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Manufacturing and Characterisation of Thermoplastic Composite of Hemp Shives and recycled Expanded Polystyrene

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Abstract. There are two main problems caused by the huge volume of expanded polystyrene (Styrofoam) waste: the large amount of space that would be needed if it were to be disposed of in landfills and the excessive transport cost if it were to be recycled or incinerated. Consequently, the solution to these problems is the execution of two processes: the first one is the process of recycling the polystyrene with acetone, which allows us to separate the polystyrene from the other wastes, thereby reducing the volume by more than 98%. Then the resulting fresh polystyrene paste is used in the second process as a binder with 60 wt % of hemp shive to produce lightweight (porous) biobased-thermoplastic composites. The hemp shive particles significantly reduce the time of acetone evaporation to be three hours instead of three weeks for drying the net polystyrene paste. As a result, the recycling and the mixing processes produce a non-thermoformed lightweight composite. While the thermoforming process has been adapted to improve the mechanical properties of this composite, this ductile composite has specific mechanical properties that are better than those of the brittle net recycled polystyrene.

Keywords: Polystyrene; Reinforced thermoplastics; Characterisation; Hemp Shive.
PACS: (62. 20.-x); (65. 60. +a)

INTRODUCTION

The greatest challenge of the recycling process is obtaining high quality recycled plastic. The high purity and the compatibility between the different types of plastic are forcing us to pass through many steps (collection, sorting, chipping, washing, and pelleting). [1][2]

The polystyrene waste represents the worst negative impact on the environment due to its low price (high commercial productions and few recycling companies) which will increase its huge quantity in municipal waste. A number of researchers have suggested dissolving the polystyrene by many organic solvents [3] and acetone is one of the best solvents [4], allowing us to eliminate most of the recycling steps, especially for expanded polystyrene (EPS), which has huge volume. Acetone has low health hazards, is quite solvent (reducing the volume of the EPS by 98.5%), and satisfies the economical collection step from the point of view of waste management [5]. This process is able to separate the polystyrene from the other waste: plastics, labels, oils, colors, etc., because the acetone breaks all the cross-links (Vander-Waals bonds) between the PS molecules. On the other hand, the acetone can be recycled due to its volatility and its immiscibility with water [6]. The major problem with this recycling process is the time of the acetone evaporation because the hardening of the exterior layer of polystyrene paste restricts and retards the acetone evaporation. Schmidt [4] investigated that the mechanical properties of dissolved polystyrene with acetone were not adequate due to the air bubbles and the brittleness characteristic. In our study, the mechanical properties were improved when the dissolved polystyrene (DisEPS) was reinforced with hemp shive particles. Moreover, the minimum fresh polystyrene paste percentage (40 wt %) was mixed with maximum hemp shive content (60 wt %) to produce biobased-thermoplastic composite (DisCOMP 60). This polystyrene proportion was less than that used by Poletto [7]. DisCOMP 60 has many advantages: hardening without the thermoforming process, low price, recyclability and partial biodegradability. In Borsoi's work [8], the biodegradability of polystyrene composite depended on the cotton load.

This paper explores how to produce lightweight biobased-thermoplastic composite. Accordingly, the hemp shive particle has been chosen because it contains about 78% of air voids [9]. This particle is very hydrophilic due to its nature [8] [9]. Consequently, it will absorb the acetone from the fresh polystyrene paste and reduce the hardening time. Therefore, the effect of heating and the thermoforming pressure was studied to investigate the specific mechanical properties, water-absorption and the thickness swelling of a composite of 60 weight % hemp shive.

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MANUFACTURING PROCESS

Materials

The **expanded polystyrene,** which had a density of (0.015 g/cm^3), was collected and then dissolved with acetone. The saturation percentage of acetone was 81 wt % (acetone/polystyrene), the result being a viscous liquid of polystyrene with a density of (0.96 g/cm^3). This means that the volume was reduced by (98.4 %). This commercial **acetone** was purchased from ARDEA France Ltd.

The **hemp shive particles** were purchased from CHANVRALIT France Ltd, having a bulk density of (0.121 g/cm^3). These coarse particles were washed with clean water and then air-dried at (100°C) for 24 hours. After that, they were ground by the universal cutting mill (PULVERISETTE 19) to obtain a particle size of (0.5 to 1.4 mm), this product having a bulk density of (0.171 g/cm^3). The grinding process was necessary to reduce the inter-particle voids by (30%) and the agglomeration of the particles during the mixing process.

Compounding process

The composite of 60 wt % hemp shive with dissolved polystyrene (DisCOMP 60) was chosen because of this mixture has minimal acetone percentage. The other mix proportions had higher acetone percentages; for example, in the composites of more than 60 wt % hemp shive, a lot of additional acetone was needed to wet the hemp shive particles (150 wt % acetone/hemp shive). This technique was necessary to increase the workability of these mixtures during the mixing process and to prevent the fast setting of the paste. While, the composites of less than 60 wt % of hemp shive, the acetone percentages increased proportionally when increased DisEPS paste percentage in the mixture. Accordingly, DisCOMP 60 was mixed manually within 5 minutes and then pre-formed by cold mold pressure of 5 MPa for 5 minutes to reduce the inter-particle voids, and then the matrix between the particles was redistributed.

Acetone evaporation and hardening time

The hemp shive particles significantly reduced the hardening time of this composite because the hardening time depends on the acetone evaporation from fresh DisEPS paste. In contrast, the hardening time of net DisEPS paste takes about 21 days [5]. Therefore, an approach study about the acetone evaporation was done to determine the acetone evaporation at different times for net DisEPS paste and DisCOMP 60, as shown in Figure (1).

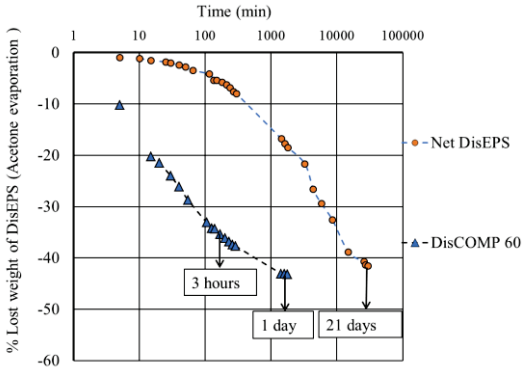


FIGURE 1. Acetone evaporation from fresh DisEPS paste versus the time.

We observed that after three hours, the fresh DisEPS paste of DisCOMP 60 lost about 35% of its weight (about 70% acetone) at the ambient temperature of 20±2°C. At this step, the composite has sufficient handling resistance and most of the acetone (≈95%) will evaporate after 24 hours, while the sample of net DisEPS (0 % hemp shive) evaporates the acetone very slowly compared with DisCOMP 60. It takes about 21 days, this result being in accordance with that obtained by Mwasha [5]. Interestingly, the acetone represents about 45% of net DisEPS.

PHYSICAL-MECHANICAL PROPERTIES

These biobased-thermoplastic composites of (50 x 50 x (2.75±0.25)) mm^3 were studied; firstly, without of thermoforming process and secondly when thermoformed them at 130°C for 30 minutes. Moreover, the thermoforming pressure was changed to be (0.5, 2.5, 5 and 20 MPa) in order to investigate the pressure effect on the physical and the mechanical properties.

The Density and the Voids Content

The apparent composites' densities were measured by dividing their sample weights by their volumes, as seen in Figure (2.a). Then, the voids content of the composites were calculated according to ASTM (D 2734), for this reason the theoretical density of DisCOMP (without voids) was calculated by using the rule of mixture, it was about (1.308 g/cm3), considering that the absolute density of polystyrene and hemp fiber were (1.05 g/cm^3) [10] and (1.48 g/cm^3) [11], respectively.

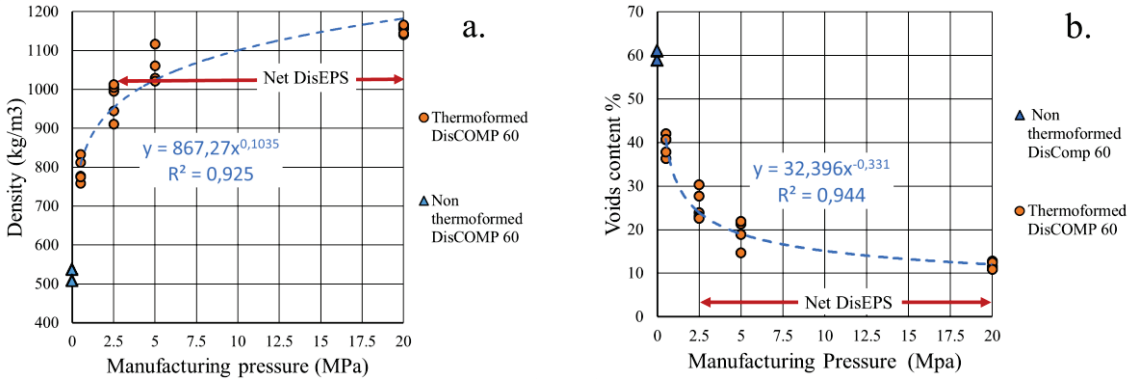


FIGURE 2. Effect of thermoforming and manufacturing pressure on (a) the density and (b) the voids content.

The non-thermoformed composite had a minimum density, then the density jumped due to temperature effects and light pressure of (0.5 MPa). This behavior can be explained by the collapse of the small gas bubbles inside of dried DisEPS, as shown in Figure (5.c). After that, the density increased more and more when the manufacturing pressure was increased because the hemp shive particles are very compressible materials. On the contrary, the voids content (intra-particle and inter-particle) decreased when this composite was thermoformed at (130°C) and when the manufacturing pressure was increased.

Flexural Strength and Modulus of Elasticity

A flexural test of a sample of (50 x 10 x (2.5 to 3)) mm^3 at 3-point of load was achieved according to ASTM (D 790, ISO 178) to investigate the mechanical properties of these composites by using the universal tester (TA-XT2i) of cell load of (500N) and crosshead speed of (6 mm/min). The ultimate flexural strength and the modulus of elasticity were calculated and illustrated in Figure (3).

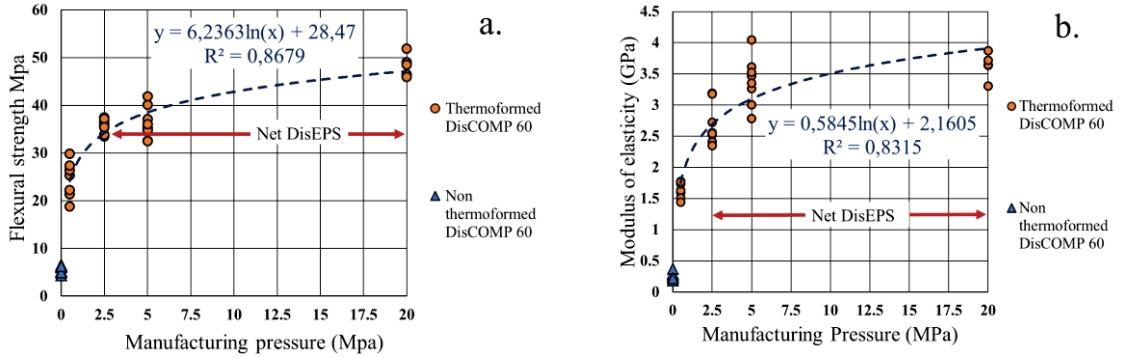


FIGURE 3. Effect of thermoforming process and manufacturing pressure on DisCOMP 60% (a) flexural strength and (b) modulus of elasticity.

The modulus of rupture (MOR) and the modulus of elasticity (MOE) jumped when this composite was thermoformed in accordance with the density. While the pressure represents the second principle factor to modify the mechanical properties when reducing the composite porosity. As a result, the composites (DisCOMP 60) were thermoformed by pressure of more than (2.5 MPa) had good specific mechanical properties, which were better than the net DisEPS as listed in Table (1).

Water-Absorption and Dimensional Stability

All the composites of (50 x 50 x (2.5 to 3))mm^3 were immersed in water for 24 hours, according to ASTM (D 570-98, ISO 62) at a temperature of 20±2°C, then they were weighted to calculate the water-absorption, and their dimensions were measured to calculate the thickness swelling, as listed in Table (1).

For DisCOMP 60%, the water-absorption decreased when the composite was thermoformed and when the thermoforming pressure was increased; it was proportionally dependent on the voids content and the surface absorption. While the thickness swelling took on approximately the same value for all the composites. However, these composites lost their surface textures due to the particles swelling, whereas, the interior particles were either well enveloped by the matrix, or the interior voids content would represent a refuge space for the expanded particles.

TABLE 1. Physical and mechanical properties of net recycled expanded polystyrene and hemp shive-thermoplastic composites.

	Composite type	Density (kg/m^3)	Voids content (%)	Specific MOR (MPa)	Specific MOE (GPa)	Water absorption (%)	Thickness swelling (%)
	Net DisEPS	1017.75	3	33.63	1.263	0	0
DisCOMP 60	Non-thermoformed	523,09	60	10,73	0,518	40.48 ± 5.41	3.64 ± 1.82
	Thermoformed at 0.5 MPa	791,22	39	30,55	2,091	22.47 ± 5.47	3.04 ± 0.72
	Thermoformed at 2.5 MPa	973,73	25	36,57	2,758	13.88 ± 3.06	5.08 ± 1.32
	Thermoformed at 5 MPa	1057,14	19	34,32	3,199	9.18 ± 1.25	4.34 ± 0.44
	Thermoformed at 20 MPa	1154,10	11	41,91	3,151	7.83 ± 3.25	4.89 ± 1.20

SEM Analysis

Scanned electron micrographs of EPS, hemp shive particles, and thermoformed DisEPS are represented in Figure (4). The very large air void explains the low density of expanded polystyrene, as shown in Figure (4.a), therefore the acetone reduced the volume by more than 98.4 %. In the other hand, the fresh DisEPS paste enveloped the hemp shive particles, and the particles tried to absorb the acetone during the mixing process, as shown in Figure (4.b). Equally important, the expanded gas bubble inside of the fresh DisEPS paste that caused by the acetone evaporation (at low pressure) pushed the thin layer of fresh DisEPS paste to contact the particle's surface, as shown in Figure (4.c). This phenomenon would modify the compounding and the mechanical interlocking between the particles and the PS matrix.

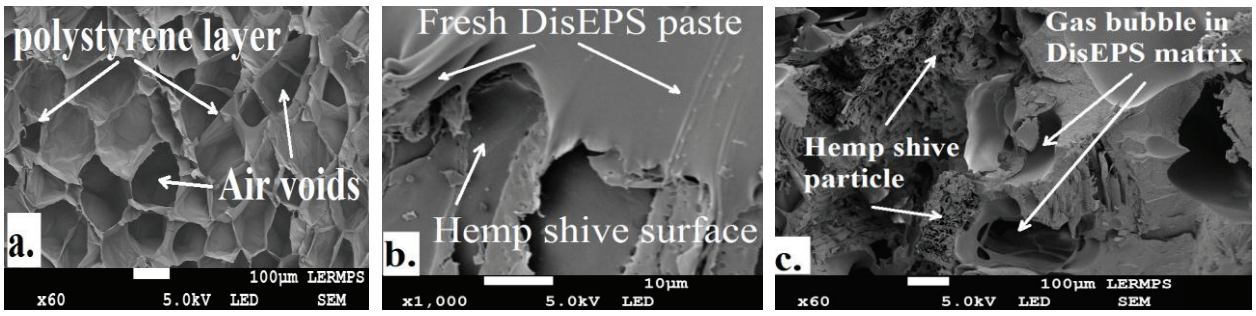


FIGURE 4. SEM pictures (a) EPS cells, (b) interface of hemp shive with fresh DisEPS paste and (c) hemp shive porosity and the interior gas bubble due to temperature effect on fresh DisEPS paste.

CONCLUSION

This experimental study succeeded in reducing the volume of recycled expanded polystyrene by more than 98.4%, separating the polystyrene from other wastes and cleaning it from the oils and the colors. As a result, we obtained a viscous liquid plastic without the use of a heating process. Then the polystyrene paste was used as a matrix in the second step to produce a biobased-thermoplastic composite of 60 wt % of hemp shive, and the results indicated that the hemp shive particles facilitated the acetone evaporation from the DisEPS paste. The non-thermoformed composite had 10.37 MPa and 518 MPa for specific flexural strength and specific modulus of elasticity, respectively. In the second steps, the temperature and the thermoforming pressure improved the mechanical properties of this composite to be better than those of the net recycled polystyrene. These results extended our knowledge to confirm that the hemp shive particles work as a reinforcement material. Further studies need to be carried out in order to validate the possibility of using this composite as a lightweight building material because it has good specific mechanical properties and is better than many construction materials such as Hempcrete.

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