

Portugal SB10

Sustainable Building

Affordable to All
Low Cost Sustainable Solutions

Conference
Proceedings

Edited by

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Contents

Foreword	V
<i>Luís Bragança, Manuel Pinheiro, Ricardo Mateus, Rogério Amoêda, Manuela Almeida, Paulo Mendonça, Ana Miguel Cunha, António Baio Dias, Fátima Farinha, Helena Gervásio, Jorge de Brito, Manuel Correia Guedes, Victor Ferreira</i>	
Welcome	VII
Chapter 1: Keynote Lectures	
Net-Zero Energy Buildings: The Next Shift in Green Building? <i>Charles J. Kibert</i>	3
Beyond Green: Changing Context - Changing Expectations <i>Raymond J. Cole</i>	23
Dealing with climate change and resource depletion in Europe <i>Nils K. Larsson</i>	29
Procuring and Financing Sustainable Buildings <i>Thomas Lützkendorf</i>	37
The shift from “less bad” to “0-impact” <i>Ronald Rovers</i>	45
Construction Counts for Climate – Also after Cop15 in Copenhagen <i>Kaarin Taipale</i>	51
Chapter 2: Policies to Low Cost Sustainable Construction	
Benefits of water efficiency <i>Armando Silva Afonso, Carla Pimentel Rodrigues</i>	61
Architecture, tourism and sustainable development for the Douro region <i>António Feio, Manuel Correia Guedes</i>	69
Life Cycle Assessment of constructive materials – a qualitative approach <i>Danielly Borges Garcia, Maria Tereza Paulino Aguilar, Francisco Carlos Rodrigues, Andréa Martins Grativol & Viviane Madureira Sales</i>	77
Portuguese Thermal Building Legislation and Strategies for the Future <i>H. J. P. Gonçalves, M. J. N. Oliveira Panão & S.M.L. Camelo</i>	83

The SURE-Africa Project: Sustainable Urban Renewal – Energy Efficient Buildings for Africa <i>Manuel Correia Guedes, Nick Baker; Torwong Chenvidyakarn; Gustavo Cantuária, Klas Borges, Luis Alves, Joana Aleixo, Italma Pereira</i>	91
Rehabilitation of rural houses as a contribution to Sustainable Construction <i>João Carlos Gonçalves Lanzinha, João Paulo de Castro Gomes</i>	97
Arquitectura Enquanto Interface Dinâmico com o Mundo Natural <i>Alexandre Loureiro</i>	105
Comparative approach to energy behavior of contemporary urban buildings in Greece <i>N. Papamanolis, M. Tsitoura</i>	113
The importance of the external envelope within energy certification of residential buildings in Portugal <i>V. M. Rato</i>	119
Sustainable Mediterranean Urban Development Affordable to All, a Morphological Approach <i>Serge Salat, Daphné Vialan</i>	127
From low cost buildings to eco neighborhoods – possibilities and contradictions in affordable housing refurbishment <i>C. Vitorino dos Santos</i>	139
Material flow analysis for reaching a sustainable model of the building sector <i>Lidia Rincón Villarreal, Gabriel Pérez Luque, Marc Medrano, Luisa F. Cabeza Fabra, Albert Cuchí i Burgos</i>	147
 Chapter 3: Low cost sustainable building solutions	
Low cost sustainable building solutions: A study in Angola <i>Joana Rosa Santos Aleixo, Manuel Correia Guedes</i>	157
Defining eco-efficiency solutions useful during maintenance activities of existing buildings <i>Cristina Allione</i>	163
Lighting Design in Workplaces: A Case Study of a Modern Library Building in Sheffield, UK <i>Dr Hasim Altan, Hasim Altan, Yuan Zhang</i>	171
An integrated approach to products and their environment <i>Cozzo, Brunella; Marino</i>	179
FGD Gypsum Based Composite for Non-Structural Applications in Construction <i>A. Camões, C. Cardoso, R. Eires, S. Cunha, G. Vasconcelos, P. Medeiros, S. Jalali, & P. Lourenço</i>	185

Materic character of constructive dry systems for prefab-House. Research and didactics experience. <i>Alberto De Capua, Francesca Giglio</i>	193
Transforming a double window into a passive heating system <i>J. S. Carlos, H. Corvacho, P. D. Silva & J. P. Castro-Gomes</i>	201
A Influência do tipo de vidro na eficiência energética da envoltória <i>Milena Sampaio Cintra, Larissa Olivier Sudbrack, Júlia Teixeira Fernandes, Cláudia Naves David Amorim</i>	209
The advantage of adaptable buildings with respect to the energy consumption over the life of the building <i>Ruth Collins, Thomas Grey, Mark Dyer</i>	217
Sugar components as a natural reinforcement of earth based construction materials <i>N. Cristelo, J. Pinto, A. Morais, E. Lucas, P. Cardoso, H. Varum</i>	225
The use of Natural Fibres on Architecture: the local economy and the Arts and Crafts <i>Alex Davico, Paulo Mendonça</i>	231
Reabilitação Sustentável de Edifícios Industriais: Melhoria de Iluminação Natural e Conforto Térmico em Miraflores <i>Maria de Lurdes Gaspar Duarte</i>	239
Affordable Houses: a sustainable concept for a light weight steel dwelling <i>H. Gervásio, L. Simões da Silva, V. Murtinho, P. Santos, D. Mateus</i>	247
Sustainable roof-top extension: a pilot project in Florence (Italy) <i>Roberto Di Giulio</i>	255
Environmental and economical viability associated to the sustainability criteria applied in commercial buildings <i>Luciana Netto Jesus, Manuela Guedes de Almeida, António Carlos de Almeida</i>	265
Alternative uses of water in buildings – An affordable sustainable solution <i>M. Maia, C. Pimentel Rodrigues, A. Silva-Afonso, V. M. Ferreira</i>	273
Advantages of using raw materials in low cost sustainable structural solutions for single-family buildings <i>A. Murta, C. Teixeira, H. Varum, I. Bentes, J. Pinto</i>	281
Structural Behaviour of Dry Stack Masonry Construction <i>Rogério Pave, Herbert Uzoegbo</i>	289
How small can a house be? <i>J. Branco Pedro</i>	297
Sustainable construction and architecture in Guinea-Bissau: Opportunities and Challenges <i>Italma Costa Pereira, Manuel Correia Guedes</i>	305

Life cycle cost as base to define low cost sustainable building solutions <i>Sofia Ferreira Real, Manuel Duarte Pinheiro</i>	313
Energy performance and thermal behaviour of light steel buildings <i>P. Santos, H. Gervásio & L. Simões da Silva, A. Gameiro, V. Murtinho</i>	321
Light school buildings. A new way to look at public educational building. <i>Teresa Pochettino, Valeria Marta Rocco</i>	329
Integration of the new component into the design method for thermal insulating connections <i>Zuzana Sulcova, Zdenek Sokol, Frantisek Wald</i>	337
 Chapter 4: High performance sustainable building solutions	
The keep Cool II idea and strategy: from “cooling” to “sustainable summer comfort” <i>S. M. L. Camelo, H. J. P. Gonçalves, C. Laia, M. Richard</i>	347
Exigências de Sustentabilidade dos Materiais de Construção na Documentação Técnica de Obras <i>Bruno Duarte, Hipólito de Sousa</i>	355
High-performance solutions for refurbishment of retail buildings - Retailers review <i>A. Ferreira, M. Pinheiro & J. Brito</i>	363
Utilization of high performance concrete in the design of sustainable buildings <i>P. Hajek, C. Fiala, M. Kynclova</i>	371
Systemic building maintenance management for Malaysian University Campuses: An Analytical Analysis <i>A. Olanrewaju Abdul Lateef, Mohd Faris Khamidi, Arazi Idrus</i>	379
Design of high tech components for controlling thermal inertia in mediterranean regions <i>M. Lemma, A. Giretti, R. Ansuini, C. Di Perna</i>	389
Sustainable environment in steel structures and industrialized insulations <i>Roberta Carvalho Machado, Henor Artur de Souza, Cláudia Barroso-Krause</i>	397
Environmental architecture design applied to high performance industrial buildings – Ladoeiro industrial production of alcohol <i>M. Manso & M. Pinheiro</i>	407
Concepção e Automatização de Sistemas Passivos e Activos para uma Escola Net Zero Energy Building <i>Artur Ribeiro, João Ramos, José Baptista</i>	415
Facades Modules for Eco-Efficient Refurbishment of Buildings: An Overview <i>Helenice Maria Sacht, Luis Bragança, Manuela G. Almeida</i>	423

Development of research related to alkali-silica reaction in concrete with recycled aggregates	433
<i>Miguel Barreto Santos, Jorge de Brito, António Santos Silva</i>	
Geopolymeric Artificial Aggregates as New Materials for Wastewater	441
<i>Isabel Silva, João Castro-Gomes, António Albuquerque</i>	
High Energy Efficiency Retrofit Module Development	449
<i>P. Pereira da Silva, M. Almeida, L. Bragança, V. Mesquita</i>	
Achieving Sustainability through Energy Efficiency while Assuring Indoor Environmental Quality	457
<i>Sandra Monteiro da Silva, Manuela Guedes de Almeida</i>	
Self-compacting concrete (SCC) - Contribution to Sustainable Development	465
<i>P.M. Silva, J. de Brito</i>	
Chapter 5: Monitoring and evaluation	
Life cycle assessment (cradle to gate) of a Portuguese brick	477
<i>M.I. Almeida, A.C. Dias & L.M. Arroja, Baio Dias</i>	
The LT-Portugal software: a design tool for Architects	483
<i>Nick Baker, Manuel Correia Guedes, Nabeel Sheik, Luis Calixto, Ricardo Aguiar</i>	
LCA Database for Portuguese Building Technologies	489
<i>Luís Bragança, Ricardo Mateus</i>	
Portal de Construção Sustentável (PCS): an online tool for sustainable designers	497
<i>M. I. Cabral, A. Delgado</i>	
Energy Performance Certification in Portugal as a tool to achieve real energy savings in buildings	505
<i>Manuel Casquiço, Paulo Santos</i>	
Use of PCM in Mediterranean building envelopes	513
<i>Albert Castell, Marc Medrano, Cristian Solé, Luisa F. Cabeza</i>	
Experimental study on the performance of buildings with different insulation materials	521
<i>Albert Castell, Marc Medrano, Ingrid Martorell, Luisa F. Cabeza</i>	
National portal for the energy certification of buildings: DOCET	527
<i>Ludovico Danza, Lorenzo Belussi, Italo Meroni</i>	
Ecological Footprint: a “switched on”, a “switched off” and “on the move” indicators for ecocompatibility building assessment	533
<i>Roberto Giordano, Silvia Tedesco</i>	

Towards a quantitative thermography for buildings - indoor measurement of thermal losses	541
<i>A. Giretti, R. Ansuini, M. Lemma, R. Larghetti, C. Di Perna</i>	
Methodology for assessing changes to participants' perceptions, awareness and behaviours around sustainable living, in response to proactive sustainable technology interventions in social housing	549
<i>Carolyn S Hayles, Jane McCullough, Moira Dean</i>	
Indoor Performance and Sustainability	557
<i>Pekka Huovila, Antonín Lupíšek, Pierre-Henri Lefebvre, Paul Steskens</i>	
The "energy cost" as performance parameter. A Decision Making Support System for retrofit actions.	565
<i>M.T. Lucarelli, M. Milardi & F. Villari</i>	
Contributo para o Módulo de Turismo da Metodologia SBToolPT	573
<i>Céline Baptista Machado, Ricardo Mateus, José Amarílio Barbosa, Luís Bragança</i>	
Sustainability Assessment of an Affordable Residential Building Using the SBToolPT Approach	581
<i>Ricardo Mateus, Luis Bragança</i>	
Survey on the main defects in ancient buildings constructed mainly with natural raw materials	589
<i>A. Murta, J. Pinto, H. Varum, J. Guedes, J. Lousada, P. Tavares</i>	
Performance measurement and improvement of non residential buildings: carbon dioxide accounting and energy saving	597
<i>Giancarlo Paganin, Cinzia Talamo, Chiara Ducoli</i>	
Behaviour of green facades in Mediterranean continental climate	605
<i>Gabriel Pérez, Lúdia Rincón, Anna Vila, Josep Maria González, Luisa F. Cabeza</i>	
Conception of Sustainable Construction in civil engineering projects. Dimensions and Indicators of Sustainability	613
<i>G. Fernández Sánchez, F. Rodríguez López</i>	
Computer simulation applied to urban analysis for the rehabilitation of sections of the Federal District - Brazil.	621
<i>Caio Frederico e Silva, Milena Sampaio Cintra, Marta Adriana Bustos Romero</i>	
Building's external walls in Life-Cycle Assessment (LCA) research studies	629
<i>J. D. Silvestre, J. de Brito & M. D. Pinheiro</i>	
Economic Feasibility Analysis of Sustainable Construction Measures	639
<i>Liliana Filipa Viana Soares</i>	

Thermal Performance of Residential Buildings with Large Glazing Areas in Temperate Climate	647
<i>M. C. P. Tavares, H. J. P. Gonçalves, J.N.T. F. C. Bastos</i>	
Life Cycle Inventory (LCI) analysis of structural steel members for the environmental impact assessment of steel buildings	655
<i>I. Zygomalas, E. Efthymiou & C.C. Baniotopoulos</i>	
 Chapter 6: Case-studies	
Assessment of Solar XXI Building Sustainability by SBToolPT Methodology	665
<i>Joana Bonifácio Andrade, Luís Bragança, Armando Oliveira</i>	
An Ergological Approach to Building Maintenance	673
<i>M. A. R. Bastos & H. A. de Souza</i>	
A post occupancy evaluation of a BREEAM ‘excellent’ rated office building in the UK	683
<i>S.J. Birchall, J.A. Tinker</i>	
A Sustainable Development Centre: Xrobb il-Ghagin Nature Park, Malta.	691
<i>R. P. Borg, C. Spiteri Staines & J. Borg, C. Fenech</i>	
Traditional vs selective demolition – comparative economic analysis applied to Portugal	699
<i>André Coelho, Jorge Brito</i>	
Building rehabilitation towards primary energy saving: case study	713
<i>Antonio A. G. Coelho, Luiz A. Pereira de Oliveira</i>	
An Integrated Approach for Sustainability (IAS): Life Cycle Assessment (LCA) as a supporting tool for Life Cycle Costing (LCC) and social issues.	721
<i>C. A. Dattilo, P. Negro, R. Landolfo</i>	
Is the Portuguese Energetic Certification System of Buildings an efficient tool to achieve the sustainability?	729
<i>Joaquim Ferreira, Manuel Duarte Pinheiro</i>	
Assesment of Hexavalent Chromium stabilization in artificially contaminated soil using Geosta as a secondary binder	737
<i>Panagiotis Fotis, Nicholas Hytiris, Helen Keenan</i>	
Selecting insulating building materials through an assessment tool	745
<i>S. Lucas, V. M. Ferreira</i>	
Bioclimatic interventions in the refurbishment of educational buildings	753
<i>S. P. Martinis</i>	
The bioclimatic dimension in the Modern residential architecture in Cyprus	761
<i>A. Michael & M. C. Phocas</i>	

Earth, wind and sun: Bioclimatic parameters in an architectural proposal <i>A. Michael & C. Hadjichristos, F. Bougiatioti, A. Oikonomou</i>	769
Life cycle energy and environmental assessment of alternative exterior wall systems <i>H. Monteiro & F. Freire</i>	777
Potential solutions to glazed facades in the tropics <i>Leonardo Marques Monteiro, Anésia Barros Frota</i>	785
Demonstrating cost-effective low energy solutions in Denmark – Results from the Class 1 EU CONCERTO project <i>Ove Mørck, Kirsten Engelund Thomsen</i>	793
Solar XXI building: proof of concept or a concept to be proved? <i>M. J. N. Oliveira Panão & H. J. P. Gonçalves</i>	801
Integrated Design of low-energy houses in Selvino, Italy <i>G. Salvalai, E. Zambelli, G. Masera, F. Frontini, G. Ghilardi</i>	807
Contribution for improving energy efficiency in Malagueira Quarter <i>Francisco Serôdio & J. J. Correia da Silva</i>	815
An experience on applying sustainability and energy efficiency in undergraduate building design <i>Roberta Vieira Gonçalves de Souza, Ana Carolina de Oliveira Veloso, Paula Rocha Leite</i>	825
Traditional and passive house energy footprint calculation methods <i>Dan Stoian, Ioana Botea, Valeriu Stoian</i>	833
Sustainable housing for all, respecting disabilities <i>András Zöld, Mónika Parti.</i>	841
Can LiderA system promote affordable sustainable built environment to all? <i>Manuel Duarte Pinheiro</i>	849

FGD Gypsum Based Composite for Non-Structural Applications in Construction

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ABSTRACT: There are many by-products created in industry that can be recovered or valued for the creation of new products allowing, in this way, the decrease of environmental damages caused by its disposal in landfills. This research work aims at the valuing of several industrial by-products, such as: flue gas desulfurization (FGD) gypsum from exhaust gases of thermoelectric power plants; granulate cork from insulation black cork boards; and textile fibres from the recycling of used tyres.

The composite materials that come from the mixture of these products may be produced according to two different procedures, moulding or pressing, and the result will be products with different features. Through moulding one gets a lighter composite and through pressing one gets a thicker composite with higher mechanical strengths and better surface's finishing. These composites may be used to fabricate masonry blocks for non-structural inner walls of buildings. Therefore, one has done several lab tests in order to obtain the mechanical behaviour of the referred composites so as to confirm the possibility of using it in construction.

1 INTRODUCTION

Knowing that, nowadays, just about 10 % (in weight) of everything what is extracted from the planet by industry will be transformed in an useful product and the remaining can be considered a residue, a sustainable management of the existent natural resources that take us to a sustainable consume too appears to be urgent.

So, the need of a sustainable world demands that more and more alternative products should be used in construction, such as materials that include in their composition industrial wastes. These materials conventionally have been referred to as "green materials".

Several are the by-products generated by the industry that can be recovered or improved to a new product generation, that this way, can minimize the environmental damage resulting from the laying on landfill.

The gypsum is a material largely used in building construction due to its diverse applications. The building sector consumes about 95% of the total gypsum produced. It is calculated that about 80 to 90% of finishing interior work and partition walls in buildings are made of gypsum products, such as plaster and card gypsum (wastebook, 2007).

According to those thermal and acoustical properties, these products contribute significantly to the comfort of millions of persons. Having an extraordinary resistance to fire, the gypsum products contribute to the buildings' security, particularly in the public ones.

FGD Gypsum is a synthetic product derived from flue gas desulfurization (FGD) systems at electric power plants. It is chemically identical to mined natural gypsum and provides more environmentally friendly applications. There are many uses for FGD gypsum, including gypsum panel products, highway construction, agriculture, mining applications, cement production, water treatment and glass making (fgdproducts 2009).

The world availability of FGD gypsum is considerable. Approximately 18 millions of FGD gypsum tons were produced in 2008 in the USA, 60 % of which were reused (acaa-usa 2009). In the European Union, according to 2007 data referring to the 15 European countries (ecoba 2009) 11 millions FGD gypsum tons were produced about, 89 % of which were reused.

Some surveys show that the actual annual world production of FGD gypsum reaches values near the 225 millions of tons and in 2020 will be around 500 millions of tons per year (Malhotra, 2008). The developing countries, namely China (the biggest world producer of FGD gypsum, exceeding the 100 millions of tons in 2004 and India (about 20 millions of tons per year), will decisively contribute to this increase. It is expected that in India the productive capacity of electrical energy coming from electric power plants will double until 2010, what will result in an increase of FGD gypsum production that will reach the 40 millions of tons by then.

The FGD gypsum is also very cheap and rather affordable material, turning it especially attractive in economic terms.

Cork (bark of the plant *Quercus Suber L*), a substance largely produced in Portugal, is a material whose characteristics are of considerable interest for the construction industry. It is regarded as a strategic material with enormous potential due to its reduced density, elasticity, compressibility, waterproofing, vibration absorption, thermal and acoustic insulation efficiency (Gil 2005 & Hernández-Olivares, 1999).

The cork is a natural and ecological product, odourless and it is considered impudrescible and unalterable, maintaining its efficiency for quite a long time.

The cork industry consumes worldwide about 280 000 tons of cork per year. However, about 20% to 30% of the raw cork used at the processing unit is discarded, mainly cork dust and granules which have low granulometry with no industrial interest (Carvalho 1996).

Thus, it has economical and environmental interest to find alternative uses for this industrial by-product from cork transformation, mainly in Portugal, since it is the world's leader producer.

In this research work it was used granulated cork with the aim of lightening the mass of gypsum based composite and, at the same time, providing an improvement of the thermal and acoustic efficiency.

In Europe tyres are produced at a rate of 250 million units per year (www.specialchem4polymers.com, 2004) and nowadays, there are recycling companies that proceed to shredding of used tyres, obtaining separated materials such as crumbed rubber particles, steel fibres and textile fibres from the tyre beads and reinforcement. The textile fibres can be reused, such as in insulation materials or as fibre reinforcing in concrete products (www.wastebook.org, 2007). In this research work the recycled used tyres textile fibres were used with the purpose of providing reinforcement for gypsum composites.

The main purpose of this research work was to develop new mixtures of FGD gypsum incorporating these by-products to value them and to turn the gypsum products more lightweight and sustainable, giving continuity to others studies that aimed at the development of eco-efficient products based on gypsum for construction applications (Eires et al. 2008, Eires et al. 2007a, Eires et al. 2007b, Eires et al. 2006).

Therefore, the characterization and improvement of the compositions was carried out. So, one has done several lab tests in order to obtain the mechanical behaviour of the referred composites so as to confirm the possibility of using them in construction.

2 MATERIALS, COMPOSITIONS, MANUFACTURE AND CONSERVATION

2.1 Materials

The FGD gypsum formed in the system of treatment gaseous effluents of a Portuguese electric power plant, is presented under the shape of calcium sulphate bi hydrated ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) with 7% of humidity. In order to be reactive with water it should be changed to calcium sulphate hemi hydrated ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$). Based on the test of differential scanning calorimetry and thermo-gravimetric analyses (DSC-TGA), it was selected the temperature of 105 °C to the dehydration, changing the material as the equation 1:



In table 1 it can be seen the chemical similarity of FGD Gypsum with the conventional gypsum, available at the market and usually known as plaster gypsum.

Table 1 – Chemical composition of FGD and conventional gypsum

Gypsum	CaO	SO ₃	F	Fe ₂ O ₃	SiO ₂	Al ₂ O ₃	MgO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	SrO	ZrO ₂
FGD	40.1	54.4	1.61	0.28	1.58	1.11	0.418	0.261	x	0.0134	0.106	0.001	0.001
Conventional	41.3	56.0	x	0.22	1.11	0.395	0.696	x	0.0567	x	x	0.183	0.024

It was achieved the granulometric distribution of the FGD gypsum and a conventional gypsum and it was verified that the first had a bigger fineness, resulting in a small percentage of the retained material on the sieve 100µm (about 2%) opposite to the conventional gypsum (54 % of material retained in sieve 100 µm).

One has also determined the compressive strength resistances of FGD and conventional gypsum, according to EN 13279-2. The FGD gypsum presents a superior strength resistance, achieving 17.4 MPa, while the conventional gypsum reached a resistance of 9.2 MPa.

The used granulated cork was a regranulated of expanded cork, a by-product of a Portuguese industry of black agglomerate cork boards, being the material constituted by different particles sizes: 2/4mm, 2/9mm and 4/8mm. The density is respectively: 166, 182 and 198 kg/m³ and the bulk density is 65, 73 and 72 kg/m³.

The used tyre fibres are a material obtained by a Portuguese recycling company of used tyres shredding. These fibres are generally composed by wires and polymeric cords and some rubber residues, being the main element the polyamide 6.

Some dimensional analyses of the fibres were done that consisted of determining the length and the diameter, using an optic microscope with photographic record. It was verified a large dispersion of the fibres length, being the minimum value obtained of 108.2 µm and the maximum value of 12469.1 µm. The average value was 20.69µm with a standard deviation of 1993.2 µm. The fibres diameter is also variable, being the minimum value obtained the 7.2 µm and the maximum 34.1 µm with an average of 20.7 µm.

In the compositions it was also used a setting time retarder for gypsum: citric acid. The incorporation of this material was essential since it was verified that FGD gypsum reacts quickly with water, solidifying the mixture, hindering the maintenance of the working time at reasonable levels during the necessary time to handle the composite at wet state.

2.2 Compositions, manufacture and conservation

Aiming at the final composition selection of the composite material to be used in the manufacture of blocks for interior building walls, it was realized an experimental campaign with the objective of characterizing, under a mechanical point of view, the produced compositions.

Thus, a pressed composition (P) and three moulded compositions (M) were studied. The P composition was constituted only by FGD gypsum, water and citric acid, and in the M compositions, with cork incorporation, the amount of granulated cork was varied from 5, 7 and 9 % (M5, M7 e M9) related with the gypsum weight used. The tested compositions are presented at Table 2.

Table 2 – Mixture compositions (at % of gypsum mass)

Typology	water	Retard.	Cork	Fibres
M5 moulded	80.0	0.05	5.0	3.0
M7 moulded	87.5	0.05	7.0	3.0
M9 moulded	93.75	0.05	9.0	3.0
P pressed	22.5	0.05	–	–

The water content of moulded compositions was determined experimentally so as to check an adequate working time, which consisted of assuring a flow spread comprised between 140 and 150 mm according to EN 13279-2.

The added water amount in the pressed mixture also resulted from an experimental procedure, done with the objective of manufacture the compositions with the minimal amount of necessary water for gypsum hydration. One has done several tests of pressing with different water percentages in the mixture until obtaining an optimal solution that assured a good superficial finishing, that was admitted as guarantee of a good compactness.

The used retarder dosage was fixed after experimenting several mixtures, containing different acid citric dosages. The tests revealed that the setting time increased with the retarder rise, the same occurred with the flow spread. However, it was verified that the mechanical resistances (compressive and flexural strength) diminished with the retarder dosage increase. So, according to the described, it was adopted a acid citric dosage of 0.05 % of gypsum mass, since that assured the obtaining of paste with enough setting and working time without affecting significantly the mechanical resistances.

The textile tyres fibres dosage was selected based on the product availability and on the fibres effect in the mechanical resistances. Considering the two aspects, it was adopted the dosage of 3 % of gypsum mass.

Regarding to the pressed composition, one has decided not to include the cork in the mixture neither the textile fibres, since this incorporation has revealed adverse, both the mechanical resistances point of view and the superficial finishing.

The mixture process and the samples manufacture were accomplished according to EN 13279-2.

To evaluate the behaviour and the mechanical properties (compressive and flexural strength and elasticity modulus) of the compositions M5, M7 and M9 6 cylindrical samples with 50 mm of diameter and 100 mm of height and 6 prismatic samples with 40x40x160 mm³ were moulded.

The samples of composition P, shaped by pressing, result of moulding of boards with 35x300x600 mm³ that were submitted to a pressure of 5 MPa after, diminishing the thickness from about 13 to 14 mm. From these boards, through the cut by damp way, 6 samples with 13x14x27 mm³ and 6 with 13x40x160 mm³ were produced.

After manufacture, all the samples were kept in the laboratory at room temperature (about 22 °C) during 7days. In relation to the samples resulting of pressed board, obtained through cut by damp way, immediately after the cut, they were placed in a drying oven at a temperature of 100 °C during about 2 hours.

3 TEST PROCEDURES

3.1 Compressive behaviour

The elasticity modulus in compression of moulded and pressed material was obtained based on the LNEC specification E 397.

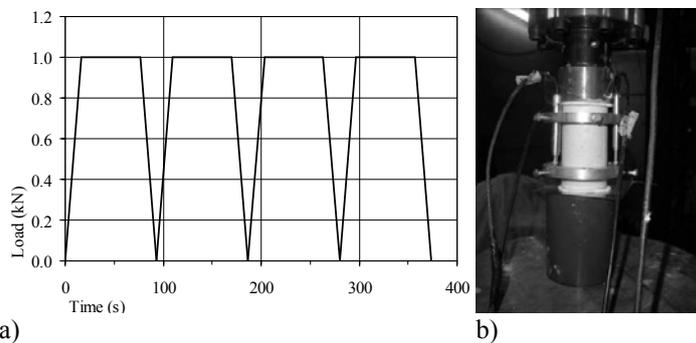


Figure 1 – Elasticity modulus tests: a) loading load; b) general setup for moulded samples

The samples were submitted to 4 load and unload cycles with constant velocity of 0.06 kN/s. The maximum and minimum values of applied load were determined through preliminary tests of uniaxial compression in order to assure that the applied stress was not superior to 30 % of compressive strength. It is generally accepted that the elastic material behaviour in compression

is developed just for load less than 30 % of that corresponding to compressive strength (Choi e Shah, 1998; Vasconcelos, 2005). After the maximum load of 30 % of average compressive strength was reached, the samples were maintained under the load action during 60 second, period after which the unload was initiated. The loading law followed in the elasticity modulus tests can be founded at Figure 1a. The load application on the sample was carried out using a thick steel board so as to be sufficiently rigid to uniform the vertical load (Fig. 1b).

In order to minimize irregularities of side samples, these were previously rectified and after covered at the base and top side with a polyester resin of rapid cure. The covering material was always applied before beginning of the test, with the sample vertical aligned and slightly compressed so as to assure the perfect adjust between the load application elements and the sample. In the moulded samples, the vertical displacement was measure through of 3 LVDTs fixed at the sample and positioned according to three equidistant generatrix lines, distanced of 120 °. The used LVDTs have a measure field of ± 2.5 mm and a precision of 0.01 %. The measured distance by the LVDTs was approximately 45 mm. Due to the reduced height of pressed samples, the vertical displacements were pointed out turning to an external transducer, that measured the displacements between the metallic side boards in contact with the sample.

The behaviour under compression of the studied compositions was analyzed based on uniaxial compression tests realized through vertical displacement control. The used loading velocity was 5 $\mu\text{m/s}$, assuring the maximum load was achieved in a period of time comprised between 2 and 15 minutes. Simultaneously, the adopted velocity had as objective the registration of the complete stress-strain diagram and, allowing this way to characterize completely the behaviour of each material after reaching the maximum stress. The vertical displacements registration was made using the same LVDT configuration used for measuring elasticity modulus.

3.2 Flexural behaviour

For the moulded samples, the flexural behaviour was evaluated based on the EN 13279-2 and on the ASTM C1018. The application load scheme was the 4-point flexure test. The used samples for flexural test were prismatic with dimensions of 40x40x160 mm³ and 13x40x160 mm³, for, moulded and pressed samples respectively. The tests were carried out with displacement control, through a LVDT placed at sample middle-span. The load velocity for the moulded samples was determined according to the recommendations of ASTM C1018, which indicates that the rupture must occur after a period of 45 s (10 $\mu\text{m/s}$). The load velocity for the pressed samples, due to the lower thickness and the high rigidity, was fixed to the minimum velocity permitted by the test equipment in order to allow a period of time near to the anterior (1 $\mu\text{m/s}$). The vertical load was applied through a metallic rigid beam supported in two steel rollers that transmitted punctually the load to the sample. The flexural test setup is illustrated at Figure 2.

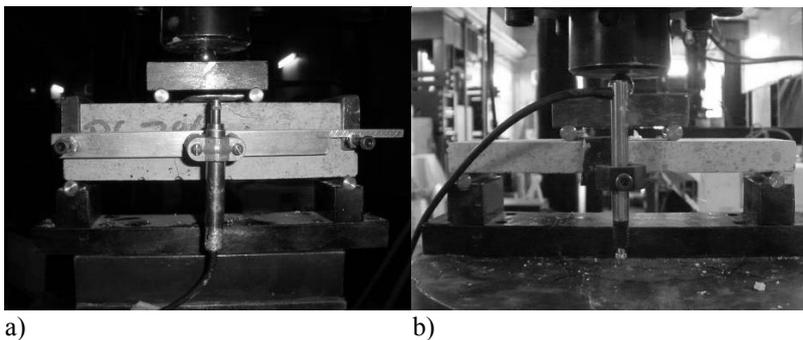


Figure 2 – Flexural test: a) moulded sample; b) pressed sample

4 PRESENTATION AND DISCUSSION OF OBTAINED RESULTS

Table 3 shows the average values of the densities, γ_m , and the mechanical properties, coming from experimental results, namely the elasticity modulus, E_m , compressive strength, f_m , and flexural strength, $f_{m,fl}$. The coefficients of variation are presented in brackets and are in percentage.

In Figure 3a it is possible to observe the behaviour in compression for the different compositions, expressed by the correspondent average stress-strain curve. Figure 3b shows the same average curves, but referring only to the moulded compositions.

Figure 4 shows the average diagrams stress vs. displacement at middle span obtained at flexural tests for the studied compositions. The flexural stress corresponds to the installed values in transversal section considering that the stress distribution along the section is elastic and linear. It is noted that the procedure for stress calculation is only approximated considering that in the pre-peak regime, and particularly in the post-peak regime, the behaviour is obviously non linear.

The global behaviour in compression and flexure of the pressed and moulded material is significantly different. The pressed material is considerably more resistant, but more brittle than the moulded one. The post-peak at the stress-strain diagrams of the pressed material expresses a stronger reduction of the stress to the same deformation than the verified at moulded material.

Table 3 – Experimental results

	M5	M7	M9	P
γ_m (kg/m ³)	825	760	675	1575
E_m (MPa)	1899.6 [4.7]	1311.8 [12.1]	823.3 [1.5]	2196.9 [17.1]
f_m (MPa)	3.1 [2.7]	2.0 [13.4]	1.1 [5.8]	13.3 [18.2]
$f_{m,fl}$ (MPa)	0.58 [5.4]	0.68 [4.9]	0.55 [6.3]	1.47 [10.0]

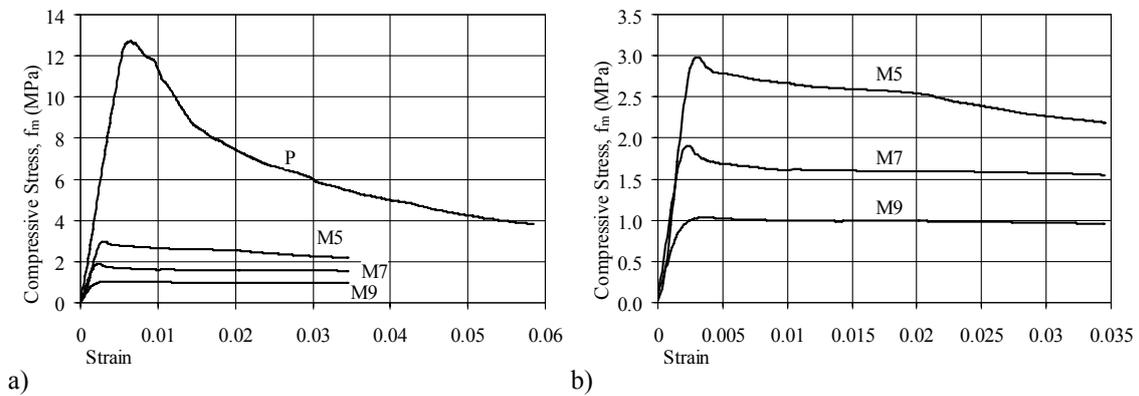


Figure 3 – Compressive behaviour (stress-strain curve): a) all compositions; b) moulded compositions

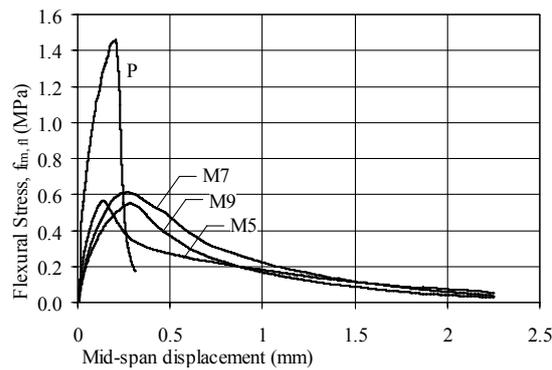


Figure 4 – Flexural behaviour: stress vs. at middle span displacement curve

In compression, the post-peak behaviour of moulded material is characterized by a slight resistance reduction for considerable displacement, expressing this way a much more ductile material. It is verified a resistance increase and a ductility reduction of the moulded material with diminish of cork percentage, in spite of not being registered a considerable difference in the flexural strength. On the other hand, it was verified that the pressed material reveals to be more brittle, with a very quickly resistance loss (without displacement increase) after achieving the maximum resistance. In terms of rupture it is verified that in moulded material the rupture developed through the base or the top, where a level of the sample is crushed and after developing

gradually with the crushing of near successive levels. The appearance of the rupture in the base or top is related to the border effect on these areas. In the pressed material the rupture occurs with the development of vertical cracks that were propagated from a sample side to other. The diagrams stress-displacement analyses for the moulded mixtures makes it possible to conclude that important differences in the global flexural behaviour were not verified.

In Figures 5a and b it is possible to observe the cork dosage influence at the elasticity modulus of the composite and at the compressive strength, respectively.

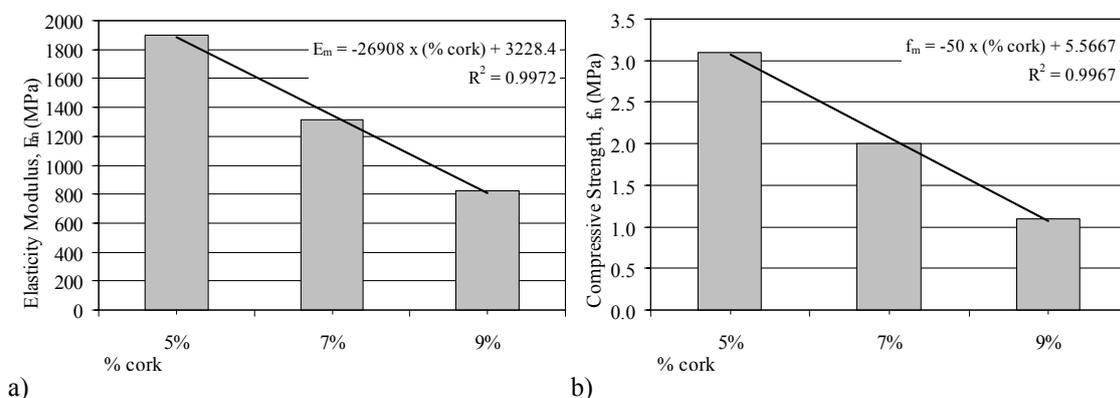


Figure 5 – The cork dosage influence: a) at the elasticity modulus; b) at the compressive strength

In general terms, based on the obtained results, showed at Table 3 and Figures 3 to 5, it is possible to notice that:

- The mechanical characteristics of the pressed composition are, as predicted, quite superior to the moulded compositions;
- The compressive strength of pressed composition is about four times superior to the moulded composition;
- The flexural strength of pressed composition is, also, superior to the verified in the moulded compositions. However, the difference was not so strong, achieving about the double of the resistance of the moulded composition;
- The elasticity modulus of pressed composition is superior to the moulded compositions. However, the difference of the moulded composition with biggest elasticity modulus was only about 15 %;
- In the moulded compositions, the decrease of the elasticity modulus with the rise of the cork amount was nearly linear. To an increase of 1% of cork corresponded a decrease of the elasticity modulus superior to 30 %;
- In the moulded compositions, the decrease of the compressive strength with the rise of cork amount was, also, nearly linear. To an increase of 1% of cork corresponded a decrease of the compressive strength superior to 35 %;
- The results of flexural tests didn't reveal sensitive to the cork amount variation of the compositions;
- The capacity of energy absorption of moulded compositions, whether in compression or in flexion, was really superior to the pressed composition, showing a better ductility behavior.

5 CONCLUSIONS

According to the results obtained, one can conclude that the use of a mixture containing FGD gypsum, granulated cork and textile fibres is viable for several applications in construction, since it is regarded as constituent material of a product with non structural functions. At this context, the initial applicability premise of this kind of material in not resistant masonry blocks seems practicable and can be a very interest way of valorisation of these industrial by-products.

The obtained results of the realized tests allow to verify that there is a clear decrease of the compressive and flexural strength with the cork incorporation related to the pressed gypsum mixture.

Furthermore, it is verified that there is a linear relation between the elasticity modulus and the compressive strength with the cork percentage at the moulded mixtures, meaning that the bigger the cork percentage, the smaller the elasticity modulus and the compressive strength.

The mechanical performance of the material based on FGD gypsum can be considerably improved if one doesn't use the incorporation of cork and tyre fibres and if one uses shaping through pressing. However, this solution is significantly heavier, the manufacture process is also more expensive and the potentialities, in shape terms, are much more limited. Nevertheless, the combined use of these two solutions (moulded and pressed), can result in an interesting product once the pressed solution presents a smaller porosity and consequently an inferior permeability.

6 ACKNOWLEDGMENTS

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