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Acoustical Efficiency and Physico-Mechanical Characteristics Study for New Composite Material: Ethylene Vinyl Acetate and Wood Sawdust

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ABSTRACT

Developing neoteric composite materials (CM) that improve the acoustic efficiency and mechanical properties become the target of many scientists in the last decade. This paper presents research on developing new CMs using Ethylene Vinyl Acetate (EVA) and sawdust (SD) of different weight concentrations which can be help to improve the acoustic and mechanical properties of the EVA polymer materials. Prototypes of EVA composite in form of flat plates with different weight concentrations of sawdust namely; 0, 2.5, 5, 10, 20 and 30% were produced. One of the interesting applications of this new CMs is to use it as a floor covering in buildings and manufactures. The acoustic efficiency parameters namely, impact noise reduction and sound absorption are experimentally studied. The obtained results articulate that covering floors with the designed composite material of EVA/SD as filler can decrease ISR up to 14 dB. Also, it gives peak sound absorption coefficient about 0.6 for 30 % of SD at mid-frequency band. The greatest proportion of SD aggregate EVA does not entail a higher acoustic performance. The tensile strength of the composite increases to 15.5% when the SD content is 5% and the tensile strength drops with increase the SD content up to 30%. Therefore, SD may be utilized as filler and consolidation in the EVA matrix, which will save expenses and assist the environment.

Key words: EVA, Impact noise reduction, sawdust, sound absorption coefficient, tensile strength, morphology

1 INTRODUCTION

Recently, the impact noise (ImNs) problems have increased, mainly because the lighter construction techniques that are recently developed and applied in new buildings. When a building's wall or floor is structurally aroused by everyday activities like falling objects or footfall on any surface, it emits structural airborne sound, or ImNs, mainly the ground, movement of furniture, blows on the wall etc. This produces intensely energetic generated airborne noise at all frequencies and little attenuation. The better solution which can be applied in buildings that need soundproof materials based on low and high densities polymers of different elastic, compressions and thermal properties to offer the best performance for each type of floor covering [1]-[6].

The production and usage of new CMs have extensively interest from scientists in last few decades especially, for that are friendly for the environment and have wide application in building life comfort and in industry. Wood polymer composites (WPC) are relatively new generation of CMs that are introduced in the 1990s, have a lesser environmental impact and lower maintenance compared to other non-sustainable glass- and carbon-reinforced composite materials [7], [8]. In addition, polymer composites produced using wood sawdust or wood fiber as filler have acceptable mechanical properties and a higher rigidity than the artificial composite or unfilled polymer materials [9]-[11]. WPCs are widely used in many items and applications, such as floor covering in building (noise pollution control), lightweight construction, railing and fencing for construction [12], and in the interior and exterior parts of automobiles [13].

Building acoustic comfort was compromised as a result of technological advancement and construction rationalization, which frequently resulted in civil complaints and disputes over time [14]. As a result of interest in development of WPCs, structures became lighter and slimmer, walls became less thick, windows and doors became finer, and some construction stages were reduced or eliminated. The environmental effects brought on by the use of natural resources or the production of trash are a current issue that must be balanced in order to maintain environmental sustainability. Habitability is a user need that includes acoustic performance. It is made up of national or international standards, thus its effectiveness in constructions should be confirmed. Building acoustic performance considers impact sound and airborne sound ratings for sound insulation. They are regarded as inside/between floors and rooms, opposed to the outside and inside to the outdoors. Living in multi-floor buildings is becoming more common in nations with dense populations. In multistory buildings, inhabitants actions might create impact sound pressure inside the apartments below, which frequently disturbs neighbors. The purpose of floor structures, floor coverings, resilient coverings, supported ceilings, floating floors, and subfloors is to reduce sound effect on bare flooring. Resilient materials mixed with mortar or a layer under tile can be added to achieve this decrease. These materials are placed on several flooring types, including homogeneous and non-homogeneous floors, which exhibit quite varied acoustic behaviors. Technology advanced as a result of the use of new materials in civil construction, particularly with the greater usage of plastic materials. The second-largest business after packaging, the supply chain for civil construction uses 20% of all plastic material consumed globally. The behavior of materials in architectural acoustics is primarily determined by impact sound reduction, sound transmission loss, acoustic impedance, and dynamic stiffness. Today's standards are the outcome of determining these criteria using various techniques. Currently, a desirable aspect of contemporary apartment buildings is interior noise [15], [16].

ImNs is a significant sound transmission issue in concrete structures, and academics have been working on its prediction and remedy for many years [17], [18]. Structure-borne sound that is unique to impact sound. This kind of noise irritates building occupants and has a negative impact on people's quality of life. Although there are other impact sound sources in buildings, it is generally agreed that footsteps are the primary one [19]. Although other authors have suggested alternate techniques to assess the sound mitigation of floor coverings, this is the standard procedure currently used in laboratories around the world [20]. As the first energy absorber, layers made of deformable elastic materials are crucial. Additionally, whether or not these layers are integrated, floating floors offer the most positive outcomes [21]. The approach that is most frequently utilized to lessen ImNs is floating floors. It entails sandwiching resilient material between the structural slab and the floor, improving sound isolation from impacts to 20 dB. Insulators (resilient materials) include plates made of glass wool, rock wool, expanded polystyrene, rubber pads, cork, and other materials equally distributed [22]. Lately, a lot of work has gone into creating composites using natural materials and recycled plastic [23]-[25]. The goal of this project is to create new composite materials that may be utilized as floor covering in buildings and manufacturing facilities by reinforcing them with EVA and filler SD. As well as, to specify the acoustical efficiency (sound absorption, impact sound reduction), mechanical and thermal properties of these materials. The novelty of this work arises from that we used a new material suggested as a floor covering material with better acoustical, mechanical and thermal properties utilized in different building applications.

2 MATERIALS AND METHODS

2.1 Materials

Elvax 670 Ethylene-co-vinyl acetate (EVA) copolymer was obtained from DuPont Packaging and Industrial Polymers (Wilmington, Delaware U.S.A.). The vinyl acetate content of the copolymer used was 12 wt% (Density is 0.933 g cm−3, Melt Flow Index was 0.35 g/10 min @190 °C). WSDF were procured from local wood carpentry workshop.

Preparation of EVA/Sawdust filer: the EVA copolymer was mixed with WSDF at 160 °C for 10 minutes at 85 rpm in a closed Brabender Plasti Corder Lab Station, USA. Then, the EVA composites were molded using a hot press at 160 °C for 45 s followed by a cold press machine. The test specimens were conditioned for 48 h at 23±2 °C and 50±5 % relative humidity before the tests [1]. The formulation of EVA composites was shown in Table 1.

Table 1: Formulation of EVA/WSDF composites.

	ES0	**ES1**	**ES2**	**ES3**	**ES4**	**ES5**
EVA, gm	100	100	100	100	100	100
WSDF, gm	0	2.5	5	10	20	30

2.2 Surface Morphology

The morphologies of the blank EVA and EVA/sawdust composite were investigated using a field emission scanning electron microscope (SEM). The imaging was performed at a constant voltage of 20 kV.

2.3 Mechanical Properties

Tensile characteristics were measured by a tensile testing machine (Zwick Z010, Germany) according to ASTM D638-14. The crosshead's speed was set at 50 mm/min. For each composite, five samples were measured. The samples were preconditioned for 48 hours at 23±2 oC and 50 5% relative humidity before testing, and these conditions were maintained throughout the test [27, 28].

2.4 Acoustics Performance

2.4.1. Impact Sound Reduction

ISO 10140-3 provides a detailed description of the methodology for measuring ISR in the laboratory owing to floor coverings in connection to structurally transmitted ImNs [29]. Additionally, different categories of tested floor coverings are described in ISO 10140-1. BS EN 16205: 2013 is the standard used to rate "in-room" ImNs delivered by an airborne path. It primarily addresses walking noise as an impact source [30]. The impulse sound reduction (ISR) based on SPL measurement is more accurate than vibration acceleration measurement, the ISR is determined by using a standard tapping machine to produce a consistent source of impact vibration on the floor surface and then measuring the SPLs in the space [31]. In accordance to ISO 10140-3, the impulse noise reduction value required two rooms above each other, which are separated by standard floor of homogeneous concrete, the above one is standard reverberation chamber with a homogeneous (diffused) sound field and the inhibition of flanking sound transmission to the reception chamber are necessary for laboratory test procedures. The impact noise reduction of a particular floor covering can be estimated by measuring the A-weighted sound pressure level in upper chamber with and without covering floor The ISR (insulation), ΔL can be defined as [31].

$$\Delta L = L_{bf} - L_{wc}, \tag{1}$$

where L_{bf} is the impact sound pressure level of a base floor and L_{wc} is the impact sound pressure level of a floor with floating floor.

The measurements are achieved in one-third octave bands accordance to the standard in frequency range 100Hz–3160Hz. Such measurements can be applied for large specimen coverage which covers the whole area of the floor or small (pads specimen) which is as large as the hitting areas of the hammers of tapping machine. A specialized laboratory is necessary to conduct such measurements; however, it is much more expensive and less available to those who do not have access to standard coupled chambers. Therefore, some scientists are developing an engineering alternative method of measuring the ΔL parameter that do not require specialized chambers and floors. [20], [32], [33]. Moreover, Bethke [32] showed that, the engineering method gives about 3 dB lower than the values stated in ISO10140-3.

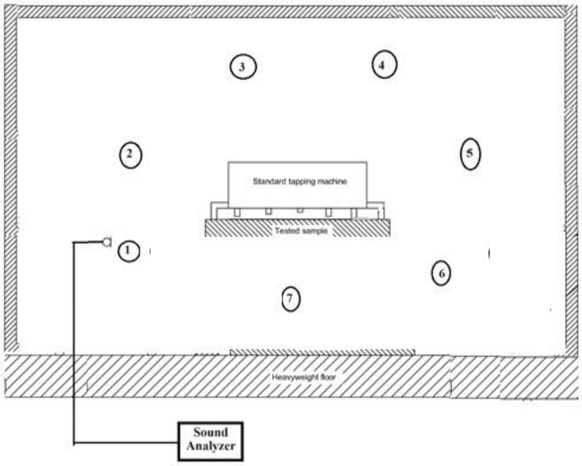


Figure 1: Represent the measurement setup for impact noise reduction.

This work implies an engineering method according to BS EN 16205: 2013, in which the sample under test put under the hammers of tapping machine. The impact sound reduction level is measured in standard reverberation room by measuring the average *SPL* in reverberation room (the SPL is measured at seven positions) in case of with and without a floating cover, Figure 1. Measurements were made for six samples of different weight percentages of sawdust as filer to EVA polymer, in 1/3 octave bands in the range 100 – 3150 Hz.

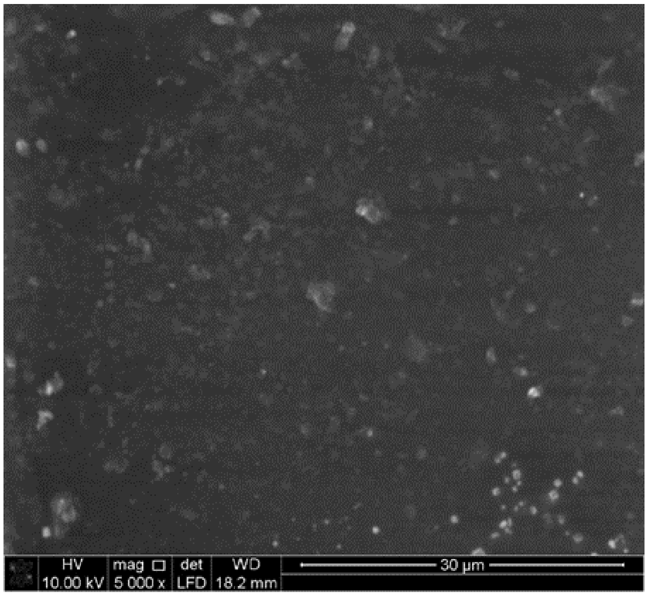
2.4.2. *Sound Absorption* ***(SA)***

The SA of the samples is measured using the two-microphone technique, which based on the transfer-function approach [34]. Measurements were carried out in accordance to the international standards ASTM E1050 and ISO10534-2 using measurement system type 4206 B & K. The measurements were carried out in frequency range from 200Hz to 6300Hz in two circular impedance tube diameters, 10 cm (20Hz-1600Hz) and 3 cm (200Hz-6300Hz).

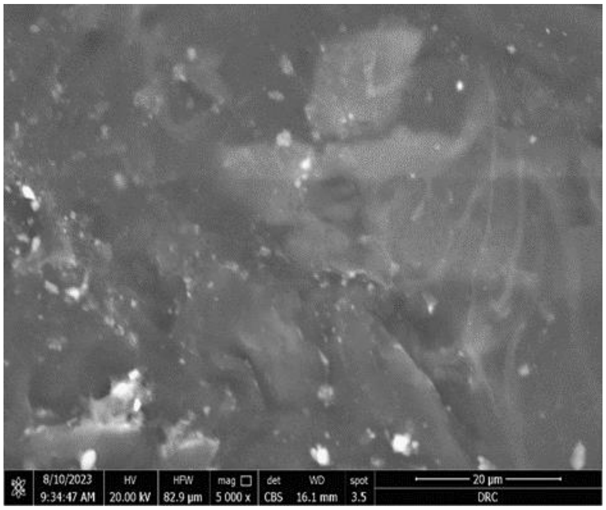
3 RESULTS AND DISCUSSION

3.1 Surface Morphology

Figures 2(a, b) display the SEM micrographs of the various blank sample EVA and EVA/10 SD (10wt.%) composite. From Fig. 2(a) one can notice holes in the EVA matrix with smooth walls can be seen in the SEM. This may be reflected in the acoustical properties that discussed in the next sections. Figure 2(b) makes it abundantly evident that there are little to no voids surrounding the fibers, there are hints that EVA sticks to the SD surfaces.



(a)



(b)

Figure 2: SEM micrograph for (a) blank EVA (b) for EVA/10SD.

3.2 Tensile Properties

Figure 3 depicts the influence of WSDF loading level on mechanical characteristics of EVA/WSDF composites.

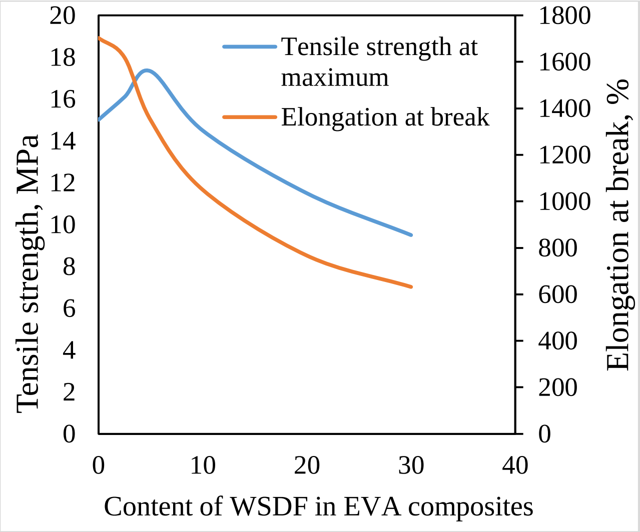


Figure 3: Tensile strength and elongation at break of EVA/WSDF composites in different loading level of WSDF.

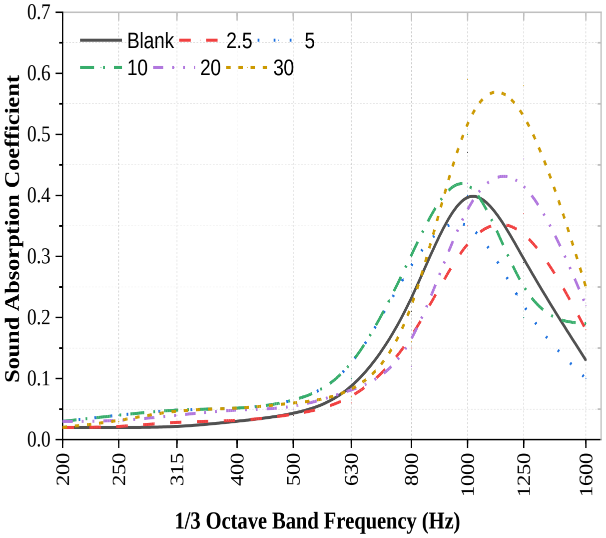
The tensile strength of EVA/WSDF composites increased following the addition of 2.5% and 5% WSDF, as shown in Figure 3. Beyond this weight percentage level, the tensile strength started to decrease. The improvement in tensile strength recorded at 2.5% and 5% of WSDF was 7.3 % and 15.5% in comparison with that of ES0 respectively. At higher loading level the tensile strength decreased compared to ES0 by 3.4%, 23.4% and 36.7% for ES3, ES4 and ES5, respectively. The elongation at break of EVA/WSDF composites decreases as the WSDF loading amount increases. The decrease in tensile strength at a high loading level of WSDF may be due to the agglomeration of WSDF at high concentrations as shown from SEM micrographs [35].

3.3 Acoustics Performance

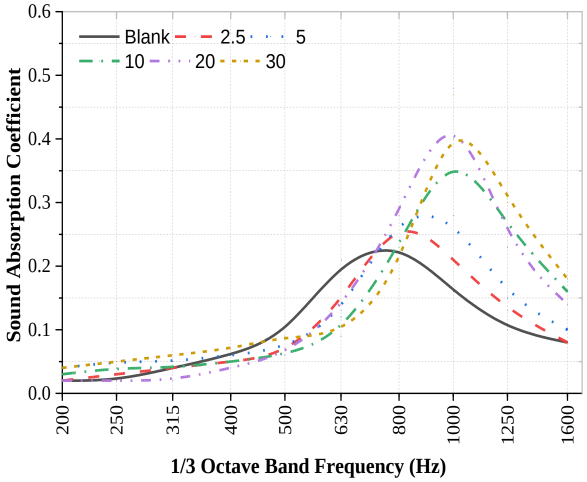
The acoustic performance is characterized by two acoustics parameters, namely; the SA and the impact noise reduction.

1.3.1 Sound Absorption ***(SA)***

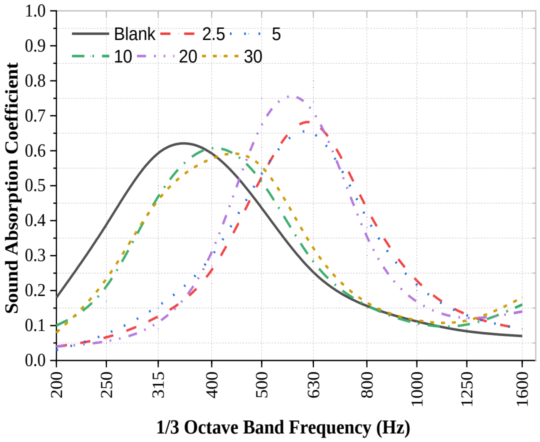
The sound absorption of the prepared samples is measured in different configuration of samples combined with an air cavity. The obtained results are presented in Figure (4a-4f).



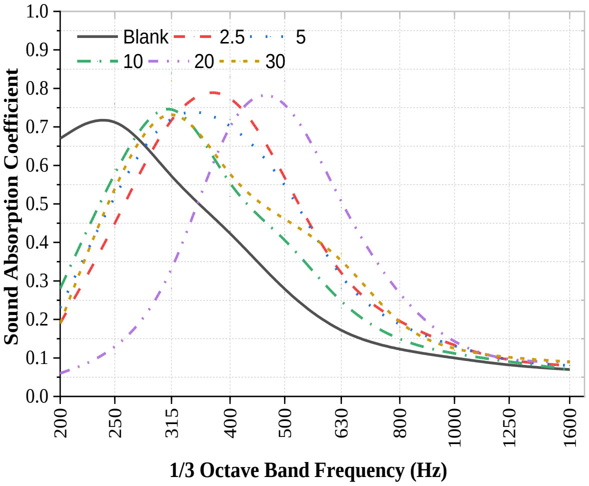
(a) Sound absorption of single layer.



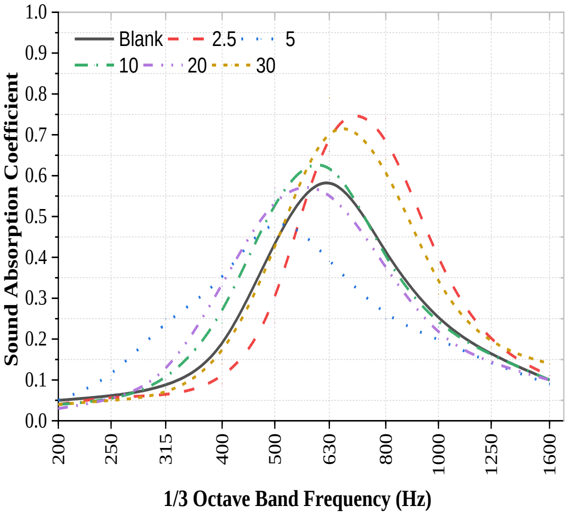
(b) Sound absorption of double layers.



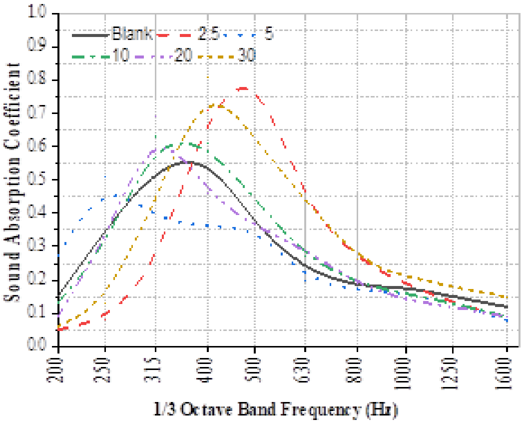
(c) Sound absorption of single layer backed by air cavity of 2 cm depth



(d) Sound absorption of single layer backed by air cavity of 4 cm depth



(e) SA of double layers with inter air cavity of depth 2 cm between two identical samples



(f) SA of double layers with inter air cavity of depth 2 cm between two identical samples

Figure 4: Sound absorption coefficient versus frequency for all prepared samples (a-f)

Fig. 4(a) shows the sound absorption versus frequency for blank sample in comparing to the other prepared samples of different SD wt., percentage for single layer (one layer in the front of the tube back plate). There is a noticeable impact as WSDF increases, percentage in the composites where the absorption of sound occurs at frequencies 1000-1250Hz. Fig. 4(b) shows the obtained results from double layers of the same sample. It is clear from the figure that the double layers give higher sound absorption coefficient, this may be due to increasing the thickness of material. As well as, the peak of absorption is shifted to low frequency with small wide bad frequency. Both samples the ES0 and ES1 WSDF show sound absorption ability at 800Hz but with small amplitude (~0.3) while the other remaining samples record absorption at frequency 1000 Hz instead of 1250 Hz and with higher amplitude than blank and ES1 WSDF. The shift in the absorption frequency and the little broadening could be caused by the thickness growing. One of the physical parameters that is thought to influence a material's absorption performance is its thickness; a greater thickness results in a greater absorption

Figs. 4(c, d) show the measured sound absorption of the samples backed by air cavity of different depths, namely 2 and 4 cm. The figures are shown that the increases of the air cavity depth leads to shifting the peak of sound absorption towards the low frequency. In this case the mechanism of absorption may be not only due to the thermal losses but also the resonance phenomenon due to the air cavity behind the sample. Figures 4(e)) and 4(f) present the measured sound absorption in case which the air gap between two identical samples with different depths namely 2 and 4 cm. The increasing of air cavity depth between samples leads to shifting the peak of absorption towards the lower frequency.

The highest amplitude observed for sample ES5 WSDF at frequency 1250 Hz. One can observe that increasing the WSDF percentage in the sample increase the absorption ability and this may be due to the increment of WSDF which enhance the ability of sound absorption. While the blank has higher absorption behavior than for the samples ES1 and ES2 WSDF, this may be due to increasing the WSDF to this extent may be the reason for the filler not to interact well and agglomeration inside the materials observed in addition to closing the vacancies. When sound waves travel through an acoustic material, three common phenomena take place: sound transmission, sound absorption, and sound. Theoretically, the value of α fluctuates with frequency and can range from 0 to 1, with α = 0 denoting complete reflection of incident sound energy and α =1 denoting complete absorption of sound energy by the material

1.3.1 Impact noise reduction

The obtained measurements of impact noise reduction ΔL, for different samples are represented in Fig. 5 below.

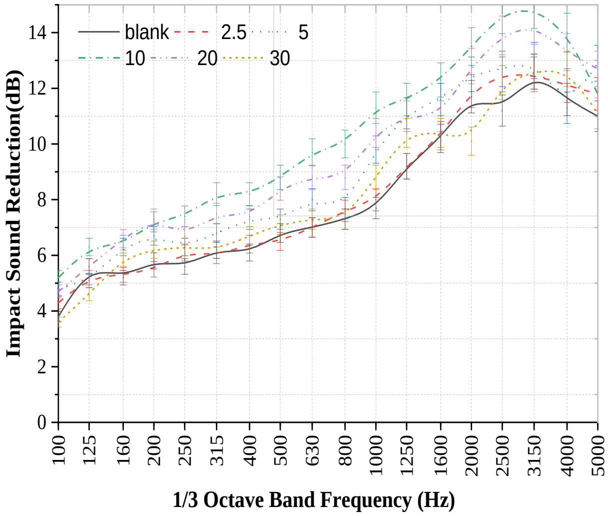
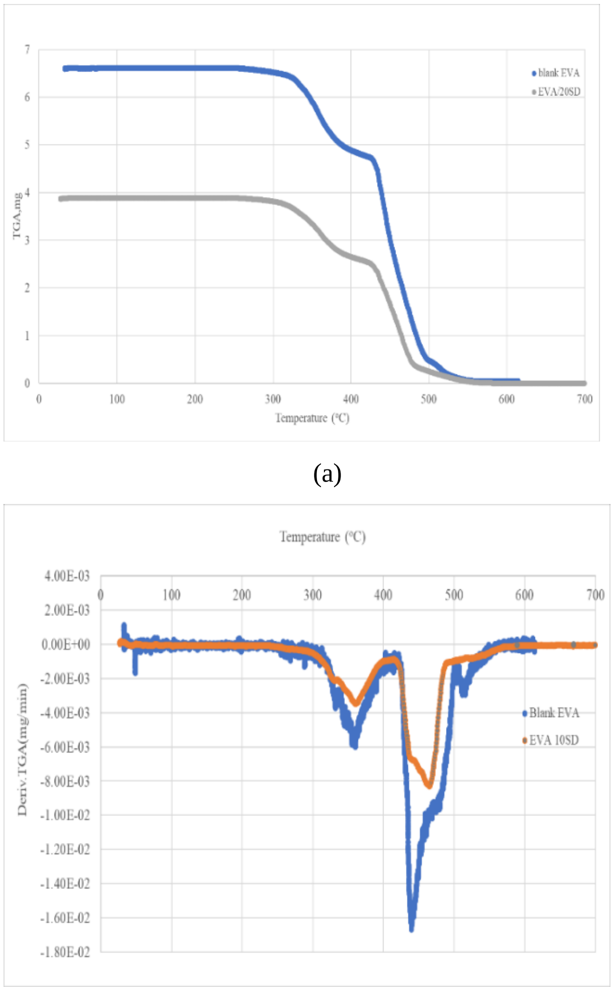


Figure 5: Impact sound reduction (dB) versus frequency for all samples.

The estimation of ΔL is obtained from the difference between the average SPLs radiated due to tapping machine that are measured in cases without, L_{bf} (base floor) and with the covering under test (L_{cw}). It is clear from the figure that ΔL can be reaches to 15dB for the sample ES3 composite, gives the highest impact noise reduction overall the whole frequency range (100-5000 Hz), and give about 14 dB at frequency 1.25 kHz. The increasing of ΔL with adding WSDF to EVA polymer may be due to increasing the ability of EVA/ WSDF to absorb the impact energy. From the Fig. 5. we can also observe that increasing the percentage of WSDF to the EVA/ WSDF composite is not condition for increasing ΔL, because more increasing of WSDF percentage leads to increases the agglomeration and strength of samples, this leads to decreases the ability for absorbing the impact energy. So, one can observe better performance for ES2 WSDF than ES5 WSDF.

3.4 Thermogravimetric Analysis

Thermogravimetry (TGA) data indicate the polymer composites' thermal heat stability. The ES0 and ES3 composites thermograms, which depict the change of mass loss versus temperature, are displayed in Figure 6. There were four steps involved in the breakdown of the ES0 and ES3 composites. The first step due to water evaporation between 25-100^{o}C.The deacetylation process, which releases gaseous acetic acid and forms carbon-carbon double bonds along the polymer backbone, is responsible for the second mass loss step that occurs between 100 and 300°C. the third step occur between 300-450 ^{o}C . The breakdown of the EVA copolymer backbone resulted in the oxidation and volatilization of hydrocarbons, which caused the fourth second mass loss stage (between 450 and 700°C) [37]. Table 2 shows that the mass loss for the ES0 and ES3 composites in the four stages, and that the $T_{\max}$ values for each stage in the ES3 composite scenario are significantly better than those for the ES0 composite.



(a)

(b)

Figure 6: Represents(a) the thermogravimetry analysis (TGA) and (b) Derivative thermos-gravimetry for blank and EVA10SD composite

Table 2: Thermal decomposition characteristics for ES0 and ES3.

Composite	Step	Temp.range, °C	Tmax., °C	Wt. loss%
ES0	1st	25-100	78	0.63
	2nd	100-300	190.14	15.7
	3rd	300-450	339.3	52.52
	4th	450-700	531.2	10
ES3	1st	25-100	78.3	0.2
	2nd	100-300	201.1	14.8
	3rd	300-450	345.1	51.4
	4th	450-700	536.1	13.4

Table 2 shows that the mass loss for the EVA and EVA10SD composites in the four stages is less than that of the EVA alone, and that the T_{max} values for each stage in the EVA10SD composite scenario are significantly better than those for the clean EVA

4.CONCLUSIONS

The experimental study of the acoustical efficiency and mechanical properties of wood sawdust-reinforced ethylene vinyl Acetate composite came up to the following conclusions:

(i) The result show that covering floors with a composite material made of wood sawdust and ethylene vinyl Acetate can lower impact noise levels by up to 14 dB; however, a higher percentage of sawdust aggregate EVA does not necessarily translate into a better acoustic performance.

(ii) Two factors that influence sample sound absorption are sample thickness and WSDF percentage. Increasing WSDF causes an increase in sound absorption, and increasing sample thickness increases sound absorption accordingly.

(iii) Moreover, the peak of sound absorption can be tunable by changing the air gap depth behind or in between the samples, in a way such that, the increasing of the air gap thickness depth leads to shifting the peak absorption to lower frequency, while decreasing it leas to shifting the absorption peak to high frequency.

(iv) The results indicated an increase in tensile, and compressive strength of composites with the addition of wood sawdust content up to ES3. Further addition of the reinforcement above ES3 resulted in a decrement of the mechanical properties.

(v) The result of the present study reveals that WSDF composite with good mechanical properties could be successfully developed using the appropriate concentration of wood sawdust. The wood sawdust can be used as filler and reinforcement in the EVA matrix, which will reduce cost and give environmental benefits.

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Author Contributions

El Aidy: conceptualization, investigation, reviewing and editing project administration; ***Elwakil***: preparing the test samples, investigation, writing an original draft; ***Al-Basheer***: methodology conceptualization, data curation, writing—reviewing and editing, funding acquisition, All authors have contributed in data analysis, read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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