Effect of oil bean stalk filler on the thermo-mechanical properties of developed aluminium dross composites for building ceilings

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Abstract
Standard quality building material is the demand of this present age. It is a good attempt to draw some ideas about the use of composites in modern building materials. This study experimentally investigates the effect of varying oil beanstalk (OBS) filler and portland cement (Cmt) additives on thermo-mechanical properties of aluminium dross (Aldr)-portland cement-oil bean reinforced composites. The specific heat capacity, thermal conductivity, thermal resistivity, thermal diffusivity, thermal effusivity, and compressive strength were determined at a different variation of filler content to investigate its effects on the developed composites' behaviour building ceilings application. Result shows that the physical and mechanical properties of triad $_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$, $_{0.6}Aldr_{0.32}Cmt_{0.05}G_{0.03}OBS$ composites are better than $_{0.6}Aldr_{0.34}Cmt_{0.05}G_{0.01}OBS$ composites. Developed samples with portland cement binders were observed not supporting combustion in the combustion calorimeter, confirming their flame retardant characteristics. Thermal analysis indicates that reduced additive results in poor thermal performance despite an increment in portland cement content. The least thermal conductivity value (0.0195 W/m^2K) was obtained for sample 2. The developed ceiling materials' specific heat capacities increased by 10.33 - 386.83 % compared to asbestos. Compared to PVC ceiling material gave a 40.81 % reduction in sample 2. The calorific value of oil bean stalk obtained using the combustion calorimeter is 17.80 MJ/kg, lower compared to pulverized coconut shells. It is observed that the best performance of the composite is achieved at moderate portland cement and filler ratios. A new method of curbing fire spread and providing thermal comfort is essential in this new age of building composite, sustainable cities and communities; this will come to the fore when inbred exceptional thermal, combustion, and mechanical properties are found in developed building ceilings. The percentage variation of filler on the matrix material necessitates improvement in their behaviour in performance.
Keywords: combustion calorimeter, thermal analysis, aluminium dross, building ceiling, oil beanstalk, sustainable cities

1. Introduction
The devastating consequence of fire outbreaks within domestic and commercial buildings is a significant concern globally [1]. Fire is an exothermic reaction in combustible material, oxygen, and an ignition source. It is helpful, but its dangerous effect becomes a disaster capable of destroying anything close to it [2-3]. Fire outbreaks are mainly caused by human negligence. Storing flammable material within confined spaces in an undesirable temperature surge from faulty apartment wiring often leads to a fire outbreak [4]. Other factors responsible for fire outbreaks in buildings include: (i) the use of sub-standard and defective equipment [5], (ii) the application of non-compliant building materials, and (iii) unrestrained children's access to fire lighter [6]. Although increasing fire outbreaks have been reported recently, fire outbreaks can be averted or minimized by controlling fuel type, oxidizing agent, and combustible material [7]. In a study conducted by Young *et al*. [8], fuel load reduction and landscape modification were presented as fire outbreak control strategies within areas susceptible to seasonal fire hazards. The selection of eco-friendly and flame truncating materials for buildings was presented as fire control strategies [9].
Presently, buildings are retrofitted with either PVC ceiling composite, plant-based ceiling, or asbestos materials. Unfortunately, these materials have harmful elements that produce noxious emissions at the instance of a fire outbreak. These ceiling materials' elemental makeup is responsible for forming harmful emissions resulting in trapped occupants' losses. Furthermore, about ₦54bn worth of properties is lost to fire inferno every three years across Lagos, Nigeria [25]. Similarly, a 4% reduction in the capital expenditure of Kwara state, Nigeria, was attributed to the fire outbreak [10].
Aluminium dross (Aldr) is a by-waste product of the aluminium production process [11]. In the work of [12], Aldr was reported to have prospective flame retardant constituents [12]. Other waste Aldr as an additive in concrete

brought about reduced portland cement utilization and cost [13]. Author(s) reported improved mechanical and durability characteristics within the Aldr-concrete mixture [13]. An experimental study [14] concluded that a light-weighted building ceiling material with moderate thermal resistance could be produced by mixing Al dross with appropriate epoxy resins [14]. Significant improvements in the hardness and impact strength of a silicon carbide material were observed when filler glass fibre was introduced to the matrix in a study conducted by [15]. However, the silicon carbide material's tensile strength and shear strength slightly decreased.
Presently across Nigeria, Aldr is readily available as suburban and rural road fillers. While disposing of Aldr is still a significant challenge, scanty applications for Aldr are the principal justification for experimentally accessing the effect of varying percentages of oil beanstalk (0.01, 0.03, and 0.05%) and portland cement (0.30, 0.32, 0.34%) on the thermal and mechanical properties of constant 0.6/0.05% Aldr-graphite percentage blend material.
This study aims to assess the effect of varying the portland cement and additive percentage ratios on the thermal and mechanical properties of the triad-developed composite material as a potential building ceiling material.

2. Materials and Methods

2.1 Materials

This work obtained aluminium dross, the base material, from Aluminium Rolling Mill (ARM), Ogun Housing Estate, Ota, Nigeria. Oil Bean Stalk (OBS) was obtained from remote areas in Iju, Ogun state, and covenant university premises. Natural Carbon graphite powder and portland cement were obtained from Covenant University campus and vendors in Ota, Nigeria. The OBS and aluminium dross were milled using a grinding mill to obtain both fine and coarse sizes. The tree, oil beanstalk, and other materials in use are shown in **Figure 1**.

2.2 Methods

The MakerBot Replicator+ 3-D Printed mould shown in **Figure 2** was employed to design the circular mould template for the aluminium dross composite. The dimension is θ50 mm x 10 holes. Aluminium dross was sieved using a 90 µm sieve size to obtain fine particulate. Hand tools were used, such as a hand trowel, spatula, digital weighing balance, and empty pan to prepare the production sample. The empty pan was zeroed on the weighing balance to read out the actual weight of the sample. The percentage of admixture is presented in **Table 1**, and the terminologies of advanced composites are shown in **Table 2,** where the subscripts indicate the fraction or percentage of the material. The mould was lubricated to easily withdraw samples from the mould. Prepared composites were cured and heat-treated in an oven at a temperature of 50ºC for 24 hours. The specific heat capacity was determined using a copper calorimeter and thermometers by employing mixtures as fully expounded by [16-19, 31, 32]. The thermal conductivity was obtained by using an automatic Lee's disc apparatus. The work of [20] can find for the entire procedure.

Carbon Graphite

Aluminium Dross

Oil Bean Tree

Oil Bean Stalk

Cement Powder

Figure 1: Start-ups materials for Aluminium dross ceiling composite

MakerBot 3D Printer

3D Printed Circular Template

Figure 2: 3D Printer and Ceiling Sample Circular Template

Table 1: Composition of Three developed building ceiling Materials

Sample	Al Dross (base Material) (wt%)	Binder (wt%)	Flame retardant (Carbon Graphite powder (CG))	Additive(A) (wt%)	Total Quantity (g)	Weight of empty can (EC) (g)	Base material and EC (g)	Binder and EC (g)	CG and EC (g)	A and EC (g)	Empty bottle water (EBW) (g)	water (wt%)	water and EBW (g)
		Portland cement		**Oil Bean Stalk (OBS)**									
1	60	30	5	5	500	169.2	469.2	319.2	194.2	194.2	6.5	50	256.5
2	60	32	5	3	400	169.2	409.2	297.2	189.2	181.2	6.5	50	206.5
3	60	34	5	1	450	169.2	439.2	322.2	191.7	173.7	6.5	50	231.5

Table 2: Nomenclatures of Developed Ceiling Materials

Sample Number	Name
1	$_{0.6}\mathbf{Aldr}_{0.3}\mathbf{Cmt}_{0.05}\mathbf{G}_{0.05}\mathbf{OBS}$
2	$_{0.6}\mathbf{Aldr}_{0.32}\mathbf{Cmt}_{0.05}\mathbf{G}_{0.03}\mathbf{OBS}$
3	$_{0.6}\mathbf{Aldr}_{0.34}\mathbf{Cmt}_{0.05}\mathbf{G}_{0.01}\mathbf{OBS}$

Where **Aldr** is Aluminium dross, **Cmt** is Portland cement, **G** is Carbon Graphite powder, **OBS** is Oil Bean Stalk

3. Result and Discussion

Table 3 shows the thermo-mechanical properties of the developed aluminium dross-based composite (portland cement, natural carbon graphite powder, and oil beanstalk) ceiling material as an alternative ceiling material (PVC and Asbestos). At a constant proportion of the aluminium dross (0.6 wt%) and natural carbon graphite powder (0.05 wt%) with increasing (0.3, 0.32, and 0.34 wt%) portland cement binder and decreasing (0.05, 0.03, and 0.01 wt%) oil beanstalk percentages, the thermal conductivity of the developed ceiling materials was found to vary by 0.0195–0.049 W/m^{2}K (see **Figure 3**). These values are within the range of poor heat conductors. Their thermal conductivities are lower by 78.33 – 91.38 % and 38.90 – 75.69 % compared to the asbestos and PVC materials described in George et al. [22]. The least thermal conductivity value (0.0195 W/m^{2}K) was obtained for sample 2. However, increasing and decreasing the concentration of portland cement and oil bean stalk beyond sample 2 increased the thermal conductivity of sample 3. Although sample 3 has the lowest value from the error bar, sample 1 doesn't overlap in terms of the lowest thermal conductivity; therefore, most of the data for sample 1 is significantly different from other developed and existing samples, so sample 1 conclusively has the lowest thermal conductivity. PVC has the highest thermal conductivity for both values and the non-overlapping error bar from **Figure 3**. According to [23], low thermal conductivity ceiling materials are desirable for their capacity to prevent building temperature loss.

Thus, sample 2 is a suitable retrofit for both asbestos and PVC ceiling materials. The highest thermal resistivity value of 51.369 Km^2/W was obtained with sample 2, as illustrated in **Figure 4**. This infers that sample 2 has the best ability to inhibit heat flow and temperature rise. Overall, the thermal resistivity of the ceiling materials ranged between 4.423 – 51.369 Km^2/W. There isn't a significant conclusion between sample 2 and sample 3 due to the overlapping error bar. However, sample 2 doesn't overlap with other materials besides sample 3, as seen in **Figure 4**. The variation in specific heat capacity of the developed ceiling materials is shown in **Figure 5**. The developed ceiling materials' specific heat capacities increased by 10.33 - 386.83 % compared to asbestos. Compared to PVC ceiling material gave a 40.81 % reduction in sample 2. Specific heat capacity variations within the developed ceiling materials make them appropriate replacements for asbestos material, while only samples 1 and 3 can adequately retrofit the PVC material. This is in line with the suggestion to select materials with high specific heat capacity materials by [24]. A denser material provides higher mechanical strength and reduced air voids within the interstices, thus reducing porosity [22,31]. PVC is the least permeable to water and densest among all the materials in **Figure 6**. Sample 2 is significant in density among the three composite materials. A low compressive strength value is seen in sample 2, unlike its high density among the developed samples. The matrix's composite materials orientation is responsible for its low value among the samples, as purported by [30]. High thermal effusivity values are seen in PVC and Sample 1 ceiling materials compared to other building materials. Thermal effusivity, a surface property, presents the material's capacity to attain thermal equilibrium with the surrounding air. This requires high thermal energy dissipation and a longer duration to achieve thermal equilibrium, implying a reluctance to support burning compared to air [26]. PVC and sample 1 will have low energy demand than other materials [27] in **Figure 7**.

Table 3: Thermo-mechanical Properties of Triad Ceiling Composites

Sample	Density ρ (Kg/m^3)	Specific Heat Capacity $kJkg^{-1}K^{-1}$	Thermal Conductivity k (W/m^2K)	Thermal Resistivity r (Km^2/W)	Thermal Diffusivity α x 10^{-8} (m^2/s)	Thermal Effusivity Ɛ ($Jm^{-2}K^{-1}s^{-1/2}$)	Compressive strength (MN/m^2)
Sample1	1405.3	4.07	0.049	20.388	0.856	529.525	3.158
Sample 2	1593.69	0.93	0.0195	51.369	1.318	169.854	1.604
Sample 3	1211.82	2.36	0.0271	36.84	0.946	278.655	2.866

Table 4 shows the calorific value of oil bean stalk additives, Portland cement binder, and the three developed ceiling composites. The calorific value of oil bean stalk obtained using the combustion calorimeter is 17.80 MJ/kg. The calorific value relates closely to the coconut shell amount employed as an additive by [28] at 17.40 MJ/kg. The lower the calorific value, the better the developed composites serve as flame retardance, which is well established in the study carried out by [29, 19] on comparing calorific values of PVC ceiling composites and plant origin ceilings. The calorific values of PVC ceiling composites range from 39-41 MJ/kg, cardboard 37 MJ/kg, plywood 15 MJ/kg, and Particleboard 46 MJ/kg, as presented in **Figure 8**. These values establish their combustibility and flame friendliness in the instance of fire. Particleboard will propagate fire most rapidly, followed by cardboard, while the developed samples will be non-combustible and may slightly reduce weight after combustion. Sample 1-3 was non-combustible due to the stable bond pair of the base material and binder unified against heat impregnation into the material composite, an implication of flame retardance during application. The inhibition of flame spread makes the materials suitable for building ceilings and serves as a measure of escape for occupants when smoke is detected within the roof frame structure's truss.

Table 4: Calorific Values of Aluminium dross composite and oil bean stalk additives

S/N	**Name of material**	**Mass (kg)**	**Calorific Value (MJ/kg)**
1	Oil beanstalk (additive)	0.005	17.80
2	Portland cement (Binder)	0.05	Non-Combustible
3	Aluminium dross(base material)	0.05	Non-Combustible
4	Developed Ceilings Sample 1-3	0.05	Non-Combustible

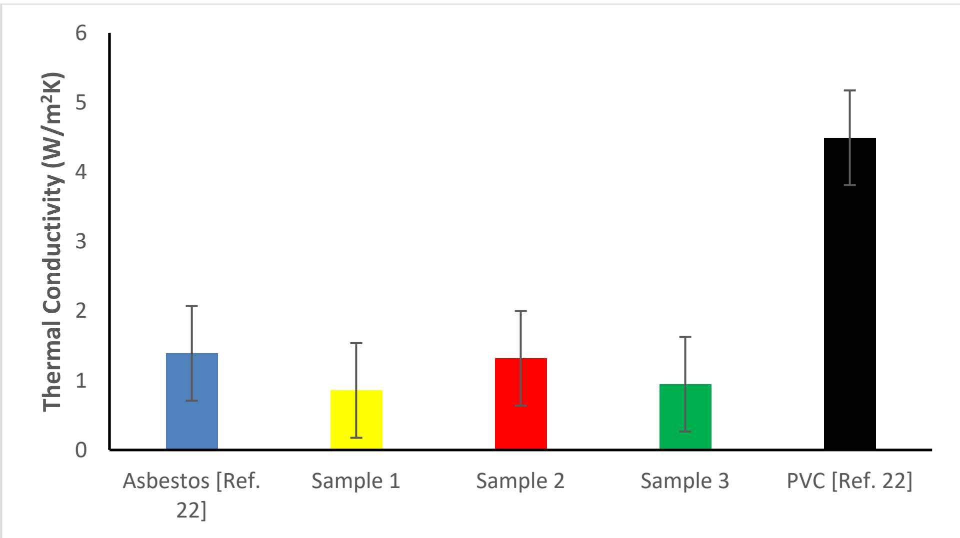

Figure 3: Thermal Conductivity Variation

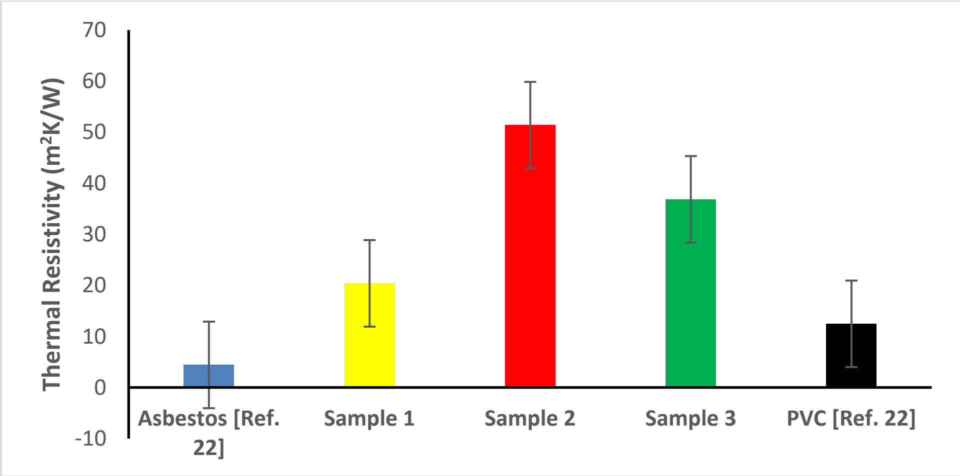

Figure 4: Thermal Resistivity Variation

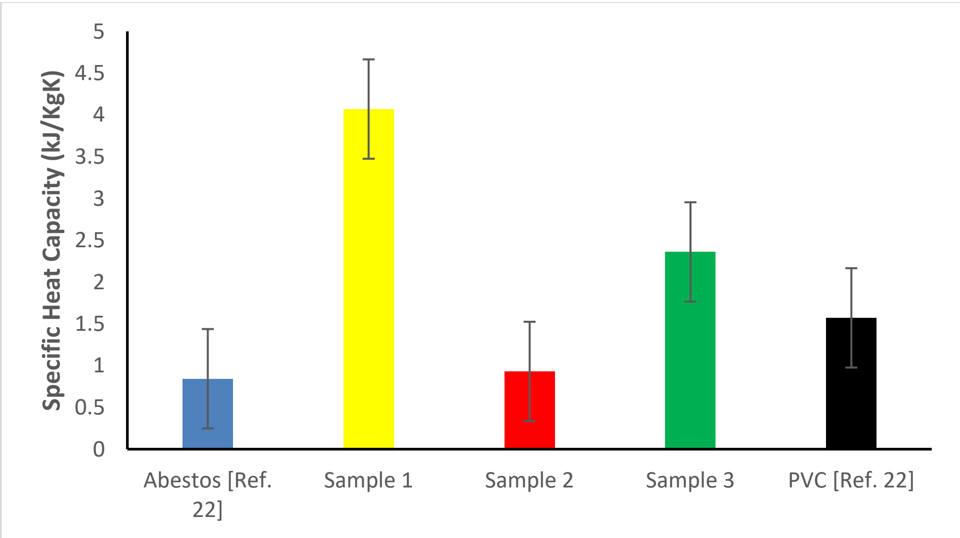

Figure 5: Specific heat capacity Variation

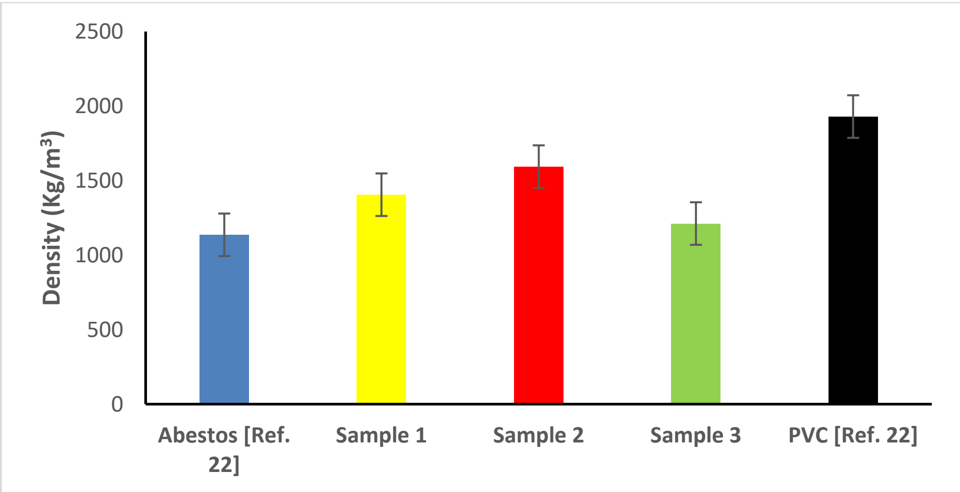

Figure 6: Density Variation

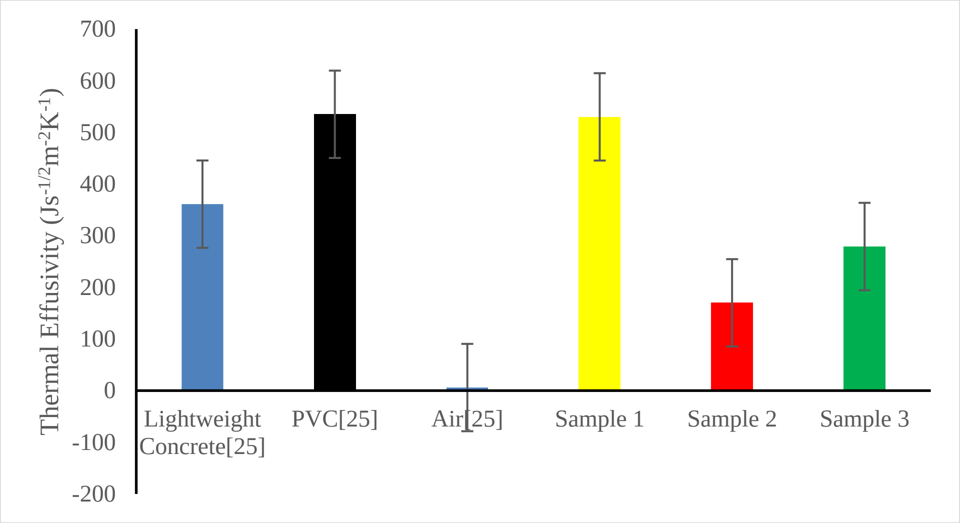

Figure 7: Thermal Effusivity Variation

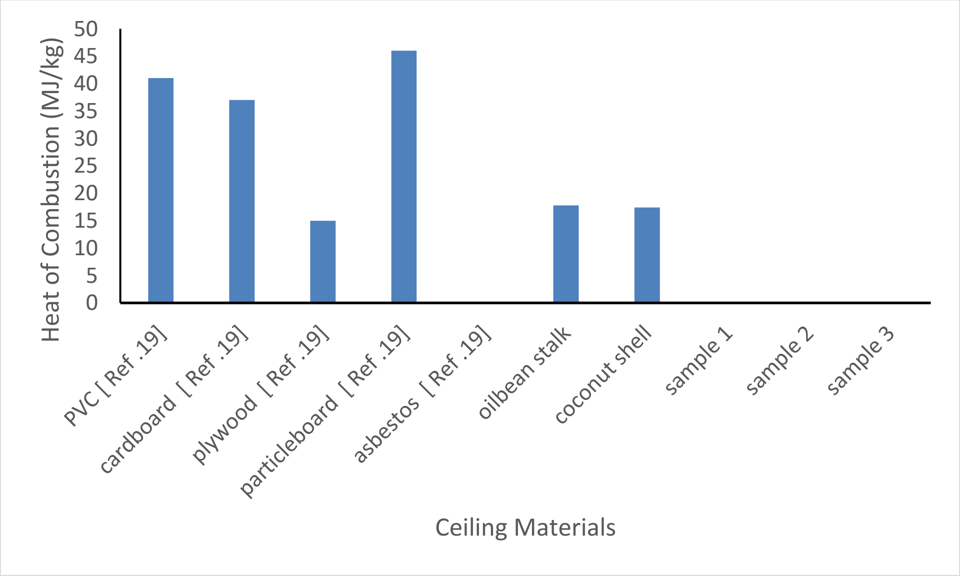

Figure 8: Heat of Combustion of Ceiling Samples

4. Conclusion

In this study, the variation in percentage weight of pulverized oil beanstalk impacts the thermo-mechanical properties studied. This study shows that the percentage variation doesn't significantly impact the thermal and mechanical properties due to the lowest additive and highest values of portland cement, as seen in $_{0.6}Aldr_{0.34}Cmt_{0.05}G_{0.01}OBS$. Samples, $_{0.6}Aldr_{0.3}Cmt_{0.05}G_{0.05}OBS$ and $_{0.6}Aldr_{0.32}Cmt_{0.05}G_{0.03}OBS$ composites possess expected properties for flame retardance in a ceiling application. The triad-developed ceilings are flame retardant due to their non-combustibility and low thermal conductivities. Oil beanstalk is among the reinforcement materials group and can be employed suitably as an additive to base material. The non-combustibility of the developed samples and excellent thermal properties can reduce building energy demand and provide a competitive substitute for existing building ceilings in the markets.

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References

1. de Andrade, C. F., Duarte, J. B., Barbosa, M. L. F., de Andrade, M. D., de Oliveira, R. O., Delgado, R. C., & Teodoro, P. E. (2019). Fire outbreaks in extreme climate years in the State of Rio de Janeiro, Brazil. Land Degradation & Development, 30(11), 1379-1389
2. Ramos-Neto, M. B., & Pivello, V. R. (2000). Lightning fires in a Brazilian Savanna National Park: rethinking management strategies. Environmental Management, 26(6), 675-684.
3. Aderibigbe, A. (2017). Root cause analysis of a jet fuel tanker accident. International Journal of Applied Engineering Research, 12(24), 14974-14983.
4. Sunday, O. U., Zubairu, S., & Isah, A. (2019). Assessment of The Causes of Fire Incidents in Garki Model Market of Abuja and Prevention Measures Against Recurrence. Ethiopian Journal of Environmental Studies & Management, 12(2),202-213.
5. Ibrahim, T. A., Suleiman, B., & Bello, N. A. (2019). Causes and Effects of Building Collapse in Nigeria. KIU Journal of Social Sciences, 4(4), 81-90.
6. Kim, D. (2019). Characteristics of Korean Forest Fires and Forest Fire Policies in the Joseon Dynasty Period (1392–1910) Derived from Historical Records. Forests, 10(1), 29.
7. Kaye, A. D., Kolinsky, D., & Urman, R. D. (2014). Management of a fire in the operating room. Journal of anaesthesia, 28(2), 279-287.
8. Young, J. D., Thode, A. E., May Huang, C. H., & Ager, A. A. (2019). Strategic response to wildland fire hazards in the southwestern United States. Journal of environmental management.
9. Bar, M., Alagirusamy, R., & Das, A. (2015). Flame retardant polymer composites. Fibres and polymers, 16(4), 705-717.
10. Shittu, A, J. E Idiake, and W. P. Akamu. 2015. Effect of petroleum price increase on the cost of selected building finishing materials in the Nigerian construction industry (2006-2012). Journal of Economics and Sustainable Development 6(8), 141–51.
11. Sedo, J., Polakova, S., & Cuchtova, D. (2015). Various methods of aluminum melting dust dross fraction granulation and the research of continuous granulation possibilities. European Scientific Journal, ESJ, 11(18), 59-68.
12. 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).
13. 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.
14. 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). https://doi.org/10.5539/jmsr.v3n2p23
15. Agarwal, G., Patnaik, A., & Sharma, R. K. (2014). Thermo-mechanical properties and abrasive wear behaviour of silicon carbide filled woven glass fibre composites. *Silicon*, *6*(3), 155-168.
16. 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.
17. Sudharsan, B., Kumar, M. L., & Kumar, R. M. L. (2014). The mechanical behaviour of eggshell and coconut coir reinforced composites. *International Journal of Engineering Trends and Technology (IJETT)*, *18*(1), 9-13.
18. Gesa, F. N., Atser, R. A., & Aondoakaa, S. I. (2014). Investigation of the thermal insulation properties of selected ceiling materials used in Makurdi Metropolis (Benue State-Nigeria). *Am. J. Eng. Res*, *3*(11), 245-250.
19. Oyekunle, J. A. O., Dirisu, J. O., Okokpujie, I. P., & Asere, A. A. (2018). Determination of Heat Transfer Properties of Various PVC and Non-PVC Ceiling Materials Available in Nigerian Markets. International Journal of Mechanical Engineering and Technology (IJMET), 9(8), 963-973.
20. 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.
21. 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.
22. George, N. J., Obianwu, V. I., Akpabio, G. T., & Obot, I. B. (2010). Comparison of thermal insulation efficiency of some select materials used as ceiling in building design. *Archives of Applied Science Research*, *2*(3), 253-259.
23. Ezenwa O. N., Obika, E. N., Umembamalu, C., Nwoye F. C. 2019. Development of ceiling board using breadfruit seed coat and recycled low density polyethylene. Heliyon 5(11), 02712.

24. Pooley LI, Abu-Bakar AS, Cran MJ, Wadhwani R, Moinuddin K.A. (2019). Measurements of specific heat capacity of common building materials at elevated temperatures: a comparison of DSC and HDA. Journal of Thermal Analysis and Calorimetry. 9:1-1.
25. http://thermalanalysislabs.com/thermal-properties-of-commonmaterials/ materials/#sf_form_salesforce
26. Verbeke, S., & Audenaert, A. (2018). Thermal inertia in buildings: A review of impacts across climate and building use. *Renewable and Sustainable Energy Reviews*, *82*, 2300-2318.
27. 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.
28. Amoako, G., & Mensah-Amoah, P. (2019). Determination of Calorific Values of Coconut Shells and Coconut Husks. Journal of Materials Science Research and Reviews, 1-7.
29. 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.
30. Iffat, S. (2015). Relation between density and compressive strength of hardened concrete. *Concrete Research Letters*, *6*(4), 182-189.
31. Dirisu, J. O., Oyedepo, S. O., & Fayomi, O. S. I. (2019, December). Thermal energy assessment of oil bean stalk as a novel additive to building ceilings. In *AIP Conference Proceedings* (Vol. 2190, No. 1, p. 020076). AIP Publishing LLC.
32. Dirisu, J. O., Oyedepo, S. O., Fayomi, O. S. I., Joseph, O. O., Akinlabi, E. T., Babalola, P. O., ... & Oluwasegun, K. M. (2022). Thermal-emission assessment of building ceilings from agro-industrial wastes. *Fuel Communications, 10*, 100042.