encountered along the Norwegian coast, some aggregates do not meet the requirements established by the design guidelines. Two types of innovative additives, based on organosilane and lignosulfonate, are employed to improve the mechanical performance of the “weak” rocks. The behaviour of different types of rocks are assessed in the laboratory using Repeated Load Triaxial Tests. The two main mechanical properties, namely resilient modulus and resistance against permanent deformation, are significantly enhanced by the stabilization agents.

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Engineered Cementitious Composites for the conservation of 20th century concrete architectural heritage

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Architectural heritage nowadays includes non-vernacular concrete structures constructed in the 20th century. These buildings are usually under-detailed, since the actual behavior of reinforced concrete at the time of their construction was not clearly understood. Additionally, the lack of Codes incorporating seismic resistance design, especially in seismic prone areas, when early concrete buildings were constructed, has led to their inefficient design and consequently to severe damages in many of them during past seismic events. This paper explores the use of novel Engineered (Fiber Reinforced) Cementitious Composites (ECCs), with strain hardening abilities in tension, for the repair and strengthening of old sub-standard reinforced concrete columns, focusing on their confining and shear strengthening potentials. The experimental results show that, when replacing the reinforcement cover with fiber reinforced ECCs, the fibers bridge tensile cracks, limiting their opening and increasing their resistance against volumetric expansion, ultimately leading to increased amounts of energy dissipation.

Feasibility of using ashes glass fibre reinforced polymer materials as a supplementary cementitious material in concrete

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This work explores the feasibility of using ashes glass fibre reinforced polymer (GFRP) powder as an alternative source of supplementary cementitious material (SCM). GFRP from two sources - reinforcement bars and spent wind blades are evaluated for this purpose. The materials were cut and heated in a furnace to 600 °C and 1000 °C and ground using a mortar and pestle to obtain fine powders. Physical and chemical characterization of the powders was performed. The “modified R3 test” was used to obtain direct measures of powder reactivity. Cementitious pastes were prepared at 30% SCM replacement level to evaluate potential negative effects of the powders on cement hydration. Isothermal calorimetry (up to 7 days) and thermogravimetric analysis (at 7 and 91 days) were measured on these pastes. Preliminary results are promising and GFRP powders did not show significant negative effects on the cement hydration suggesting a potential usage for demolition waste containing GFRP.

Mechanical properties of high strength concrete incorporating Calcined Ebonyi Shale (CES) at elevated temperature

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The increasing rate of fire disaster especially in the developing countries has renewed the demand for utilization of more economically sustainable materials for built environment. In this paper, the effect of calcined Ebonyi shale (CES) incorporated as partial replacement (15%) of cement on the thermo-mechanical properties of high strength concrete were investigated. The preparation of the CES was carried out by calcining the Ebonyi shale at a temperature of 900°C for duration of 2 hours. Both raw and calcined Ebonyi shale (CES) were analyzed using scanning electron microscope (SEM) and x-ray fluorescence (XRF). After curing time of 28 days, several samples were exposed to varying temperatures. A comparison of the results showed that incorporation of CES enhanced high strength properties of concrete at elevated temperature. Consequently, economical and eco-friendly mixes that reduces CO_2 emissions of the overall cement production of clinker were achieved.

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Eco-sustainable approach for cementitious mix construction materials: a preliminary comparison between geopolymer and cement-based matrices incorporating Tyre recycled rubber

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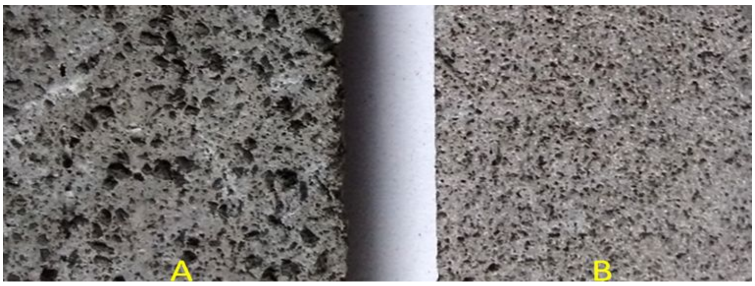
Sustainability concept in the cement and concrete industry involves various environmental and socio-economic aspects such as, low energy consumption, CO_2 emission reduction, natural resources preservation, and recyclability [1]. "Green" concrete technology, has the potential for eco-friendly development, where industrial waste or low-carbon binders can reduce consumption of Portland cement and natural resource, leading to less environment pollutions [2]. This work presents an experimental study for the comparison between geopolymer matrix and a traditional cementitious matrix (i.e. Portland cement) filled with rubber particles, deriving from end-of-life tires, as replacement of raw mineral aggregates. Rubberized geopolymers can be attractive solutions to reduce dangerous emissions and promote the clean disposal of waste tires [3]. Rubber-modification could confer to the material specific performances in terms of lightweight, durability, deformability, and thermo-acoustic insulation properties [4]. To explore the potential of rubber-geopolymer compounds for the construction sector, an experimental comparative study with rubber-Portland mortars (Figure) was performed. Preliminary investigations were conducted on rubber-cement samples obtained by varying the binder, the sand-rubber replacement ratio, and the rubber particle size.



Rubber-Portland samples incorporating ground tire rubber of different size: a) 2-3 mm rubber granules; b) 0-1 mm rubber powder

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Microstructural and mechanical characterization of different hempcrete mix design for prefabricated blocks production

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Nature-based solutions are sustainable building materials produced recovering and enhancing agricultural biomasses which are by-products or waste of crops as, for example, rice, flax or hemp. Specifically, this research investigates the properties of hempcrete which is produced mixing lime, which acts as binder, and hemp shives, as vegetal aggregate. Hempcrete is characterized by breathability and excellent insulating properties, moreover it is a sustainable material due to the introduction of vegetal material and due to the carbonation of lime which gives further carbon dioxide sequestration. The latter determines the development of the strength of the material and it has been investigated through microstructural characterization of the material performing different analyses, e.g. X-ray diffractometry (XRD), scanning electron microscopy (SEM) and thermogravimetry (TG-DTG), and mechanical characterization e.g. uniaxial compression and triaxial tests. Hence, the influence of the microstructure on the mechanical properties has been studied analysing different hempcrete mix design, developed for prefabricated blocks production. Actually, these building components are used as non-loadbearing blocks, they are introduced in building envelopes or in indoor partition walls as insulating elements.

Use of recycled textile fibres for sustainable and thermal insulating Fibre Reinforced Cement

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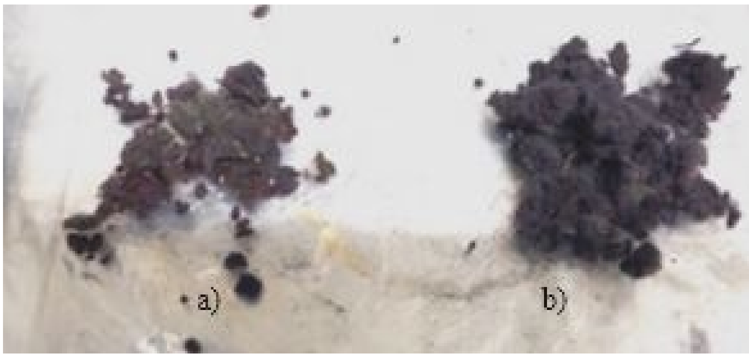
Recycling and sustainability are hot topics for Civil applications. Since 37.4% of Italian non-hazardous waste comes from the textile field [1], many studies focused on their reuse. This work investigates the recovery of waste textile microfibres, deriving from finishing of fabrics, into sustainable and low conductive Fibre-Reinforced Cement (FRC). The microfibres are characterized through FTIR technique and Scanning Electron Microscopy; moreover, water content and water absorption are evaluated for mix design. Unsaturated, saturated and NaOH treated microfibres are considered. Following a preliminary workability evaluation, they are introduced in Portland cement in 1%, 2%, 3%, 4% by weight. At increasing fibre percentage, the three-point bending test displays an enhance from 1.5 to 4 times the maximum bending load of non-reinforced Portland and a marked increase in toughness is observed. The linear shrinkage is reduced from 20% to 80%, and NaOH microfibres result in more efficiency. Stereomicroscopy confirmed a high fibre dispersion into the cement matrix. A reduction in thermal conductivity is observed when increasing percentage of the untreated fibres, and for 4% fibre percentage the Portland insulation power is doubled. The feasibility of using recycled textile microfibre into FRC is demonstrated and results in improving sustainability, mechanical properties and power insulating.



Recycled textile microfibres a) untreated; b) treated with NaOH

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Use of modified magnesium oxysulfate (MOS) cement for the production of lightweight hemp concretes

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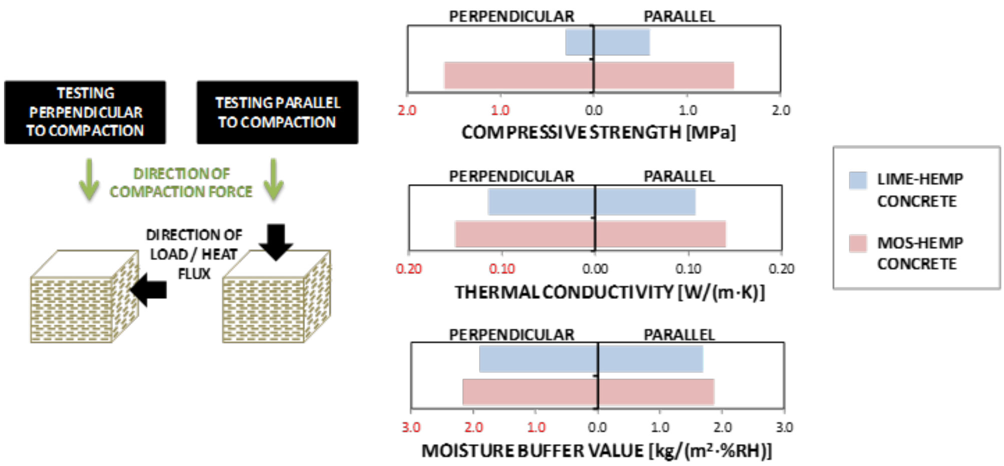
The use of lightweight building materials based on local vegetable resources and carbon-neutral binders is not only an important step towards reducing the environmental impact of the construction sector but also highly interesting for recycling of agricultural residue, whose management is an important issue. Most attention has been paid to lime-based agro-concretes, but low binder-aggregate compatibility, as well as slow strength gain, are drawbacks. The use of magnesia-based binders has the potential to mitigate these problems.

This work presents a comparative study between lightweight hemp concretes manufactured using modified magnesium oxysulfate (MOS) or lime as binder. A traditional casting method was used, i.e. uniaxial compaction in molds. Compressive strength, thermal conductivity and moisture buffer capacity of the two types of concretes were measured in the directions parallel and perpendicular to the applied compaction force. The results show a strong direction dependence of the mechanical performances, being higher parallel to the compaction force, whereas no significant differences were observed for thermal conductivity and moisture buffer values in the two orthogonal directions.

The feasibility to develop lightweight magnesia-hemp concretes technologically competitive with lime-based ones will be evidenced. It will be shown that the trade-off between mechanical strength and thermal insulation properties is improved in MOS-hemp concrete with respect to traditional lime-hemp concrete, possibly due to a mechanically stronger matrix.



Graphical abstract

Parametric analysis of binder-powder interaction in binder jet 3D printing of cement-based materials

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The present work addresses the powder bed binder jet printing as an additive manufacturing process for cement-based materials in the constructions industry. Features are created through the interaction among the droplets of the liquid binding agent and the layered powder bed. The printhead movement over the powder bed at a given feed rate forms a single-line from the coalesce of successive droplets and adjacent lines are consolidated to create the designed cross-section. Therefore, a comprehensive understanding of the formation of a single line is essential for ensuring the quality of printed parts. Statistical models have been developed to study the effect of printing parameters (aggregate particle size, feed rate, velocity of powder spread, pressure of the fluid, and nozzle diameter) on the resultant dimension of a single printed line, using a factorial design of experiment. Droplets impact on powder beds were studied experimentally to explain the different resulting granule formation of a single line. Powder bed density measured as a function of aggregate particle size and powder spreading speed, during the printing process. The determined Ohnesorge number of the developed binder reflects the behavior of the liquid jet exiting from the nozzle. The results demonstrate a fundamental understanding of the binder–powder interaction for cementitious materials; and it can be leveraged to determine the minimum printable feature with required dimensional accuracy, based on the chosen process parameters.

Progress of fibre coatings in fabric-reinforced lime-based composites: materials selection and property optimisation

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Lime-based fabric-reinforced composite materials (FRCM) are increasingly popular in the restoration of historical masonry. However, FRCM systems often fail to take full advantage of the theoretical tensile strength of high-performance fabrics. In order to improve current-day FRCMs, proper fibre coatings have proven to foster the chemical affinity and hence the bonding strength at the matrix-to-fibre interphase, whereas organic coatings are known to bind the yarn filaments together, avoiding the so-called telescopic failure. In this contribution, alkali-resistant (AR) glass fibres are coated with epoxy resin using either m-phenylenediamine (aromatic compound) or diethylenetriamine (aliphatic compound) as the hardener. The choice of the curing agent deeply affects the behaviour of the obtained FRCM systems, changing both their mechanical response under uni-axial tensile loads [1] and their resistance to high temperature [2]. Notably, the behaviour at high temperature of organic-matrix reinforcing systems is a very delicate point that needs further scrutiny by the scientific community. Finally, it is shown that tuning the viscosity of the coating may have major advantages [3,4], increasing the mechanical performance of the whole FRCM and boosting the economic viability.

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Materials characterization and thermal analysis of PCM-silica mixtures for back-filling of ground heat exchangers

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In this study two paraffin-based phase change materials (PCMs) were mixed separately with common silica (30% v/v) and characterized to evaluate their potential for latent heat thermal energy storage (LHTES). Each mixture underwent 16 thermal cycles and physical, structural, and thermal characterization were performed through a multidisciplinary approach. Structural properties were investigated through environmental scanning electron microscopy coupled with X-Ray spectrometry (ESEM-EDS) and Fourier transform infrared spectroscopy (FTIR). Physical properties were measured by grain size laser diffraction, pore analysis and optical microscopy. Finally, thermal properties were investigated through differential scanning calorimetry (DSC) and laboratory-scale experimental simulation of a melting-freezing thermal bath. Results shown that silica addition to PCMs lead to a reduction of the melting and freezing time of the mixtures, that can be enhanced by employing n-octadecane as PCM. A reduction in grain and pore size was detected and attributed to mechanical friction among particles, while chemical composition remained constant through cycles. Despite changes in mixtures' physical properties, thermal performances remained constant through cycles, demonstrating the feasibility of silica - PCMs mixtures for distributed LHTES coupled with ground heat exchangers for shallow geothermal applications.

Cementitious matrixes for nuclear waste management: effect of admixtures on fresh state properties

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Ion exchange resins are widely used to purify liquid effluents from nuclear power plants. The spent resins are managed by their immobilization in Portland cement matrixes, representing the largest contribution in volume and activity to the inventory of intermediate- and low-level radioactive waste in Spain. This study proposes a more sustainable and safe immobilization solution replacing 100% of Portland clinker by alkali-activated solid aluminosilicate powders. With this aim, fresh state properties of these activated matrixes have been assessed previously to the incorporation of ion exchange resins to know their fluidity and their workability. In order to improve the workability of the samples and control the setting times, superplasticizer admixtures with different compositions have been considered. The alkali-activated matrixes have been designed with a mixture of 70% blast furnace slag and 30% fly ash activated with two different alkaline solutions: sodium silicate and sodium carbonate. Moreover, a comparative study of the fresh state properties of the cementitious matrix based on Portland cement that is currently used in Spain for the disposal of resins has been carried out, using minislump, setting time, and calorimetry tests. The results show the workability of the different cement matrixes is influenced by the nature and the dose of admixture. Smaller amounts of the polycarboxylate admixtures are required to enhance the fluidity of the system based on Portland cement. These admixtures reach, from the point of view of workability, the best improvement in the properties of the cementitious materials, in which inter-particle electrostatic repulsion prevails over the complex formation.

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Mechanics of Solids and Structures

Antiplane surface waves in the framework of strongly anisotropic surface elasticity

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Within the recently proposed in [1] model of surface elasticity the propagation of anti-plane surface waves is discussed. The model was motivated by the microstructure of hyperbolic metasurfaces. For the proposed model, the surface strain energy coincides with 2D strain gradient continuum with reduced dependence on second derivatives of displacements. From the physical point of view the model describes finite deformations of an elastic solid with an elastic fiber-reinforced membrane attached on its boundary. The reinforcement consists of long flexible fibers with essential bending stiffness. The equations of motion are derived using the least action variational principle. The dispersion relations for surface anti-plane waves are analysed. We show that the bending stiffness changes essentially the dispersion relation and conditions of anti-plane surface wave propagation. Some similar problems for isotropic media were considered in [2,3].

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Snap-through of a bi-stable truss in finite elasticity

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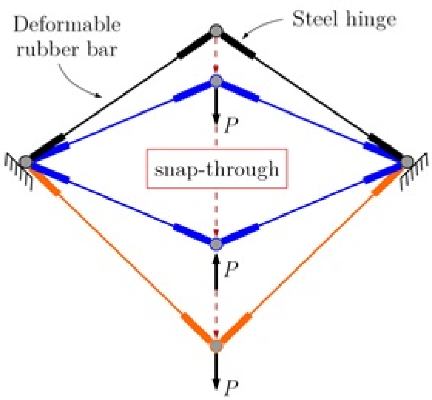
Equilibrium and stability of truss structures are often analyzed considering only geometric nonlinearities. However, the assumption of linear elastic material is not consistent with the response of solids subjected to large deformations. Therefore, an accurate model should take into account both geometric and constitutive nonlinearities. In this contribution, we consider a von Mises truss [1] composed of rubber bars and subjected to a vertical load (Figure). The highly deformable material allows to observe large displacements and deformations. We present a theoretical model that is entirely developed in three-dimensional finite elasticity [2]. The nonlinear constitutive behavior of the rubber is simulated using a Mooney-Rivlin law, whose parameters are identified by fitting experimental data from uniaxial tests. Experiments are carried out and snap-through instability [3] is observed. It is shown that the experimental results are in good agreement with the theoretical simulations.



The von Mises (or two-bar) truss subjected to a vertical load

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Equivalent particle in conduction homogenization and application to a composite spheroid

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The notion of morphologically representative pattern (MRP) has been introduced to extend the scope of homogenization schemes and bounds beyond the case of uniform ellipsoids [1]. In the framework of estimation schemes for the conductivity property, the present work aims at revisiting the issue of the replacement of a heterogeneous MRP by an equivalent homogeneous one in the auxiliary Eshelby problem. First it is shown that if the outer boundary of the MRP is ellipsoidal then Eshelby-type expressions of the concentration tensors still hold provided that an equivalent conduction is correctly assigned to the MRP. This equivalent conduction is shown to satisfy the major symmetry but is not necessarily intrinsic to the particle insofar as it may depend on the surrounding reference medium as illustrated by peculiar composite spheres [2]. To increase the set of available patterns, the problem of an n-layer confocal spheroid with imperfect interfaces embedded in an infinite matrix is then resolved. In the case of perfect interfaces, the equivalent conduction is independent from the surrounding medium and provided by a recursive algorithm. The case of a homogeneous spheroid surrounded by an imperfect interface is finally developed together with simplified approximated models of equivalent particle [3].

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Temperature-induced textures on nematic shells

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Based on the Landau-de Gennes theory for liquid crystal shells [1], we study the isotropic-nematic phase transition induced by cooling on a spherical shell [2]. It turns out that the transition temperature is affected by curvature. The nematic alignment at the critical temperature, calculated analytically, is compatible with experimental observations [3]. The textures around the defects, not imposed a priori, are in agreement with the prediction of the Poincaré-Hopf index theorem [4].

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Post-buckling of an elastic half-space coated by double layers

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We investigate the buckling and post-buckling properties of a hyperelastic half-space coated by two hyperelastic layers when the composite structure is subjected to a uniaxial compression. In the case of a half-space coated with a *single layer*, it is known that when the shear modulus μf of the layer is larger than the shear modulus μs of the half-space, a linear analysis predicts the existence of a critical stretch and wave number, whereas a weakly nonlinear analysis predicts the existence of a threshold value of the modulus ratio μs/μf $\sim$ 0.57 below which the buckling is super-critical and above which the buckling is sub-critical [1–3]. It is shown in this paper that when another layer is added, a larger variety of behaviour can be observed. For instance, buckling can occur at a preferred wavenumber super-critically even if both layers are softer than the half-space although the top layer would need to be harder than the bottom layer. When the shear modulus of the bottom layer lies in a certain interval, the super-critical to sub-critical transition can happen a number of times as the shear modulus of the top layer is increased gradually. Thus, an extra layer imparts more flexibility in producing wrinkling patterns with desired properties, and our weakly nonlinear analysis provides a road map on the parameter regimes where this can be achieved.

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Reduced dimensional models for microstructured plates

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A model describing elongation and extension of plates accounting for size-dependence is derived by asymptotic reduction. Size dependence is described by the couple stress theory of elasticity with micro-inertia. The role of the microstructure is especially important when expressing inertia terms [1–3]. Also, the asymptotic model is the same whether the reduced couple-stress or the strain-gradient 3D theory is adopted. Higher order models are also asymptotically derived which incorporate the role of thickness-stretch and thickness-shear vibrations.

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Asymptotic methods in nonlocal elasticity

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The equations in nonlocal elasticity are considered, taking into account the presence of a small parameter originating from a typical microscale. The emphasis is on the boundary layers localized near surfaces and interfaces.

As an example, anti-plane shear motion of an elastic half-space is studied. It is shown that the first order correction to the classical elasticity comes namely from taking into account the aforementioned boundary layers. This phenomenon manifests itself as effective boundary conditions on the surface. The equivalence of the differential and integral formulations in nonlocal elasticity is demonstrated for several types of nonlocal kernels. The generalizations to 3D elasticity earlier tackled in the papers [1, 2] are also revisited.

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Asymptotic analysis of vibrations in membranes with clusters of small inclusions

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We discuss formal asymptotic algorithms that can be employed to model vibrations supported by elastic membranes containing clusters of inertial inclusions distributed along contours of pre-defined smooth shapes. Attention is given to the approximation of (i) wave scattering produced by clusters of inclusions in infinite membranes, and (ii) the asymptotic analysis of low-frequency eigenvalues and eigenmodes for finite membranes with clusters of small inclusions. Effective conditions characterising the inertial interfaces in the low-frequency regime are discussed. Numerical illustrations are provided that demonstrate the effectiveness of the asymptotic approaches.

General framework for evaluation of finite Energy Release Rate in Linear Elastic Fracture Mechanics and beyond

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One of the LEFM assumptions is that the crack faces are traction-free or, at most, loaded by bounded tractions. Additionally to the Rice formula, Irwin's crack closure integral is widely used for the computation of ERR. However, there are practical situations where the load acting on the crack boundaries is singular. This is the case, for instance, in hydraulic fracturing, where the fluid inside the crack exerts singular tangential tractions at its front. Another example of unbounded tractions is the case of a rigid inclusion (anticrack) embedded into an elastic body. In such situations, the classical Irwin's crack closure integral fails to provide the correct ERR. We present the results in the most general form, where six Stress Intensity Factors are present: three of them are classical SIFs corresponding to the modes I-II-III and computed under the assumption of homogeneous boundary conditions at the defect surfaces, while the other three SIFs are associated with singular admissible tractions (those that lead to a finite ERR value). The general theory (with the corrected Irwin's crack closure integral representation) allow to analyse, among others, hydraulic fracturing, soft materials containing stiff inclusions, rigid inclusions, shear bands and cracks characterized by the Gurtin-Murdoch surface stress elasticity. It also resolves an ambiguity in using the same SIF's terminology in the cases of open cracks and rigid inclusions.

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Measuring stress levels in structures directly with ultrasonic waves

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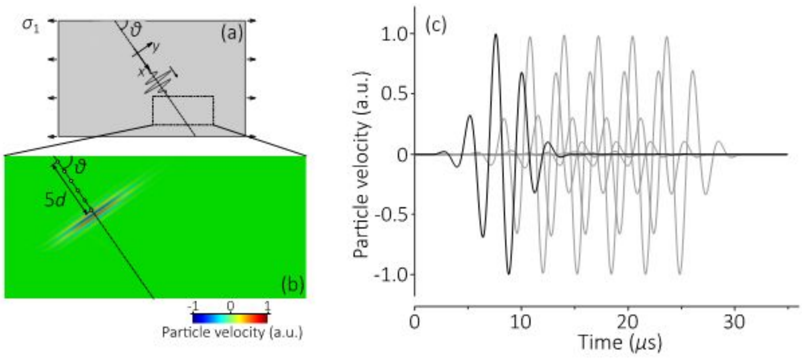
Measuring stress levels in loaded structures is crucial to assess and monitor their health, and to predict the length of their remaining structural life. However, measuring stress non-destructively has proved quite challenging. Many ultrasonic methods are able to accurately predict in-plane stresses inside a controlled laboratory environment, but struggle to be robust outside, in a real-world setting. That is because they rely either on knowing beforehand the material constants (which are difficult to acquire) or they require significant calibration for each specimen. We present an ultrasonic method to evaluate the in-plane stress *in situ* directly, without knowing any material constants *a priori*. The method is simple in principle, as it only requires measuring the speed of two shear waves travelling at an angle to the direction of stress. It is based on a formula which is exact for incompressible solids, such as soft gels or tissues, and is approximately true for compressible "hard" solids, such as steel and other metals. We validate the formula with Finite Element simulations, showing that it displays excellent accuracy, with a small error of the order of 1%.



Finite Element simulation of the quasi-shear wave propagation. (a) Schematic of the FE model. The stress is determined by σ_1 and the out-of-plane strain. The wave is induced by a body force defined in the local coordinate systems. (b) Snapshot of the shear wave propagation. Six points at equal distance d are used to measure the wave speed. (c) Time profiles of the particle velocities at these points shown in (b)

Some results for surface waves in the framework of gradient theories for microstructures materials

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It is well known that the classical theory of elasticity predicts Rayleigh-wave motions, which are not dispersive at any frequency [1]. Of course, at high frequencies, this is a result that contradicts experimental data and does not agree with the results of atomic-lattice theories. Moreover, the classical theory fails completely to predict the existence of torsional and antiplane SH (horizontally polarized) surface waves in a homogeneous (isotropic or anisotropic) half-space with a free surface [1]. In such cases, dispersion phenomena can be explained on the basis of generalized continuum theories. In particular, gradient theories enrich the classical continuum with an augmented Euler-Cauchy stress principle and additional material lengths (characteristic lengths), in order to describe the scale effects resulting from the material microstructure. In this way, gradient theories extend the range of applicability of the 'continuum' concept in an effort to bridge the gap between classical continuum theories and atomic-lattice theories.

The present work studies the propagation and dispersion of surface waves in the context of the complete Toupin-Mindlin theory of strain-gradient elasticity that includes micro-inertial effects [2]. Our purpose here is to examine the possible deviations from the predictions of the classical theory of elasticity as well as other generalized continuum theories such as the couple-stress theory and the simplified strain-gradient theory which are frequently utilized in the last decade for the solution of wave propagation problems [3-6]. It is shown that unlike the simplified gradient elasticity theory, the complete Toupin-Mindlin gradient elasticity (with five microstructural parameters) is capable of predicting torsional and SH surface waves in a purely isotropic and homogeneous material. In fact, it is shown that torsional and SH surface waves are dispersive and can propagate at any frequency (i.e. no cut-off frequencies appear). Moreover, it is shown that Rayleigh waves become dispersive with dispersion characteristics that depend strongly upon the microstructural length scales of the Toupin-Mindlin theory. The dispersion curves obtained in both cases are of prime importance for the conception of tailored meta-materials since they allow linking the geometric properties of the unit cell with the dynamic properties of the lattice.

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Thermoelastic dispersion and dissipation of surface waves in an orthorhombic half-space

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Thermoelastic coupling produces dispersion and dissipation of elastic waves that is often so weak that it tends to be ignored in engineering practice. However, the effect grows stronger for shorter wavelengths, to the extent that thermoelastic effects dominate dissipation in modern SAW devices. Direct modelling of such effects is possible, but results in unwieldly algebra, especially for anisotropic media. We explore an alternative, asymptotic approach, which exploits the presence of a natural small parameter expressing departure from the purely adiabatic response. The resulting problem possesses a boundary layer, which can be used to formulate effective boundary conditions for the equations of orthorhombic elasticity with adiabatic material constants. We demonstrate that this formulation is sufficient to reproduce thermoelastic dispersion and dissipation of surface waves travelling along the isothermal boundary. We also discuss the case of the perfectly insulated boundary.

Metamaterials and Shear Bands

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Imagine a material in which shear bands and other instabilities may occur well inside the elastic range and far from failure. A material that can be designed to produce shear bands with a desired inclination, or in which shear bands are the first instability occurring at increasing stress, or in which the anisotropy (not imperfections) allows the formation of only one shear band. Imagine that this material would be characterized by rigorously determined elastic constitutive laws (thus avoiding complications such as the double branch of the incremental constitutive laws of plasticity) and would be, at least in principle, a material realizable (for instance via 3D printing technology) and testable in laboratory conditions. This material would be ideal not only to theoretically analyze instabilities, but also to practically realize the porous architected materials which are preconized to yield extreme mechanical properties such as foldability, channelled response, and surface effects [1–2]. Works of Ponte Castañeda and Triantafyllidis [3-7] addressing homogenization of composites are generalized to rigorously show that prestressed elastic lattices can be made equivalent to elastic materials and metamaterials capable of extreme mechanical performances, to be used for advanced applications.

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Effective properties and generalized Floquet-Bloch spectrum of periodic thermodiffusive laminates

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Laminate materials subject to thermodiffusive phenomena are of interest for many important engineering and technological applications. For example, several energy devices such as solide oxide fuel cells and lithium ions batteries are caracterized by multi-layered configuration possessing many phases of different composite materials. Estimating the overall properties of these materials is crucial in order to optimize their performances. By means of a multi-field asymptotic homogenization method, exact expressions for the elastic and thermo-diffusive tensors and for the overall inertial terms of the first order equivalent Cauchy continuum are derived. Considering the cases of two-phase and three-phase thermo-diffusive layered materials, the analytical solution performed by the first order homogenization approach is compared with the numerical results obtained by the heterogeneous model assuming periodic body forces, heat and mass sources.

The generalized Floquet-Bloch spectrum of a plane two-phase thermo-diffusive layered material is also studied. Quasi-periodicity conditions are imposed on the boundary of the periodic unit cell, and the dispersion curves for the heterogeneous material are obtained. The acoustic branches obtained by the solution of the heterogeneous problem through rigorous Floquet-Bloch analysis are compared with those derived by applying the proposed first order homogenized model, and a fair good agreement is achieved.

On generalised canonical axial waveguides

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The dynamic behaviour of the class of periodic phononic waveguides whose unit cells are generated through a quasicrystalline sequence can be interpreted geometrically in terms of a trace map that embodies the recursive rule obeyed by traces of the transmission matrices. It has been recently shown [1,2] that for a *canonical* waveguide, the orbits predicted by the trace map at specific frequencies, called *canonical frequencies*, are periodic onto a surface in a 3D space associated with the invariant of the problem. In this talk, we extend the concept of canonical phononic axial waveguide to generalised Fibonacci sequences and show specific behaviours of the canonical configurations for the so-called *silver*-mean sequence. We explore various kind of periodic orbits for the trace map associated with different self-similar properties of the stop/pass band layout. The obtained results represent both a key to a better understanding of the dynamic properties of classical two-phase composite waveguides and an important advancement towards the realisation of composite quasicrystalline metamaterials.

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Solitary waves in a non linear chain

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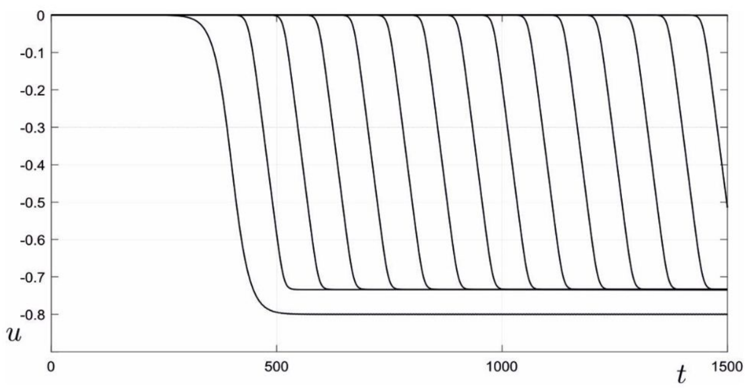
Wave propagation in a non-linear discrete system is analysed. The mechanical system is a one-dimensional lattice composed of masses m and non-linear chains. The chains are characterised by a shifted sigmoidal force-displacement behaviour, in which only tensile stresses are transmitted as in a cable. The existence of solitary waves is demonstrated numerically by solving a system of first order non/linear ordinary differential equations (see Figure). A further analytical approximation is given, and the closed form solution is shown to be in perfect agreement with the numerical results. Interestingly, once the material parameters have been assigned, it is shown that the solitary wave is uniquely determined by the velocity of propagation c.



Displacement u as a function of time t, of the first 15 nodes in a semi-infinite chain.

Characterization of partially disordered microstructures of heterogeneous materials

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We consider composite containing spherical inhomogeneities with their positions varying from perfectly ordered to completely disordered microstructure. The partially disordered periodic packings of spheres are generated in the framework of the reprehensive unit cell model with aid of the Metropolis type algorithm. The orientation order invariants Q_i introduced in [1] in the molecular physics context are taken as the structural parameters providing a quantitative measure of disorder. Variation of these parameters due to gradual disordering of the cubic symmetry packings is accounted in computer simulation. The effective conductivity and elastic moduli of the spherical particle composites with partially disordered periodic microstructure is found by the multipole expansion method. We identified a close relationship between the order metrics and macroscopic properties of composite. The micromechanics-prompted approximation of this relationship is suggested and tested on the numerical data obtained by computer simulation.

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Waves in nonlinear elastodynamics

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We address the problem of plane waves in nonlinear elastodynamics. Despite this is a classical topic we show that the usual results we expect in the isotropic classical materials about volume and shear wave are contradicted when anisotropy and/or pre-strain are taken into account.

A unified methodology for computation of compliance and stiffness contribution tensors of inhomogeneities of arbitrary 2D and 3D shapes–open access software

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Compliance and stiffness contribution tensors of the inhomogeneities constitute basic building blocks for evaluation of composites' effective properties using homogenization methods. Most of the existing results, however, are obtained for inhomogeneities of simple shapes, like ellipsoidal. Moreover, there is no general package comprising all softwares necessary to compute property contribution tensors. The available tools do not have the accuracy and the functionalities required by the homogenization methods. Consequently, newcomers must spend much time to handle incompatibilities of definitions and gather different tools to achieve each task. As a result, each team working in the area of micromechanics has developed its own tools which has scattered the efforts.

We have developed an open access program to calculate compliance and stiffness contribution tensors for inhomogeneities of arbitrary shape that may be described either by explicit equation or graphically using .STL file. The software uses mesh free method based on a class of Gaussian approximating functions developed by [1,2]. First, to illustrate the accuracy of the procedure, we considered test cases for which analytical solution is known such as spheroidal inhomogeneity, elliptical crack and rigid toroidal inhomogeneity. Finally, we showed how the program can be applied to inhomogeneities of irregular shape described graphically.

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Dynamics of prestressed elastic lattices: Homogenization, instabilities, and strain localization

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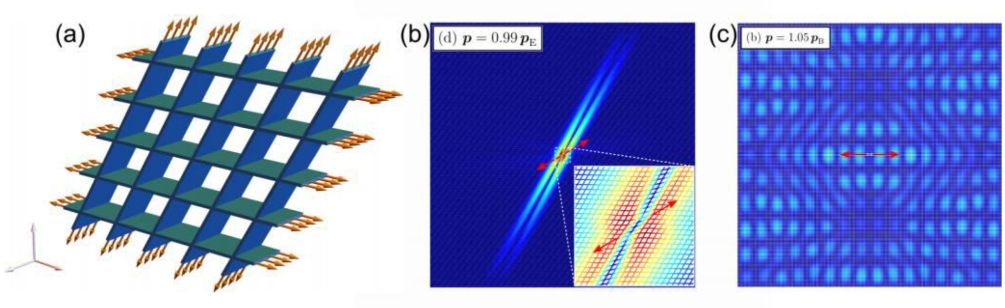
A lattice of elastic Rayleigh rods (possessing a distributed mass density, together with rotational inertia) organized in a parallelepiped geometry can be axially loaded up to an arbitrary amount without distortion and then be subject to incremental time harmonic dynamic motion. At certain threshold levels of axial load, the grid manifests instabilities and displays non trivial axial and flexural incremental vibrations. Including ever y possible structural geometry and for an arbitrary amount of axial stretching, Floquet Bloch wave asymptotics is used to homogenize the in plane mechanical response, so to obtain an equivalent prestressed elastic solid subject to incremental time harmonic vibration, which includes, as a particular case, the incremental quasi static response. The equivalent elastic solid is obtained from its acoustic tensor, directly derived from homogenization and shown to be independent of the rods rotational inertia. Lo ss of strong ellipticity in the equivalent continuum coincides with macro bifurcation in the lattice, while micro bifurcation remains undetected in the continuum and corresponds to a vibration of vanishing frequency of the lowest dispersion branch of the lattice, occurring at finite wavelength. Dynamic homogenization reveals the structure of the acoustic branches close to ellipticity loss and the analysis of forced vibrations (both in physical space and Fourier space) shows low frequency wave localizations. In this way, features such as shear band inclination, or the emergence of a single shear band, or competition between micro and macro instabilities become all designable features. Therefore, the presented results pave the way for the design of architected cellular materials to be used in applications where extreme deformations are involved.



(a) A lattice of prestressed rods; (b)Macroscopic bifurcation (shear band) at the verge of ellipticity loss; (c) Microsc opic bifurcation inside the strong ellipticity range

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Tensegrity modeling of the spider dragline silk fiber and biomimetic fibers

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Tensegrity concepts are ubiquitous in nature and appear, e.g., in every cell, in the microstructure of the spider silk, and in the arrangement of bones and tendons for control of locomotion. The project study is focused on the formulation of a tensegrity model of spider dragline silk fiber at the mesoscale through a multi-domain network approach [1, 2] with tensegrity architecture [3]. We describe the fiber as a multi-walled tube formed by coaxial cylindrical networks of b-sheet crystals (crystalline domains) [4] and polypeptide (amorphous) chains (noncrystalline domains) [5]. Each tube consists of a network of helical-shaped elements loaded in tension (or strings) [6] and circumferential elements loaded in compression (or bars). The strings correspond to domains of amorphous chains attached to crystalline domains at their extremities, while the bars reproduce the compressive stiffening effect that is played by beta-sheet plated crystals in the circumferential direction, when the fiber is longitudinally stretched [3, 6]. Radial links transfer the compressive stresses from one tube to another. The different tubes forming the fiber model describe the homogenized properties of different sections of the core of the fiber. It is indeed largely accepted in the up-to-date literature that the outer lipid, glycol and skin layers minimally contribute to the overall mechanical response of the fiber [6, 8]. The presented model generalizes that recently proposed by Fraternali et al. [9] and paves the way the optimal design of innovative biomimetic fibers with tensegrity architecture.

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Effect of pore coalescence on the effective conductivity of an isotropic material

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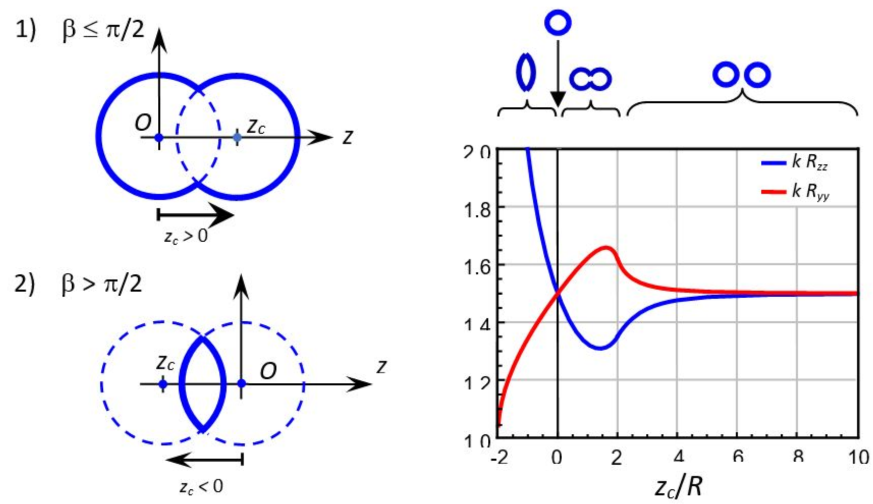
The purpose of this work is to evaluate effect of two coalesced pores or insulating inhomogeneities on the overall conductive properties of an isotropic material. Analytical modeling of the effective properties of materials with microstructures formed by inhomogeneities of non-ellipsoidal shape has not been well developed. The inhomogeneities are typically assumed to be ellipsoids of identical aspect ratios. This unrealistic assumption is largely responsible for insufficient linkage between methods of micromechanics and material science applications. The resistivity contribution tensor gives the extra temperature gradient produced by introduction of the inhomogeneity into a material subjected to otherwise uniform heat flux. The main goal of this work is to obtain an analytical solution for the components of the resistivity contribution tensor of two overlapping pores, in the 2D and 3D frameworks [1, 2].



Variation of the components of the resistivity contribution tensor of two overlapped spheres with the distance between their centers.

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Effective elastic properties of heterogeneous material with concave pores and transversely isotropic matrix

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The aim of present work is to estimate the effective elastic properties of anisotropic materials containing concave pores. In the first part, the concentration and contribution tensors of pores of two reference 3D shapes, supersphere and axisymmetry superspheroid are numerically calculated by Finite Element Method (FEM) [1]. A recently developed corrected boundary condition [2] is adopted and extended to transversely isotropic case in order to accelerate the convergence of simulation, by which, the classical infinite domain are replaced by a finite one. The correction of boundary conditions is given as function of the gradient of Green Function which depends on the anisotropic elasticity of matrix. Then approximate semi-analytical formula of compliance contribution tensors are established on the basis of 3D FEM results and known exact solutions for the limiting cases of spherical pores and circular crack. Finally, the effective elastic coefficients of transversely isotropic materials are presented through different homogenization schemes: Non-interaction approximation, Mori-Tanaka-Benveniste and Maxwell [3]. The impact of concavity parameter is estimated on overall elastic properties.

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An electrochemo-poromechanical theory for actuation and sensing of ionic polymer metal composites

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Ionic polymer metal composites (IPMCs) consist of an ionomer plated with metal electrodes, and are employed as actuators and sensors. Their capabilities ensue from the motion, through the ionomer thickness, of ions dispersed in a solvent. By leveraging on the cross-diffusion of solvent and ions, we propose a finite deformation theory combining electrochemistry and poromechanics that explains the main features of the IPMC behaviour. In actuation, an applied voltage triggers ion migration by electro- osmosis, thus transporting the solvent to the cathode and determining bending towards the anode; then, back-relaxation occurs due to both solvent counter-diffusion and asymmetric ions redistribution. In sensing, a mechanical load triggers solvent motion and ions are transported to the cathode by convection, thus determining charge accumulation at the electrodes; then, ions counter-diffuse thus decreasing the stored charge.

Analytical estimates of the pull-in voltage in MEMS and NEMS

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Micro- or Nano-Electro-Mechanical Systems, MEMS-NEMS, are currently employed in a wide variety of applications, ranging from mechanical or electronic engineering to chemistry or biology. The growing interest in this technology is due to notable need for accurate ultrasmall instruments and equipment characterized by very diminutive size, low power consumption, high precision, reliability and compatibility with the integrated circuits [1]. The micro- or nanocantilever beam electrode, suspended above a conductive substrate and actuated by a voltage difference, is the fundamental component of many MEMS and NEMS devices. Moreover, due to their smart mechanical and electronic properties and the recent progress in their fabrication, carbon nanotubes are significantly exploited in industrial applications, such as sensors, nanoactuators, memory devices and nanotweezers, becoming essential components in NEMS [2]. Recent research remarks the role of micropumps in drug delivery systems able to regulate very small and accurate volumes in various industrial, chemical and biomedical applications. Electrostatic micropumps typically are composed of two parallel, thin, circular micro- or nanoplates. The membrane of the electrostatic micro¬pump can be actuated and displaced towards the fixed electrode by applying a voltage across the electrodes. When the actuation voltage is removed, the displaced membrane releases and returns to its original position. In general, under the action of the electrostatic force and intermolecular surface forces, particularly significant at the micro- or nanoscale, the movable electrode deflects toward to the substrate, thus reducing the separation distance between the electrodes. Correspondingly, the magnitude of the attractive forces increases until at a critical voltage, named the pull-in voltage, the flexible electrode collapses onto the substrate. In this work, an analytical method is proposed for estimating the pull-in voltage and the correspondent deflection accurately, thus providing a useful tool for the effective design of innovative MEMS and NEMS devices [3].

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The structural mechanics of the Vienna tramway rails: advanced beam theory-assisted 1D/2D FE modelling

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Vienna disposes over the sixth largest tramway system in the world, having continuously grown until its inception as a horse-drawn system in 1865 and its full electrification completed in 1902. Given the considerable age of the system, rail durability issues and fractures increase, motivating deeper scientific scrutiny of chemo-mechanical characteristics of the respective grooved rails, a type of rails much less investigated and understood than the Vignole rails used for inter-city rail connections. We here report three recently studied aspects of the mechanics of grooved rails: (i) the 3D stress distribution throughout grooved rail can be efficiently computed through a novel 1D/2D Finite Element approach derived from the Principle of Virtual Power applied to beams with strongly warping cross sections [1,2], (ii) the macroscopic elastic properties are fairly homogeneously distributed across the rail cross sections, their magnitude being driven by metal matrix embedding microcracks [3], and (iii) discontinuities in the elastic support increase the rail stresses [4]. Given the almost perfect match of stress peaks predicted by the novel 1D/2D approach with actual failure patterns impressively highlights (e.g. decay- or maintenance-induced) discontinuities in the elastic support of the rails as an important factor increasing the fracture risk of ageing rails, on top of the temperature and production-induced residual stresses which have been comparatively well studied in the past.

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Elastica catastrophe machine

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Based on the recent concept of universal snap surface disclosed for planar elasticae with kinematically controlled ends [1], a catastrophe machine based on an elastic continuous element has been designed and realized for the first time [2]. A general theoretical framework has been developed by extending that of the classical catastrophe machines made up of discrete elastic systems [3]. Similarly to the classical system, the elastica catastrophe machine splits the plane in monostable and bistable regions, but now it is a flexible continuous element that displays a snapping mechanism when the controlled end properly crosses the catastrophe locus from inside to outside. Furthermore, substantial changes in the catastrophe locus properties, such as convexity and number of bifurcation points, are achievable by tuning the design parameters. These findings open new perspectives in the design of cycle mechanisms for actuation and dissipation devices towards energy harvesting, locomotion and wave mitigation, by combining catastrophe theory with snapping mechanisms in structural mechanics.

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On models of imperfect interfaces

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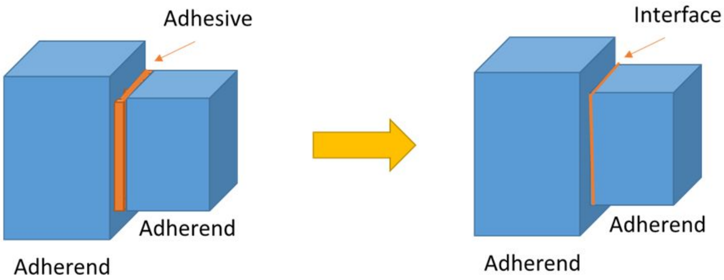
Adhesive-bonded composite joints are widely used in a variety of industrial and technological applications, for example in aerospace, electronics, biomedical, automotive, shipbuilding and construction. In this paper, the focus is on layered structures consisting of two adhesively bonded beams glued together by a thin adhesive layer. In this context, the asymptotic behaviour of this thin interphase [1] is modelled assuming that thickness is the small parameter of the analysis (see Figure). This approach makes it possible to propose linear or non-linear spring type models depending on the behaviour of the adhesive. In particular, it is possible to obtain non-penetration conditions, models taking into account a damage variable [2] or to integrate multiphysical couplings [3]. In this paper, we will insist on how it is possible to obtain unilateral behaviours with damage and how these models can be related to porosity measurements.



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Fiber reorientation in active viscoelastic media

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In the recent years, we have studied fiber reorientation in anisotropic elastic media and considered both passive [1], i.e., driven by mechanical loads, and active processes, e.g., driven by magnetic fields [2]. In another recent work, we have introduced a structurally frame-indifferent model for anisotropic visco-hyperelastic materials [3] in which the evolution laws of the dissipative process were determined by the elastic strain energy and the dissipation densities. In this talk, we will present a model able to account for both previous effects: the reorientation of the fibres due to the viscous relaxation of the matrix and to the fibre remodelling eventually caused by an external source. Each effect is controlled by its own characteristic times. This model reconciles the two approaches in [1] and [2] and can be used to describe the time-dependent response of active metamaterials and biological tissues. Examples will be given to discuss the role of the relaxation times in the constitutive response.

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Damage-based hysteresis Bouc-Wen model for reinforced concrete elements

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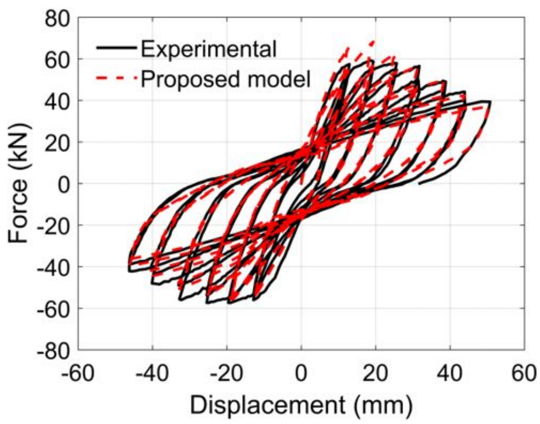
Hysteresis is observed is various mechanical systems [1]. For structural elements, cyclic loads cause deterioration of their characteristics due to cracks opening, yielding and buckling of metallic elements, etc. This contribution presents a smooth hysteresis model for reinforced concrete (RC) structural elements that accounts for both damage and pinching effects [2]. The model is based on the Bouc-Wen differential equation [3]. Deterioration of the mechanical properties is introduced through a damage index that includes energy dissipation and ductility. Pinching is simulated by acting directly on the stiffness of the system. The parameters of the model have clear physical meanings, which helps in the identification and interpretation of the results. Applications to RC elements show that the model is suitable for describing complex cyclic behaviours involving effects of damage (see Figure). Being defined by a smooth hysteresis law, the model is a computationally-effective tool for dynamic and stochastic simulations.



Hysteresis cycles for a RC column: experimental data and model simulation.

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Advanced Composite Materials for Structural Purposes

Resilience Meets Sustainability in Coastal Construction

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More than any other regions of the planet, coastal areas are subject to unprecedented challenges deriving from extreme weather events, sea-level rise, depletion of natural resources and population growth. Engineers and technologists are proposing potential solutions intended to mitigate risks, enhance safety and preserve the environment without disregarding the need for cost control. In the world of construction, changes can occur and innovation be deployed only when new provisions and policies are developed and enforced by local or state agencies, or when enlighten public or private owners are willing to embrace novel technology. This is the case for coastal construction where resilience meets sustainability creating a quantum-leap opportunity. A possible outcome are structures made of precast and cast-in-place concrete reinforced with fiber-reinforced-polymer (FRP) composites, materials immune to chlorides that do not corrode. This presentation will briefly cover recently completed projects using FRP reinforcement for concrete structures with emphasis on coastal environments.

Modeling SRG interfacial bond behaviour and strength

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In the field of external strengthening and repairing of existing structures, Fiber Reinforced Polymer (FRP) composites represent now the most common and effective technological systems thanks to the ease of application, ability to limit the aesthetic impact of the repair work on the original structure and, of course, to their high strength performances. In order to overcome some disadvantages related to the epoxy resin, Fabric Reinforced Cementitious Matrix (FRCM) systems, consisting of fiber textiles embedded into an inorganic matrix, generally cement-based mortar, have recently enter the market as a "green" alternative to FRPs, proving to be very competitive in increasing the performance of both masonry and concrete structures. Among the typologies of FRCM systems, those made of steel fibers – investigated in the present study – have recently captured the interest of the scientific community by emerging as a competitive solution to the use of the more popular G- and C- FRCM composites, both in terms of strength performance and cost-efficiency. FRCM performances are more affected by the stress transfer mechanisms at the interface between the fabric reinforcement and inorganic matrix, since the failure is often expected at this interface. Within this aspect, the interfacial bond-slip response plays a crucial role insofar as interfacial debonding initiation and ultimate failure are concerned. The quantification of the interfacial response requires a reliable local bond-slip constitutive law or model which is preparatory to the development of reliable design procedure. The present paper deals with the development of bond-slip models for SRG systems applied to concrete. In particular, six existing bond-slip interface models for FRP-concrete interface were selected from the technical literature and modified to be applied to the case of SRG systems. The different parameters characterizing the models were calibrated using an experimental database available by the authors [1] which includes results of several direct single-lap shear (DSLS) tests performed on SRG strips bonded to concrete prisms.

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Tensile and pull-out behaviour of Steel Reinforced Grout connectors

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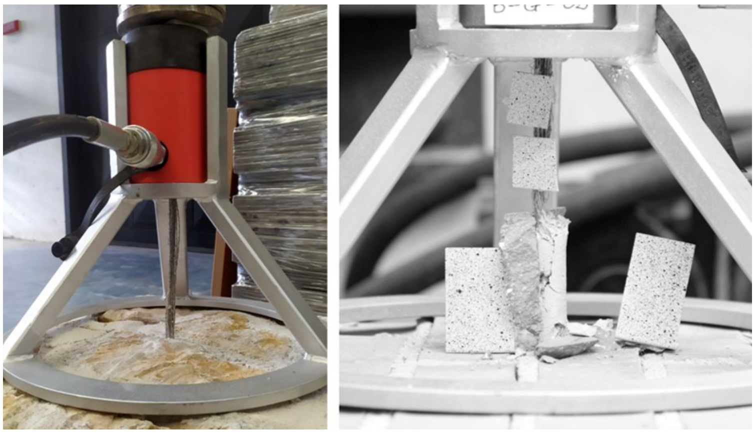
Mortar-based composites are an emerging technology for the repair and strengthening of reinforced concrete and masonry structures. They are externally bonded to structural members and, thanks to their high strength-to-weight ratio, provide a significant gain in structural capacity with minimum mass increase and can be integrated in the plaster layer [1]. In most cases, the effectiveness of the retrofitting work relies on the substrate-to-composite bond capacity. In some applications, mechanical connectors are also used to prevent debonding and improve the performance of the retrofitted structure. The use of connectors is recommended by design guidelines and suppliers are required to test them for acceptance [2]. The paper presents a laboratory investigation on steel reinforced grout connectors, made by rolling ultra-high tensile strength steel textiles, comprising either galvanized or stainless-steel micro cords. Tensile tests were carried out for mechanical characterization. Pull-out tests were performed on connectors installed in holes drilled in wall panels and injected with either cement or lime mortars. Brickwork, tuff masonry and limestone masonry as well as concrete were used as substrate materials (Figure). Test results are commented to analyse the effect of textile rolling on tensile response, of textile and matrix properties on pull-out strength and failure mode, as well as to highlight their significance for design purposes.



Experimental setup and final stage of the execution of pull-out tests

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Investigation of multi-scale fibre-reinforced cementitious mortar (FRCM), developed using microcrystalline cellulose (MCC) and sisal fibres

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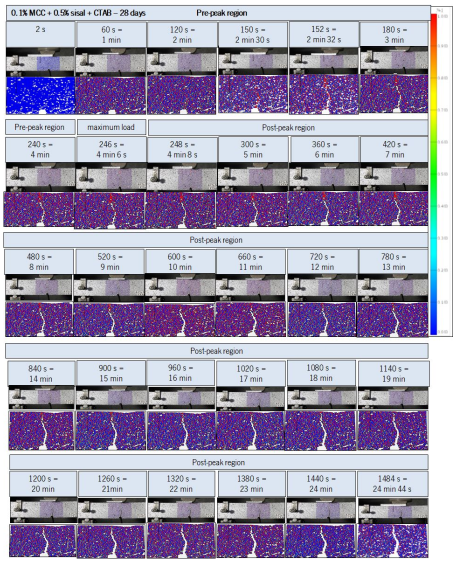
In this work, multi-scale FRCM were developed using MCC (0.1-1.5 wt.% of cement), and sisal fibers (20 mm, 0.50 wt.%), as reinforcements. MCC was first dispersed in water with surfactants - cetyltrimethylammonium bromide/CTAB (40% of MCC wt.) or Pluronic F-127 (20% of MCC wt.) - using ultrasonication. The properties as mechanical behaviour and microstructure of this innovative reinforcements were investigated. This advanced composite material presented distinct advantages over only sisal fibre or MCC-based reinforcements. The multi-scale FRCM exhibited a synergistic effect, with a slower crack initiation and propagation, and an improvement of fracture energy up to 40%, leading to contributions concerning innovative materials in construction [1].



Crack propagation analysis by digital image processing for the multi-scale FRCM reinforced with 0.1% MCC + 0.5% sisal + 40% CTAB, at 28 days.

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Advanced Composites with Alkali-Activated Matrices for Strengthening of Structures: Review Study

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Old and seismically prone buildings are in need of strengthening to meet up with the latest building codes and to prolong their service life. For over two decades Fibre Reinforced Polymers (FRP) have been successfully used for this purpose. However, the poor performance in high temperatures of organic matrices has led researchers to investigate the use of inorganic matrices. Consequently, Textile Reinforced Mortars (TRM) have been opted for strengthening, since they incorporate textiles impregnated in inorganic cementitious matrices. Lately, in order to promote sustainability and lower the high carbon emissions of cement, alkali-activated mortars, also called geopolymers, have been investigated as an alternative. Their high performance and fireproof properties have made them excellent candidates as matrices in advanced composites for strengthening. This review aims to provide an overview of past research in the field of advanced composites with alkali-activated matrices.

NFRCM-strengthened masonry, numerical and experimental analysis

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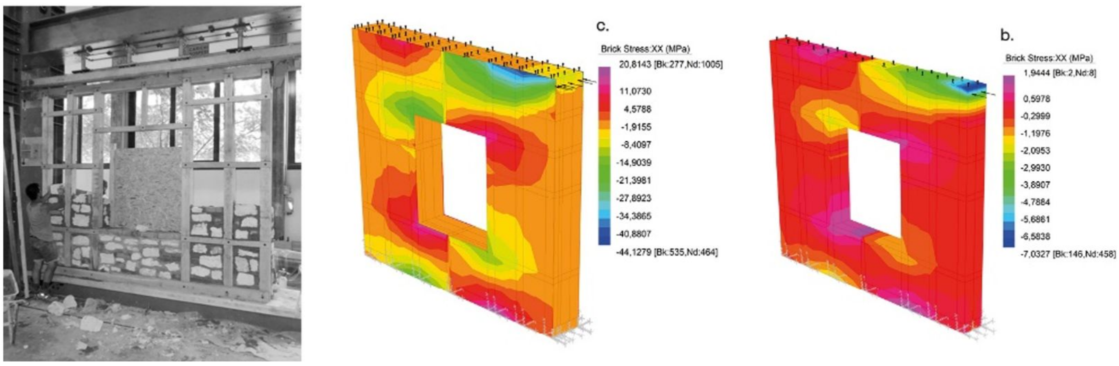
The innovative sustainable technology based on natural fabric-reinforced cementitious matrix (NFRCM) is analysed for strengthening masonry [1]. The new frontier of composite material is proposed as an alternative to well-known traditional technologies used to improve the seismic behaviour of buildings, such as the portuguese technique “*gaiola pombalina*”, the Italian “*baraccata house*” and the turkish “*himis house*”[2]. Preliminary sensitivity analysis is performed on NFRCM and “baraccata” numerical models. Both technologies are numerically compared considering out-of-plane behaviour to emphasize the interface effects. From the experimental results of in-plan incremental load test carried out by CNR-Ivalsa [3] a numerical model is calibrated by non-linear pushover analysis to evaluate the behaviour of wall strengthened with natural fibers. The efficacious of NFRCM technology is demonstrated by: i) not invasive intervention for insignificant thickness; ii) sustainable technology; iii) global intervention involving whole surface avoiding failure local mechanisms.



(a) (b) (c)

Experimental test on “baraccata” wall (a), numerical analyses on masonry (b) and NFRCM-strengthened masonry (c) walls

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The Influence of Second Order Transitions in the Structural Applications of Composites in Building and Constructions

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Transitions in composite materials for structural applications play a crucial role in the determination of the mechanical and thermal behaviour of the reinforcing systems. This state-of-the-art review focuses on the definition of first and second order transitions in polymeric materials (thermoplastics and thermosetting), commonly adopted as embedding matrices in high-performance FRP systems. The transitions of the 2nd order of thermosetting resins have a dramatic impact on the morphological behaviour of the polymeric material. Indeed, the glass-transition temperature (T_g) influences the cross-linking reaction of the resin, as a function of the polymerization conditions. The measurement techniques for the T_g are mentioned. Furthermore, the behaviour of the cross-linked thermosetting materials in different conditions depending on the T_g, with particular emphasis on the mechanical response, is analysed. From a structural standpoint, the thermal properties of the embedding medium are crucial in order to predict the composite response during service life. The safety specifications, as well as serviceability requirements for the T_g are here outlined, in order to identify the most reasonable criteria to be adopted at the design stage.

Determination of the matrix-fiber cohesive material law using FRCM-concrete joints

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Fiber-reinforced cementitious matrix (FRCM) composites have been increasingly used to strengthen existing concrete and masonry structures in the last decade. Two guidelines are available for the design and construction of FRCM strengthened members: ACI 549.4R (2013) and CNR-DT 215 (2018). Both these guidelines employ the effective strain, i.e. the strain at which the composite action is lost, as key parameter for the evaluation of the capacity of FRCM strengthened members. The American guideline ACI 549.4R (2013) employs the results of clevis-grip tensile tests on FRCM coupons to determine the composite effective strain. Such strain is determined by the Italian guideline CNR-DT 215 (2018) combining the results of direct shear tests on FRCM-substrate joints and of tensile test of bare fiber textile. The effective strain is strictly related to the matrix-fiber bond behavior, which can be expressed by the interface shear stress-slip relationship, i.e. the cohesive material law (CML). The effective strain is not sufficient for a full understanding of the structural response of strengthened members, since the knowledge of the CML is needed to predict important parameters such as the crack pattern or the location where debonding occurs in beams strengthened in flexure. This paper provides a simple method to obtain the CML from the load response obtained by direct shear tests of FRCM-substrate joints. The method is discussed and applied to the case of poliparaphenilene benzobisoxazole (PBO) FRCM-concrete joints previously tested by the authors.

Influencing parameters for the failure mechanism of carbon-FRCM (Fibre Reinforced Cementitious Matrix systems)

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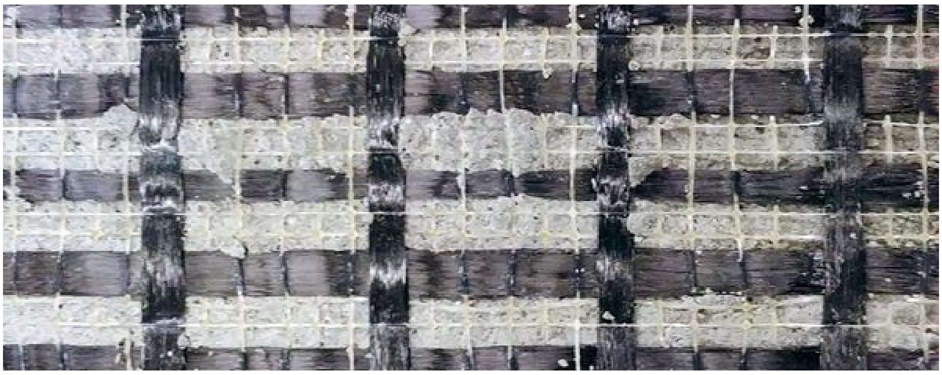
Nowadays, FRCM (Fibre-Reinforced Cementitious Matrix) systems are highly attractive for the building materials market; thus, their optimization and development cover an essential role. This work points out the chemical and physical parameters influencing the carbon-FRCM mechanical behaviour. Three different FRCM composed of commercially available carbon fabric and different inorganic matrices were involved. Matrices were specifically developed to enhance the adhesion with the fabric and differ in organic additive used. Moreover, different fabric weavings and fibre coatings were considered: silica-fume, fine silica aggregate and coarse silica aggregate. A new shear test set-up was designed to obtain an inexpensive characterization method and employed with traditional mechanical tests. Morphological and compositional analyses were performed on the surface fractures. Despite macro evidence due to the different matrix type and fibres treatment involved, no significant differences in FRCM mechanical behaviour were observed. Otherwise, a simple pull-out test displayed that, in comparison with a non-woven yarn, the fabric weaving promoted the fibre-to-matrix adhesion and modified the sample failure mechanism. Finally, the FRCM mechanical performance is primarily influenced by the fabric weaving but, since the inexpensive shear test set-up showed a wide data dispersion, the effectiveness of matrix type and fibre treatment requires statistical support.



Carbon-FRCM system after shear test failure

Functionalisation techniques for polypropylene fibres in Fibre Reinforced Concrete (FRC): experimental and analytical study of the pull-out mechanisms

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Polypropylene (PP) short fibres are regarded as performing and durable dispersed reinforcement for fibre-reinforced concrete (FRC). Indeed, PP fibres induce remarkable anti-spalling properties associated with a moderate cost, high degree of recyclability, and magnetic transparency. The outstanding durability of PP is mainly due to its superficial inertness, which is also responsible for the weak interphase bond with the surrounding matrix, resulting in a poor mechanical response of the composite material. Several chemical and physical methods have been proposed in the literature to improve the fibre-to-matrix adhesion, like e.g. ozone treatment, chemical etching and surface coating of the fibres [1–3]. In this paper, we discuss the effects of a fast acid-catalysed sol-gel silica coating for PP fibres on the mechanical performance of FRC joists. It is found that the enhancement of the fibre-to-matrix bond induced by silica coating is able to move the failure mechanism from delamination at the interface to failure in the interphase transition zone (ITZ). In the former case, failure is inconsistent and occurs independently from the curing time, whereas, in the latter case, failure is driven by the matrix quality. Failure modes and fibre-to-matrix interactions generally govern the predictive models of the mechanical behaviour of FRC. To this aim, we present a simple one-dimensional analytical model of the pull-out process of an elastic fibre embedded in a cement matrix. The shear stress due to friction arising at the interface between fibre and matrix is assumed to increase with the slippage distance as a consequence of the growing abrasion of the fibre surface occurring during the pull-out [4]. The model is validated by the comparison with experimental data available in the literature [2], both for untreated and silica coated fibres. The model here proposed may also predict the non-linear relation between the tensile load and the fibre displacement for different kinds of fibre, by setting adequately the constitutive parameters.

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Mechanical characterization of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) under quasi-static and cyclic loads

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Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) is an innovative cement-based composite material which exhibits advanced mechanical properties, excellent durability and high toughness [1]. In this study, the flexural behavior of UHPFRC has been investigated by four-point bending tests on prismatic specimens, by varying the amount of brass-coated steel fibers (diameter of 0.20 mm and length of 13 mm) up to 2% by volume. Bending tests have been performed under quasi-static and cyclic loads. Damage progress, number and width of cracks on the specimen surface were monitored by means of a Digital Image Correlation (DIC) system. The effects of brass-coated steel fibers on the flexural behavior of UHPFRC was investigated. Then, a phase-field model has been implemented in a FE code and numerical simulations have been performed to better understand the effects of different fiber dosages on the mechanical behavior of UHPFRC composites under quasi-static and cyclic loads. Concrete matrix and fiber reinforcement have been modeled as brittle and elasto-plastic phases of a mixture, whose internal energies are enriched by non-local damage and plasticity contributions. The different failure mechanisms observed in experiments have been reproduced and the potential of the numerical model has been described and commented.

Four-point bending test setup

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Mechanical properties of cement composites reinforced with fully-recycled plastic fibres

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In recent years, the use of recycled plastic fibres as reinforcement in construction and building materials has gained increasing attention from researchers, due to their large-scale availability, low cost, and sustainability. In the present study, we investigate the performance of Fibre Reinforced Cement Composites (FRCCs) including fully-recycled plastic fibres. Specifically, we add to a cementitious matrix flattened polyolefin fibres treated with a sol-gel silica coating and polyethylene terephthalate (PET)/polyethylene (PE) cylindrical draw-wire filaments. We assess the flexural response of the composites in the light of reference performance of FRCCs including virgin polypropylene (PP) fibres only. We observe that the different properties of fibres only marginally influence the first cracking strength of the composite, while their shape plays a crucial role in the post-peak branch. Moreover, the silica coating significantly improves the interphase adhesion between reinforcement and cement matrix during the pull-out stage, representing a rapid, viable, and effective solution largely improving the FRCCs dissipation capability. Therefore, balancing the significance of mechanical performance and environmental sustainability, both fully-recycled fibres here investigated can be regarded as promising candidates for innovative structural applications.

Fully-recycled (PET/PE and polyolefins) and virgin (PP) fibres

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Retrofitting with FRCM composites: shear and flexural behaviour of strengthened masonry walls

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Structural strengthening using composite materials is nowadays one of the most interesting techniques to overcome weaknesses of masonry structures constituting large part of the building heritage. The use of FRCM composites is becoming more and more widespread due to some limitations of FRP retrofitting systems. In this framework, the presented experimental study is aimed at evaluating the in-plane and the out-of-plane behaviour of masonry walls strengthened with different types of FRCMs, analysing in detail failure modes, capacity increments and efficiency of the strengthening systems when tested using two different configurations. To this purpose, bidirectional basalt grids and unidirectional steel fibre sheets, coupled with a lime based mortar, were used for retrofitting clay brick masonry walls subjected to diagonal compression tests and out-of-plane flexural tests. Experimental outcomes, when considering the in-plane or the out-of-plane direction, show that the different layout adopted strictly influences the flexural and shear strengthening efficiency of the reinforcement.

Durability and Corrosion

Alkali-activated materials: Corrosion of steel reinforcement

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The development of alkali-activated materials (AAMs) has been promoted by the growing demand for sustainable concretes with specialised performance characteristics in recent decades. These materials are the products of the reaction between an aluminosilicate source (usually industrial by-products such as blast furnace slags and coal fly ashes, among others) and highly alkaline solutions including caustic alkalis or alkaline salts (hydroxide, silicate, carbonate, or sulfate). Considering that rebar corrosion is the main cause of reinforced concrete structure failure, the capacity of alkali-activated materials to passivate steel rebars may be very important to guarantee the durability of reinforced concrete structures constructed using these new materials. Steel rebars embedded in Portland cement-based concretes are protected from corrosion by a thin oxide film that is formed and maintained on rebar surfaces due to the high pH level of the surrounding concrete through a buffering mechanism originated by the presence of portlandite. However, in AAMs portlandite is not typically identified as a reaction product, the availability of OH^- ions from the pore solution at the steel-concrete interface will have a greater influence in ensuring the stability of this protective layer in AAMs. Several works have demonstrated that the passivating capacity and permanence of the passive state once reached in the alkali-activated fly ash or slag systems depend on the nature, dose, and chemical composition of raw materials, on the type of activator used, and on the environmental conditions.

Durability of reinforced concretes containing biochar and recycled polymers

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In the field of sustainable construction materials, the production of eco-friendly concretes, obtained by the addition of waste products such as biochar and recycled polymer particles, offers interesting alternatives to traditional materials. Biochar is a carbonaceous solid by-product obtained from the thermo-chemical conversion of biomass and its addition into concrete admixtures can offer an eco-friendly carbon sequestration solution, capable to slightly improve the concrete fracture energy. Recycled polymer materials can be used to partially replace conventional aggregates in the preparation of lighter concretes helping to face the disposal challenge presented by this non-degradable plastic waste. However, for both concrete types the influence of these additions on the corrosion behaviour of embedded steel rebars is still unexplored. Within this context, this work presents the first results in terms of corrosion potential and polarization resistance measurements and electrochemical impedance spectroscopy analysis, of an extensive study dealing with the reinforcement corrosion resistance during cyclic exposures to chloride-containing solutions.

Monitoring of steel corrosion in Alkali-Activated Mortars

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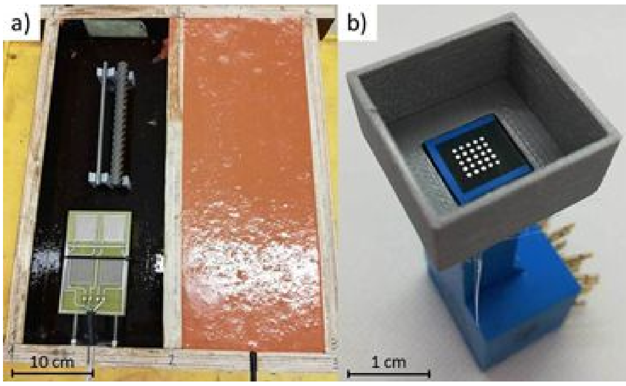
Alkali-Activated Materials (AAMs) are alternative to Ordinary Portland Cement (OPC), reducing greenhouse gases and consuming industrial by products (e.g. steel slags, fly ash, etc.) [1]. The corrosion monitoring methods used for OPC materials in some cases cannot be directly used for monitoring steel corrosion in AAMs [2]. Furthermore, some critical parameters of corrosion in concrete (i.e. the type of corrosion damages, spatiotemporal distribution of corrosion initiation and propagation) cannot be obtained by conventional electrochemical methods. Therefore some alternative methods were proposed: measuring corrosion rates by Electrical Resistance (ER) sensor and measuring spatio-temporal evolution of corrosion currents by Coupled Multi-Electrode Arrays (CMEA) [3]. The aim of this study was to evaluate proposed methods for monitoring steel corrosion in different alkali-activated mortars. ER and CMEA sensors were installed in three different reinforced alkali-activated mortar mixtures based on fly ash, slag and metakaolin. Specimens were exposed to wet/dry cycles with saline solution. Measurements of ER sensors thickness reduction were performed and partial currents (anodic and cathodic) on CMEA sensors were continuously measured. Corrosion monitoring results will be evaluated and compared to damages on steel electrodes, obtained by X-ray computed microtomography (μCT) and 3D deviation measuring system



a) Specimen with ER sensor and 2 steel reinforcing bars before (left) and after (right) casting metakaolin based AAM; b) CMEA sensor before casting AAM.

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Coatings based on light-weight alkali activated mortars as sustainable system for steel corrosion protection

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Alkali activated materials and geopolymers have attracted a lot of attention in the last 20 years thanks to their excellent mechanical performances, durability and sustainability properties, especially for civil applications. These materials exhibit also promising properties as fire- and corrosion-resistant protection systems. Recently, we have developed and tested a 2-cm coating based on light-weight alkali activated mortars (LWAAMs) for the protection of steel structures against fire [1,2]. To understand if the developed LWAAM-based coating is also able to ensure durability to steel reinforcement, this study reports the results of chloride-induced corrosion. The corrosion performance of the new system based on steel coated by LWAAMs (using expanded perlite and hydrogen peroxide) was compared with a steel coated by a traditional alkali activated mortar (NWAAM) in which silica sand was used. Electrochemical tests on steel samples immersed in a leachate pore solution or embedded in LWAAM and NWAAM, respectively, were carried out in presence of different chloride concentrations. It was found that the increased porosity of the LWAAMs did not impair the steel corrosion resistance, when compared with NWAAMs. Moreover, the pore solution chemistry and the alkaline environment of alkali activation are mainly responsible of the steel corrosion protection for long exposure.

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Effect of locally sourced fly ash and GGBS on the compressive strength and chloride resistance of concrete

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The paper investigated the effect of locally sourced fly ash and GGBS on the compressive strength and chloride resistance of concrete. The mix proportion was cementitious material (total of original Portland cement (OPC), fly ash and GGBS): sand: coarse aggregate: water of 1:2:3:0.6 in which 20% by mass of total cementitious materials was replaced by class F fly ash and GGBS. Compressive strength and rapid chloride penetration tests were conducted at 28, 56 and 120 days. The results shows that fly ash and GGBS reduces slightly the compressive strength but improves significantly the choloride resistance of concrete. Within the range of investigation, 10% of fly ash and 10% of GGBS is recommended to replace original Portland cement as they improve the chloride resistance and maintain the compressive strength of concrete.

Corrosion behaviour of carbon steel in sulfoaluminate-based binders and blended binders

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The paper deals with the study of the passive film formation on steel reinforcements embedded in traditional and CSA-based binders by means of combined electrochemical techniques. In the specific, the corrosion behaviour of steel was evaluated by means of open circuit monitoring (OCV) and Electrochemical Impedance Spectroscopy (EIS) in concretes manufactured with ordinary Portland cement (OPC) and CSA-based binders. The work examines the fundamental aspects that determine the protective behaviour of carbon steel reinforcements in concrete made with traditional binders based on Portland cement and defines the peculiarities with respect to CSA-based binders. The paper analyses the role of alkalinity and its maintenance on the corrosion behaviour of carbon steel. The protective action of Portland cement and passivation kinetics are strictly dependent upon the pH of the pore solution – i.e., the availability of hydroxyl ions – and the oxygen content just since the early periods of exposure, in fresh conditions. The pH and alkalinity reservoir also play a fundamental role for the qualification of the new binders for the building industry as far as the resistance to the depassivating action of chlorides is concerned. New methodologies are proposed for the assessment of pH of cement matrix to determine the protective action respect to carbon steel reinforcements. Qualitative test is proposed by using an alternative indicator to phenolphthalein and quantitative technique based on indirect pH measurement of the cement matrix are presented. Corrosion tests confirm different passivation kinetics moving from traditional to innovative binders. Data collected by means of EIS tests showed a marked shift-to-the-left of the time constant over time since early exposures for rebars embedded in OPC compared to CSA. Behaviour that is more complex was noticed for rebars embedded in CSA-based binders.

Preliminary assessment on durability of high performance fiber reinforced concrete with CSA cement

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Calcium sulfoaluminate (CSA) cement could be a potential alternative to ordinary Portland cement (OPC) to reduce environmental impact of concrete industry, due to its lower production temperature and thus lower CO_2 emission. Therefore, there is an essential need to assess the durability properties of concrete produced with CSA cement. In this work a preliminary study on durability of high performance fiber reinforced concretes produced with CSA cement in total or partial substitution of OPC, also with ground granulated blast-furnace slag (GGBS), was performed. Compressive strength and electrical resistivity of the different concrete mixes and electrochemical tests to evaluate corrosion condition of the embedded steel fibers, were assessed. The results show that substitution of OPC with CSA cement improves the mechanical properties of concrete but promotes corrosion of the steel fibers, affecting the durability of this material. Misleading results were attained with the corrosion potential measurement, conventionally used for the evaluation of the corrosion condition of the steel reinforcement, in CSA concrete.

Durability of mortars manufactured with low-carbon binders exposed to calcium chloride-based de-icing salts

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Calcium chloride is widespread used de-icing salts for removing snow and ice from roads, infrastructures and service area. It is well known that reinforced concrete structures, if exposed to calcium chloride, can suffer from severe damages due to both corrosion of the steel reinforcement and chemical attack of the cement paste. This paper aims at evaluating the resistance to chemical attack of mortars manufactured with different low-carbon binders (alkali activated slags, calcium sulphoaluminate cement-based blends, high volume ultrafine fly ashes cements) in presence of $CaCl_2$-based de-icing salts in cold climate (about 4°C). Results indicated that alkali activated slag-based mortars are quasi-immune to calcium chloride attack due to their mineralogical composition. On the contrary, calcium sulphoaluminate-based blends show the total loss of binding capacity, especially when calcium sulphoaluminate cement is used with gypsum and Portland cement. Finally, the partial substitution of Portland cement with ultrafine fly ash strongly reduce the mass change and the strength loss of mortars immersed in 30 wt.% $CaCl_2$ solutions due to the strong reduction of calcium hydroxide responsible for the calcium oxychloride formation in the cement paste.

The PARC_CL 2.1 crack model for reinforced concrete elements subjected to corrosion and long-term effects

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During the service life, existing structures may suffer a combination of time-dependent effects, such as creep, shrinkage and reinforcement corrosion. The corrosion deterioration can significantly affect the durability of reinforced concrete (RC) elements causing premature concrete crushing, size reduction of reinforcement cross-section, degradation of mechanical properties of steel and concrete, and stirrups rupture. Furthermore, to ensure adequate safety and serviceability throughout the life of the structure, the prediction of long-term strains, due to creep and shrinkage, is important. Creep and shrinkage have a considerable impact on the performance of RC structures, affecting stress and strain distribution, increasing deflections and crack width. For this reason, a nonlinear finite element approach, based on multi-layer shell elements and PARC_CL 2.0 crack model is presented in this paper. The PARC_CL 2.1 model is a fixed crack model developed at the University of Parma and implemented in a FORTRAN subroutine UMAT for for ABAQUS that incorporates cyclic constitutive laws of materials and the evolution of corrosion, shrinkage and creep over the time. The effectiveness of the proposed model is validated through comparison with experimental data available in literature.

Ensuring both eco-efficiency and durability of reinforced concrete through scientifically understanding corrosion of steel in carbonated concrete

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Blended cementitious binders offer great opportunities to reduce energy consumption and greenhouse gas emissions during the production of cements. Thus, structures built with these materials can have an improved environmental footprint compared to traditional binders such as Portland cements. To ensure sustainability on the long-term, however, it is crucial that these engineered eco-friendly materials are durable in the exposure environments of the structures the materials are used in. A major concern is the relatively fast carbonation of blended cements compared to binders forming higher amounts of Portlandite, and the risk for reinforcing steel corrosion associated with carbonation. To keep corrosion in check, common approaches in durability design are based on increasing cover depth or making the matrix denser. These approaches generally lead to an increase in amounts of binders used in construction, which may almost defeat the purpose of reducing emissions in cement production. This contribution discusses the mechanism of steel corrosion in carbonated concrete, summarizing experience from engineering practice and latest scientific advances. Experimental results from corrosion rate measurements in different binders are shown and influencing factors are discussed. It is concluded that reinforced concrete can still be a very durable material once the concrete has carbonated. Based on this scientific understanding, new ideas emerge to facilitate the sustainable design of durable reinforced concrete structures.

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Evaluation of different preventative methods to prevent corrosion in concrete

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Starting from the end of the years '70, the increased number of damaged structures, as well as the failures of some important structures made evident that rebars corrosion (carbonation or chloride induced) shall be seriously taken into consideration [1]. Prevention of rebars corrosion is a way to increase reliability, reduce energy consumption and improve sustainability of concrete sector. Prevention of rebar corrosion is achieved in the design and construction phases, by means of suitable mix design, casting and curing, and adequate cover depth [2, 3]. Preventative methods, such as cathodic protection, stainless steel or galvanised rebars, corrosion inhibitors, concrete coatings, can be used in very aggressive environment, especially in presence of chlorides, or when increased service life is required. In this work, the achievements of our research group in the field of preventative methods, namely polymeric-cementitious concrete coating and corrosion inhibitors are briefly recalled. Moreover the service life of reinforced concrete structures exposed to chloride environments has been evaluated by means of a simplified approach, based on Monte Carlo simulation. Different preventative methods and concrete type (manufactured with Portland, pozzoloanic or slag cement) have been taken into account. Cathodic prevention and stainless steels are the most effective protection methods in very aggressive environments. The use of pozzolanic or slag cement is confirmed as an effective way to slow chloride transport and by this way to increase the service life [4, 5].

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Stainless steels as sustainable solution for concrete reinforcement – from laboratory to practice

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Stainless steel reinforcing bars show excellent corrosion resistance in concrete exposed to harsh environments. In this combined electrochemical and surface analytical work, a reason for this behaviour is proposed. XPS surface analytical results (thickness, composition of the passive film and of the interface beneath the film) obtained on black steel, FeCr alloys, and a series of stainless steels after exposure to alkaline solutions simulating concrete are reported. Pitting potentials were determined in the same solutions with electrochemical experiments. It is shown that the pitting potentials of the steels can be related to the Cr(III)oxy-hydroxide and Mo(VI) content in the passive film. It is proposed to calculate a Cr and Mo oxide equivalent similar to the well known "Wirksumme" or pitting resistance equivalent (PRE). A correlation between the critical chloride content in concrete (reported in literature for CEM II A/LL and CEM I) and the pitting potential for carbon steel, Fe12%Cr alloy, DIN 1.4301 and DIN 1.4571 stainless steels is proposed as "missing link" between results of analysis in solutions and performance in concrete.

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Corrosion behavior of steel reinforced geopolymer concrete: A pathway towards long-lasting and sustainable structures

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Corrosion of reinforced concrete structures is nowadays one of the major concerns on the durability and serviceability of buildings and constructions. Corrosion management and monitoring of infrastructure and civil engineering structures is required to guarantee their lifetime in service. Sustainability of reinforced concrete structure is crucial for better social development, because of the importance of structural safety, preservation of environment, and economy. The construction sector has demonstrated and increased interest and demand for novel environmentally friendly cementitious materials, such a geopolymer concrete, which is driven by the need to decrease the vast amounts of CO_2 produced by traditional Portland cement and concrete industry. The effects of increased greenhouse gas emissions include global warming, ocean acidification, smog pollution, ozone depletion and altered plant health, all contributing to global climate change. In this regard, alkali activated fly ash (FA) stands as an outstanding alternative material for the building and construction sector. Therefore, it is of paramount importance to study the corrosion behavior of reinforcing steel in geopolymer concrete, to prevent corrosion and extend the lifetime. Corrosion of steel in geopolymer concrete requires extensive research to determine the corrosion mechanisms governing passivity breakdown.

Corrosion behaviour of galvanized steel in cement- and geopolymer-based concrete: a review on scientific work at the Polytechnic University of Marche

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Hot-dip galvanized steel rebars are effective to increase the durability of reinforced construction materials, based on traditional cement and on recently studied alkali-activated binders, such as geopolymers. Instead of steel reinforcements, galvanized reinforcements in concrete are protected by calcium hydroxyzincate (CaHZn) layer, which, under carbonation, transforms into a less protective hydrozincite (HZ), but corrosion resistant layer [1,2]. In the case of chlorides ingress, the threshold for localized corrosion initiation is at least three times higher for galvanized rebars than for steel rebars: 1.3 wt% vs 0.4 wt%, respectively, with respect to the weight of cement [3]. Therefore, galvanized rebars increase considerably the durability of reinforced concrete structures, without significantly impairing construction costs. Concerning geopolymers, the matrix is more alkaline than the traditional cementitious ones and the scarce presence of calcium ions cannot guarantee the protection of galvanized steel by CaHZn. Actually, also in these conditions, galvanized steel passivates even if with a certain delay (4-7 days) from the cast, by the formation of ZnO passive layer [4]. In particular, geopolymers obtained by fly ash slow the ingress of chlorides, protecting the reinforcements, if galvanized, from a penetrating localized corrosion of Zn-Fe alloys.

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Increase sustainability of aged prestressed concrete structures by improving knowledge on degradation mechanisms and proper corrosion monitoring systems

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Existing road infrastructures, built mostly in the second half of the last century, are now quickly ageing leading to face the problem of an increasingly fragile road network while the expansion of the current infrastructure constitutes a minor portion of construction activities. Post-tensioned and prestressed concrete structures have been extensively adopted on road infrastructures from late 50's. The current still lack of knowledge on actual corrosion mechanisms and mechanical behaviour of aged infrastructures forces engineers to take conservative decisions, i.e. to repair or replace structures relatively early [1]. Considering the expected increase in needed repair works over the coming decades there is certainly an urgent need to quit the current relatively conservative and thus costly approach by providing innovative and cost-effective technologies as well as fundamental understanding of corrosion deterioration mechanisms [2]. A sustainable approach based upon a holistic treatment of needs and impacts, life-cycle cost and environmental impacts, should be considered as a fundamental requirement, at the basis of any decision on structure intervention. As stressed in the upcoming new fib Model Code 2020 [3] "these overarching requirements will have defining implications for subsidiary performance requirements critical to structural design and assessment procedures. These are matters such as human and environmental safety, serviceability and durability, and other specific performances such as the robustness of the structure and the resilience of its functionality". A detailed analysis of all these aspects are reported in the conference paper.

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Life Cycle Assessment (LCA)

Life Cycle Sustainability Assessment (LCSA) in building and construction as tool supporting the European green transition

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Because of the high responsibility in terms of environmental impact, construction and buildings represent one of the key topics for the green transition proposed by the European New Green Deal [1]. In the European Union, this sector is responsible for 40% of total energy consumption and 36% of greenhouse gas emissions. Improving environmental efficiency can play a key role to reach carbon neutrality of Europe that is expected to be achieved by 2050.

Considerable efforts are underway to build global knowledge and capacity for understanding, developing, and promoting more sustainable construction processes on the base of comprehensive information on materials and products over their life cycle by evaluating energy, raw materials, land, and water consumption, and related emissions into water, air, and soil. A holistic observation is obtained by the use of LCSA, considering an integration in environmental, economic, social impact assessment.

In this issue it was explored how a Life Cycle Sustainability Assessment approach [2], as fundamental supporting tools in sustainability, can be applied in construction.

The research will show an application of LCSA in selective demolition processes and construction and demolition waste recycling for an end-of-life building proper management optimization.

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Economic evaluation of circular schemes for managing Construction and Demolition waste

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Among the obstacles that prevent the widespread use of secondary resources produced from construction and demolition waste (CDW), the distrust of the constructors is the most impactful. As pointed out from a previous research, the presence of soil and gypsum in the recycled aggregate negatively impacts on its quality, weakening the market competitiveness of recycled materials compared to the natural ones. Thus, the natural aggregate still remains the preferred choice for the sector operators. This prevents the establishment of a circular economic model in the construction industry. This work explores the potential advantages of using recycled aggregates from an economic point of view, through the application of the Life Cycle Costing (LCC) methodology. The LCC analysis evaluates the internal costs borne by the different stakeholders of the CDW value chain, starting from the process generating the inert waste (i.e. the demolition step) till the waste has become a new product. As the waste must come out as pure as possible from the demolition site, so that the downstream processes of re-using and recycling are improved, a selective demolition can decisively help to reach this aim but could require greater economic efforts. The results of this work will be the starting point for policy makers to implement incentive and support tools for the development of circularity in the construction sector.

Life cycle cost analysis: a useful tool for reaching sustainable objectives in buildings sector

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Buildings sector is one of the main energy consuming sector. In fact, in European Union, buildings accounts for approximately 40% of energy consumption and they generate 36% of the CO_2 emissions [1]. Therefore, reducing energy consumption in this sector will play a decisive role to achieve the objective of reducing energy consumption by at least 32.5% by means of improvements in energy efficiency by 2030 [2]. Limit the transmission of heat through the building envelope might be a solution for saving of energy and guarantee better thermal comfort [3]. Buildings insulation represents a forerunner in achieving energy conservation [4] but it has to be accompanied by a proper design capable of determining the appropriate amount of insulating material. In fact, although building insulation helps in reducing heat transmission through the envelope and therefore improved energy saving, it increases installation cost of the insulation. For this reason, it is essential to determine the optimum combination between the building energy performance and buildings initial investment for thermal insulation. Life-Cycle Cost Analysis (LCCA) represents the right tool to determine this optimum combination and thus reaching sustainable objectives that guarantee better long-term performance of the building with lower operating costs.

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Benefits and opportunities of reusing waste rotor blades in cementitius materials from a life cycle perspective

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The wind power industry has been growing in the last two decades, meaning that many of the first-generation wind turbines will be soon reaching the end of their service life. According to Schmidl, 2010 [1] the total weight of rotor blades to be disposed of will amount to almost 50,000 t/a by 2020, with predictions of 200,000 t/a by year 2034. A sustainable disposal method for recycled GFRP waste is the reutilization in cementitious materials [1-3]. The major technical benefit of using GRP waste powder in concrete composites is the improvement of binding and adhesion of concrete due to the presence of polymeric compounds, CaO, Al_2O_3 and SiO_2 in GRP waste. Furthermore, the glass fibre content in GRP waste improves the reinforcement of the cement composites [4].

Life Cycle Assessmet (LCA) methodology is used to evaluate the beneficial environmental impact due to the increase in material substitution [5].

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Environmental impact assessment of geopolymeric hydraulic pipeline

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The awareness of environmental protection, with the conservation of resources and the efficient use of industrial waste, has attracted the attention in recent decades as both the overexploitation of natural resources and the disposal of industrial waste have a negative impact on the environment and sustainability [1]. Under such circumstances, replacing ordinary Portland cement (OPC) with industrial waste has been shown as a sustainable and practical way to reduce the use of natural resources, as well as landfill waste and pollution [2]. The discussion of this issue is part of a path, which sees as its starting point the design of a hydraulic pipeline prototype (Figure) made of geopolymer mortar instead of conventional concrete pipes. The environmental sustainability of geopolymer mortars was demonstrated through the Life Cycle Assessment (LCA) methodology. The results of the analysis indicate that the use of eco-friendly materials contributes to minimizing the environmental impact of new technologies for hydraulic engineering.

Hydraulic pipeline prototype in geopolymer mortar

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Porcelain stoneware tiles production minimizing the use of importes raw materials

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The path to highly recycled ceramic tiles passes through 4 stages:

1. Basic research able to demonstrate the feasibility of the work also considering the availability of waste
2. Research applied at the laboratory level
3. Technology transfer to the pre-industrial scale
4. Pilot production in the industrial plant.

The final goal includes correct industrial production, product certification and market diffusion. Only when all these steps are successfully passed the path is consolidated and innovation becomes "practical" and it is possible to achieve the concrete benefits of sustainability (social, environmental and economic). This presentation shows a concrete example of success thanks to the precious collaboration of an Italian ceramic tiles industry.

Recycled materials for circular economy in construction sector. A review

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The energy used in the manufacture of construction products and in the construction process plays a major role in the overall environmental impact of a building. Some studies show that 5-10% of total energy consumption across the EU is related to the manufacture of construction products [1]. In addition, Construction and Demolition Waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled. Therefore, a growing trend towards more sustainable construction processes has been taking place for several years, with a particular focus on resources and materials with lower environmental impacts on the entire life cycle. This attention requires a unified vision that integrates social, environmental and economic aspects into a single strategic framework. For this reason, it is essential to find new methods and new applications in order to use resources more efficiently both from the point of view of materials and the reuse of existing buildings. In this field, the objective of the study is to run a review to evaluate the research gap, strategies to reduce construction waste and to promote the recycled materials use for a circular economy [2] in construction sector.

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Circularity performances of the production of a cement mortar reinforced with recycled synthetic fibers

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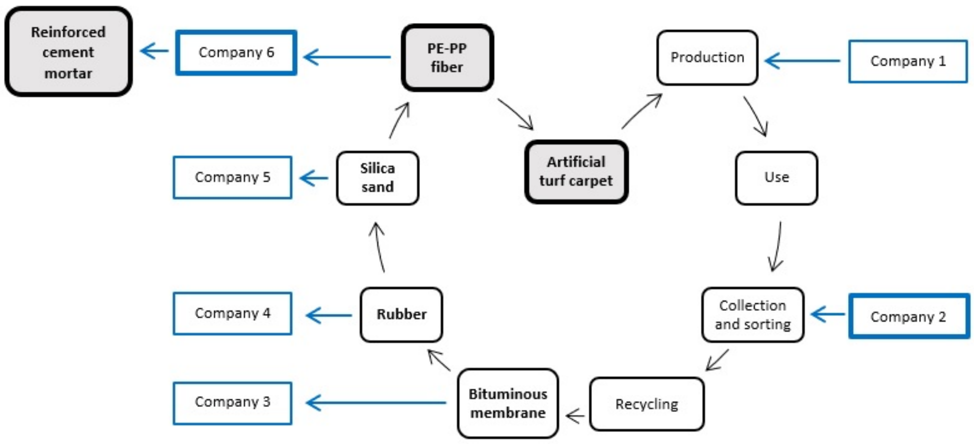
Forced by environmental implications and by legislation requirements, the cement sector is moving towards more circular economy practices, with the primary aim to enhance the sustainability. This commitment translates into product technology innovation, but also into innovative development perspectives for the industries involved in the supply chain. Moreover, dealing with recycled materials, it modifies the interaction among stakeholders from a conventional supply chain to an industrial symbiosis approach, where companies mutually exchange products and by-products into circular interactions. The purpose of this article is to investigate the circularity performances coming from the production of a cement mortar reinforced with recycled synthetic fibers coming from artificial turf carpets. From the collection of artificial turf carpets at the end-of-life stage it is possible to recover several materials: plastic fibers used in the cement mortar, and in addition, silica sand, rubber, and bituminous membrane. The production of the innovative reinforced cement mortar leads to the connection between industries belonging to different sectors and consequently to uneven economic and environmental implications. Starting from the available literature, this study aims at evaluating the circularity of the unusual interaction among companies to support the development of an effective strategy, reducing environmental and economic pressures.



Schematic diagram showing circularity interactions among companies.

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Life cycle assessment of a wall made with agro-concrete blocks with wheat husk

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The purpose of this study is to evaluate the environmental impact, through the Life Cycle Assessment (LCA) methodology, of the entire life cycle of an exterior curtain wall composed of lightweight agro-concrete blocks with aggregates of plant origin, based on wheat husk.

The case study was compared to a traditional hollow brick wall and a wall composed of a single pour of the wheat husk-based mixture.

Assuming the same thermal transmittance as the case study for the alternative scenarios, it was found that the full life cycle damage of the traditional wall is higher (8.6E-2 Pt), followed by the wall composed of a single pour (8E-2 Pt), and the case study (7.9E-2 Pt). The difference is due to production and also partly due to the assumed end of life (landfilling and recycling, respectively, according to the use of glues in the traditional wall that do not allow selective separation).

LCA of fiber-reinforced concrete industrial flooring with recycled plastics

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In the construction sector, in order to reduce environmental impacts in terms of resource use and waste generation, in recent years an increasing number of researchers are studying the potential of recycled waste materials in replacing traditional fibers for the production of fiber-reinforced concrete (FRC), one of the most popular composite materials in construction.

The presented study, realized by LCA Working Group (UNIMORE) according to the LCA methodology and by means of the software SimaPro9.1.1, provides detailed and rigorous information on the impact and on the environmental advantages/disadvantages of this construction technique: starting from the production process of the PET/PE fibers and recycled PET, through the realization of the composite on site and the installation, up to the use and the end of life of the flooring.

The role of product certification in the transition towards the circular economy for construction sector

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In a recent report, the Environmental European Agency [1], evidenced that Member States mainly addressed the 70% recovery target for non-hazardous C&DW set by 2008 Waste framework directive [2] by adopting low-value recycling options. In that, the directive contributed to avoid landfilling disposal and incineration but did not stimulated for C&DW a better-quality recycling standard. The suggested measures for improving the state of the art also include the increase of users’ confidence on the quality of secondary materials such as recycling aggregates (RA) [1]. One of the barriers to their use is the very low preference by designers due to the lack of proper information about the quality of recycled products [3, 4]. At this regard, the information sharing about the quality of the materials [1] and the adoption of product certification schemes [5] - also based on the traceability throughout their life cycle such as Remade in Italy [6] - can increase the acceptance of RA by reducing the negative perception of their quality standard [7]. This study explores by means of case studies the current contribution of product certification including Remade in Italy to improve the acceptance and the diffusion of RA and recycled products for construction sector.

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An environmental sustainability database to support the identification of green construction products

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An approximately 10% of the global energy consumption goes to building materials manufacturing [1]. One of the most prominent trends of recent years is the evaluation of the environmental performance of alternative construction materials (e.g. natural and recycled) that aim to the increase sustainability level of buildings [2]. Life Cycle Assessment (LCA) methodology and tools have been suggested for raising the sustainability level of the built environment and very numerous examples and case studies are proposed in the literature. To support the identification of best solutions, the present paper proposes a simplified tool to collect, use and share knowledge on the environmental sustainability of construction materials. Knowledge is structured on a database and developed by collecting literature LCA results on building materials. The flexible database structure allows customizing its content according to company specificity. The output of the tool consists of charts, maps, and graphical materials; using them designers can compare, in environmental terms, design alternatives to select the best one in environmental terms.

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The EPD as a competitive and transparency tool on the environmental impacts of products and services

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Considering the need of producers to enhance the sustainable products and materials on the market, the EPD Environmentl Product Declaration plays a fundamental role, as guarantee of the declared performances of a product or a service. There are numerous advantages for companies in chosing the EPD that is an effective marketing tool, able to enhance their products, favoring positioning on international markets:

- optimize production processes and reduce costs within the company, monitoring the improvement over time of the environmental performance of products or services,

- enhance the company brand by adopting a transparency policy towards stakeholders,

- counteract the phenomenon of Greenwashing through the help of independent third party bodies that validate the information communicated,

- trace the environmental performance along the entire production chain in a clear, transparent and objective way,

- demonstrate compliance with the Minimum Environmental Criteria CAM Edilizia, which mention EPDItaly as a tool for verifying compliance with the requirements (for example the percentage of recycled material).

Sustainability in building and construction: LCA of 21 mural paints

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Sustainability and environmental impact assessment are essential to orient new generation materials for building and construction. In this study, life cycle assessment [1-2] was applied to a set of 21 mural paints produced by a paint factory in Italy. Data collection covered upstream processes (i.e., raw materials extraction and supply), the core process (i.e., paint manufacture and packaging) and downstream processes (i.e., transport to retailers). Material and energy inputs and outputs for the main additives employed in paint manufacturing (e.g., antifoaming agents, dispersants, coalescing agents, additives, biocides and similar) were gathered from primary and secondary data sources [3-6]. Life cycle impact assessment results were estimated using the EPD method for global warming potential (on average, 0.4÷1.6 kg CO_2/kg paint), photochemical oxidation (0.1÷1.1 g C_2H_4/kg paint), abiotic depletion (0.4÷3.5 g Sb/kg paint), acidification (0.2÷13.4 g SO2/kg paint), and eutrophication (0.5÷3.4 g PO4/kg paint). Overall, upstream processes are responsible for the greatest environmental impact (>44%), with titanium rutile from sulfates being the most impacting raw material. The results informed decision makers and provided a basis for achieving improvement and greener production strategies in the paint factory.

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Limits and potential innovation to a more circular design approach in public procurement refurbishment works

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In 2015, the European Action Plan for Circular Economy had established a set of actions which would have helped to "close the loop" of products lifecycles. It is common knowledge that the building sector alone produces 33% of the total amount of waste in Europe (Eurostat, 2016), therefore "closing the loop" is crucial in order to reduce its impacts and increase its environmental efficiency (Ecorys, 2014). In 2017, the European Commission published a brochure entitled "Public Procurement for a Circular Economy", in which there are illustrated some case studies to encourage a new approach in public procurement construction works. Public authorities could play a key role but unfortunately there isn't enough evidence in this field yet. In Italy, green public procurement in building sector has become mandatory since 2015 but still, there are several barriers to be overcome (e.g. "traditional" design approach; the inadequate construction and demolition waste materials collection and recycling network; the absence of an End of Waste scheme; very few products with an EPD; etc).

As regards refurbishment interventions of pre-existing buildings, this contribution will highlight both the current limits and the potential innovations, in order to reach a more circular design approach throughout technical choices, by analysing official contract documents -drawings and specifications in particular- in which the corresponding author was involved as a consultant to apply the minimum environmental criteria (CAM).

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The environmental sustainability of CBI Europe products through the EPD certification with the aim of implementing circular economy actions

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Environmental sustainability in construction sector has become an absolute value all over the world. There are different green protocol, depending on geographic area, but most of them recognize great importance to LCA study and consequently EPD system ("Environmental Product Declaration") has become a strategic instrument to give value to single construction product.

CBI Europe S.p.A. produces technological and innovative systems for a complete interior installation, with passion and precision, for thirty years, worldwide. The company operates in the production of ceilings in MDF, wood, steel, aluminium, mineral fibre and lightened plaster, partition walls, raised floors.

A sustainability path was started to answer to a Client's requirement, related to a green project in Doha and a product's certification (EPD) project was performed to obtain 4 EPDs related to 4 product's families (about 50 products). Now we are working to extend EPDs and so doing, we realize how many relations are with principles of Circular Economy and which improving actions may be applied. And we are studying how to effectively apply these projects, to decrease use of some raw materials and to obtain better green products for green markets.

2 certified and published EPD

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