Portugal SB07

Sustainable Construction

Materials and Practices

Challenge of the Industry for the New Millennium

edited by
Luis Bragança
Manuel Pinheiro
Said Jalali
Ricardo Mateus
Rogério Amoêda
Manuel Correia Guedes

IOS Press
Contents

Part 1

Foreword
Luis Bragança, Manuel Pinheiro, Said Jalali, Ricardo Mateus, Rogério Amoêda and Manuel Correia Guedes

Welcome

Chapter 1. Actions and Policies to Implement Sustainable Construction

Energy Ratings Based on Measured Energy Consumption: A Practical Approach for Implementation of EPBD and Identification of High-Energy Use Buildings
P. Hernandez, P. Kenny and R. Cohen

Achieving Sustainable Infrastructure in Washington DC
M. Cederoth

Sustainability Recommendations for a Social Housing Project: Barreiros, Vitória (BR)
M. Bissoh, J.L. Calmon and K. Caser

Sustainable Housing: From Consensual Guidelines to Broader Challenges
J. Mourão and J. Branco Pedro

The Impacts of Residential Buildings – How to Identify Life Cycle Based Improvement Potentials
B. Wittstock, C. Makishi, A. Braune, J. Kreißig, N. Gallon and C. Wetzkel

The Contribution of the National Laboratory of Civil Engineering (LNEC) to a Sustainable Built Environment
C. Pina Santos, J. Branco Pedro and J. Vasconcelos Paiva

Energy Efficiency of Old and New Buildings in Romania
D. Dan, V. Stoian, T. Nagy-Gyorgy and C. Dăscău

Construction Sites Environment Management: Establishing Measures to Mitigate the Noise and Waste Impact
J.P. Couto and A.M. Couto

How to Attract Consumers and Real Estate Agents to Sustainable Housing
A. van Hal

Integrating the Environmental Management Systems into Construction Industry:
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasons to Consider the Deconstruction Process as an Important Practice to Sustainable Construction</td>
<td>76</td>
</tr>
<tr>
<td>J.P. Couto and A.M. Couto</td>
<td></td>
</tr>
<tr>
<td>Methodology for the Application of Sustainable Construction</td>
<td>82</td>
</tr>
<tr>
<td>L.N. Jesus, M.G. Almeida and A.C. Almeida</td>
<td></td>
</tr>
<tr>
<td>The Calculation Model of the New Portuguese Thermal Regulation – Put Side by Side with Dynamic Simulation</td>
<td>90</td>
</tr>
<tr>
<td>P. Silva, L. Braga Bessa and M. Almeida</td>
<td></td>
</tr>
<tr>
<td>Local Actions to Improve the Sustainable Construction in Italy</td>
<td>98</td>
</tr>
<tr>
<td>C. Clemente</td>
<td></td>
</tr>
<tr>
<td>Alternative Network Geometry of Essential Networks for Enduring Sustainable Development</td>
<td>105</td>
</tr>
<tr>
<td>A. van Turnhout, J. Kristinsson and L.C. Röling</td>
<td></td>
</tr>
<tr>
<td>The Certification of Buildings as an Enterprise Strategy of the Real Estate Sector: A National Scope Analysis</td>
<td>113</td>
</tr>
<tr>
<td>E. Cepinska, P. Ferrão and S. Santos</td>
<td></td>
</tr>
<tr>
<td>The Sustainability in Rehabilitation and in its Education</td>
<td>121</td>
</tr>
<tr>
<td>J.S. Elizário, A.R. Pereira Roderi and I. Valverde</td>
<td></td>
</tr>
</tbody>
</table>

**Chapter 2. Sustainable Management of Existing Building Stock**

A Framework to Sustainable Renewal of Existing Building Stock in Brazil

M.A.S. González and A.P. Kern

Sustainability and Natural Resources Uses at a South Brazilian University: Proposing an Environmental Plan to University of Passo Fundo


The Service Integrated Envelope Applied for Sustainable Office Refurbishment

T. Ebert and U. Knack

Characterization of the Lisbon Elementary Public School Building Stock

S. Raposo, M. Fonseca and J. de Brito

Overcoming the Barriers to Improving the Sustainability of Existing Commercial Office Buildings

J.B. Storey

Sustainable Management of Existing Building Stock: A Strategy to Reduce the Energy Consumption and the Environmental Impact

E. Mata, F. López and A. Cucli

Housing and Information Society: Integration of ICT in the Existing Housing Stock

Thermal Rehabilitation of a Student’s Hostel Belonging to the “Politehnica” University of Timișoara

D. Dan, V. Stoian, T. Nagy-Gyorgy and C. Dăescu

Existence and Progress of Deterioration of Concrete Facades

J. Olińska, J. Wielga and U. Marttila

Environmental Assessment of the Maintenance of Façade Openings in Dwellings – The Dutch Case

I.S. Blohm and L.C.M. Ibari

How Sustainable Rehabilitation Designers Really Are

A.R. Pereira Roderi, J. Post and P.A. Kerkens

Sustainable Management of Building Stock Refurbishment by Using MCDM

J. Selih

Renewal of a Big High Density Housing Block in Berlin Kreuzberg

S. Giussani

Sustainable Management of Buildings

T. Håkkinen, E. Vestakari and S. Palakka

Effect of Balcony Glazing on the Durability of Concrete Structures in Nordic Climate

J.S. Mattila

Technical Solutions for Sustainability in Post-War Residential Areas

S. Fiddien

Sustainable Technologies in the Refurbishment of Existing Building Envelopes in Italy

S. Brunoro

Sustainable Recovery Approach to the Existing Housing Stock in Italy

P. Civiero

Living Building Concept: New Approach to Value Delivery in the Built Environment

R. Vrijhoef and H. de Ridder

Measuring the Effect of Design Changes by a Neuro-Fuzzy System

S. Durmesevic, S. Sarıyıldız and Ö. Ciftcioglu

**Chapter 3. Building Sustainability Assessment Tools**

Early Design Stage Evaluation Tool for Sustainable Energy Systems in Large New Buildings

K. Shank

The Use of EPDs in Building Assessment – Towards the Complete Picture

A. Braune, J. Kreßl and K. Stollbauer
Hygrothermal Profiles of Building Elements in the Context of Service Life Design .......................... 553
C. Giramma, D. Bisiks and D. Aravaninos

Comparison of Two Structural Reuse Options of Two-by-Four Salvaged Lumbers .......................... 561
S. Nakajima and T. Murakami

Building Deconstruction and Building Heritage Preservation: A Case Study at Porto’s World Heritage Historical Centre .......................... 569
R. Amédia and C. Pinheiro

Organisation of Reverse Logistics Tasks in the Construction Industry .............................................. 577
F. Schützmann and N. Sunke

Overview of Deconstruction Activities in Portugal .............................................................................. 583
A. Samos and J. de Brito

Salvageability of Building Materials ................................................................................................. 593
A.S. Nordby, B. Berge and A.G. Hestnes

Reusability of Massive Wood Components ....................................................................................... 600
A.S. Nordby, B. Berge and A.G. Hestnes

Motives for Design for Disassembly in Building Construction .......................................................... 607
C. Thorunmark

Bionic Breathing Skin for Buildings .................................................................................................. 612
L. Badarnah and U. Knaack

An Ecosystem Based Biomimetic Theory for a Regenerative Built Environment .............................. 620
M. Pedersen Zari and J.B. Storey

Practices and Sustainable Principles on the Rural Constructions in Molise Region (Italy) ................. 628
G. Anselmi and D. Fornebro

Author Index ........................................................................................................................................ 634

Part 2

Foreword ................................................................................................................................................ 645
Luis Branqo, Manuel Pinheiro, Said Jalali, Ricardo Mateus, Rogério Amoêda and Manuel Correia Guedes

Welcome ............................................................................................................................................... 653

Chapter 5. Designing the Sustainable City of Tomorrow and Urban Sustainability
Environmental Performance and Management of Sustainable Urban Projects ................................. 677

Chapter 6. Sustainable Resources, Eco-Materials and Technologies
Chapter 7. Use of Industrial Waste

Composite Panels Reinforced with Waste Fibrous Materials
M.G. Gomes, R. Farguelo and C. Gonilho Pereira

Using Mine Waste Mud to Produce Environmentally Friendly New Binders
F.P. Torgol, J.P. de Castro Gomes and S. Jalali

Use of Cellulose Sludge in the Production of Fibrecont Building Materials
R. Modolo, J.A. Labricha, V.M. Ferreira and L.M. Machado

Application of Crushed Glass Residues in Mortars

Optimization of Pozzolanic Reaction of Ground Waste Glass Incorporated in
Cement Mortars
L.A. Pereira de Oliveira, J.P. Castro Gomes and P. Santos

Chemical Characterization and Leaching of Treated Fly Ash from a MSWI Plant
L.M. Martinis, A.M. Esteves and J.P. Forth

Eco-Friendly Construction Materials Using Gypsum and Industrial Wastes
R. Eires, A. Camões and S. Jalali

Concrete Produced Using Crushed Bricks as Aggregate
P.B. Cachim

Chapter 8. Innovative Sustainable Construction Systems

Glocal Structural System in a Seismic Desert City
S. Shahmorad and A.I.M. Voorbix

Coolhouse: Integrating Very Low Energy Geothermal Cooling with Sustainable
Construction
P. Malinowski
Sustainable Building Structures for Housing
D. Dubina, V. Ungureanu and M. Mutlu

Sustainability of Constructions, Van Abbenmuseum, Eindhoven
Y.K. Aktuglu

Sustainability of Constructions, Suleyman’s Mosque, Istanbul
Y.K. Aktuglu, M. Altin, M. Tanac Kiray, O. Yilmaz Karaman,
M. Secer, O. Bozkugu and I. Kahraman

Case Study: LEED™ by Design in the School of the Future
J. Klédyński

Influence of End-of-Life Scenarios on the Environmental Performance of a
Low-Rise Residential Dwelling
H. Gervásio and L. Simões da Silva

The SHE Project: Sustainable Housing in Europe. Social Housing Coops’ Best
Practices for Sustainable Communities
A. Lasardi and A. Braccioni

Natural Illumination Availability in Ponte Da Pedra Apartment Block —
A Case Study
C. Cardoso, M. Almeida and L. Bragança

Author Index
Using mine waste mud to produce environmentally friendly new binders

Fernando Pacheco Torgal  
Polytechnic Institute of Castelo Branco, Castelo Branco, Portugal

J.P. de Castro Gomes  
Universidade da Beira Interior, Covilhã, Portugal

Said Jalali  
Universidade de Minho, Guimarães, Portugal

ABSTRACT: It is now accepted that new binders, such as alkali-activated binders, are needed to replace portland cement for enhanced environmental and durability performance. Alkali-activated binders have emerged as an alternative to (ordinary portland cement) OPC binders, which seem to have superior durability and environmental impact. This paper reports results of a research project on the development of an alkali-activated binder using mineral waste mud from the Panasqueira tungsten mine in Portugal. Results show that with proper mix design, this new binder presents exceptionally high compressive strength even at early ages. Results also indicate better abrasion and acid resistance compared with concrete using OPC. Leaching tests show that the new binder is considered an inert material which indicates that it could be used as a building material.

1 INTRODUCTION

Alkali-activated binders have a long history in the former Soviet Union, Scandinavia, and Eastern Europe (Roy, 1999). In 1978, Davidovits coined the term “geopolymer”, to describe new materials with the ability to transform, polycondense and adopt a shape rapidly at low temperatures like “polymers” (Davidovits, 1991).

The polymerisation process involves a chemical reaction under highly alkaline conditions in which Al-Si minerals yield polymeric Si-O-Al-O bonds with an empirical formula Mn·[(Si-O)x·(Al-O)y]·nH2O, where n is the degree of polymerization, x = 1, 2 or 3, and M is an alkali cation, such as potassium or sodium (Davidovits, 1999). Davidovits reported several advantages of geopolymeric cementsitious systems over Portland cement, mainly environmental, due to the fact that geopolymeric-based concrete has a much longer service life than Portland cement based ones, high capacity for heavy metals waste encapsulation, and lower CO2 emissions, 0.18 tones of CO2 per tonne of cement (Davidovits, 2002).

The geopolymerisation requires a precursor that contains significant quantities of silicon and aluminium in an amorphous phase such as fly ashes from electrical power stations. Portuguese generation of fly ash is near 3% of the annual Portuguese Portland cement production. This means that aluminosilicates from geologic origin are probably the only reasonable alternative material for production of alkali activated environmental friendly binders.

Previous studies concerning the geopolymerization of different minerals suggest that a wide range of Al-Si based minerals can be used as sources of materials (Davidovits, 1996).

2 THE RESEARCH

2.1 Mine waste raw material

Panasqueira is an underground mine utilizing room and pillar mining methods situated in central Portugal on the southern edge of the Sierra da Estrela mountain range, a natural park, close to Serra do Açor, a protected landscape, and also near the Zêzere river (Fig. 1).

Figure1. Aerial View of the Panasqueira tungsten mine

Tungsten and tin have been mined in the Panasqueira area since the 1890s. In the mid 1980s, Panasqueira’s had over 1,000 employees in its underground mining and plant operations that processed 600 000 tonnes of ore per annum to produce in excess of 2,000 tonnes of tungsten oxide (WO3) representing 0.3% of excavated rock. During the mining process two types of mine waste are generated, coarse aggregates derived from rock blasting which is in fact a by-product used in minor quantities by the road pavement industry and waste mud conveyed by pipelines into lagoons amounting to several million tonnes of deposited material, while still generating almost 100 ton per day.

Tungsten mine waste mud used in this study was subjected to a thermal treatment at 950 °C during 2 hours, mineralogical composition and thermal conditions are described elsewhere (Torgal, 2007). The XRD patterns indicated that mine waste mud consists mainly of muscovite and quartz which were identified by their characteristic patterns as follows: muscovite (card 46 - 1409) and quartz (card 46 - 1045). For wastes treated under these thermal conditions XRD patterns indicated that dehydroxylation did not result in a complete collapse of muscovite structure. Calcinations leads to formation of an amorphous phase, causing an increase in the general back-
although it decreased considerably. Peak area measurements revealed that about 12% of muscovite survived calcination at 950°C.

Molecular changes during dehydroxylation were also examined with infrared emission spectra (FTIR), confirming decrease in the absorption peaks at 3600-3700 (OH stretch), however the main muscovite peak did not disappear totally indicating only a partial transformation. Compressive strength data related to geopolymeric mortars made using raw waste mud and calcined waste mud showed an increase of more than 300%, hence, justifying the thermal treatment.

Caleinations of mine waste mud in a static furnace, as the one used in this study, need large amounts and may become expensive and less environmentally friendly. However, industrial flash calcination have been already developed with 800 Kg/h production units, capable of reducing calcination time to a few seconds and with the additional advantage of dispensing with the further grinding operations (Salvador, 2006). This process apparently cuts down significantly the cost of thermal treatment.

2.2 Chemical composition and specific surface

The chemical composition and specific surface of the mine waste mud are shown in Table 1.

<table>
<thead>
<tr>
<th>Constituents (%)</th>
<th>Mine waste mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>53.48</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.66</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>12.33</td>
</tr>
<tr>
<td>K₂O</td>
<td>7.45</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.62</td>
</tr>
<tr>
<td>MgO</td>
<td>1.27</td>
</tr>
<tr>
<td>S O₄</td>
<td>3.10</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.39</td>
</tr>
<tr>
<td>As</td>
<td>1.28</td>
</tr>
<tr>
<td>Other minor oxides</td>
<td>2.22</td>
</tr>
<tr>
<td>Blaine fineness (m²/kg)</td>
<td>357</td>
</tr>
</tbody>
</table>

The figures clearly show that mine waste mud consists essentially of silica and alumina, contaminated with arsenic and sulfur and with a high content of iron and potassium oxide content. Although it is known that iron oxide contributes to the strength gain of Portland cement its contribution in geopolymer cement is still not well understood. The SiO₂/Al₂O₃ atomic ratio is 5.5 higher ~2 suggested by Davidovits for making cement and concrete. However, Pinto (2004) using alkali-activated metakaolin based mixtures found that some mixtures with calcium hydrosilicate and an atomic ratio of SiO₂/Al₂O₃ = 5.1 lead to higher compressive strength gains. Nonetheless, the final SiO₂/Al₂O₃ atomic ratio in the hardened binder depends mainly on the reactivity of Al-Si because not all the silica and alumina are reactive. In spite of the fact that Al and Si have synchro-dissolution behaviour in alkaline solution, e.g. they dissolve from the mineral in some linked form; one can not expect the same Si/Al ratio in the final hydration product as the one present in the original precursor material. Indeed most of the Al-Si materials cannot even supply sufficient Si in alkaline solution to start geopolymerization, this explains why they need extra silica provided in solution by waterglass, which influences the Si/Al ratio of the hardened binder.

The Blaine fineness of the mine waste is relatively low, but is still in the range of the most used slag based alkaline binders. To compensate for this lack of high fineness, highly alkaline-silicate activators can be used. Some authors analyzed the joint effect of specific surface, curing

cress in specific surface has been reported when NaOH and waterglass activator has been used (Fernandez-Jimenez et al., 1999).

2.3 Mix design

Given the proper mix design geopolymeric mine waste mud (GMWM) binders shows significant early age cementing properties. The H₂O/Na₂O molar ratio in the mixture is an important parameter being closely related to compressive strength and structure formation. This can be attributed to increased dissolution of mine waste in the presence of sodium hydroxide at higher concentrations. The use of waterglass/sodium hydroxide mass ratios of 2:1 and 1:5:1 and high levels of calcium hydroxide content and sodium hydroxide concentration leads to unfeasible mixtures due to a very fast setting time and hardening rate. Early age compressive strength of alkali-activated MWM mortars is highly dependent on the calcium hydroxide content. The use of alkali-activated MWM mortars with a waterglass/sodium hydroxide mass ratio of 2:1 and a calcium hydroxide content of 10% leads to the highest early age strength resulting in 31 MPa for 7 days curing (Torgel et al., 2006). The strength data for long curing ages, show that the parameters which lead to optimum strength for 7 days curing remain the same for long curing times. However, when calcium hydroxide percentages above 10% are used, a relevant strength decrease after 140 curing day is noticed. The use of an activator with a sodium hydroxide concentration of 24 M leads to very high compressive strength, for early ages with 30 MPa after just 1 day and 70 MPa for 28 days curing (Torgel et al., 2007). The highest compressive strength is obtained with a mixture containing 10% calcium hydroxide. The strength performance is typical of a very reactive binder, presumably due to the presence of calcium hydroxide and also to the nucleation centers provide by the iron oxide of the mine waste mud.

2.4 Durability

For the durability performance, abrasion and acid resistance were assessed for GMWM and comparable OPC binders. GMWM binder specimens show a low level of weight loss while in OPC specimens a severe weight loss is observed (Fig. 1). GMWM binder specimens show a low level of weight loss while in OPC specimens a severe weight loss was observed. For GMWM binders the higher abrasion resistance was achieved in paste specimens. This result is related to the fact that GMWM paste had the highest compressive strength. As for OPC specimens, abrasion resistance seems to be more influenced by the compressive strength than for the aggregates used in the mix.
As for acid resistance results are dependent not only on the type of acid but also on the type of aggregate used. For GMWM binders, the mixtures with granite and schist aggregates showed low weight loss results when exposed to different acids. As for the mixtures with limestone aggregates, their weight loss showed to be influenced by the type of acid. Specimens immersed in chloridric acid showed low weight loss performance independent of aggregate type, as for specimens submitted to nitric and sulphuric acid attack are influenced by the presence of limestone aggregates. GMWM binders without limestone aggregates show good acid resistance better than the OPC concrete. This behaviour may be due to the low water absorption and to their lower content in calcium.

2.5 Environmental assessment

The use of new binder as a building material requires the assessment of its environmental performance. For that leaching tests have been carried out according to DIN 38414 – S4. Leaching results show that all chemical parameters are below the limits established by the standard and can be considered for inert material (Table 2). As to the limits for water contamination set by the Decrease 236/98, it can be stated that although some chemical parameters are above the limits for drinkable, all limits are met concerning water for irrigation purposes.

Table 2. Contaminant concentration in the wastewater by leaching process standard DIN 38414 – S4

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Test results (mg/l)</th>
<th>Limits (DIN 38414 – S4)</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>0.011</td>
<td></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Arsenic</td>
<td>&lt;0.002</td>
<td>0.1</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>0.197</td>
<td>0.5</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>0.062</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>0.019</td>
<td>0.1</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>0.203</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium</td>
<td>123.75</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>3792.5</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.163</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulpates</td>
<td>&lt;0.003</td>
<td>500</td>
<td>1500</td>
<td></td>
</tr>
</tbody>
</table>

3 CONCLUSIONS

The calculation of mine waste mud at 950 °C during 2 hours leads to an increase of more than 300% in the compressive strength of alkali-activated mortars, thus justifying its thermal treatment.

The use of alkali-activated GMWM mortars with a waterglass/sodium hydroxide mass ratio of 2.5:1, with a sodium hydroxide concentration of 24 M and a calcium hydroxide content of 10% leads to the highest strength, indicating 30 MPa after one day curing and 70 MPa after 28 days curing.

Abrasion resistance of GMWM binders is higher than that of the current OPC binders. GMWM binders without limestone aggregates show good acid resistance, much higher than the one presented by OPC concrete. It is believed that this performance is due to the fact that the new binders have low water absorption and also to their lower calcium content resulting in less soluble compounds.

As for the environmental assessment, the new binder is considered an inert material which.

REFERENCES


He, Changling; Makovic, Emilj; O'Shaughnessy, Brian - Thermal stability and pozzolanic activity of raw and calcined Illite. Applied Clay Science 8 (1995) 337-354


Wang, Shao-Dong; Schroeter, Karen; Pratt, P., Factors affecting the strength of alkali-activated slag. Cement and Concrete Research 24 (1994) 1033-1043