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ASSESSMENT OF ACOUSTIC PROPERTY OF SAWDUST AND FINE SHARP SAND FOR THE FABRICATION OF SOUND-PROOF SECURITY DOOR

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ABSTRACT
The current economic recession and rising cost of building materials in Nigeria has created a severe decline in housing affordability for Nigerians. On this account, this research aimed to assess the acoustic property of Saw-dust and Fine Sharp Sand (SFSS) and its application for the fabrication of purpose made Sound-proof Security Doors (SPS-Door). The ingenuity of the research is to offer an alternative fabricated door to the high priced foreign made sound-proof security doors that are not affordable to most Nigerian for housing delivery. The wooden sawdust mixed with fine sharp as a core in-fill material for the door are readily available as natural material and environment waste. Model Sample Panels (MSP) infills produced and tested at the Acoustic Laboratory for noise absorption capacity as established by ASTM E 1050-98 international standards. The research findings revealed that the MSP infills for the SS-Door scored 0.78 to 0.92 for the frequency ranges 50Hz to 5000Hz while foreign Turkey doors infill's Noise Absorption Coefficient is 0.95 for the same ranges of frequencies. Comparatively, MSP infill is a sustainable and alternative material for the locally fabricated sound-proof security door to the expensive imported brands. In addition, properties of SFSS at the ratio of 5:1 presented high porosity characteristic which had a significant effect on the sound absorption properties of SS-Door. Therefore, architects could specify this innovative infill product for doors panel, walls cavity and floor inside layer for the spaces that require sound insulation and security in the building construction.

Keywords: Sound-proof security door, Fabrication, Environmental Waste, Nigeria

INTRODUCTION
The current wave of the global economic recession is creating financial adversity for the citizen of many nations and Nigerians are no exception. Nigerians purchasing power reduces by the day and above all the cost of building material has become very expensive and unaffordable. Architects, builders and researchers are in search of affordable building materials for sustainable housing delivery. As a part of this search, a locally fabricated Sound-Proof Door (SPS-Door) with a Sawdust and Fine Sharp Sand (SFSS) infill was developed as a cheaper option to pricey imported alternatives. The goal is to turn waste into wealth by utilizing local resources and cost-cutting strategies in the building sector. In addition, it is a job creation channel and for the enhancement of self-reliance which is essential for sustainable economic development in Nigeria.

Sawdust is a wood waste that is readily available in every timber/log milling outlet in Nigeria. Massive amounts of wood are employed in many parts of human endeavour, with building construction accounting for up to 56% (Izekor & Kalu, 2008). The process of cutting/sawing wood/logs into standard sizes for the building construction generate large quantities of sawdust as waste. Sawdust particles size practically depends on the nature of the wood and the saw teeth size used for cutting. Kehinde, Ayoyemi, Omonona & Akande (2009) stated that about a 5.2milllion tonnes of sawdust is generated annually from different timber/log milling outlets in Nigeria. According to the same paper, the sawmill process reduces ten to thirteen per cent of the timber harvested in Nigeria's forest to sawdust. Izekor and Kalu (2008) affirmed that the annual quantities of sawdust production in the two-state of Nigeria (Edo and Delta) is around 1.8 million tonnes. Sawdust generation is available in most of the logging sawmills in Nigeria. Therefore, the availability and accessibility to this waste are vast, and the potential opportunity to use it as a raw material is enormous.

Several scholars have identified the tremendous economic potential of sawdust as a sustainable material for building construction (Raut, Ralegaonkar & Mandavgane, 2012). In another study, agricultural waste was recycled and combined with bio-degradable plastic and used sawdust as a wood-based cement glue board which served as a reinforcement of polymers composite (Maduwar, Ralegaonkar & Mandavgane, 2013). Likewise, Usman, Ojo, and Simon (2012) showed that sawdust and palm kernel shell can be used as a sustainable alternative to fine and coarse aggregate in concrete. In addition, Aigbomian and Fan (2013) created Wood-Crete, an innovative and sustainable building material made from sawdust and waste paper. Despite, few studies have assessed the acoustic property of the sawdust and its application as a sustainable building material for acoustical insulation (Maduwar, Ralegaonkar & Mandavgane, 2013). Globally, there is a growing demand for researchers to create and develop sustainable alternative solutions for reducing the housing gap using ecologically friendly and economical construction materials, and Nigeria is no exception (Suleiman & Aliyu, 2020; Taiwo & Adebayo, 2013 and Sieffert, Huygen & Daudon, 2014).

In Nigeria, the demand for innovative local construction methods and materials is motivated by inflation and uncertainty in economic development. The high cost of conventional building materials and the requirement to sustain ecological stability, the growing population and the challenges of housing affordability are factors that motivated the call for the use of sustainable and affordable building materials for housing delivery in Nigeria (Oyemogum, Adeagbo & Marut, 2013). Notable efforts are being directed toward the replacement of imported building materials with locally produced products. Experimentation on the application of the agricultural and environmental wastes (sawdust, rice husk ash, millet/maize husk ash and wood/plastic/metal related wastes is still ongoing (Lawal, Oluyege, Bola, Aina, Falemara & Gakenou, 2020; Raut et al 2012). The recent trend on environmental sustainability has created unprecedented interest in eco-friendly building materials and methods which create additional interest among scholars to develop alternative construction materials that are energy-efficient, materially and economically sustainable.

Notable studies have employed sawdust as a sustainable component for building material (Taiwo & Adeboye 2013; Liman, Adagba & Umar, 2020). Some of the past researchers have developed cement-bonded particleboard; it is a value-added wood product produced from the combination of sawdust, agricultural waste and cement boned (Paramasivam & Luke 2010; Olakunle, Alfa, Mohammed, & Ahmadu, 2019). It is a composite product acceptable for building construction. The merit of this product is the availability of the two raw materials (cement and sawdust) for its production compared to other conventional products (resin-bonded particle board). Likewise, sawdust combined with other agricultural wastes has been used for the production of sustainable building construction materials (Adegoke, 2007). The inherent thermal and acoustic insulating properties of wood (sawdust) and other agricultural waste, as well as its light weight, made it a suitable construction material for ceilings, roofs, flooring, cladding, and partitioning. In addition, sawdust and organic fibers are positioned as sustainable sound absorber materials due to their low cost, availability, and lack of health hazards (Zulkifli & Jailani, 2010).

Other wastes, such as industrial tea leaves combined with textile materials, have sound absorption capabilities that improve as the amount of cotton cloth used increases (Ersoy & Kueuk, 2009). The study conducted by Zulkifli and Jailani (2010) showed that coir fibre has sound absorption capacity due to the presence of an air gap in its structure. Greater absorption outcome achieved with the different thicknesses of Coir fibre (20mm, 35mm and 50mm) at 0.6 to 0.95mm air gap in between the panels at the lower frequency range of 1000Hz to 1500Hz. Likewise, Yang et al. (2011) examined the absorption coefficient of other natural fibres such as Cashmere, kapok and goose down. Subsequently, findings revealed that the internal structure of these natural fibres has a positive impact on sound absorption properties (coefficient performance). In addition, Fouladi et al (2010) studied the effect of the pattern of arrangements of the same natural fibres and metal plates on sound absorption performance. The research findings showed that perforated plates padded with coir fibre and filled with air space, have good sound absorption capacity at low frequency. Fouladi et al (2010) stated that increasing the thickness of the coir fibre layers with optimum air gap 0.6mm to 0.95mm positively enhanced the acoustical performance in practical application for building's sound insulation.

Recent research conducted by Zulkifli et al. (2010) showed that the porosity and thickness of the layer have a positive influence on the sound absorption capacity of the natural coir fibre, whereas the density has no significant impact on the sound absorption except for the strength and durability. Mahzan (2010) went further to demonstrate the practicability of composite material derived coconut coir, sawdust mixed with waste plastic /rubber as alternative sound insulation building materials. The result presented a comparable and improved sound absorption coefficient.

Even though several studies on the sound absorption properties of sawdust and agro wastes have been identified and published, few studies have attempted to implement the research findings for the production of alternative or sustainable finished products in the Nigerian context. It is this gap; this study intends to fill. Therefore, this research aimed to assess the acoustic property of Saw-dust mixed with Fine Sharp Sand (SFSS) and its application as an infill for the fabrication of purpose-made Sound-proof Security Doors (SPS-Door). The ingenuity of the research is to provide an alternative locally fabricated door to the expensive imported sound-proof security doors that are not affordable to most Nigerian for housing delivery. SPS-Model Door's Sample Panels (MSP) infills were subjected to a laboratory evaluation to determine their acoustic insulation properties, as documented by the Standard Test Method for Impedance and Absorption of Acoustical Materials (ASTM E1050-98). The production process and elements that affected the sound-proof quality of SPS-Door's acoustic property were discussed based on the field testing results.

MATERIALS AND METHODS

Preparation of materials

The primary materials for this research are sawdust, fine sharp sand, metal pipe and sheets. The equipment used for the acoustical measurement are Impedance tube device set; Calibrator 94.0 dB; Microphones – GRAS 26 AK; Amplifier and Symphony – dual-channel real-time acquisition unit, and Speaker.

The sawdust was obtained from local timber sawmills and washed fine sharp sand supplied from the municipal stream. The sharp sand was sieved with a 1mm mesh size gage. As presented in Figure, both the sawdust and fine sharp sand (SFSS) was mixed in different proportion to produce Model Sample Panels (MSP1; MSP2; MSP3; MSP4 and MSP5). For the fabrication of the door, a black pipe of 1.5 mm gauge employed for the construction of the door's frame structure. A flat metal sheet of a gauge thickness of 1.5mm used for the door's panel. Other accessories used were hinges, cutting and welding machines.

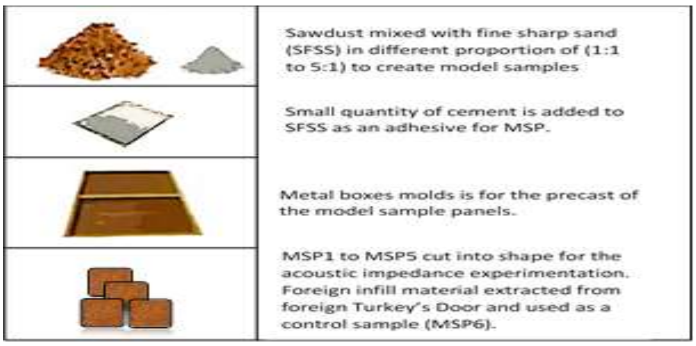

Figure 1: Procedure for preparation of the model sample panel

Before the door fabrication, the sieved SPSS were mixed in a different ratio as presented in Table 1. Different proportions of SPSS were designed to establish their effect on the acoustic insulation property of the SPS-Door documented by ASTM E 1050-98 international standards. At the same time, infill of fine sharp sand used was based on the economic and strength considerations while sawdust used was based on the scholars' research that has identified wood as an excellent sound-insulating material, environmentally friendly and recyclable (Ogunwusi, 2014; Madurwar et al., 2013; Mahzan et al., 2010).

The Model Sample Panels (MSP) as infill for the SPS-Door were precast with five rectangular moulds using a metal plate measuring 300mm x 300mm and 20mm veneer edge tape to define the height. The purpose is to create a model of the infill for a door panel with a thickness of 20mm. To form a structure for the SFSS sheets, SFSS was uniformly mixed with small quantity of cement as an adhesive for sawdust and fine sharp sand. Then, five rectangular boxes were filled with a different mixed ratio of SFSS as presented in Figure 1 and Table 1 respectively. Prepared samples for testing the acoustic insulation property of the MSP followed the stipulated standard as described by Baranek and Ver (2010). The computation of density for each sample used the weight and volume of the specimens. In addition, the compressive strength of each sample was tested to establish the security strength component of the MSP as infill material for the final product (SPS-Door).

Table 1: Model sample panel mixture design

Samples	Sawdust and fine sand ratio	Density Kg/m^2	Compressive strength (N/mm^2)
MSP1	1:1	421	0.41
MSP2	2:1	408	0.30
MSP3	3:1	385	0.25
MSP4	4:1	366	0.23
MSP5	5:1	335	0.21
MSP6	As control sample	308	0.17

The samples were placed on a machine with a metal base and a flat steel plate, and a normal load (8mm/min) was applied up to the maximum failure load (in Newton). The compressive strength was calculated using the greatest load (maximum failure stress) and the sample's unit area.

The 100mm and 28mm diameters were used as the sample test for low and high frequency respectively. 100mm steel rod was used to fit the SFSS's samples into the acoustic measurement tube by the instrument's specified manual. Three sets of measurements were made for the five model samples panel (MSP) with different proportions of SFSS mixture and the mean of the measurements were presented in Table 1. A control sample MSP6 was extracted from the foreign soundproof door. The idea is to establish a comparative analysis of both the local and foreign infill materials used for the soundproof doors.

The sound absorption capacity is usually considered within the value range of 0 and 1. Hence sound absorption capacity is the degree of noise a given material could absorb in the built environment. Following international standards, two microphones transfer testing was conducted. The experimental setup of the impedance tube device set and other measurement equipment (Calibrator 94.0 dB; Microphones – GRAS 26 AK; Amplifier and symphony – dual-channel real-time acquisition unit; Speaker) were illustrated in Figure 2.

Figure 2: Experimental setup for the acoustic impedance measurement

The impedance tube device set comprises both the high and low frequency tubes as well as the sample holders; an audio amplifier; loudspeakers case with two microphones. The high frequency – small tube could be used as an independent device or mounted on the low frequency – big tube. Both the microphones and noise generator were connected to the laptop computer. An acoustical software (SCS8100) provided the user-friendly interface for the statistical analysis of the MSP Sample sound absorption property.

RESULTS AND DISCUSSION

The research finding showed that the densities of the MSP1 to MSP5 relatively depended on the compositional ratio of sawdust and fine sharp sand as presented in Table 1. The result suggested that the density of MPS increases with the reduction of the sawdust added. The density of MPS is inversely proportional to the quantity of sawdust in the sample composition might be explained by the fact that the weight of sawdust is lower than the weight of fine sharp sand. The research outcome showed that sawdust has a significant effect on the density of MPS.

As presented in Table 1, it is evident that the compressive strength of MSP decreases diagonally with an increase in the ratio of sawdust in the composition. Likewise, the result showed that there was a proportional decrease in compression strength and density of the five-set of MSP samples (MSP1 to MSP5). Possibly, the increase in the ratio of the sawdust in the MSP's composition acted as a fibrous agent that influenced the reduction in the compressive strength and improved the lightweight and density of the MSP as infill materials for the purpose made doors. The compressive strength and density of MPS5 and MPS6 are comparable, as shown in Table 1. As presented in Table 1, compressive strength and the density of MPS5 and MPS6 (control infill sample) are comparatively similar. MSP was developed with the primary aim of using it as an acoustical infill material and, MPS5 may be used to improve sound absorption between two spaces/rooms in a building since it has the lowest density – 335 kg/m^3 (lightweight). Also, MPS1 and MPS2 with the first and second highest densities – 421kg/m^3 to 408 kg/m^3 and compressive strength 0.41 N/mm^2 to 0.30 N/mm^2 could prefer infill materials for the security door. The outcome of this experimentation is consistent with the laboratory works of Usman et al. (2012) on the use of sawdust as a sustainable option for aggregates in concrete construction in Nigeria.

The impedance tube measurements were employed to establish the acoustic property of the MSP1 to MSP6. MSP6 was used as a control sample to determine the comparative analysis of the locally developed infill and foreign infilled material at low and high frequencies between the range of 50 Hz to 5000 Hz. For each sample, five sets of measurements were taken in order to determine the best possible mean value. As presented in Figure 3, data recorded from the experiment showed that the noise absorption coefficient of MSP6 (imported infill sample) with 20mm thickness scored the highest mean value of 0.95. MPS5 generated the second highest mean value of 0.92, while MSP1 scored the least value of 0.78 from about 3480Hz to 3760 Hz frequency range. Hence MPS5 recorded an excellent noise absorption capacity that is closely related to the foreign infill material. As a result, it can be safely concluded that MSP5 with a 5:1 mixture of sawdust and fine sharp sand may effectively replace imported infills material for soundproof doors.

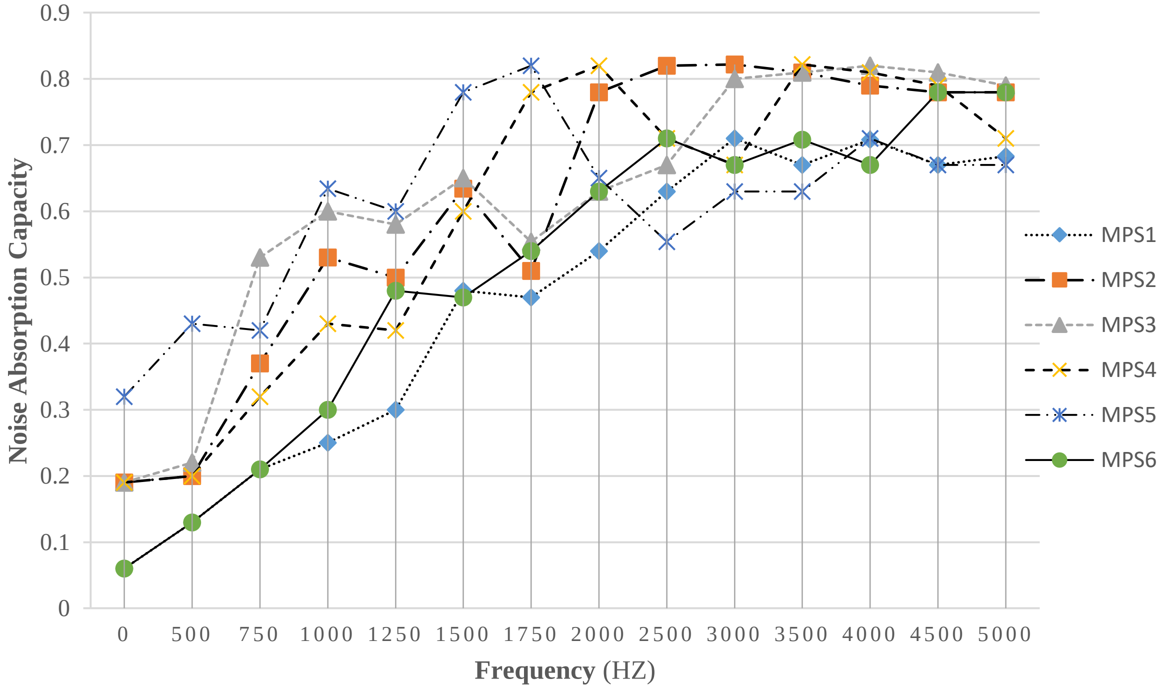

Figure 3: Comparison of Noise Absorption Capacity of MPS 1- 5 and Control Sample (MPS6)

Conversely, the noise absorption capacity of the MSP1 to MSP6 deceased at 4285 Hz to 4922 Hz respectively. Notable works of the past researchers have shown that sawdust is a fibrous material that possessed acoustic absorption capacity (Zulkifli & Jailani, 2010; Tokan et al. 2012). Likewise, the outcome of this research has reaffirmed that sawdust possesses absorbency characteristics as reflected in the consistent increase in the noise absorption capacity of the MPS1 to MPS5.
As previously stated, despite numerous studies on the sound absorption qualities of natural and agricultural wastes, few of these studies have attempted to utilize research findings in the manufacture of alternative or sustainable final goods in the Nigerian context. The uniqueness of this research is that the innovative infill material was used to create a sustainable purpose-made soundproof door that is comparable to the more expensive foreign doors (see Figure 3). Apart from the sound insulation quality of the SPS-Door, maintainability, cost-effectiveness and durability are additional merits of this finished product.

CONCLUSION

The rising cost of building materials has set a new high bar for house affordability. Sustainable construction materials have been identified as one of the most important elements for home affordability in previous research. The outcome of this research has demonstrated the development of sustainable infill soundproof building material with the use of sawdust and fine sharp sand that could enhance housing affordability. The noise absorption and compressive strength of the Model sample panels (MSP) revealed that this innovative material is comparable to that of foreign infill materials, and SPS-Doors constructed with this material are suitable to replace expensive imported soundproof doors. In addition, the produced Sawdust and fine sharp sand as infill material had a compressive strength of 0.21 to 0.41, indicating that it may be utilized as infills for wall, floor, and ceiling panels in high-demand silent spaces in structures. Finally, the fabrication of the SPS-Door as a sustainable finished product is evident that Nigeria has the potentiality of finding her rightful place in the league of self-sufficient nations.

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