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Flame Behaviour Comparison of Building Ceiling Composite using Combustion Calorimeter

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Abstract-
This study determined the heat of combustion characteristics of selected building ceilings materials. The study was intending to appraise the flame affinity or retardance of building ceiling materials during combustion. Careful selection of ceiling composite was carried out in areas like Osun state, Ogun state, Lagos state, and Kaduna State. The heat of combustion was determined, having identified the heating value from the XRY-1C Oxygen Bomb Calorimeter. The heat flux and heat release rates were determined from the results of the combustion experiment. Based on the data obtained from the discrete experiments, the combustion integrity of the samples was appraised. Particleboard has the highest heat of combustion of 45.666J/kg, while asbestos failed to ignite. Other Polyvinyl chlorides (PVC) left ≤ 0.0007kg of char after combustion and became deliquescent after long minutes of exposure to air. The heat release rate is highest with particleboard, 118.9219 J/s, and lowest with sample 7, 2.230 J/s. The study thus establishes that PVC is safer in terms of combustion properties compared to plant-based building ceilings. Asbestos has the overall most reliable properties, but for asbestosis, its use isn't safe for use. It is necessary to develop building ceilings with flame retardant characteristics of asbestos as an alternative to it.

Keywords: building ceilings, combustion, heat flux, heat release rate, sustainable development

1. Introduction

The existence of ceiling material is as old as a man [1], and its varied types, to date, are influenced by advancement in technology to match man's thirst for thermal comfort and aesthetics environment. Plant-originated ceiling such as thatches, plywood, and cardboard ceiling are gradually giving way for synthetic and composite ceiling materials such as asbestos, POP, and more recently, PVC. The ignorance to take cognizance of the thermal properties as well as the environmental impact of the more recent ceiling material, PVC, can be detrimental [2]. Observation in the present competitive world reveals that people that are economically favoured usually go for costly appealing ceiling materials. In contrast, the less privileged ones go for just any ceiling material. However, stakeholders failed to take cognizance of the thermal characteristics or possible environmental hazards that may be associated with the material selection should there be an outbreak of fire [3].

The lack of preventive and predictive maintenance culture is a peculiarity of man, hence the dearth of standard data to serve as a benchmark for any intending ceiling product [4]. The lack of forecast into likely fire outbreak and last-minute approach to fire occurrence has been our persistent habit, which can be avoidable. There is a need to carefully investigate more, especially the thermal and combustion characteristics of the prevalent use of PVC as ceiling material. Reduction in death due to fire outbreaks can be prevented if proper orientation is done on probable causes. There is a shortage of data on the thermal properties as well as the combustion emission characteristics of these PVC ceiling materials available in our markets

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[5-7]. Hence, this study aims at investigating the thermal and combustion characteristics of PVC ceiling materials to give informed advice to the stakeholders and Standard Organization of Nigeria, as to the suitability of the current PVC available in the market as ceiling materials.

2. Combustion Effect on Human

According to Hilado [8], the entire process of combustion is perhaps best described by considering it on three scales: micro, macro, and mass. Some results of the burning process are apparent threats to human life, wherever occupants are present within the burning system and in adjacent systems. Still, their relative importance can vary with the conditions of each fire. Because there can be such a wide variety in types of plastic materials and in their extent of exposure and involvement, the hazard of each situation must be judged on an individual basis. The results of the burning process which can threaten human life can be summarized as the following: (1) oxygen depletion, (2) flame, (3) heat, (4) toxic gases, (5) smoke, and (6) structural strength reduction [8]. The average human being is accustomed to operating satisfactorily with the usual level of about 21 percent oxygen in the atmosphere. When the oxygen level falls to 17 percent, muscular skill is diminished because of a phenomenon called anoxia. At oxygen levels of 10 to 14 percent, a man is still conscious but may exhibit faulty judgment, not apparent to him. At oxygen levels of 6 to 8 percent, breathing ceases, and death by asphyxiation occurs in 6 to 8 minutes [9,10]. The excitement and exercise occasioned by a fire tend to increase the oxygen demands of the body, and oxygen deficiency systems may appear at higher oxygen levels than would be the case without excitement or exercise. An oxygen concentration of 10 percent is considered the minimum level for survival.

Whether this level is reached, and how rapidly, varies with each fire and location in the system. It is affected by concentration of combustibles, rate of burning, volume of the system, and rate of ventilation [11]. Burns can be caused by direct contact with flames or by heat radiated from fire. Burns can result if skin temperature is held above 150°F for one second [12]. Flame temperatures and their radiant heat may prove immediately or eventually fatal. Unlike direct flame, heat can be a hazard to occupants of adjacent systems in addition to occupants of the burning system. Hot air and gases from a fire, ignoring any effects of oxygen depletion or toxicity, can cause burns, heat exhaustion, dehydration, and blockage of the respiratory tract [13].

A breathing level temperature of 300 °F is considered to be the maximum value for survival. Breathing level, the distance above the floor, is considered to be about 5 feet, although the 4-foot level is sometimes used when children comprise a significant fraction of the occupants. Temperatures above 150 °F are considered untenable, and temperatures in this range can hold back firefighters and keep occupants from entering passages leading to exits [14].

3. Combustion and Flame Resistance

Fire is an exothermic reaction that is self-sustaining after ignition. Fire evolves from solid, liquid, or gas that emits energy in the form of light and heat [15]. Combustion is a chemical process that supports a fire. Equation 1 and 2 show a complete and incomplete combustion process.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) + \Delta H_c \quad (1)$$

$$6CH_4(g) + 9O_2(g) \rightarrow 2CO_2(g) + 2CO(g) + 12H_2O(g) + 2C(s) + \Delta H_2 \quad (2)$$

The absence of combustion in a material is an indication of fire resistance, which is a required material in building industries. Fire resistance indicates null penetration of fuel, heat, and oxidizer into the interstices of the material into consideration. Various materials have degrees of flammability. The variation in flammability or retardance finds its application in the industry. Fire retardant materials interrupt combustion reaction by breaking the chain of combustion, promotes char formation, and provides an insulating barrier to flame impregnation [16]. Fire resisting material resists burning while flame retardant material burns slowly. Examples of flame resisting materials are bunker gear worn by firefighters, cement, bricks, precast shapes, ceramics, alumina, chromite, fire clays, magnesite, and silicon carbide. In contrast, flame retardant materials employed in buildings are Mineral wool, Gypsum boards, Asbestos cement, Perlite boards, Corriboard, Calcium silicate, Sodium silicate, Potassium silicate, amongst others [17-19].

4.Materials

Figure 1 shows 14 ceiling tiles that were selected in Osun, Lagos, and Kaduna states in Nigeria. The PVC ceiling tiles are renamed as A1-A10 for simplified discussion while particleboard, cardboard, plywood, and asbestos retain their nomenclature. Each sample was cut, pulverized, and weighed to obtain 5g for the bomb calorimeter experiment.

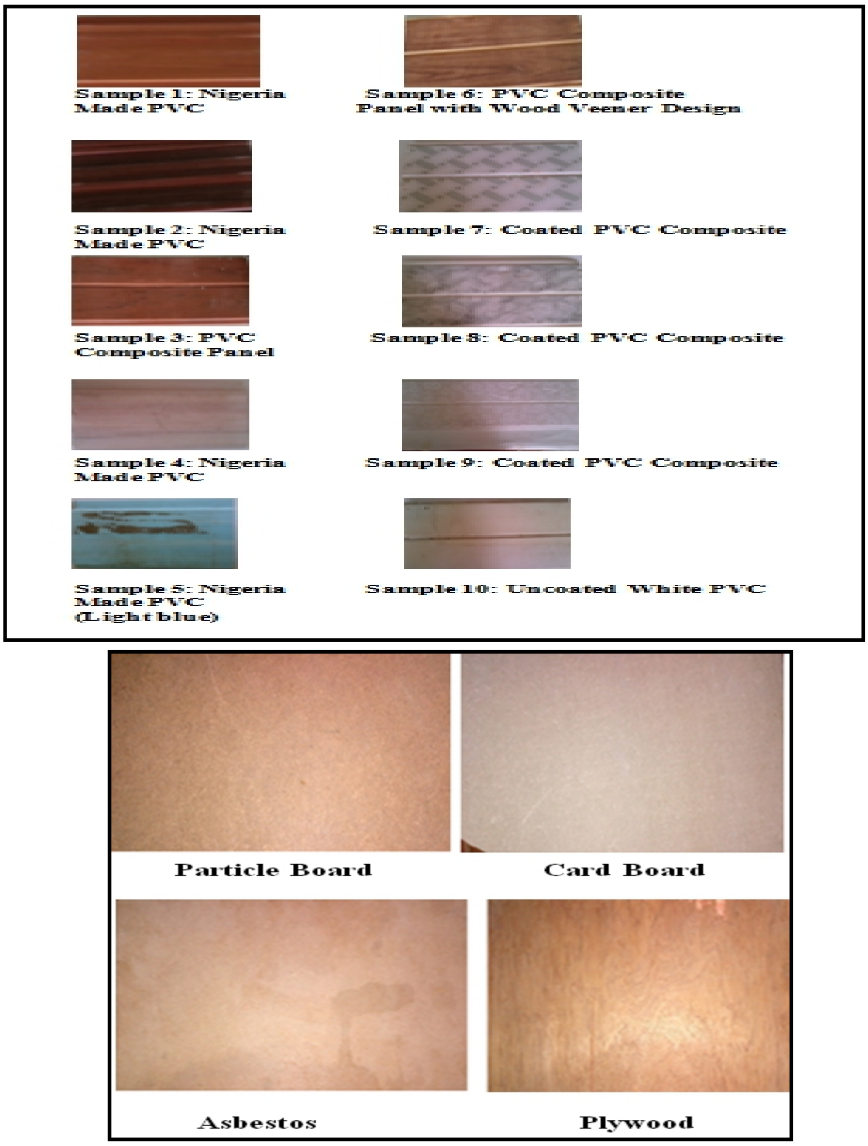

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Figure 1: Selected Ceiling Tiles in Nigerian Markets

5. XRY Bomb Calorimeter for Heat of Combustion of Ceiling Materials

XRY-1C Oxygen Bomb Calorimeter is employed to obtain the heat of combustion of a material and designed according to ASTM D240, ASTM D4809, and ISO 1928 by Shanghai Changji Geological Instrument Co., Ltd, 2010. The instrument adopts a high precision thermal sensor and high-powered A/D converter, using MCS buildup intelligent temperature gather and transform system, and compose intelligent with the computer. It is automatic and quick in operation. The instrument is widely used to determine the calorie of coal, oil, coke, olefin, and flammable materials. It has a thermal capacity of 14000~ 15000 J/K, temperature measuring range of 10~35ºC, temperature solvent at 0.001ºC, repeatability error of ≤ 0.2% (º C), oxygen bomb endure pressure of 20 MPa, ambient temperature of 15~28 ºC, surrounding humidity at < 85% and power supply AC 220V ± 10%, 50 Hz (Shanghai Changji Geological Instrument Co., Ltd, 2010) [16]. The instrument is comprising calorimeter mainframe, oxygen, and its accessories, computer, and printer.

Figure 2: XRY-1C Oxygen Bomb Calorimeter [24]

6.Procedure for Bomb Calorimeter

The mainframe was placed on a level desk and kept more than 10 cm between surroundings to join the wire conveniently and avoid affecting the instrument constant temperature system. Caution was taken to ensure there was no heating or refrigerating device around the instrument. The computer was installed, and a connection was made with the communication cable of the calorimeter mainframe. The calorimeter mainframe comprises the stirrer, ignition wire, and thermal sensor. About 15 litres of water was poured into the outside canister for manual stirring (the red handle in the outer canister is the manual stirring stick). The water was left for a day and stirred about ten times to attain a steady temperature. The samples were equally weighted to 0.5 g using the electronic balance. It was then placed into the crucible of the burning vessel. The electrothermal tinsel was installed by placing the bomb lid into the bomb bracket and carefully cut the electrothermal tinsel (Ni-Cr wire) about 9 cm. Both ends are carefully hung on the electrode shaft from the burning vessel to avoid short-circuiting. The firing cotton was then tied axially to the electrothermal tinsel. The bomb lid and burning vessel were carefully airproof tightened. Near 1.5 litres of distilled water was poured into the inside canister up to the level the electronic stirrer can detect, and below the reach of the ignition wire to avoid ignition failure. The inflator of the oxygen pipe was joined to the industrial oxygen cylinder. The other end was joined to the bomb. The oxygen of 2.5 KPa was supplied to the bomb. The bomb was inserted into the inside canister. The lid was then closed, ready to prompt the XRY-1C software for combustion. The computer system is made to boot, XRY-1C software was prompted; name of the sample typed, mass of sample indicated, and heat capacity of the samples indicated. The bomb calorimeter is switched on and the software is immediately communicated by the temperature sensor the temperature readout in the inside canister. Regnault-Pfaunder formula was chosen as the formula to use for software calculation. The start button was clicked for burning operations to start. The power and stirring indicators turn on at the fore period of burning, while the measurement indicator comes on only during the main period of burning. The measurement indicator disconnects at the after a period of combustion; the power indicator is left to on at the end of the burning process. The bomb is first degassed by the deflator valve and then opened. The software automatically calculates the gross and net calorific value at the end of the burning process.

7.Results and Discussion

7.1 Heat of Combustion of PVC and Non-PVC Ceiling Tiles

The heat of combustion of selected ceiling tiles in this study is presented in Figure 3, 6 and Table 1. In Figure 3, Particleboard has the highest heat of combustion of 45.666J/kg while the asbestos ceiling failed to ignite, as it only becomes brittle; hence no value. The high flame inclination in particleboard and flammability of other ceiling tiles is due to the presence of combustible elements. The non-combustibility of asbestos is evident due to failure to ignite. The implication here is that asbestos is safest in terms of resistance to combustion in the cause of fire outbreak. Asbestos is considered a fire resisting material as it resists burning and withstands heat. It contains silicon, magnesium, and oxygen. Other elements present in asbestos, depending on the group, are calcium, sodium, and iron. There are six varieties of asbestos which are chrysolite ($Mg_6Si_4O_{16}(OH)_8$, Amosite $(Fe^{2+}Mg)_7Si_8O_{22}(OH)_2$, Crocidolite $Na_2Fe^{3+}(Fe^{2+}Mg)_3Si_8O_{22}(OH)_2$, Anthophyllite $Mg_7Si_8O_{22}(OH)_2$, Actinolite $Ca_2Fe_4{}^{2+}MgSi_8O_{22}(OH)_2$ and Tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$. Chrysolite, which is known as white asbestos, is the most used asbestos worldwide by 95% [21]. Silicon, calcium and magnesium are known flame resisting element. "The term asbestos is derived from a Greek word meaning "inextinguishable, unquenchable or inconsumable." It is a generic name for a group of fibrous silicate minerals, the most common of which are chrysotile, crocidolite and amosite. Asbestos is non-flammable even at very high temperatures and is extremely flexible and durable" [22, 23, 25].

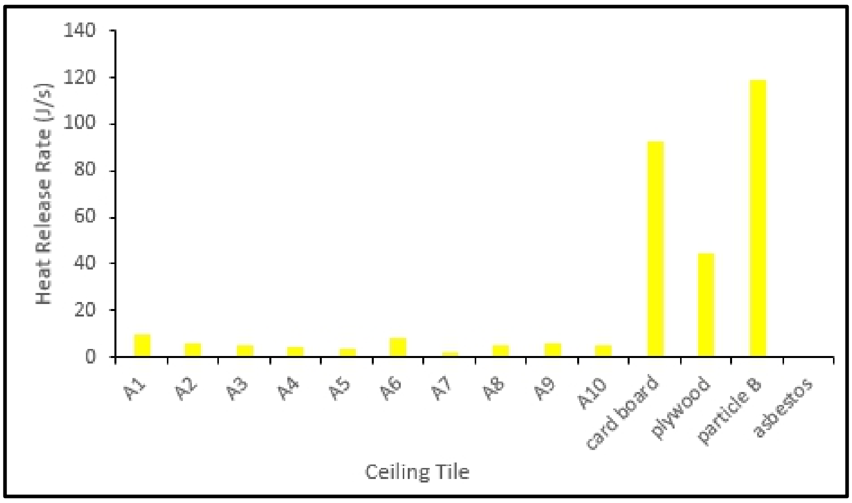


Figure 3: Heat of Combustion of PVC and non-PVC ceiling Tiles

Non-PVC samples except asbestos ignite without having a trace of char in the crucible of the oxygen bomb calorimeter. Other PVCs left ≤ 0.0007 kg of char after combustion and became deliquescent after long minutes of exposure to air. Figure 4 presents the burning time of the ceiling tiles. Asbestos ceiling failed to ignite, therefore, becomes a flame resisting material. No ignition further establishes that asbestos is safe as it will not support fire propagation. The time of the combustion of all samples in the bomb calorimeter is of the range of 23.5≤x≤33 minutes.

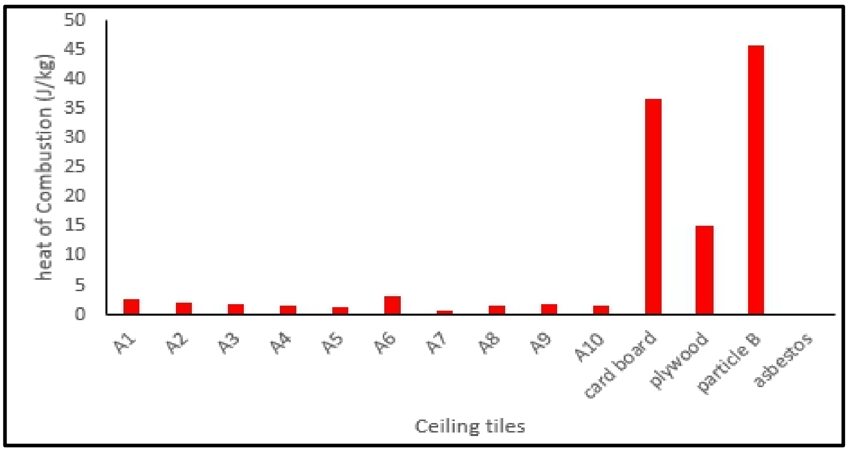
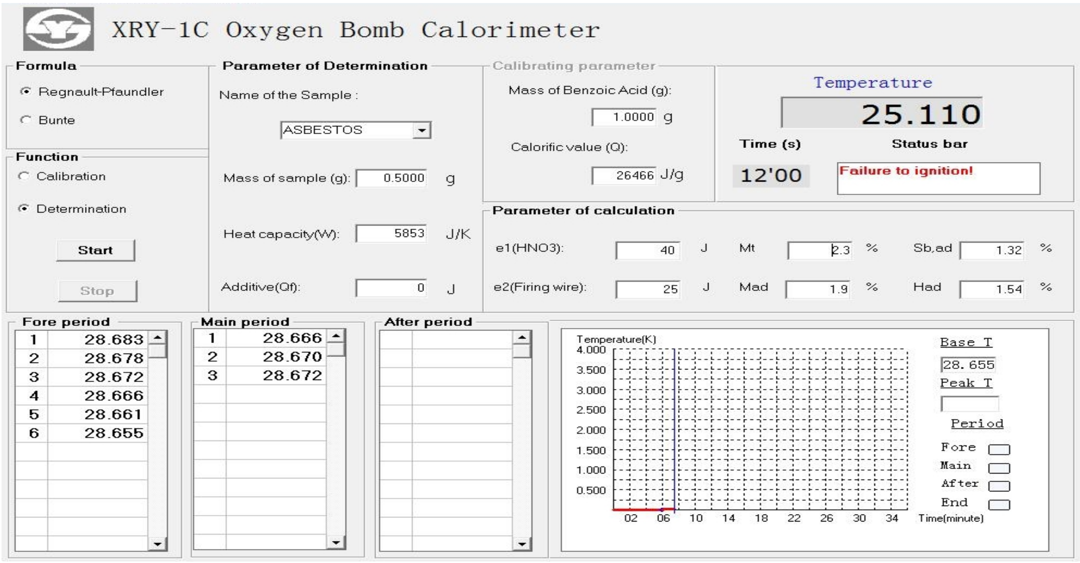


Figure 4: Burning time of Ceiling Tiles



The Heat Release Rate (HRR) is shown in Figure 5. HRR is highest with particleboard, 118.9219 J/s, and lowest with sample A7, 2.230 J/s. The asbestos ceiling shows an apparent flame resistance with insignificant HRR.

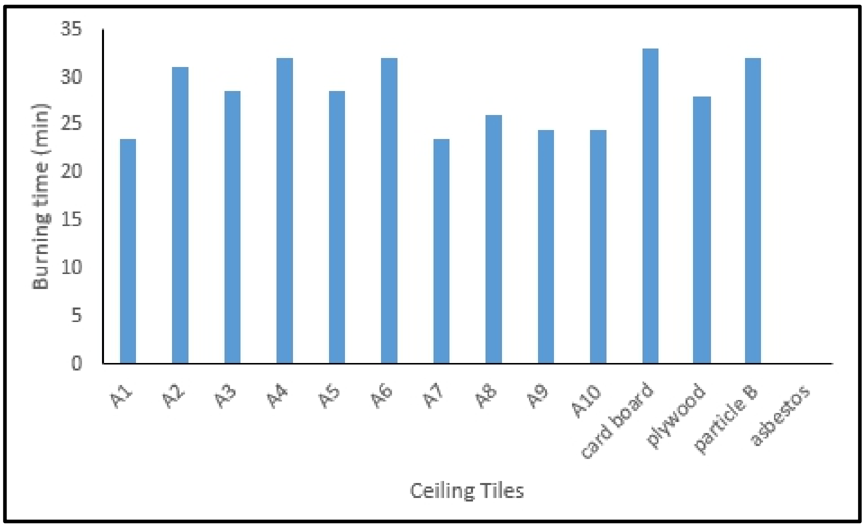


Figure 5: Heat release rate of Selected Ceiling Samples

Figure 6: Calorific value determination of asbestos ceiling

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Table 1: Example of Heat of Combustion Experiment for Ceiling Sample

Determination Sample name: Sample A3		Operator: Dirisu Joseph	
Sample Mass(g): 0.5000		Formula: R-P	
Capacity(J/K)	2166		
Mad(%)	1.9	Mt(%)	2.3
Sb,ad(%)	1.32	Had(%)	1.54
AutoID	Fore period	Main period	After period
1	28.285	28.293	28.771
2	28.281	28.401	28.770
3	28.277	28.492	28.770
4	28.273	28.555	28.769
5	28.270	28.599	28.768
6	28.266	28.632	28.766
7		28.657	28.765
8		28.677	28.764
9		28.694	28.762
10		28.707	28.760
11		28.718	
12		28.729	
13		28.737	
14		28.744	
15		28.749	
16		28.754	
17		28.758	
18		28.762	
19		28.764	
20		28.767	
21		28.768	
22		28.770	
23		28.770	
24		28.771	
25		28.772	
26		28.772	
27		28.771	
	Qb,ad(J/g)	Qgr,ad(J/g)	Qnet,ar(J/g)
	2295	2168	1790
	Time: 10/20/2014 3:22:28 PM		

8. Conclusion

The flame behaviour of typical building ceilings in the Nigerian market has been investigated. The study will assist manufacturers and stakeholders in the building industry to ensure the safety of lives and to provide data for firefighters in the cause of carrying out rescue missions.

Asbestos shows a consistent level of flame resistance and retardance, which makes it the most suitable building ceiling in the prevention of fire spread from the roof truss. PVC ceilings show a low heat release rate compared to plant-based building ceilings. Plant-based ceilings are a flame risk to users and should be avoided. Flame retardant building ceiling that doesn't pose health hazards such as asbestosis should be developed.

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