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THE EFFECT OF PULVERIZED OIL BEAN (PENTACLETHRA MACROPHYLLAA BENTH.) STALK ADDITIVE ON THE THERMO-MECHANICAL PROPERTIES AND MICROSTRUCTURE OF $_{0.6}$ALDR$_{0.3}$CMT$_{0.05}$G$_{0.05}$OBS ALUMINIUM DROSS COMPOSITE FOR BUILDING CEILINGS APPLICATIONS

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ABSTRACT

Advanced material selection provides a favourable ceiling composite for building sectors against the effect of flammability and eco-environmental discomfort. The combustion tendency of combustible materials with building structure is pivotal to the selection of appropriate materials for ceiling application. Thermo physical properties of the developed material were examined using an automated Lee's disc apparatus, copper calorimeter and Ultimate Tensile Tester for compressive test. The structural property of the ceiling material is determined using Scanning Electron Microscope (SEM) fortified with energy dispersive spectroscopy (EDS). The result shows the dispersion of oil bean stalk particle in the matrix resulting in enhanced bond nature of the composite. The developed aluminium dross composite ceiling, $_{0.6}$Aldr$_{0.3}$Cmt$_{0.05}$G$_{0.05}$OBS, had thermal conductivity within the range of poor conductor at 0.049Wm^{-1}K^{-1}an appreciable lower thermal diffusivity when compared to polyvinylchloride (PVC) ceilings. This work provides development of building ceiling with exclusive distinct characteristics for overall thermal comfort in buildings.

KEYWORDS: Thermal conductivity, Thermal comfort, Poor conductor, Composite & Flammability

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Original Article

1. INTRODUCTION

Aluminium dross is an industrial waste from aluminium processing [1-2]. It is seen as the process-waste product of aluminium [3] with minute aluminium constituents [4]. The formation of aluminium dross implies the losses in aluminium which manufacturers aim at reducing to minimal level [5]. Composite with aluminium dross have divers' areas of engineering applications. Pratumma *et al*. [6] combined aluminium dross with ADC12 and Aluminium 6063 to develop plant fertilizer. The composition in Figure 1 revealed the absence of harmful heavy metals. Alumina was the main composition in the dross by more than 50%. The percentage composition of aluminium dross, as shown in Figure 1 also reveals essential elements such as silicon, calcium, potassium, magnesium, sodium and aluminium that enable the parent compound to be compatible with product such as cement.

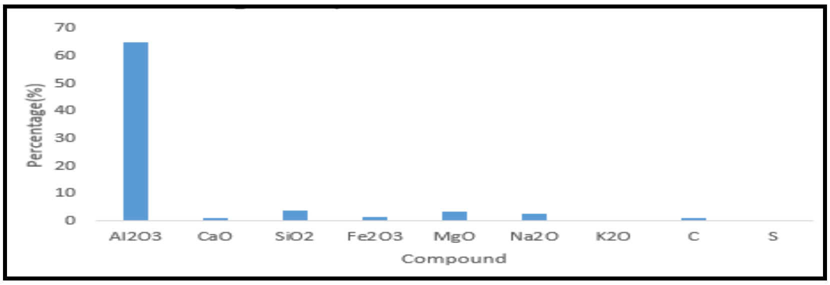

Figure 1: Chemical Composition of Aluminium Dross [6].

Harmful compounds such as ammonium compound and H_2S, emitted by dross when in contact with water can be suppressed when dross is transformed to other products. Suppressing these environmentally hazardous chemicals was achieved by stabilizing aluminium dross in liquor thereby reducing the evolution of ammonia drastically [7]. Aluminium dross were successfully combined with cement thereby reducing cement consumption in building structure such as combining different ratios of aluminium dross, aluminium sludge and aluminium sinister to produce calcium aluminate cement. Such calcium-aluminate cement was used to fabricate fire-retardant brick. Aluminium dross was used as a substitute refractory material by Yoshimura *et al*.[7]. Other applications of aluminium dross are raw materials for ceramic, semiconductor, metallurgy and cement [1].

There is an increasing quest for utilizing aluminium dross waste so as to curb indiscriminate land mass occupancy and incurred production loss. The recovery of aluminium production incurred cost requires the utilization of aluminium dross by developing composite material for construction application such as building ceiling. Various authors reported the potentials of applying aluminium dross and this current research seek to explore its capacities in building ceilings. Al dross was introduced to concrete at 20% as partial replacement of cement which resulted in an improved mechanical and durability characteristics [8]. Al dross was also combined with epoxy resin by [9] to produce a viable composite that can be applied to construction purpose that require light weight and slight thermal resistivity. Aluminium oxychloride solution was produced from chemical treatment of aluminium dross. This can be applied in paper making industry, purification of water and used as a binding agent. Utilizing dross waste exist such as in partial replacement of cement and concrete in building construction, hydrogen fuel production from aluminium dross[10], conversion of aluminium dross to fine alumina powder etc. [11]. Recently, studies revealed the possibility of reutilizing aluminium dross using response surface methodology [12]. Despite potential utilization of aluminium dross in other field of applications, it is still limited in building ceiling application. Thus the aim of this research is to examine the influence of additive on employing aluminium dross waste and study the effect of additive on the developed aluminium dross composite matrix.

1.1 Composite Materials

Composite materials are different distinct materials that are combined to form a component material. This as a result helps to promote the strength of the composite material and make less obvious the weakness of the individual material make-up. Figure 2 shows the schematic components of composites. The choice for composite product is based on either cost or performance of a system.

Bio-composites, an offshoot of composite is a recent method of administering filler to base material such as plastics. This green technological innovation came on board due to sustainability and environmental pollution issue.

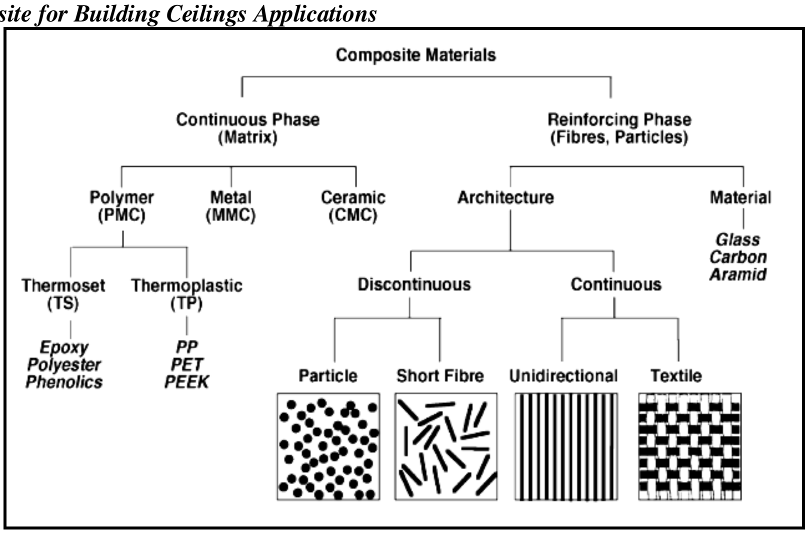

Figure 2: Systematic Illustration of the Structural Components of Composite Materials [15].

Bio-composites has the advantages of low cost, biodegradability and ease of processing. However, the main obstacle emanates from its humidity, moisture absorption and reduced long term stability [13]. Bio-composite technology was applied to PolyLactic Acid (PLA) to improve its flame retardancy incorporating sepiolite nano clay and multi walled nanotubes. This reduces heat release rate significantly when tested in a cone calorimeter. Polysterene was used as a binder for wood-saw dust ceiling tile. The sawdust as a filler improved the thermal resistivity of the product due to its poor thermal conductivity. The wear resistance was also enhanced [14].

1.3 Oil Bean Stalk

African oil bean with the botanical name pentaclethra macrophyllaa belong to the leguminous family [16]. It is widely explored in medical and food journals due to its medicinal value. It is proven to be a rich source of protein and can be cheaply obtained [17] from the environment. The whole part of the oil bean tree has probable usefulness if fully investigated [18]. Oil bean seed, the most researched in the oil bean tree was fermented to produce ugba, a south-Eastern Nigerian local soup condiment [19].

The physical properties of the oil bean seed such as moisture content, seed density, seed weight and seed volume were identified by [20] to ascertain its suitability as additive for the design of machine tools. Oil bean stalk is the curvy exocarp that houses the oil bean seed, as presented in Figure 3. There is dearth of data addressing the potential of oil bean stalk when compared to oil bean seed. This article seeks to employ the oil bean stalk as an additive to aluminium dross composite. The heating value is of oil bean stalk is reported to be 17.80MJ/kg according to [21-23]. Oyeleke *et al*. [24] showed that the heating value of oil bean seed is 577.04kcal/100g≈24.16MJ/kg.

Figure 3: Oil Bean Stalk.

1.3 Cement

Cement is a particulate binding agent on similar and dissimilar materials which functions to bond solid matter to form compacted solid matter [25]. The chief constituent of cement is lime which function primarily to bind sand, granite and stone particles together. Cements can be hydraulic and non-hydraulic type. Non-hydraulic type does not stabilize in water unlike non-hydraulic lime and Plaster of Paris (POP). The hydraulic type solidifies and stabilizes in water and yield a pasty mixture such as Portland cement [25].

Cement is obtained naturally from limestone or made artificially by using calcium carbonate and clay-like materials [25]. Naturally obtained cements types are Roman cement, Puzzolana cement and Medina cement and those of synthetic cement are Portland type and unique cements. It can be applied in various construction works; high strength structures where high strength such as bridge berths, maritime houses, towers, and great edifices such as channels, silos, funnels and also in constructions open to the action of water, e.g. basins, dams, wharf etc. Cement plaster, concrete, reinforced block work, synthetic stones, coating, mortar and panel walls are consistently applied in structures. The three components of cements are lime, silica and alumina with trace quantities of iron oxide, magnesia, sulphur trioxide and alkalis [25]. There has been variation in the composition of cement over the decade, predominantly replicated in increasing the lime content and a minor reduction in silica content. Table 1 presents the chemical structure of cement. An uncontrolled addition in lime content makes it challenging to bond totally with other compounds. Subsequently, free lime will occur in the residue and will end in a faulty cement product. An addition in silica content on the other hand compared to alumina and ferric oxide will make the cement hard to bond [25].

Table 1: Chemical Structure of Cement [25]

Oxide	Function	Percentage Composition
SiO_2	Provides mechanical strength. Excess of it reduces setting time.	17-23
CaO	Controls strength and soundness. Lack of it reduces setting time and strength	59-64
Al_2O_3	Helps quick setting but lowers strength if in excess	3-8
MgO	Surplus of it causes crack in concrete.	0.5-4
Na_2O+K_2O	These are residues, which causes cracking and efflorescence if in excess.	0.5-1.3
P_2O_5		0.1-0.4
TiO_2		0.1-0.2
SO_3	Causes the cement to sound	1-2

Conventionally in building the physical properties are the point of consideration, and these properties mostly dictate entirely the materials to be selected for use with the exception of considering the chemical properties for materials exposed to extreme chemical environments such as the reaction of the materials to humidity, oxygen or gaseous emission. Micro-structural properties will be employed in this sense which is required from material selection to final specimen production due to the increase in pollutants that aggressively attack the products and reduce the service life of structures [26].

To ascertain sustainability of product and users in the environment, an ecological evaluation of the product comes to fore which involves finding out which material can be appropriate and how they react to the environment and each other and if they don't pose a threat to the environment. This chemical test will instantly reveal noxious elements within the material or product and the extent of ecological risk it poses when dumped or installed in the environment that is expected to maintain a natural state. An awareness of the quality of air indoors will generate a greater quest for morphological analysis. A green environment will be achieved if problems of emissions from building materials are addressed by employing quality assessment at each process of design and production as materials react with each other and environment causing collapse, poor bonding, reduced performance life and pollution threat [26].

To achieve thermal comfort of indoor climate, materials suitable to regulate temperature, air, moisture and noise of indoors have to be well thought-out [26].

Temperature regulating materials include thermal insulation materials that regulate the heat transfer by conduction, convection and radiation into the walls and roof of the building envelope and as well stabilize the indoor temperature making it suitable for relaxation. The focal motives for employing temperature control materials are to add thermal comfort and lessen energy demand for space adaptation in terms of heating and cooling [26].

Air regulating materials mainly comprise tiny obstacles enclosing the complete building covering to prevent air flows in the edifice. The three main reasons are to step-up the thermal comfort for the occupants, lessen the threat from moisture and maximize energy conservation and utilization for space cooling and heating. Air barricades are also used in internal walls between cold and warm rooms, where there is a probability of large flow of unpleasant air into the room [26].

Moisture regulating materials are used for water sealant, and to control condensation as a result of water vapour from occupant's body and matter in the building posing problem of moisture upsurge. They also involve materials that can adjust and make steady excess moisture both within the structure and in the interior air [26].

Noise regulating materials are required to moderate transfer of sound from different source either emanating in the building or outside so as to provide a minimal noise free environment [26].

1.3 Carbon Fibre

Carbon is an element located largely in the in the Earth's crust and in the composition of the human body. It possesses excellent bonding capabilities that allow it to form so many sundry diversities of compounds including the many solids, liquids and gasses. The carbon compounds are encompassing such as that they are present in nutrients, in fossil fuels, in the building materials from plants, and many other molecules found in the body. It is safe to infer that carbon is basically the element of all living species as water is the molecule of life. Carbon allotropes like diamond and graphite are made of only one carbon element, and the method of their evolution is different from the commercially produced ceramics due to the high melting temperature of carbon [27].

Carbon fibre(CF) according to [28], has been used to reinforce composite materials due to its high tensile strength and thermal conductivity. CF is a promising candidate for enhancing the thermal and mechanical properties of structural-functional integrated building material. Some carbon materials can improve the mechanical properties, electrical properties and flame retardant properties of composites.

Carbon fibre was used in automotive industry to reduce weight by partially replacing metal of vehicle body frame thus enhancing fuel economy [29]. Carbon, basalt and flax fibres were employed as ternary hybrids with carbon fibre orientated outside the laminate while arraying basalt and flax fibres internally. Carbon fibre is outstanding in terms of tensile strength hence serve as a worthwhile reinforcement for composites [30].

1.3 Carbon-based Materials and Flame Retardancy

Fire hazard poses an everyday risk as the environment is saturated with combustible materials, abundant oxygen, polymers and wood plant. To control its spread is a major challenge [31] and focal theme of investigation, there have been proactive measures to respond to fire outbreaks such as fire alarm, fire hydrants, emergency exit in building designs, muster points, sprinkler systems amongst others which have reduced the number of deaths but haven't eliminated fire disaster as a subject matter in the globe [32]. Flame hazard comes in form of smoke inhalation, direct fire burn, toxic gas emission, heat generation [33]. The part solution to fire hazard lies in the introduction of materials that can reduce the spread of fire enough for it to be extinguished without causing unfortunate occurrences [32].

Flame retardant materials are used to suppress flame spread. They possess chemical elements and compounds that perform the function of combustion fission thus preventing its dispersion. Combustion is a complex process which involve physical and chemical processes. It takes place vigorously at the supply of oxygen. Therefore, a cut at the supply of oxygen will stop the flame spread, which flame retardant materials are inclined to achieve. Figure 4 shows the activity of flame retardant in polymer composite. Different zones are shown such as flame zone, heat zone, gas phase, volatiles, char layer [34]. Flame retardant functions in a way to uphold the formation of char on the surface which serves as an obstruction to constrain combustible volatiles from dispersing to the flame and to protect the polymer from heat and air [35].

Carbon based materials are fascinating, new product from its composite brings a fresh reason for study. Materials evolve from carbon such as carbon nanotubes, graphene, carbon black, fullerene, 3-D graphite, expandable graphite amongst others. Carbon materials where successfully dispersed in flammable polymer to inhibit combustion. Expandable graphite has been employed as flame retardant additive for various polymer matrices for some decades now. Lately, carbon nanotubes and graphene were used due to their high flame inhibitive capacities [36].

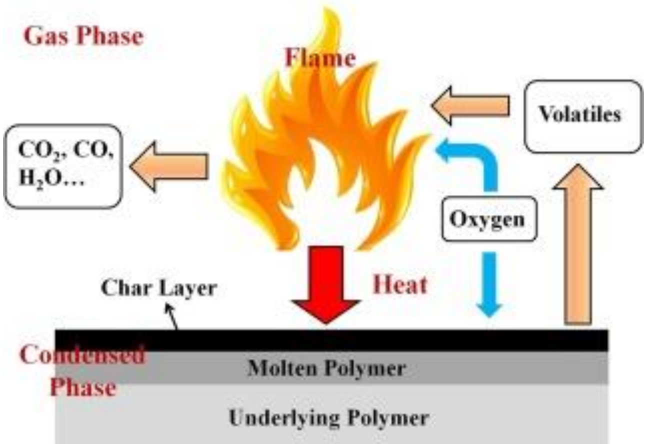

Figure 4: Flame Retardant Activity [34].

Various flame retardants have been developed that are originated in mineral, halogen and other synthetic compounds. However, some of the flame retardants were reported to be harmful to human, to ecosystem and the environment as such their use have been restricted especially halogen based flame retardants such as Chlorinated organophosphate flame retardants [37], Brominated flame retardants [38], Polybrominated diphenyl ether (PBDE) flame retardants. Bromine is reported to be one of the greatest noxious elements in the world and is seen in products including recent flame retardants, known as brominated flame retardants. These flame retardants are at present banned out of the market and were totally outlawed in the EU as of 2015 [39]. Sanctioned flame retardants types possess the capacity to disrupt human body system [40].

Eco-friendly flame retardants were developed from clay and plants used as coating on flammable foam. Nano fibrils gotten from plants cell wall were incorporated alongside with nano platelets from vermiculite clay. The dried solution changes into a thin transparent film whereby the fibres and platelets are piled together to form a brick wall-like structure. This brick wall became the obstruction to combustion and impermeable to oxygen diffusion thereby reducing the amount of heat that can spread to the foam beneath [41-42]. The nanobrick wall structure was reported to reduce the temperature by the underlying foam, which slowed down combustion and also serves to support thermal insulation. Char formation and fumes inhibited in this process and thus eliminating the formation of fire [42]. Ammonium polyphosphate (APP), silica, carbon nanotubes are eco-friendly flame retardants. Oxidised starch substrate was developed as an environmentally friendly flame suppressant by applying renewable materials; oxidised polysaccharides and lignin. The authors reported that minimal mass loss was identified when the specimens were subjected to combustion which verified the flame retardance capacity [43]. The quest to develop eco-friendly and renewable materials for composites especially for polymer materials is an ongoing concern in the research community. There is also dogged interest in developing highly efficient eco-flame retardant materials as a response to sustainability pursuit [32].

The limiting oxygen index (LOI), thermal gravimetric analysis (TGA) and cone colorimeter (CONE) were the test equipment employed for the investigation of fire retardance. They were inferred to be effective flame retardants for wood fibre composites [44]. Investigation made by [45] revealed ferrite yellow (FeOOH) as an effective flame inhibitor with reduced heat release rate (HRR), reduced total heat release (THR), and reduced total smoke release (TSR), etc. It was inferred to be an effective smoke suppression agent and a good flame retardant [46].

2. MATERIALS AND METHODS

Pulverized oil bean stalk, graphite, aluminium dross and powdered Portland cement were acquired for this research. A mixing ratio of 60 (wt.%) aluminium dross, 30 (wt.%) cement, 5 (wt.%) graphite and 5 (wt.%) oil bean stalk (OBS) make up the nomenclature $_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$. A 90µm sieve was used to obtain fine particle size to develop the ceiling sample. The method of composite development used in this study is by mould process. The constructed mould is of dimension 150 mm x 150 mm x 10 mm thickness made of plywood. Water was introduced at 50% of total mixture of 400g to achieve good bonding. The mixture was stirred manually and precast on the mould profile. The developed ceiling sample was left to cure for 7 days so as to achieve good mechanical properties. The produced sample matrix was post cured by 250ºC oven which was preset to 100ºC for 24 hours so as to extract completely the moisture content. Figure 5 presents a flowchart for the preparation of aluminium dross and oil bean stalk particulates. Figure 6 shows the sieve shaker for sieving pulverized aluminium dross and oil bean stalk respectively. Figure 7 shows aluminium dross and cement materials employed for this research. Specific heat capacity of the developed ceiling composite was determined by method of mixture using the copper calorimeter and thermometer while the thermal conductivity was determined using automated Lee's disc apparatus [47]. Scanning Electron Microscope {SEM} equipped with Energy Dispersive Spectrometer {EDS} was used to characterize the microstructure.

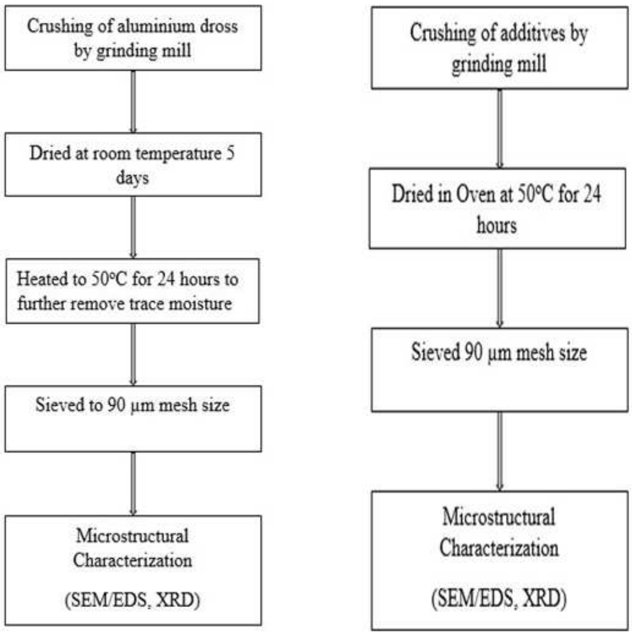

Figure 5: (a) Flowchart for the Processing of Aluminium Dross (b) Flowchart for the processing of Oil Bean Stalk Additives.

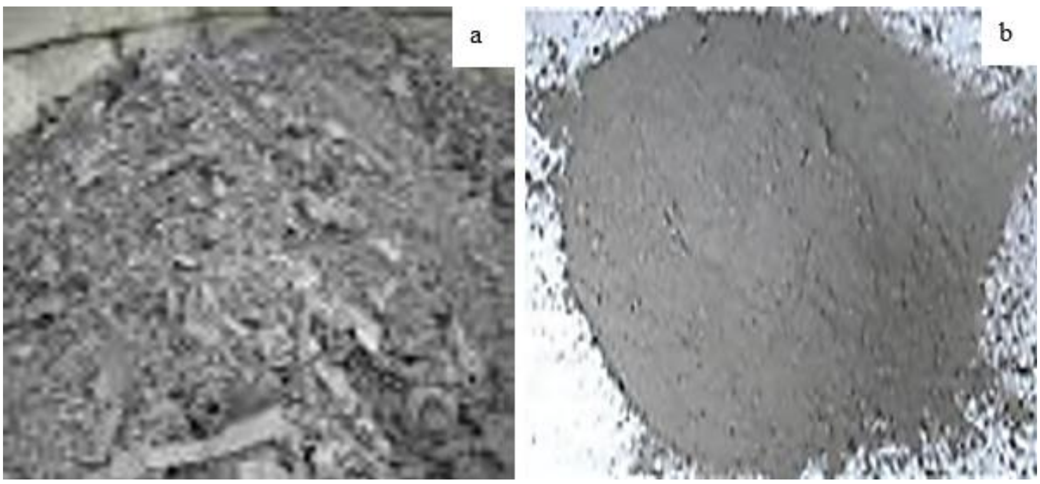

Figure 7: (a) Coarse Aluminium Dross (b) Cement Powder.

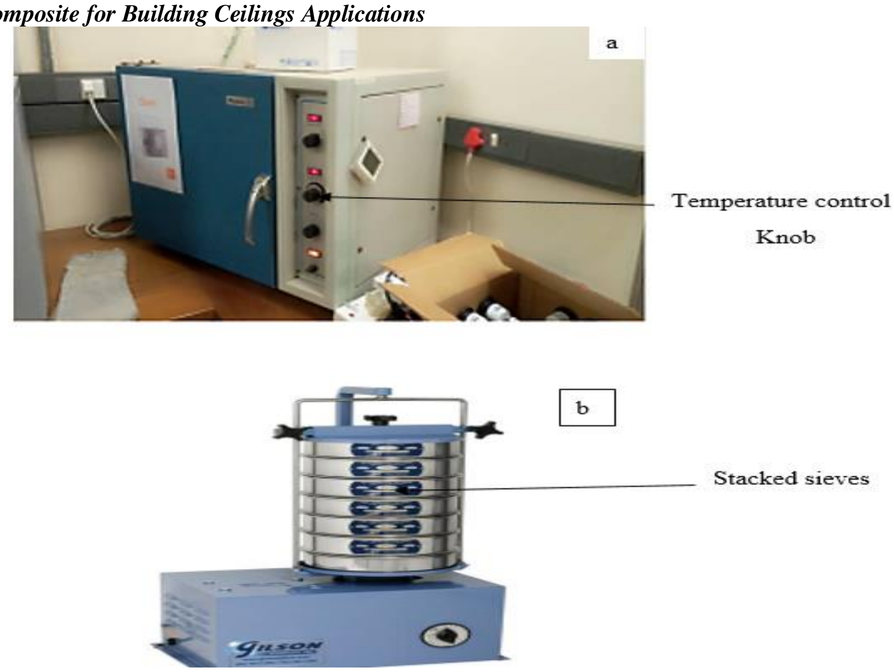

Figure 6: (a) Protea 250°C Oven (b) Sieve Shaker.

3. RESULTS AND CONCLUSIONS

Table 2 presents thermal and mechanical properties of ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$ ceiling composite. From Table 2, Specific Heat Capacity (SHC) and thermal conductivity of the sample are 4.07 $Jkg^{-1}K^{-1}$ and 0.049 W/mK respectively. The thermal conductivity of the developed ceiling composite is relatively close to the thermal conductivity of fibre board of 0.06W/mK [48-49]. That is, the thermal conductivity is within the values of poor conductors. Thermal density, thickness, space geometry and temperature distribution are among many factors that influence thermal conductivity as observed in this study which correlates with the result of [50].The closeness of the atomic structure of the material framework of the ceiling sample also accounts for its low thermal conductivity which is desirable in building structure application. Reluctance in heat transmittance and combustion is an expected behaviour of this sample. Thermal resistance is a reciprocal of thermal conductivity whose high value is an evidence that the ceiling composite developed is a good flame retardant as affirmed by [51]. The thermal resistivity for this ceiling sample is 20.3878Km^2/W.

Table 2: Thermal and Mechanical Properties of ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$ Ceiling Composite

Specific Heat Capacity	Thermal Conductivity	Thermal Resistivity	Thermal Diffusivity	Thermal Effusivity	Crushing Force	Compressive Strength
$Jkg^{-1}K^{-1}$	$Wm^{-1}K^{-1}$	$Km^{-2}W^{-1}$	$m^{-2}s^{-1}$	$Jm^{-2}K^{-1}s^{-1/2}$	kN	MNm^{-2}
4.070	0.049	20.388	0.856×10^{-8}	520.000	6.200	3.158

Thermal diffusivity for the developed ceiling sample is $0.856287 \times 10^{-8}(m^2/s)$ which is in proximity with brick which shares part composition with developed ceiling at thermal diffusivity of 0.52×10^{-8} m^2/s. PVC is a type of ceiling material with thermal diffusivity of 8×10^{-8} m^2s^{-1}. This value is quite high in comparison to aluminium dross ceiling composite which is the reason for its rapid combustion as attested in [52].

Thermal effusivity of the developed ceiling composite is 520 $Jm^{-2}K^{-1}s^{-1/2}$.Mounir [53] got values of thermal effusivity for clay-wool composites at different admixtures in the range of 739 $Jm^{-2}K^{-1}s^{-1/2}$ to 864 $Jm^{-2}K^{-1}s^{-1/2}$. This value obtained for clay-wool composites is due to the material chemistry, volumetric capacity and material mixture. Materials with high thermal effusivity are adjudged to have low energy demand [54] which will reduce energy consumption and assure ecological sustainability [55].

3.1 SEM/EDS Analysis of Aluminium Dross Composite ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$

The elemental composition of ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$ is presented in Table 3 and SEM/EDS image in Figure 8. From Figure 8, it is seen that the elements present in aluminium dross composite are iron, calcium, potassium, chlorine, sulphur, silicone, aluminium, magnesium, sodium, oxygen and carbon. Aluminium, oxygen and calcium are evidence of the compound captured by XRD and revealed the presence of both silicate and aluminium dross.

The element carbon shows the presence of carbon graphite. The interaction of carbon at insufficient oxygen may release carbon (II) oxide. Trace elements such as sulphur are expected during combustion even at minimal percentage and due to coating of the material before the EDS analysis. Its emission is a function of the fire source and responsible for the degree of scorches experienced by fire victim. However, it is not inherent in the sample as revealed by the XRD composition which shows that a perfect flame retardant ceiling composite requires other frame structure to contribute to overall safety of occupants in order to inhibit fire spread and noxious emissions.

Table 3: Elemental Composition of ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$

Element	Weight%	Atomic%
C K	19.26	27.70
O K	52.63	56.83
Na K	0.83	0.62
Mg K	0.45	0.32
Al K	12.70	8.13
Si K	1.27	0.78
S K	0.33	0.18
Cl K	1.49	0.73
K K	0.36	0.16
Ca K	10.33	4.45
Fe K	0.37	0.11
Totals	**100.00**	

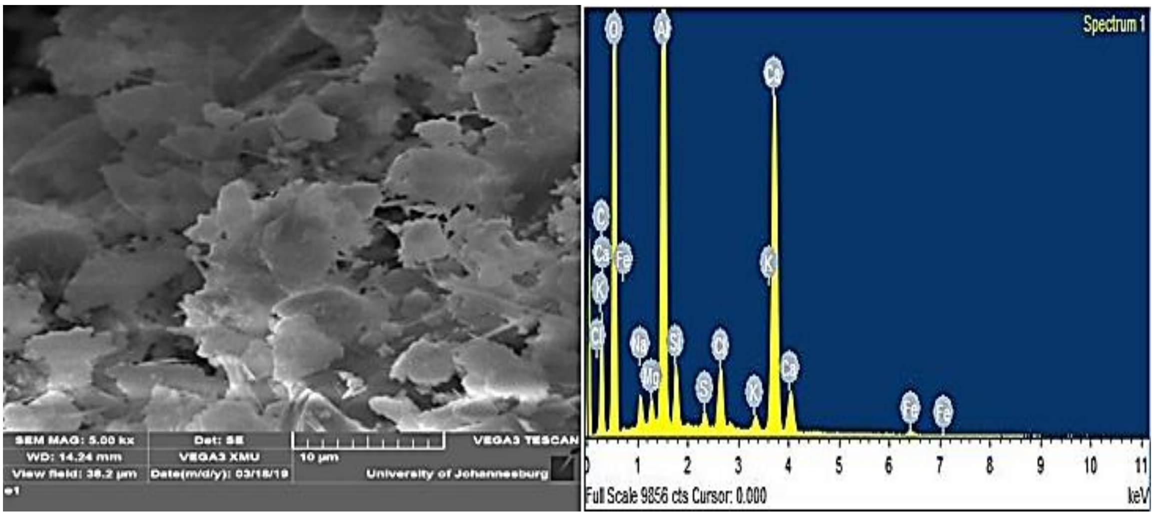

Figure 8: EDS image of ${}_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$.

From the SEM image in Figure 8, flakes of oil bean stalk particles are seen intertwined in the composite. This dispersion enhances the strength and bond nature of the developed ceiling composite. Sparkling trace of aluminium from aluminium dross is seen while amorphous $CaCO_3$ and cloudy CaO are also spotted. These have inherent bonds that enhance element and flame retardance constituents.

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REFERENCES

1. *Li, X., Li, X., Li, Y., Dong, C., Tian, H., Wang, S., & Zhao, Q. (2019). Growth mechanism of micro-arc oxidation film on 6061 aluminum alloy. Materials Research Express, 6(6), 066404.*
2. *Gautam, G., Kumar, N., Mohan, A., Mohan, S., & Singh, D. (2019). ZrB 2 nanoparticles transmuting tribological properties of Al 3 Zr/AA5052 composite. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 41(10), 469.*
3. *Sedo, J. (2015). Processing method and dross dust fractions properties in the confal Inc. European Scientific Journal, 11(15).*
4. *Puksisuwan, P., Laoratanakul, P., &Cherdhirunkorn, B. (2018). Utilization of aluminium dross as a main raw material for synthesis of geopolymer. Journal of Metals, Materials and Minerals, 27(2).*
5. *Kevorkijan, V. (2019). Isothermal Hot Pressing of Skimmed Aluminium Dross: Influence of the Main Processing Parameters on In-House Molten-Metal Recovery. In Light Metals 2019 (pp. 1389-1392). Springer, Cham.*
6. *Pratumma, A., Piyamongkala, K., Siengchin, S., Srisuk, R., &Dangtungee, R. (2016). Acid treatment of aluminium dross: properties and application. In Materials Science Forum (Vol. 857, pp. 547-552). Trans Tech Publications.*
7. *Yoshimura, H. N., Abreu, A. P., Molisani, A. L., De Camargo, A. C., Portela, J. C. S., & Narita, N. E. (2008). Evaluation of aluminum dross waste as raw material for refractories. Ceramics international, 34(3), 581-591.*
8. *Mailar, G., Raghavendra, S., Sreedhara, B. M., Manu, D. S., Hiremath, P., &Jayakesh, K. (2016). Investigation of concrete produced using recycled aluminium dross for hot weather concreting conditions. Resource-Efficient Technologies, 2(2), 68-80.*
9. *Agunsoye, J. O., Talabi, S. I., Hassan, S. B., Awe, I. O., Bello, S. A., &Aziakpono, E. (2014). The development and characterisation of aluminium dross-epoxy resin composite materials. Journal of Materials Science Research, 3(2), 23.*
10. *Singh, K. K., Meshram, A., Jain, A., &Gautam, D. (2019). Hydrogen production using waste aluminium dross: from industrial waste to next-generation fuel.*
11. *Saravanakumar, R., Ramachandran, K., Laly, L. G., Ananthapadmanabhan, P. V., &Yugeswaran, S. (2018). Plasma assisted synthesis of c-alumina from waste aluminium dross.*
12. *Zhang, Y., Guo, Z. H., Han, Z. Y., & Xiao, X. Y. (2018). Effects of AlN hydrolysis on fractal geometry characteristics of residue from secondary aluminium dross using response surface methodology. Transactions of Nonferrous Metals Society of China, 28(12), 2574-2581*
13. *Faruk, O., Bledzki, A. K., Fink, H. P., &Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. Progress in polymer science, 37(11), 1552-1596.*

14. *Mogaji, P. B., Ayodeji, S. P., Olatise, A. D., &Oladele, I. O. (2017). Investigation of the properties and production of sawdust ceiling tile using polystyrene as a binder. African Journal of Science, Technology, Innovation and Development, 9(6), 655-659.*
15. *Zhang, Z., & Friedrich, K. (2003). Artificial neural networks applied to polymer composites: a review. Composites Science and technology, 63(14), 2029-2044.*
16. *Achinewhu, S. C. (1986). The Effect of Fermentation on Carbohydrate and Fatty Acid Composition of African Oil Bean Seed (Pentaclethra macrophyllaa)*
17. *Ogueke, C.C., Nwosu, J.N., Owuamanam, C.I., Ugba, Iwouno J.N. (2010). The Fermented African Oilbean Seeds; its Production, Chemical Composition, Preservation, Safety and Health Benefits.*
18. *Ishiqu, C.N., Obiegbuna J.E., Aniagolu N.M. (2013). Evaluation of Chemical Properties of Mistletoe leaves from Three Different Trees.*
19. *Ahaotu, I., Anyogu, A., Njoku, o.H., Odu, N.N., Sutherland, J.P., Ouoba L.I.I. (2013). Molecular Identification and Safety of Bacillus species involved in the fermentation of African oil beans (Pentaclethra macrophyllaaBenth) for production of ugba*
20. *S. Asoegwu, S. Ohanyere, O. Kanu and C. Iwueke "Physical Properties of African Oil Bean Seed (Pentaclethra macrophyllaa)" Agricultural Engineering International: the CIGR Ejournal. Manuscript FP 05 006. Vol. VIII. August, 2006.*
21. *Dirisu, J. O., Fayomi, O. S. I., & Oyedepo, S. O. (2019). Thermal Emission and heat transfer characteristics of ceiling materials: a necessity. Energy Procedia, 157, 331-342.*
22. *Dirisu, J. O., Oyedepo, S. O., Fayomi, O. S. I., Okokpujie, I. P., Asere, A. A., Oyekunle, J. A., & Abioye, A. A. (2018). Effects of Emission Characteristics on Elemental Composition of Selected PVC Ceiling Materials. Materials Focus, 7(4), 566-572.*
23. *Dirisu, J. O., Asere, A. A., Oyekunle, J. A., Ajayi, O. O., Afolalu, S. A., Joseph, O. O., & Abioye, A. A. (2017). Comparison of the elemental structure and emission characteristics of selected PVC and non PVC ceiling materials available in Nigerian markets. International Journal of Applied Engineering Research, 12(23), 14755-14758.*
24. *Oyeleke, G. O., Odedeji, J. O., Ishola, A. D., &Afolabi, O. (2014). Phytochemical screening and nutritional evaluation of African Oil Bean (Pentaclethra macrophyllaa) seeds. IOSR Journal of Environmental Science, Toxicology and Food Technology, 8(2), 14-17.*
25. *Duggal, S. K. (2017). Building materials. Routledge.*
26. *Berge, B. (2009). The ecology of building materials. Routledge.*
27. *Hasirci, V., &Hasirci, N. (2018). Carbon as a Biomaterial. In Fundamentals of Biomaterials (pp. 83-94). Springer, New York, NY.*
28. *Zhang, B., Tian, Y., Jin, X., Lo, T., & Cui, H. (2018). Thermal and mechanical properties of expanded graphite/paraffin gypsum-based composite material reinforced by carbon fiber. Materials, 11(11), 2205.*
29. *Corbridge, D. M. (2018). Compression moulding of hybrid carbon fibre composites for structural applications (Doctoral dissertation, University of Nottingham).*
30. *Nisini, E., Santulli, C., &Liverani, A. (2017). Mechanical and impact characterization of hybrid composite laminates with carbon, basalt and flax fibres. Composites Part B: Engineering, 127, 92-99.*
31. *Beyler, C. L. (2016). Fire hazard calculations for large, open hydrocarbon fires. In SFPE handbook of fire protection engineering (pp. 2591-2663). Springer, New York, NY.*

32. Costes, L., Laoutid, F., Brohez, S., & Dubois, P. (2017). Bio-based flame retardants: When nature meets fire protection. Materials Science and Engineering: R: Reports, 117, 1-25.

33. Jiao, C., Wang, H., Li, S., & Chen, X. (2017). Fire hazard reduction of hollow glass microspheres in thermoplastic polyurethane composites. Journal of hazardous materials, 332, 176-184.

34. Laoutid, F., Bonnaud, L., Alexandre, M., Lopez-Cuesta, J. M., & Dubois, P. (2009). New prospects in flame retardant polymer materials: from fundamentals to nanocomposites. Materials Science and Engineering: R: Reports, 63(3), 100-125.

35. Dasari, A., Yu, Z. Z., Cai, G. P., & Mai, Y. W. (2013). Recent developments in the fire retardancy of polymeric materials. Progress in Polymer Science, 38(9), 1357-1387.

36. Wang, X., Kalali, E. N., Wan, J. T., & Wang, D. Y. (2017). Carbon-family materials for flame retardant polymeric materials. Progress in Polymer Science, 69, 22-46.

37. Schreder, E. D., Uding, N., & La Guardia, M. J. (2016). Inhalation a significant exposure route for chlorinated organophosphate flame retardants. Chemosphere, 150, 499-504.

38. Fromme, H., Becher, G., Hilger, B., &Völkel, W. (2016). Brominated flame retardants–exposure and risk assessment for the general population. International journal of hygiene and environmental health, 219(1), 1-23.

39. Eco-fire Protection AB. Eco-friendly fire protection for Sustainability. https://ecofireprotection.se/index.cfm?lg=2&gclid=EAIaIQobChMIqbm1scXn5gIVU4jVCh233A01EAMYASAAEgJhevD_BwE#contact-us

40. Rahman, F., Langford, K. H., Scrimshaw, M. D., & Lester, J. N. (2001). Polybrominated diphenyl ether (PBDE) flame retardants. Science of the Total Environment, 275(1-3), 1-17.

41. Sharma, N. K., Verma, C. S., Chariar, V. M., & Prasad, R. (2015). Eco-friendly flame-retardant treatments for cellulosic green building materials. Indoor and Built Environment, 24(3), 422-432.

42. Coxworth B. (2019). Eco-friendly flame-retardant coating made from plants and clay. https://newatlas.com/eco-friendly-flame-retardant-coating/58470/

43. Lomakin, S. M., Sakharov, A. M., Sakharov, P. A., &Zaikov, G. E. (2012). Environmentally friendly flame retardants based on renewable raw materials. International Polymer Science and Technology, 39(7), 5-11.

44. Jeencham, R., Suppakarn, N., &Jarukumjorn, K. (2014). Effect of flame retardants on flame retardant, mechanical, and thermal properties of sisal fiber/polypropylene composites. Composites Part B: Engineering, 56, 249-253.

45. Chen, X., Jiang, Y., & Jiao, C. (2014). Smoke suppression properties of ferrite yellow on flame retardant thermoplastic polyurethane based on ammonium polyphosphate. Journal of hazardous materials, 266, 114-121.

46. Manfredi, L. B., Rodríguez, E. S., Wladyka-Przybylak, M., & Vázquez, A. (2006). Thermal degradation and fire resistance of unsaturated polyester, modified acrylic resins and their composites with natural fibres. Polymer degradation and stability, 91(2), 255-261.

47. Philip P., and Fagbenle L., "Design of Lee' s Disc Electrical Method for Determining Thermal Conductivity of a Poor Conductor in the form of a Flat Disc," Int. J. Innov. Sci. Res., vol. 9, no. 2, pp. 335–343, 2014.

48. Etuk, S. E., Akpabio, L. E., &Akpabio, K. E. (2005). Determination of thermal properties of Cocos Nucifera trunk for predicting temperature variation with its thickness. Arabian J. Sci. Eng, 30, 121-126.

49. Zhu, S., Li, C., Su, C. H., Lin, B., Ban, H., Scripa, R. N., &Lehoczky, S. L. (2003). Thermal diffusivity, thermal conductivity,

and specific heat capacity measurements of molten tellurium. Journal of Crystal Growth, 250(1-2), 269-273.

50. *Seo, J., Jeon, J., Lee, J. H., & Kim, S. (2011). Thermal performance analysis according to wood flooring structure for energy conservation in radiant floor heating systems. Energy and Buildings, 43(8), 2039-2042.*
51. *Onyeanju, M. C., Osarolube, E., Chukwuocha, E. O., Ekuma, C. E., &Omadheye, G. A. (2012). Comparison of the thermal properties of asbestos and polyvinylchloride ceiling sheets. Materials Science and Application, 3, 240-244.*
52. *Weidenfeller, B., Höfer, M., & Schilling, F. R. (2004). Thermal conductivity, thermal diffusivity, and specific heat capacity of particle filled polypropylene. Composites Part A: applied science and manufacturing, 35(4), 423-429.*
53. *Mounir, S., Khabbazi, A., Khaldoun, A., Maaloufa, Y., & El Hamdouni, Y. (2015). Thermal inertia and thermal properties of the composite material clay–wool. Sustainable Cities and Society, 19, 191-199.*
54. *Evola, G., Gullo, F., &Marletta, L. (2017). The role of shading devices to improve thermal and visual comfort in existing glazed buildings. Energy Procedia, 134, 346-355.*
55. *Aste, N., Angelotti, A., &Buzzetti, M. (2009). The influence of the external walls thermal inertia on the energy performance of well insulated buildings. Energy and buildings, 41(11), 1181-1187.*
56. *Jaafar M. Mousa, Sadeer M. Majeed & Oday. M. Abed Al-Hussein, "Modification Polymer Matrix Composites by Addition Graphene", IMPACT: International Journal of Research in Applied, Natural and Social Sciences (IMPACT: IJRANSS), Vol. 4, Issue 5, pp. 41-46*
57. *S. Y. Sawant, Sagar E. More & H. M. Dange, "Design, Development and Performance Analysis of Anticorrosive Heat Exchanger", IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET), Vol. 2, Issue 5, pp. 285-292*
58. *Walaa A. Hussein, Amal S. I. Ahmed, Wafaa A. Ghanem & Ghalia A. Gaber, "Electrochemical Corrosion Behavior of Cu-Zn Alloys in Oxy-Acid Solution", IASET: International Journal of Metallurgical, Materials and Chemical Engineering (IASET: IJMMCE), Vol. 1, Issue 1, pp. 41-46*
59. *Lawakush Jaiswal, Mohammad Ul Hassan & Arun Kumar, "Experimentation and Thermal Analysis of Cylindrical and Conical Shaped Fins", International Journal of Mechanical Engineering (IJME), Vol. 7, Issue 4, pp. 1-10*