COMPOSITE MATERIALS FOR ECO-FRIENDLY FIRE RETARDANT BUILDING CEILINGS FOR TROPICAL REGION

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN MECHANICAL ENGINEERING, IN THE DEPARTMENT OF MECHANICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA

SEPTEMBER, 2020

ACCEPTANCE

This is to attest that this thesis is accepted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Mechanical Engineering in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota.

Mr. John A. Philip ……

Secretary, School of Postgraduate Studies Signature and Date

Prof. Abiodun H. Adebayo ……

Dean, School of Postgraduate Studies Signature and Date

DECLARATION

I, **DIRISU, JOSEPH OSEKHOGHENE (16PCM01441),** declared that I carried out this research under the supervision of Prof. Sunday O. Oyedepo and Dr. Ojo S.I. Fayomi of the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Nigeria. I attest that the thesis has not been presented either wholly or partially for the award of any degree elsewhere. All sources of data and scholarly information used in this thesis are duly acknowledged.

DIRISU, JOSEPH OSEKHOGHENE ……

Signature and Date

CERTIFICATION

We certify that the thesis titled **"Composite Materials for Eco-Friendly Fire Retardant Building Ceilings for Tropical Region"** is the original research work carried out by **DIRISU, JOSEPH OSEKHOGHENE (16PCM01441)** in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria under the supervision of Prof. Sunday O. Oyedepo and Dr. Ojo S.I. Fayomi. We have examined and found this work acceptable as part of the requirements for the award of Doctor of Philosophy (Ph.D) in Mechanical Engineering.

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(Dean, School of Postgraduate Studies)	Signature and Date

DEDICATION

This work is dedicated to all who need God’s help.

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LIST OF ACRONYMNS AND ABBREVIATIONS

Aldr	Aluminium dross
ARM	Aluminium Rolling Mill
Cmt	Cement
CS	Coconut Shell
CSH	calcium silicate hydrate
EDS	Energy Dispersive Spectrometry
EU	European Union
Ɛ	thermal effusivity
G	Carbon Graphite
GDP	Gross National Product
k	thermal Conductivity
OBS	Oil Bean Stalk
Ppm	part per million
r	thermal resistivity
SEM	Scanning Electron Microscopy
SG	Specific Gravity
SHC	Specific Heat Capacity
Si	Silicate
UES	Uncarbonized Egg Shell
WHO	World Health Organization
XRD	X-ray powder Diffraction
XRF	X-ray Fluorescence
α	thermal diffusivity
ρ	density

DEFINITION OF OPERATIONAL TERMS

Additive	a substance added to something in small quantities to improve or preserve it
Base material	Parent material apart from the additive and reinforcement
Binder	any material or substance that holds or draws other materials together to form a cohesive whole mechanically, chemically, by adhesion or cohesion.
Calorific value	the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions
Combustion	a high-temperature exothermic redox chemical reaction between a fuel and an oxidant, usually atmospheric oxygen, that produces oxidized, often gaseous products, in a mixture termed as smoke
Composite materials	material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components
Compressive strength	the capacity of a material or structure to withstand loads tending to reduce size, as opposed to which withstands loads tending to elongate
Cooling rate	the change in the temperature divided by the change in time
Density	the degree of compactness of a substance
Eco-friendliness	not harmful to the environment
Emission	the production and discharge of something, especially gas or radiation
Flame	a hot glowing body of ignited gas that is generated by something on fire
Flame retardant	a substance that prevents or inhibits the outbreak of fire
Heat flux	Heat flux or thermal flux, sometimes also referred to as heat flux density, heat-flow density or heat flow rate intensity is a flow of energy per unit of area per unit of time
Microstructure	the fine structure (in a metal or other material) which can be made visible and examined with a microscope
Morphology	The shape and size of a line, an area, or a volume; the texture or topography of a surface; the habit of a crystal; the distribution of phases in a material
Noxious	harmful, poisonous, or very unpleasant
NO	Nitric oxide (a toxic gas)
NO_2	Nitrogen dioxide (a toxic gas)
NO_x	Oxides of nitrogen (a toxic mixture of nitric oxide and nitrogen dioxide gases)

Particulate matter	The sum of all solid and liquid particles suspended in air many of which are hazardous. This complex mixture includes both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets.
Pozzolanic material	Pozzolanic materials are silica or silica-alumina–based materials and can be incorporated in concrete as partial substitution of cement. A pozzolanic material may be defined by its ability to react with calcium hydroxide.
PPM	Parts (of pollutant) per million (volume basis-dry)
Reinforcement	the action or process of reinforcing or strengthening
SO_2	Sulfur dioxide (a toxic gas)
Specific gravity	Relative density, or specific gravity, is the ratio of the density of a substance to the density of a given reference material
Specific heat capacity	the amount of heat energy required to raise the temperature of a substance per unit of mass
Ta	Ambient (room) temperature
Tg	Gas temperature
Thermal conductivity	measure of its ability to conduct heat
Thermal diffusivity	measures the rate of transfer of heat of a material from the hot end to the cold end
Thermal effusivity	the thermal effusivity, thermal inertia or thermal responsivity of a material is defined as the square root of the product of the material's thermal conductivity and its volumetric heat capacity
Thermal insulation	the process of reduction of heat transfer between objects in thermal contact or in range of radiative influence. Thermal insulations consist of low thermal conductivity materials combined to achieve an even lower system thermal conductivity
Thermal resistivity	a heat property and a measurement of a temperature difference by which an object or material resists a heat flow. Thermal resistance is the reciprocal of thermal conductance.
Volatile organic compounds	any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions’
Water absorption	the amount of water absorbed under specified conditions

ABSTRACT

The emission of noxious elements from building ceiling fire is increasingly becoming a source of concern globally. Hence, there is the need to develop eco-friendly flame-retardant building ceilings from composite materials to forestall the unwanted toxic emissions. This study aims at developing a bio-degradable hybrid aluminium dross ceiling utilizing varying material percentages using the moulding process. Box-Behnken factorial design from Minitab 17 was used to analyze the effect of the variables and runs on the performance properties. The developed ceiling samples were characterized by optical microscope, scanning electron microscope (SEM) equipped with energy dispersive spectroscopy (EDS) for structural examination. X-ray Diffraction (XRD) analysis was used for phase quantification. The calorific values and thermal properties were examined by the combustion calorimeter and automated Lee's Disc apparatus, respectively. The mechanical properties were identified using a universal testing machine (UTM) for compressive test and E550 combustion gas analyzer for emission characterization. The results showed that aluminium dross carbon graphite developed from $_{0.3}Aldr_{0.25}Cmt_{0.3}Si_{0.05}G_{0.1}CS$ exhibited the highest specific heat capacity (SHC) of about 7771.94 $Jkg^{-1}K^{-1}$compared to eggshell and oil bean stalk ceiling composite materials. An increase of 90% was noted against the control. The thermal studies showed that there was an excellent thermal conductivity of all the developed composites in the range of 0.0075 $Wm^{-1}K^{-1}$ -0.1458 $Wm^{-1}K^{-1}$. $_{0.3}Aldr_{0.2}Cmt_{0.3}Bt_{0.05}G_{0.15}OBS$ shows outstanding improvement with the lowest value of 0.0075$Wm^{-1}K^{-1}$ and desirable highest thermal resistivity of 133.9 $m^2K^{-1}W^{-1}$. Thermal absorptivity revealed $_{0.3}Aldr_{0.25}Cmt_{0.3}Si_{0.05}G_{0.1}CS$ with value of 0.42 10^{-8} m^2s^{-1} as lowest among developed ceilings and $_{0.3}Aldr_{0.2}Cmt_{0.3}Bt_{0.05}G_{0.15}CS$ has required highest thermal effusivity value of 669.2 $Jm^{-2}K^{-1}s^{-1/2}$. Combustion studies revealed that heat flux is not desirable in ceiling application; therefore, the least hazardous heat flux value is $_{0.3}Aldr_{0.23}Cmt_{0.3}Bt_{0.05}G_{0.12}OBS$ at 12.6 W/m^2. All the developed composite ceilings and binders show non-combustible characteristics. There is an absence of volatile organic compounds (VOC) and noxious constituents from the fabricated $_{0.3}Aldr_{0.2}Cmt_{0.3}Bt_{0.05}G_{0.15}OBS$. More importantly, quasi negligible SO_2 level and CO_2 exist; however, $_{0.3}Aldr_{0.25}Cmt_{0.3}Si_{0.05}G_{0.1}OBS$ recorded maximum CO and NO levels, an indication of toxic affluence. The low mass losses of all of the composite materials, especially for $_{0.3}Aldr_{0.2}Cmt_{0.3}Si_{0.05}G_{0.15}UES$ retard significantly due to its activities by the retardant constituent. The highest crushing force of 6.6 kN and crushing strength 3.4 MN/m^2 was attained for $_{0.3}Aldr_{0.2}Cmt_{0.3}Bt_{0.05}G_{0.15}OBS$ developed product due to the compact arrangement of the inter-molecular hybrid formation of the composite formed. The flame retardant nature of all produced composite is evidenced in their elemental composition, as there is an absence of flammable element and presence of stable insulating compounds providing retardance to flame occurrences. These suppressions in the flame inclination of the reinforced materials are noticed within the boundaries of the ceiling crystals from the structural examination. The intermetallic phase from the diffraction intensities shows the presence of a significant second bond interstitial solid-phase across the matrix, especially for $_{0.6}Aldr_{0.34}Cmt_{0.05}G_{0.01}OBS$ ceiling material. This research will help in enhancing the flame retardant influence of eco-materials in building applications. The result has shown that the existing ceiling materials would be replaced with this flame-retarding ceiling material since it is more stable and fire-resistant.

Keywords: Building ceilings; Calorimeter; Eco-materials; emission; Flame retardant; Thermal conductivity