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BIOBASED POLYMERS

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Lime Hemp and Rice Husk-Based Concretes for Building Envelopes

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This series is aimed at advanced undergraduates, academic and industrial researchers and professionals studying or using biobased polymers. Each brief will bear a general introduction enabling any reader to understand its topic.

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Contents

Nomenclature

LHC	Lime and hemp concrete
LRC	Lime and Rice husk concrete
ρ_B	Bulk density of plant aggregates
ρ_A	Apparent density of a particle
ρ_T	True density of the solid phase
η_O	Open porosity in the particle
η_I	Intergranular porosity in bulk aggregates
η_T	Total porosity in bulk aggregates
C, S, H, A	CaO, SiO_2, H_2O, Al_2O_3 (cement chemist notation)
SEM	Scanning electron microscopy
BSE-SEM	Back-scattered scanning electron microscopy
TGA	Thermogravimetric analysis
XRD	X-ray diffraction
A, B and W	Aggregate, binder and water contents
B/A	Binder-on-aggregates mass ratio
W/B	Water-on-binder mass ratio
W_P	Prewetting water
W_M	Mixing water
ISC	Indoor standard conditions
OC	Outdoor exposure conditions
ACC	Accelerating carbonation curing
MC	Moist curing
TA	Thermal activation
CS	Compressive strength
E_C	Tangent modulus on the loading cycle
η_{IP}	Intergranular porosity within the hardened concrete
η_{TOT}	Total porosity within the hardened concrete
λ_P	Thermal conductivity (flow parallel to compaction axis)
λ_O	Thermal conductivity (flow orthogonal to compaction axis)
MT	Manual tamping

VC	Vibro-compaction
ROC	Rate of carbonation
d,m	Days, months
ITZ	Interfacial transition zone
p'_0	Initial effective confining pressure
q	Deviatoric stress
σ'_m	Mean effective pressure
M′	Stress ratio
φ_P	Peak friction angle
C	Cohesion
FM	Failure mode

Chapter 1
Introduction

According to the International Energy Agency (IEA), the building sector accounts for one-third of final energy consumption and global carbon emissions in the world [1]. In Europe, most countries adopted their own thermal regulations after the first oil crisis in the 1970s in order to limit heat loss in buildings. In an effort to reduce energy consumption for the heating, some buildings were sealed too tightly without adequate ventilation, leading to poor indoor air quality. Furthermore, the thermal comfort in summer has been gradually considered through the different amendments of thermal regulations but it was largely ignored until the 1990s. The energy demand for air conditioning has increased in southern countries but not exclusively. It also applies to countries with a cold climate. Overheating in summer or even in the mid-season is frequently noted in Germany or Nordic countries where buildings are designed with high levels of thermal insulation, low permeability and solar heat gain through the glazing. Air conditioning has become relatively common in tertiary buildings even though it strongly affects the climate [2]. Within the framework of the Kyoto protocol, the European Union (EU) adopted a directive for the energy efficiency of buildings (Energy Performance of Building Directive known as EPBD) in 2002. It was revised in 2010 in order to provide harmonized methods for calculating the energy performance of buildings in thermal regulations, taking greater account of heating and cooling installations [3]. The French Thermal Regulation has been developed and strengthened several times. In 2012, the aim of the latest version was to achieve a decrease of 38% in the energy consumption of residential and tertiary buildings by 2020 compared to 2008 and a fourfold reduction of greenhouse gas emissions by 2050 in comparison to the level of emissions in 1990 [4]. Half of the building stock was built before 1970 and thus without any thermal insulation. Furthermore, over the following decades, heat insulation systems and design methods were not necessarily appropriate as briefly mentioned above (overheating, tight houses without efficient ventilation, lack of breathability, wall condensation, excessive use of air conditioning). Due to the low

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renewal rate of the building stock, the energy retrofit of existing buildings is absolutely fundamental to achieve the targets in terms of environmental impact. The construction industry is able to provide a significant potential for the reduction of greenhouse gas emissions. The energy efficiency of buildings during their operational phase tends to improve over time as a result of increasingly advanced insulating materials. Nevertheless, it is essential to pay close attention to the carbon footprint of selected materials. The environmental impact of building materials is not taken into account in European and French standards even though the embodied energy of materials is a key factor of the whole life cycle of buildings (Life Cycle Analysis approach). Conventional construction systems used for residential buildings mostly combine an insulating layer with a load bearing structure (concrete blocks). Mineral wools and polystyrene cover almost the whole market of insulating materials despite their high carbon footprint [5]. In order to keep buildings free from the risk of water condensation in traditional envelopes using mineral wools and plasterboard, self-insulating blocks like autoclaved aerated concrete or lightweight clay bricks have expanded in recent years. These load-bearing blocks have attractive hygrothermal properties [6] but they use non-renewable resources and their carbon footprint remains high (especially that of fired-clay bricks) [5]. The last two decades have witnessed the emergence of bio-based building materials mixing plant-derived aggregates with mineral binders. This return to old building methods is arousing great interest. In this field, hemp concrete has been well researched. It is designed by mixing hemp shives (the woody part of hemp stems) with lime or other binders. Crop residues are renewable resources and their use does not harm the environment. The carbon footprint of hemp-based concretes was found to be negative due to carbon sequestration during hemp growth and lime carbonation during the hardening of the concrete [5, 7]. Hemp concretes are manufactured with a high volume fraction of shives providing an important porosity to the hardened material. As a result, they show low thermal conductivity and good ability to buffer temperature and humidity variations. Hemp concrete prevents condensation, allows buildings to breathe (air-tight but water permeable). Thus, this bio-based concrete reduces heating and air conditioning needs while ensuring good indoor thermal comfort [8–10].

It is obvious that the diversification of renewable and easily available plant resources promotes and develops biomass-based construction contributing to carbon storage and sequestration. Rice is the first cereal in the world for human food. It is locally grown in the South of France. The outer covering of rice grains (called rice husk) is often considered as a waste material. This crop residue causes critical problems in rice growing areas given that high volumes are generated and not used in a beneficial way. The recovery of whole rice husk without any burning or grinding to design a lightweight insulating bio-based concrete was almost unexplored before. The new plant aggregate is mixed with lime-based binders and macroscopic properties of the innovative rice husk concrete are compared with those of hemp concrete.