Ceramic Materials

Synthesis, Performance and Applications

MATERIALS SCIENCE
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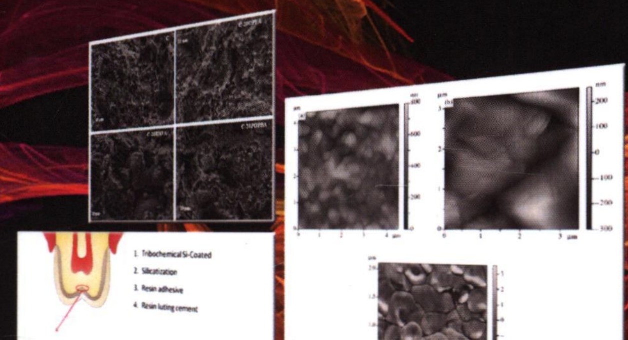

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SYNTHESIS, PERFORMANCE AND APPLICATIONS

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PREFACE

This book discusses the synthesis, performance and applications of ceramic materials. Chapter One presents the recycling of biomass ashes in the obtaining of clay bricks for possible use as construction material. Chapter Two summarizes the use of nanostructured ceramics for the control of heat flows. Chapter Three deals with analytical modelling of thermal stresses in a multi-particle-matrix system with isotropic cylindrical particles which are periodically distributed in an isotropic infinite matrix. Chapter Four deals with analytical modelling of thermal stresses which originate during a cooling process of an elastic solid continuum. Chapter Five provides recent information on the use of zirconia in dentistry, its characteristics and indications, with a particular emphasis on surface conditioning methods to promote adhesion of resin-based materials to zirconia.

In Chapter 1, various fly and bottom biomass ash, such as: rice husk fly ash, wood bottom ash, fly and bottom pine-olive pruning ash, olive stone bottom ash, olive pomace bottom and fly ash, were individually blended with clay to produce ceramic bricks. The clay and biomass ash waste were characterized by X-ray fluorescence, elemental chemical analysis and thermogravimetric and differential thermal analysis. The bricks were manufactured by mixing clay and 20 wt% of ash. These bricks were fired at 900ºC. The influence of the type of biomass ash added on the linear shrinkage, bulk density, water absorption, apparent porosity and mechanical properties was investigated. The results indicated that the addition of biomass ash decreased the bulk density and the compressive strength (25% lower) although the incorporation of fly rice husk ash produced a maximum decreased of 60.8%. Instead it was observed an increment in water absorption from 4.0 to 17.3% with respect to the control bricks containing only clay. Heavy metal concentration in the leachates of the biomass ash-clay bricks was far lower than those recommended in the Spanish legislation (OM AAA/661/2013) and US-EPA standard. Therefore, fired bricks fulfill standard requirements for clay masonry units, offering, at the same time, good mechanical properties.

The recycling of these biomass ashes in the obtaining of clay bricks for possible use as construction material is presented as a potentially feasible solution according to the technical qualities of the manufactured bricks, as well as, the economic and environmental benefits that implies its use in replacement of natural raw materials.

As described in Chapter 2, nowadays considerable attention is paid to the creation of a new type of nanostructured materials in which one can control the heat flow. Since it is believed that the basic element of such thermocrystals should be phononic lattices with a wide forbidden gap, it is an urgent task to find new methods for their synthesis that strikes a balance between the thermocrystal efficiency and ease of fabrication.

It is shown both theoretically and experimentally that the compacted ceramics can exhibit the properties of a phononic lattice, i.e., a forbidden gap may arise in the phonon spectrum. The position and width of the gap in such systems are determined by the average grain size of ceramics, as well as by the thickness and elastic properties of the grain boundaries. Inclusions of metal phase in dielectric matrix can create photonic traps for the nanocomposite materials and determine their diffusion ratio.

The approach for the synthesis of nanocomposites by use of ceramics technology was introduced. It allows to create materials with required characteristics by the compaction and sintering process and to give a practical advice on synthesis of nanostructured ceramics with specified parameters.

Chapter 3 deals with analytical modelling of thermal stresses in a multi-particle-matrix system with isotropic cylindrical particles which are periodically distributed in an isotropic infinite matrix. This multi-particle-matrix system represents a model system which is applicable to real two-component materials of with precipitates of a cylindrical shape. The thermal stresses as functions of microstructural parameters (particle volume fraction, particle radius, inter-particle distance) originate during a cooling process as a consequence of the difference in thermal expansion coefficients of the cylindrical particle and the matrix. The analytical modeling is based on an application of suitable mathematical techniques on fundamental equations of mechanics of solid elastic continuum. The mathematical techniques thus result in analytical solutions for both the cylindrical particle and the infinite matrix.

Finally, numerical values of the thermal stresses in a real two-component material with cylindrical precipitates are determined.

Chapter 4 deals with analytical modelling of thermal stresses which originate during a cooling process of an elastic solid continuum. This continuum consists of an isotropic infinite matrix with isotropic spherical particles and spherical pores. The particles and pores are both periodically distributed in the infinite matrix which is imaginarily divided into identical cubic cells. Each cell contains either a central particle or a central pore. This porous multi-particle-matrix system represents a model system which is applicable to porous two-component materials of a precipitate-matrix type characterized by microstructural parameters, i.e. the cubic cell dimension; radii and volume fractions of both the particles and of the pores. The thermal stresses are a consequence of different thermal expansion coefficients of the isotropic matrix and isotropic particle. Resulting from fundamental equations of mechanics of an elastic solid continuum, the thermal stresses are determined within this cell, and thus represent functions of these microstructural parameters. Finally, numerical values for a real porous two-component material of the precipitate-matrix type are obtained.

As explained in Chapter 5, Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) has been used in dentistry in order to manufacture prosthetic frameworks, monolithic crowns and implant abutments due to its superior mechanical properties, biocompatibility, chemical stability and appropriate aesthetics as opposed to other materials. The survival of dental ceramic restorations depends on durable bond strength between the restorative material, composite resin luting cement and the tooth surface. However, it is difficult to establish a durable mechanical or chemical adhesion in zirconia-based prostheses since yttrium-stabilized zirconia is an oxide ceramic that does not contain silicon dioxide (SiO_2) phase in its microstructure. In order to achieve strong and reliable adhesion between resin composite luting cements and zirconia surfaces, it is crucial to employ a method that does not impair the mechanical properties and at the same time rendering it compatible with the luting cement. Furthermore, the chosen method should be practical, easy to perform and should not cause $t \rightarrow m$ phase transformation. Several methods and protocols for conditioning zirconia surfaces prior to adhesive cementation have been suggested in the literature such as physical, physicochemical and chemical methods. Typically, while physical surface conditioning methods are based on employing air-borne particle abrasion with alumina particles, physicochemical methods use silica-coated alumina particles followed by silanization. It is also possible to activate the zirconia surface chemically using functional-monomer containing adhesive promoters in the form of adhesive cements or primers. Generally, combination of micromechanical and chemical surface conditioning methods are preferred to enhance adhesion to zirconia. As this ceramic demonstrates superior properties compared to other ceramics, it is essential to study the peculiar characteristics of dental zirconia after surface conditioning methods and suggest one that does not damage its favorable mechanical properties. Chapter 5 will provide the recent information on the use of zirconia in dentistry, its characteristics and indications, with a particular emphasis on surface conditioning methods to promote adhesion of resin-based materials to zirconia.

CONTENTS

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Chapter 1

EVALUATION OF FLY AND BOTTOM ASH OF DIFFERENT BIOMASS COMBUSTION AS RAW MATERIALS IN CLAY-BASED CERAMICS

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Abstract

In this work, various fly and bottom biomass ash, such as: rice husk fly ash, wood bottom ash, fly and bottom pine-olive pruning ash, olive stone bottom ash, olive pomace bottom and fly ash, were individually blended with clay to produce ceramic bricks. The clay and biomass ash waste were characterized by X-ray fluorescence, elemental chemical analysis and thermogravimetric and differential thermal analysis. The bricks were manufactured by mixing clay and 20 wt% of

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ash. These bricks were fired at 900ºC. The influence of the type of biomass ash added on the linear shrinkage, bulk density, water absorption, apparent porosity and mechanical properties was investigated. The results indicated that the addition of biomass ash decreased the bulk density and the compressive strength (25% lower) although the incorporation of fly rice husk ash produced a maximum decreased of 60.8%. Instead it was observed an increment in water absorption from 4.0 to17.3% with respect to the control bricks containing only clay. Heavy metal concentration in the leachates of the biomass ash-clay bricks was far lower than those recommended in the Spanish legislation (OM AAA/661/2013) and US-EPA standard. Therefore, fired bricks fulfill standard requirements for clay masonry units, offering, at the same time, good mechanical properties.

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Keywords: fly and bottom biomass ash, recycling, ceramics, technological properties, sustainability

1. Introduction

Economic and social development requires energy, in a manner that the need for energy consumption in developed countries is increasing at at a rate of nearly 1% a year, whereas the rate is higher in emerging countries, approximately 5% a year [1].

It is estimated that oil and gas reserves will only cover energy needs for the next 40 and 60 years, respectively. Furthermore, emissions generated as a result of fossil fuels combustion are responsible of serious environmental problems such as global warming. As a result, renewable energy seems to be one the most effective solution due to its renewable and environmentally sustainable nature [2] in order to ensure a high quality of life and the well-being of coming generations [3].

The energy generated from biomass is one of the most promising ways of reducing, in significant quantities, CO_2 from the combustion of coal and natural gas. According to definition in Directive 2003/54/EC, "biomass" is the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (Directive 2003/54/EC) [4].

Spain, following the ambitious European Union objectives has assumed the challenge to establish an ambitious energy model with the intention of promoting renewable resources like biomass to fulfill the energy targets. This is the aim of the "Plan de Acción Nacional de Energías Renovables" (PANER) (2010-2020) [5].

Andalusia (Spain) is the second-largest autonomous community in Spain, with wide forest and farmland surface and is the region that records the highest consumption in the country of the most promising source of renewable energy, biomass [6], with 18 generators of electricity from residual biomass which produce 257,48 MW [7].

Solid biomass is the best known type of biomass and can be included within this group: wood obtained from silviculture and forestry activities; wastes from industries dealing with any kind of solid biomass (e.g., carpentry, paper industry…); residues obtained from the pruning and cleaning of parks and gardens; energy crops; peat; agriculture and agro-industrial waste (such as pomace, sawdust, olive stones…); and organic fraction of solid urban wastes. Different sources of solid biomass are used in Andalusia to produce electric energy: olive pomace (218,3 Ktoe), energetic crops (190,4 Ktoe), forestry residues (106,7 Ktoe) and industrial wastes (175,6 Ktoe) depicted the main sources of solid biomass in 2013 of the total quantity (723,7 ktoe) [7].

The wastes generated from the olive sector in Andalusia, is the most important source of residual biomass for electric and thermal energy. Approximately 50% of biomass is olive tree residues; the other half is principally obtained from sunflowers, cotton and fruit trees [8]. It should be born in mind that Spain is the main world olive producer (4,577,800 tonnes) [9] and the production is mainly concentrated in Andalusia. The potential exploitation of solid olive wastes for energy purposes have been extensively researched [10-15].

However, an environmental and economic problem inherent to solid biomass combustion, stems from the large quantities of fly and bottom ashes generated from the process. Ash is usually accumulated in landfills which lead to a clear damage to the land and the surrounding area, contributing to air pollution and water contamination. In addition, the occupation of a territory stops it from being productive and the disposal in landfills is also problematic due to space limitations. The composition of the ash depends on the minerals absorbed or incorporated into the biomass during cultivation and harvesting. Likewise, ash is usually composed by organic material unburned during the usual inefficient processes [16]. Accordingly, the potential reuse of the ash is determined by its physical, chemical and environmental properties. Obviously, quality and quantity of the ash are directly influenced by the characteristics of the biomass and the combustion technology employed [17]. Regarding the type of ash, bottom ash is the portion of residue that remains in the incinerator or furnace, while fly ash is the portion of ash that goes through the chimney and is retained to prevent it from being released into the atmosphere [18].

The management of the ashes produced in great quantity as a result of the combustion processes is a challenge. There have been an increasing number of studies in all over the world regarding the characterization and the establishing of appropriated processes in which ashes can be effectively reused. As a result of this research, different areas of application of ash were proposed, depending on its composition and properties. One of the most valuable components of the ash is amorphous silica, with a wide range of applications, such as manufacturing of silica gels, silicon chip, synthesis of activated carbon and silica, production of construction materials and insulation, zeolites, catalysts, ingredients for batteries, graphene, carbon capture, drug delivery vehicles [19]. In addition, biomass ashes have been studied focusing on applications as a construction material replacing, in part or completely, traditional construction materials. This has been fostered by the growing environmental awareness in the building industry due to the large quantities of raw materials needed for ceramic production [20, 21]. As a result, the incorporation of waste in place of traditional construction material, while requirements are fulfilled, is environmentally and economically attractive. Some authors have studied building materials using as raw materials ashes from different sources with satisfactory results. So, Cabrera et al. [16] studied the properties of biomass bottom ash from the combustion of wood and olive trees residues and determined that this bottom ashes had acceptable properties to be used as a filler material in the core of road embankments over 5 m in height without additional precautionary measures, such as the construction of road shoulders. Rauta et al. [22] studied brick samples prepared from paper pulp, rice husk ash and cement. The optimal composition with paper pulp (80 wt%), rice husk ash (10 wt%) and cement (10 wt%) had a higher strength and physic-chemical characteristics than conventional burnt clay bricks. Zang et al. [23] studied the incorporation of municipal solid waste fly ash in clay bricks. The optimal mixture ratio of materials was, municipal fly ash: 20 wt%, red ceramic clay: 60 wt%, feldspar: 10 wt%, gang sand: 10 wt%. And the optimal sintering temperature was 950ºC. Other authors have studied the using of ash from coal power plants [24-29]. Eliche-Quesada and Leite-Costa [30] studied the using of bottom ash from olive pomace combustion to replace different amounts (10-50 wt%) of clay in brick manufacturing. The optimal amount of bottom ashes was 10 and 20 wt% of waste to produced bricks with lower bulk density and suitable compressive strength. Fired bricks fulfil standards requirements for clay masonry units, offering, at the same time, a reduction in thermal conductivity compared to