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# Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation

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Building materials derived from agricultural and industrial waste are becoming more attractive in the civil engineering and architectural applications because of their sustainability and lower environmental impact. In addition, substantial value can be added to the wastes by producing value added products from them. Therefore, four different types of locally available by-products (rice husk, wheat husk, wood fibers and textile waste fibers) were used to produce composites with a biodegradable poly(butylene adipate-co-terephthalate)/poly(lactic acid)(PBAT/PLA) blend binder by hot pressing. The morphological analysis of the composites revealed that the PBAT/PLA binder had more affinity with wood and textile fibers than with wheat and rice husks. The prepared composites showed thermal stability until 250 °C. All the prepared biodegradable composites exhibited good compressive strength (11–40 MPa) and flexural strength (0.80–2.25 MPa). The observed mechanical properties allow easy handling without risk of breaking them when positioned in the buildings. The biodegradable composites were characterized for their thermal conductivity, diffusivity, effusivity and heat capacity. The density and thermal conductivity of the produced composite was in the range of 378–488 kg/m<sup>3</sup> and 0.08–0.14 W/m.K, respectively. The least thermal conductivity *i.e.* 0.08 W/m.K was observed for the rice husk composite with a density of 378 kg/m<sup>3</sup>. A minimum water absorption (42%) was found in the rice husk composites after 24 h immersion in water. The composite samples were still cohesive after 24 h immersion in the water because of the water resistance nature of the binder. The prepared biodegradable composites meet most of the required properties for the indoor building insulation applications and show great potential to replace the conventional building material in current use.

## 1. Introduction

An innovative eco-friendly material development is being promoted across the world for green building applications (Guna et al., 2019; Liuzzi et al., 2017; Sassoni et al., 2014). In this regard, there has been growing interest to develop sustainable thermal insulation materials from renewable resources and industrial wastes (El Hage et al., 2019; Liu et al., 2017; Mija et al., 2017). Composites derived from natural resources have great potential because they have low density, less environmental impact and good thermal properties (Eschenhagen et al., 2019; Guna et al., 2019; Muthuraj et al., 2018a, b, c; Zach et al., 2013). Among the natural resource-based materials, rice and wheat husk are main by-products during their production. They could be used to make sustainable building materials because of their good characteristic attributes (Buratti et al., 2018; Hýsek et al., 2018; Palumbo et al., 2015).

Similar to rice and wheat husks, wood fibers are renewable material and are widely used because of their good mechanical properties and low cost (La Mantia and Morreale, 2011). Due to the demand in sustainability, recovery and recycling of the industrial (e.g. textile) wastes are nevertheless emerging. Recycling the textile wastes can minimize the use of virgin material and the problem associated with end-life disposal. One of the potential applications for the textile fibers (e.g. cotton) waste is to produce building panels because of its good thermal and acoustic properties (Asdrubali et al., 2015; Binici et al., 2014, 2012, 2010; El Hage et al., 2019; Hassanin et al., 2016; Ingrao et al., 2014; Lacoste et al., 2018).

Various binders were explored in literature to bind renewable resources such as sugarcane bagasse (Guna et al., 2019), miscanthus fiber (Eschenhagen et al., 2019), sunflower stalk fiber (Eschenhagen et al., 2019), wood fibers/textile fibers (Lacoste et al., 2018), coffee chaff

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(Buratti et al., 2018), stubble fibres (Binici et al., 2014), corn stalk (Palumbo et al., 2017), rice straw (Wei et al., 2015a, b), rice husk (Chabannes et al., 2014), and food crop by-products (Palumbo et al., 2015). For instance, alginate, starch and tannin resin have been used as biobased binders for composites manufacture from agricultural crop by-product composites, larch bark, and wood fibers/textile waste (Kain et al., 2014; Lacoste et al., 2018; Palumbo et al., 2017). The wood fiber/textile waste based composites with alginate binder could be considered for building materials because they possess sufficient thermal conductivity (0.078–0.089 W/m/K), density (308–333 kg/m<sup>3</sup>), flexural strength (0.84 MPa), and compressive strength (0.44 MPa) (Lacoste et al., 2018). Similarly, chitosan was used as a biobased binder to produce 100% eco-insulating composite from sunflower stalk particles (Mati-Baouche et al., 2014). Their mechanical and thermal performances were competitive with those of biobased insulators available on the market namely hemp concrete, coconut husk and date palm fibers insulation boards (Mati-Baouche et al., 2015). Recently, wheat gluten, starch, casein and gelatine have been used as biobased binder for biocomposites development (Eschenhagen et al., 2019; Guna et al., 2019). Similarly, Mati-Baouche et al. (Mati-Baouche et al., 2015) have explore different polysaccharides (e.g. chitosan, alginate, starch, guar gum and genipin) and their blends as binder for thermal insulation composites production. These composites showed thermal conductivities lower than 0.1 W/m.K which can be considered as thermal insulators (Al-Homoud, 2005). However, durable biobased polymer binders are not explored widely for building composite manufacturing.

Poly(lactic acid), PLA, is a biobased and biodegradable thermoplastic polymer and is commercially available in the market. It has been used to produce composites with various fibers and fillers because of its good mechanical and thermal properties (Muthuraj et al., 2018a, b, c; Muthuraj and Mekonnen, 2018a). However, the brittleness of the PLA is limiting its application. Therefore, PLA has been blended with different kinds of biodegradable polymers to improve the toughness while preserving biodegradability. Among the biodegradable polymers, poly(butylene adipate-co-terephthalate), PBAT, is a low melting, tough biodegradable thermoplastic polymer and it has been used to modify the brittleness of the PLA by melt blending (Muthuraj et al., 2014; Muthuraj et al., 2018a). Industrially, BASF has commercialized biodegradable PLA/PBAT (Ecoflex®) blends with ratio of 55/45 wt.% under the tradename of Ecovio® F Blend C2224 (Ecovio®). Therefore, the main aim of this study is to utilize the Ecovio® as a binder with four types of industrial wastes (rice husks, wheat husks, wood fibers and textile waste fibers) to develop a lightweight (density  $\leq$  500 kg/m<sup>3</sup>), thermal insulation composite for interior building materials. In addition, the thermal, mechanical, water absorption and morphological properties of the prepared composites are compared to judge whether these composites have sufficient performances for building insulation panels.

## 2. Materials and methods

### 2.1. Materials

Ecovio® F Blend C2224 with a density of 1.24–1.26 g/cm<sup>3</sup> was provided from BASF GmbH (Germany) and it is a blend of PLA and PBAT (Ecoflex®) with ratio of 55/45 wt.%. The melting temperature and melt flow index of the Ecovio® blend are 110–155 °C and < 2.5 g/10 min (at 190 °C with 2.16 kg), respectively according to the datasheet. Rice husk (Soufflet SARL, France), wheat husk (Tofagne SARL, France), wood fibers (Actis SA, France) and textile waste fibers (Le Relais, France) were used in this study to produce composites (Fig. 1). The textile waste fibers (here after referred as textile fibers) were obtained from the garments recycling company (Lacoste et al., 2018). These textile fibers were predominantly cotton with a minimum of 70% cotton content. Chloroform was supplied by Sigma Aldrich, France. All the materials were used as received without any further purification or modification.



Fig. 1. Selected husks and fibers for the composite processing.

### 2.2. Composites processing

The composite processing steps are shown in Fig. 2. Prior to prepare the composites, rice husk, wheat husk, wood fibers and textile fibers were dried in an oven at 80 °C overnight to eliminate moisture. The Ecovio® (15% by weight) was dissolved in chloroform (CHCl<sub>3</sub>) at room temperature, and the dissolved Ecovio® in CHCl<sub>3</sub> was used as a binder for the selected husks and fibers to perform composites. The selected percentage (optimal) of the Ecovio® in CHCl<sub>3</sub> was determined after preliminary experiments. A mechanical stirrer (40 rpm for 5 min) was used to mix the Ecovio® binder with fibers and husks at room temperature. Subsequently, the Ecovio® coated fibers were dried at room temperature in a laboratory fume hood for 5 h to remove the solvent from the mixture. The dried Ecovio® coated fibers and husks mixture was used to prepare the desired composites samples by hot pressing. The composite samples were processed using a rectangular mould (20 mm thickness and 40 mm width) that was hot pressed in two stages: first stage at 180 °C for 2.5 min under 1000 kPa; the second stage at 175 °C for 6 min under 5000 kPa to reach the target thickness of around 2 cm. The finished composites were cut into several pieces for the characterization. Before analysing the samples, the samples were conditioned in a climate-controlled room with a relative humidity of 50% and temperature of 23 °C.

In order to get the binder concentration in the resulting composite, the composite samples were weighed before dissolving the binder in chloroform. After removing the binder by dissolving in chloroform, the fibers were filtered and washed with excess chloroform to completely remove the binder. Then the filtered fibers were dried in an oven to remove CHCl<sub>3</sub>. Subsequently, the dried fiber weight was measured to get the binder concentration in the resulting composites. The binder content was found to be 13.5 ± 2% in the produced composites.

### 2.3. Morphological analysis

Cryo-fractured composite samples were used to observe the morphology in scanning electron microscope, SEM, (FEI Quanta 200, Holland FEI Company, Holland). A secondary electron detector was used to observe the morphology with an acceleration voltage of 20 kV. The images were produced at a magnification of 100X for all the samples. Prior to observe the morphology, the samples were sputtered using Bal-Tec CED 030, Balzers to avoid charging during analysis.

### 2.4. Density and thermal conductivity measurement

The density of the samples was calculated using the standard mass

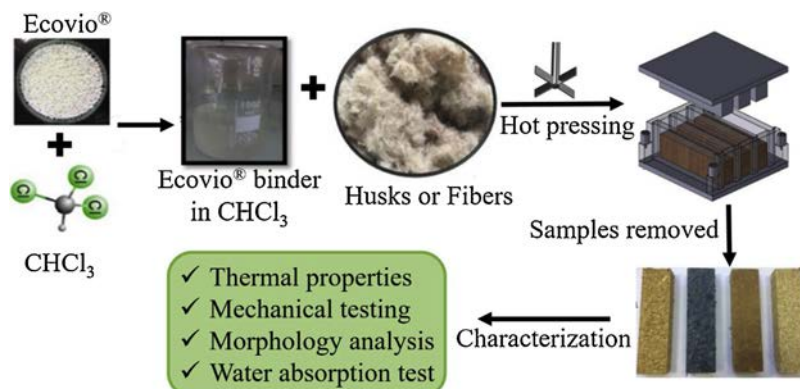


Fig. 2. Composites processing steps.

over volume formula. Samples cut in to 40 mm x 40 mm dimension were weighed and the density was calculated using the corresponding thickness of the samples. Five samples were taken from each formulation to get an average density. FP2C conductivity meter (NeoTIM®, France) was used to determine the thermal conductivity properties of the samples under a stable humidity and temperature environment. The thermal conductivity, effusivity and diffusivity were measured with a hot linear wire sensor (50 mm), a hot plane sensor (50 × 50 mm<sup>2</sup>) and a ring sensor (diameter: 15.0 mm), respectively. The thermal conductivity is a measurement of the heat flow resistance throughout the sample while the effusivity is a measurement of the heat absorption on sample surface. The diffusivity of the samples can provide the capacity of the material to conduct and store heat energy. The heat capacity (C<sub>p</sub>) was calculated using the Eq. (1)

$$C_p = \beta^2 / \lambda \cdot \rho \quad (1)$$

Where  $\lambda$  is the thermal conductivity,  $\beta$  is the thermal effusivity and  $\rho$  is the density of the sample.

### 2.5. Mechanical tests

The three-point flexural test was performed on a ZWICK TH010 universal testing machine with a cross head speed of 2 mm/min at room temperature. The samples (160 × 20 × 40 mm<sup>3</sup>) were placed between two supports at a distance of 120 mm according to the standard ASTM D790. Each measurement was done in triplicate.

The compression test was performed on the same testing machine at room temperature with a crosshead speed of 1 mm/min. The samples (80 × 20 × 40 mm<sup>3</sup>) were compressed in the same direction as the pressure applied to prepare the composites. The compressive strength and modulus of the samples were measured at 30% and 4% of strain, respectively. Each measurement was done in triplicate.

### 2.6. Thermal analysis

Differential scanning calorimetry (DSC, Perkin Elmer Diamond) was used to determine the melting and crystallization behaviour of the samples. The samples were heated from 30 to 200 °C at 10 °C/min under N<sub>2</sub> atmosphere with a flow rate of 30 mL/min. Each measurement was done in duplicate.

Thermal stability of the samples was performed on a thermogravimetric analysis (TGA) device (Perkin Elmer Pyris 1) with a heating rate of 20 °C/min from room temperature to 850 °C under N<sub>2</sub> atmosphere. Each measurement was done in duplicate.

### 2.7. Water absorption

Water absorption test was performed by immersing the samples in distilled water for different intervals. For each interval, the samples

were gently wiped with soft tissue papers to remove the excess water on the surface before measuring the weight of the samples. The water absorption (%) was calculated using following Eq. (2):

$$\text{Water absorption (\%)} = \frac{w_f - w_i}{w_f} \quad (2)$$

Where  $w_f$  is the weight of the sample after immersion in water and  $w_i$  is the sample weight (dried) before immersion in the water.

## 3. Results and discussion

### 3.1. Morphology analysis

SEM images of the composites are shown in Fig. 3. It can be seen that Ecovio® binder is coated on the surface of the fibers and husks. However, the composites based on the rice husk (Fig. 3a) and wheat husk (Fig. 3b) showed small white patches (black arrows) on the surface which suggest that the binder is not coated uniformly like wood fiber composites (Fig. 3c) and textile fiber composites (Fig. 3d). The observed difference in the morphology of the composites could be due to the difference in the chemical compatibility and polarity between the binder and husks/fibers. Furthermore, the differences in the surface chemical compositions of the fibers/husks could play a vital role to determine the adhesion properties with the polymer binders (Tran et al., 2014). Based on the surface morphology, it can be postulated that the binder did not penetrate into the cell walls of the rice and wheat husks. Therefore, the air preserving thermal insulation properties of the

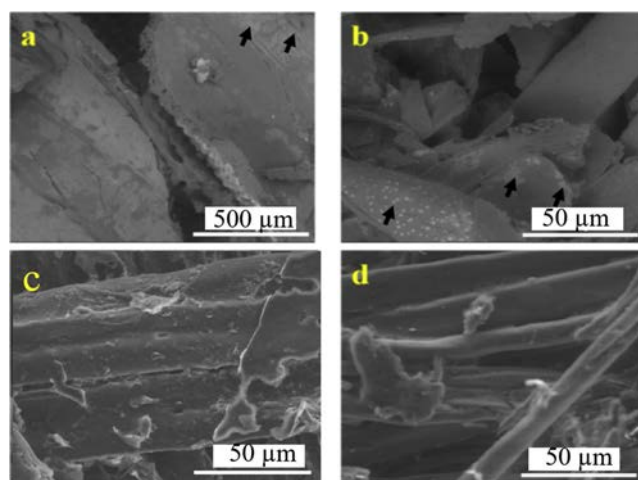


Fig. 3. SEM images (magnification 100X) of the rice husk/Ecovio® composite (a), wheat husk/Ecovio® composite (b), wood fibers/Ecovio® composite (c) and textile fibers/Ecovio® composites (d).

**Table 1**  
Density and thermal conductivity of the composites.

Sample	Density (kg/m <sup>3</sup> )	Thermal conductivity (W/m.K)	Diffusivity 10 <sup>-7</sup> (m <sup>2</sup> /s)	Effusivity (W.s <sup>1/2</sup> /m <sup>2</sup> /K)	Heat capacity (J/kg.K)
Rice husk/Ecovio <sup>®</sup>	378 ± 13	0.08 ± 0.001	421	194 ± 3	524 ± 36
Wheat husk/Ecovio <sup>®</sup>	448 ± 4	0.10 ± 0.003	312	242 ± 8	718 ± 43
Wood fiber/ Ecovio <sup>®</sup>	454 ± 11	0.11 ± 0.003	291	249 ± 3	826 ± 51
Textile fibers/Ecovio <sup>®</sup>	488 ± 13	0.14 ± 0.002	387	241 ± 6	844 ± 67

rice and wheat husks could not be significantly affected after preparing the composites. The better interaction in the wood fibers/Ecovio<sup>®</sup> binder and textile fibers/Ecovio<sup>®</sup> binder could form more compact structures. Such compact structured composite materials can give better mechanical properties but may not be good for insulation and acoustic properties as described in earlier studies (Mati-Baouche et al., 2014).

### 3.2. Density and thermal properties

Density, thermal conductivity, effusivity, diffusivity, and heat capacity value of the prepared composites are presented in Table 1. All of the produced composites exhibited low density that ranged from 378 to 488 kg/m<sup>3</sup>. These densities are comparable to the density of wheat husks based particle board composites (Hýsek et al., 2018) and completely biodegradable sugarcane bagasse composites (Guna et al., 2019). The thermal conductivity of the prepared composite samples can be related to their density and the porosity of the material. The thermal conductivity of the porous material is a combination of conduction (solid part) and convection (gaseous part, *i.e.* air in this case) (Gibson and Ashby, 1999). In the present study, the conduction depends on the chemical nature of the fibers/husks and of the binder. Therefore, the chemical composition and structure of the selected husks/fibers lead to differences in their thermal conductivity. Rice husks/Ecovio<sup>®</sup> and wheat husks/Ecovio<sup>®</sup> composites exhibited the lowest thermal conductivities (0.08 ± 0.001 and 0.10 ± 0.003 W/m.K respectively) whereas textile fibers/Ecovio<sup>®</sup> and wood fibers/Ecovio<sup>®</sup> composites had the highest ones (0.14 ± 0.002 and 0.11 ± 0.003 W/m.K respectively). The higher thermal conductivity of the composites (textile fibers and wood fibers) is due to the formation of high compact structure with less inter porosity, *i.e.* less air, compared to composites prepared from husks having a more porous nature (Chabannes et al., 2014; Gupta et al., 2007). The thermal conductivity of rice husks/Ecovio<sup>®</sup> composites (0.08 ± 0.001 W/m.K) is comparable with rice husk/polyurethane composites (Buratti et al., 2018), coffee chaff/polyurethane composites (Buratti et al., 2018) and coconut husks insulation boards (Mati-Baouche et al., 2014). The observed thermal conductivity in the present study is comparable to the wood fibers/textile waste fibers composite (0.078-0.089 W/m.K) (Lacoste et al., 2018), wheat husk-based composite (0.071-0.078 W/m.K) (Hýsek et al., 2018), nanocellulose composite (≤ 0.1 W/m.K) (Muthuraj et al., 2017a) and date palm fibers insulation board (0.15 W/m.K) (Mati-Baouche et al., 2014). Therefore husks/Ecovio<sup>®</sup> composites could be considered as suitable material for thermal insulation applications as their thermal conductivities are lower than 0.1 W/m.K (Jelle, 2011; Mati-Baouche et al., 2014).

Fig. 4 shows the thermal conductivity and density of the produced composites with a comparison of the literature values and existing materials. Even though, the observed thermal conductivity of the prepared composites is not as low as lightweight conventional insulation materials (e.g. polystyrene), it is still comparable with cardboard (Asdrubali et al., 2016; Demharter, 1998; Kim et al., 2012). For instance, the produced composites density and thermal conductivity are between the cardboard and textile fiber/alginate composites. The chemical nature of the solid part in the composite determines the diffusivity and effusivity of the composites. Rice husks/Ecovio<sup>®</sup> composites have a higher diffusivity. On the contrary, they show a lower thermal

exchange with the environment of the material (effusivity). The heat capacity of the composites was calculated from the thermal conductivity, effusivity and density of the samples. A higher heat capacity was observed for the wood fibers/Ecovio<sup>®</sup> and textile fibers/Ecovio<sup>®</sup> composites which suggest that these composites could provide thermal comfort of a building envelop.

### 3.3. Mechanical properties

The mechanical performance of the developed insulation composite is one of the important properties because some of the non-biobased insulating materials have very low mechanical properties and require very specific process for their maintenance in the buildings (Mati-Baouche et al., 2014). The compressive properties and flexural properties of the composites are shown in Figs. 5 and 6. The highest compressive strength (39.78 ± 8.71 MPa) and modulus (730 ± 69 MPa) is obtained for wood fibers composites. The other composites showed nearly the same compressive strengths. Nevertheless the compressive modulus (206 ± 38 MPa) of the textile fibers composites is lower than the other composites (Lacoste et al., 2018). These results suggest that wood fibers can give better mechanical reinforcing effect because of good interaction between the fibers and the binder (Muthuraj et al., 2017a, 2015; Muthuraj and Mekonnen, 2018b).

The flexural strength of the composites ranged from 0.8 to 2.26 MPa while flexural modulus ranged between 61 and 136 MPa (Fig. 6). The wood fiber composites showed a higher flexural strength compared to the other composites. The lowest flexural strength and modulus was observed for wheat husks/Ecovio<sup>®</sup> composite, which may be due to the poor coating of the binder on the wheat husks. The flexural properties are much lower compared to compression properties. Unlike compression test, the flexural test induces both compression and tension stresses in the samples. Therefore, Ecovio<sup>®</sup> binder is stretched rather than compressed during flexural tests. Based on these results, it can be assumed that the tensile stress induced by the flexural test was more detrimental for these composites than compressive test.

### 3.4. Differential scanning calorimetry

DSC second heating scans of the Ecovio<sup>®</sup> binder and the composites are shown in Fig. 7. The second heating scans were recorded after removing the thermal history of the samples during first heating scans. According to manufacture data sheet, Ecovio<sup>®</sup> is composed of two polymers (PBAT and PLA) and, therefore, Ecovio<sup>®</sup> should show two melting peaks *i.e.* 120 °C for PBAT and 150 °C for PLA. However, a broad single melting peak (155 °C) was observed for the Ecovio<sup>®</sup> because of the PBAT melting is overlapping with PLA cold crystallisation. It has been reported that the glass transition temperature ( $T_g$ ) of the PBAT is -35 °C while  $T_g$  of the PLA is around 60 °C (Muthuraj et al., 2017b, 2017c; Muthuraj et al., 2018a). The  $T_g$  value of the PLA was observed at around 60 °C. The melting temperature ( $T_m$ ) and  $T_g$  of the composites were not significantly different compared to Ecovio<sup>®</sup>. Nevertheless, the melting curve of composite samples showed bimodal peaks at 150–160 °C, which may be due to the formation of more or less perfect crystals during cooling. Therefore, the less perfect crystals melt at lower temperatures. Similar observations have been found for various polymer composites (Muthuraj et al., 2017d, 2017b, 2015, 2014).

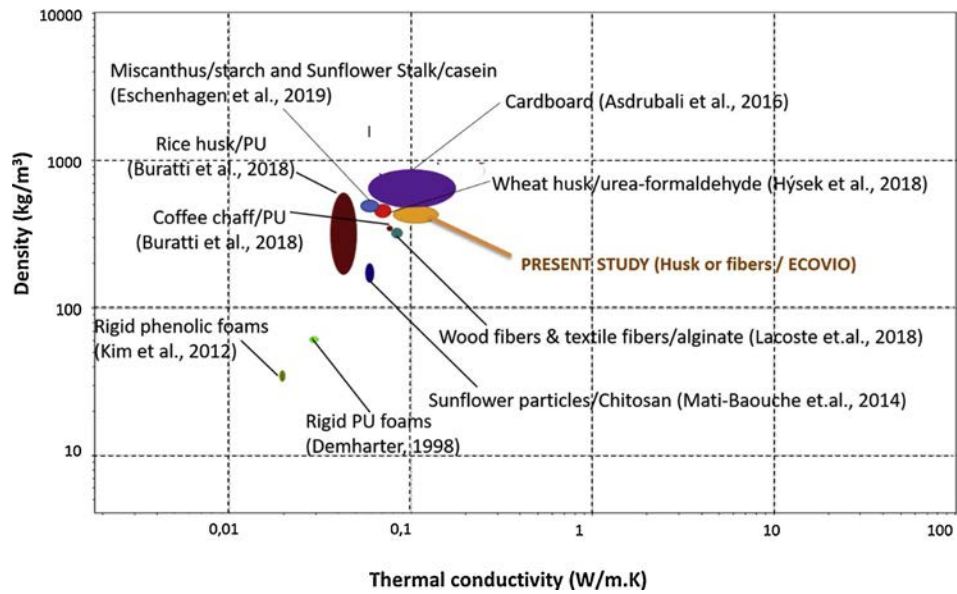


Fig. 4. Thermal conductivity vs density of the different materials (literature values) compared with the values observed in the present study.

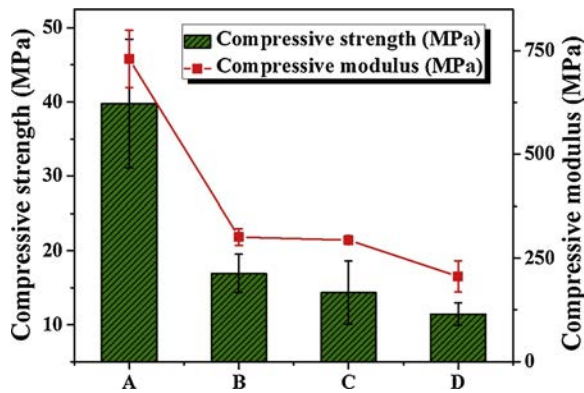


Fig. 5. Compressive properties (strength and modulus) of the composites: (A) wood fiber/Ecovio<sup>®</sup> composite, (B) wheat husk/Ecovio<sup>®</sup> composite, (C) rice husk/Ecovio<sup>®</sup> composite and (D) textile fibers/Ecovio<sup>®</sup> composite.

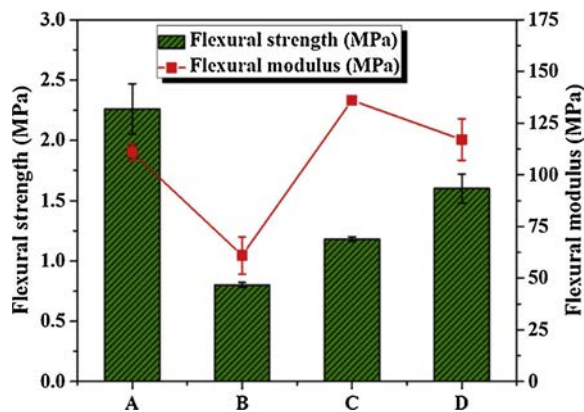


Fig. 6. Flexural properties (strength and modulus) of the composite: (A) wood fiber/Ecovio<sup>®</sup> composite, (B) wheat husk/Ecovio<sup>®</sup> composite, (C) rice husk/Ecovio<sup>®</sup> composite and (D) textile fibers/Ecovio<sup>®</sup> composite.

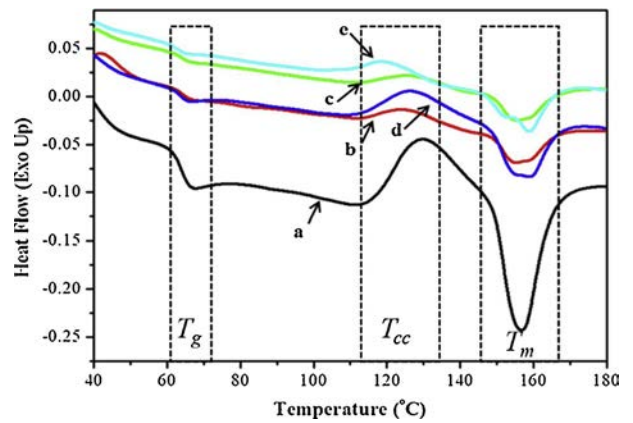


Fig. 7. DSC heating cycle: (a) Ecovio<sup>®</sup>, (b) rice husk/Ecovio<sup>®</sup> composite, (c) wheat husk/Ecovio composite, (d) wood fiber/Ecovio<sup>®</sup> composite and (e) textile fiber/Ecovio<sup>®</sup> composite.

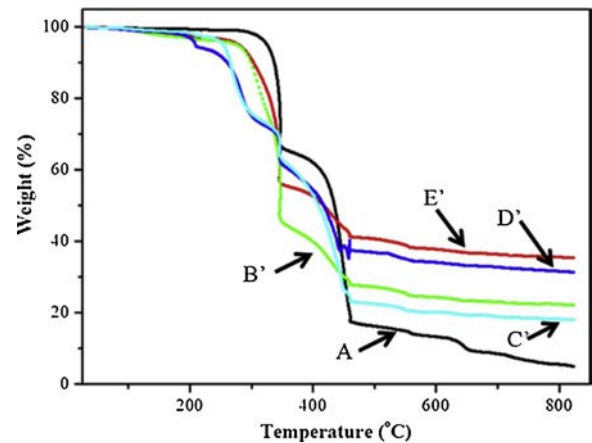


Fig. 8. TGA graph of Ecovio<sup>®</sup> (A), wheat husk composite (B'), textile fiber composite (C'), wood fiber composite (D') and rice husk composite (E').

Unlike  $T_m$  and  $T_g$ , the cold crystallization temperature ( $T_{cc}$ ) of the composite samples is reduced compared to Ecovio<sup>®</sup>. Such a reduced  $T_{cc}$  of the Ecovio<sup>®</sup> in the composite sample is attributed to the increased crystallization rate (Akindoyo et al., 2017; Liuyun et al., 2013).

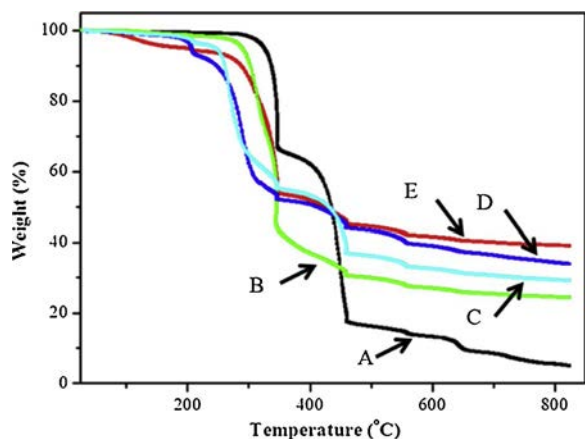


Fig. 9. TGA graph of Ecovio® (A), wheat husk (B), textile fibers (C), wood fibers (D) and rice husk (E).

### 3.5. Thermogravimetric analysis

Figs. 8 and 9 show the mass loss of Ecovio® binder, wheat and rice husks, wood and textile fibers and their composites with respect to temperatures. Both husks and fibers showed lower onset thermal stability compared to Ecovio® binder (Fig. 9). Ecovio® binder showed two clear degradation steps related to PLA (~320°C) (Nyambo et al., 2011) then PBAT degradation (~413°C) (Muthuraj et al., 2014). When compared to the onset of thermal degradation (< 300°C) of biobased binders (alginate and starch) used for thermal insulation composite prepared from food crop by-products (Palumbo et al., 2015), the Ecovio® binder thermal stability is much higher. Due to the higher thermal stability of the Ecovio®, composites present an intermediate behaviour between Ecovio® and husks or fibers. It can be seen that all the composites showed a lower onset of thermal degradation temperature compared to Ecovio® binder because of the lower onset of thermal degradation nature of husks and fibers. The maximum weight loss temperature of the textile fibers, wood fibers and their composite is lower (< 280°C) than the wheat husk, rice husk and their composites. Except Ecovio®, all the samples showed char residue of more than 22% at 820°C (Fig. 8). The maximum char residue (40% at 820°C) was observed in the rice husk and its composites. Similar char residue was observed in the literature for rice husk because of high silica content in the rice husk (Mansaray and Ghaly, 1998). Overall, all the prepared composites showed good thermal stability until 250°C which makes them suitable for the building interior applications.

### 3.6. Water absorption

Fig. 10 represents the water absorption percentage of the composite samples. According to literature, water absorption of natural fiber composite depends on fiber chemical compositions (e.g. cellulose and hemicellulose content), fiber size and surface area, density of the composites and the intra and inter porosity (Akinyemi et al., 2016; Benmansour et al., 2014; Dhakal et al., 2007; Migneault et al., 2009; Wei et al., 2015a, 2015b). In this study, all composites showed > 40% water absorption after 24 h of immersion in water. Similar observation has been reported for various natural fibers and agricultural residues (Agopyan et al., 2005; Akinyemi et al., 2016; Guna et al., 2019; Pacheco-Torgal and Jalali, 2011). It was observed that the prepared composite samples were cohesive after 24 h immersion in the water because of the water resistance of the binder compared to other bio-based ones such as protein (Nguyen et al., 2018). Among the prepared composites, the rice husk composites exhibited the lowest water absorption (43 ± 2%) after 24 h of immersion. On the contrary, wood fibers (63 ± 3.5%) and textile fibers (60 ± 2.0%) composites

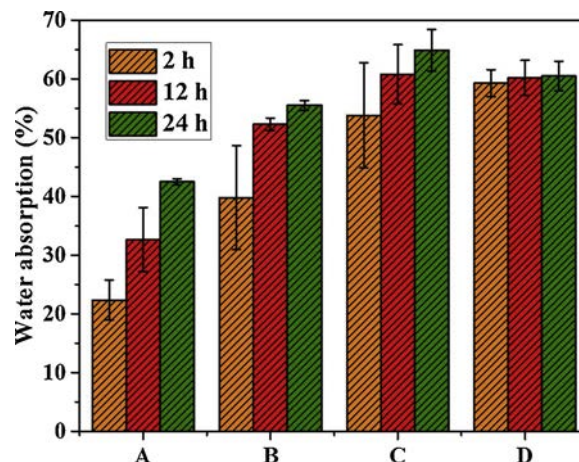


Fig. 10. Water absorption (%) of the prepared composites at different immersion times (2, 12 and 24 h): (A) rice husk/Ecovio® composites, (B) wheat husk/Ecovio® composites, (C) wood fibers/Ecovio® composites and (D) textile fibers/Ecovio® composites.

exhibited the highest water absorption after 24 h of immersion. As reported in literature, rice husk contains silicon-cellulose membrane at the surface of rice husks that could impart hydrophobicity and thus provide lower sorption capabilities (Tran et al., 2014). Saturation is quite reached after 2 h of immersion due to a high absorption kinetics (Chabannes et al., 2014). Nevertheless water absorption of prepared composites remains much lower than those of particle board composites prepared from corn cob, saw dust, and larch bark (Akinyemi et al., 2016; Kain et al., 2014). Unlike rice husks and textile fibers composites, the composites prepared with wood fibers and wheat husks showed obvious cracks after 24 h immersion in water (Fig. 11). The observed cracks are due to the swelling behaviour of the fibers/husks in the presence of water (Akinyemi et al., 2016; Kain et al., 2014) besides poor bonding between the fibers/husks and Ecovio® and insufficient binder content in the resulting composites. The high-water absorption nature of the composites is inconvenient because it leads to high shrinkage and swelling after long time exposure to water. These phenomena are known to cause damages that can affect the durability of building materials. If necessary, the water absorption of the developed composites can be further reduced by surface modification of the husks and

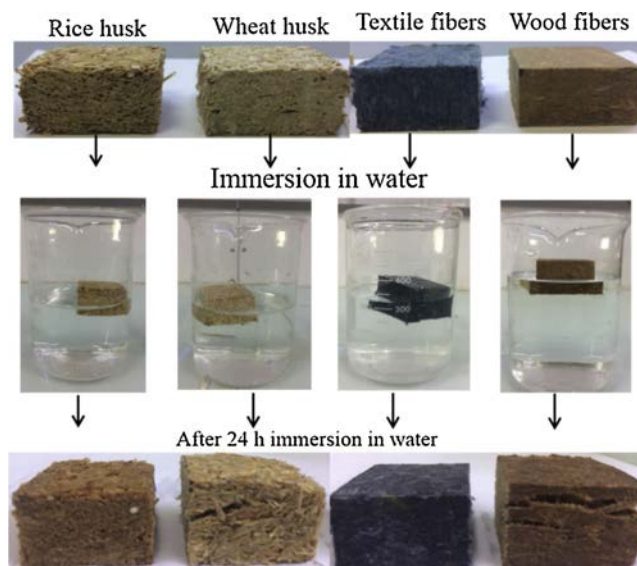


Fig. 11. Appearance of the prepared composite samples before and after water absorption test.

fibers (Hýsek et al., 2018; Tran et al., 2014).

#### 4. Conclusions

Agricultural waste (such as cereal husks) and textile waste binded with a biobased resin, Ecovio®, a poly(butylene adipate-co-terephthalate)/poly(lactic acid) (PBAT/PLA) blend, were developed for composite insulation panel applications. Although the performance of the developed composites under actual working conditions needs to be investigated, results obtained show considerable promise in developing a new class of sustainable materials for building interior insulation applications. Among the developed biocomposites, rice husks showed the better insulation property (0.08 W/m.K) with a density of 378 kg/m<sup>3</sup> and the lower water absorption (40% after 24 h immersion in water). All the biocomposites showed semi-rigid behaviour with sufficient flexural (0.80–2.25 MPa) and compressive (10–40 MPa) properties. Substituting conventional building materials with the developed biocomposites will lead to a lower environmental impact. Further investigations should be done to improve biocomposite processing for an industrial scale-up.

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