

Influence of a Mineral Filler on the Fire Behaviour and Mechanical Properties of a Wood Waste Composite Material Stabilized with Expanded Polystyrene

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Abstract

The use of vegetable fibers composites in structures sometimes presents significant fire risks because of their high flammability. This work aims to study the impact of the addition of mineral filler (clay) on the fire behaviour of wood-polystyrene composites and their mechanical properties. Thus, composites containing 25% of expanded polystyrene binder have been produced. On this base material, proportions of clay ranging from 0% to 15% were gradually added. These samples were elaborated by compaction and for some them, submitted to thermoforming after drying. Both kinds of sample were subjected to flame persistence test; flexural strength and compressive strength test were also measured. The results show that composites without mineral filler ignite continuously until the total consumption and when the mineral filler content increases the combustion time decreases. The addition of the mineral filler allows these composites to pass from class M3 of moderately flammable combustible materials to class M2 of hardly flammable materials, according to the M classification of construction and furnishing materials. The measurement of the mechanical properties shows that the strengths increase when the filler content goes from 0% to 10% and then decrease. This leads to set the optimum content of mineral filler around 10%.

Keywords

Composite, Expanded Polystyrene, Flame Test, Flammability, Mechanical Properties

1. Introduction

Synthetic polymers and plastics in particular are now part of everyday life for both urban and rural populations. Their fields of use extend to almost all activity area where they replace natural or conventional materials. According to [1], about 30% of these plastics are used for packaging applications with an annual increase of 25% in demand in this area.

In packaging industry, polystyrene is one of the most widely used plastics for packaging brittle articles, household appliances and perishable foods [2]. After its use, polystyrene is released into nature, which generates large amounts of waste due to its low recycling rate and its high dissemination due to its low density [3]. So it is easily blown away by wind and runoff. As they are not biodegradable, these wastes accumulate and have a negative impact on environment [4].

Also, wood, one of the first materials used by humans, is still essential for their comfort [5]. However, its machining causes important by-products, including wood chips. The amount of wood chips during tree processing is estimated at 40% [6]. These wood chips are not sufficiently recovered in developing countries such as Côte d'Ivoire [7] and considered as waste. They are generally incinerated resulting in the release of CO₂, otherwise, left on site causing a healthiness problem in cities.

In order to recover polystyrene waste and wood chips, and to offer a solution for their management, composite materials made of polystyrene (EPS) and wood chips have been developed [8].

Using these composites can be a way to reduce the use of primary wood in some works and thus preserve this resource. However, since these composites are made of very flammable materials, their use in some structures can present significant fire risks because according to [9] [10] [11], vegetable fiber polymer composite materials generally have low fire resistance. So it is necessary to propose a solution to reduce this risk in order to allow easy use of this material in construction. To do this, mineral filler (clay), which is a flame retardant material [12] [13], has been added to these constituents.

This work aims to study the fire behaviour of the samples and to study their mechanical properties according to mineral filler content.

2. Material and Methods

2.1. Raw Materials

The raw material used for this work consists of wood chips, expanded polystyrene and clay powder.

The wood chips used are passing of 5 mm mesh sieve. They are lamellar in shape and 90% of particles are larger than 2 mm in size (**Figure 1(a)**). They were collected in carpentry units in Abidjan (Ivory Coast).

- Expanded polystyrene (EPS) (**Figure 1(b)**) comes from the packaging of household appliances. It was collected in pre-collection bins near shops in

Abidjan. Once stripped of any labels, the polystyrene is dissolved into acetone to obtain a resin. This dissolution reduces its volume by 98% [14] and thus makes its collection profitable.

This resin will be used as a binder to make composites. The dissolution of EPS is done in a ratio of approximately 0.7 kg of EPS per liter of solvent.

The mineral filler used is a gray to slightly brown colored clay. This clay has been the subject of many characterization and valuation studies which show that it is essentially made of kaolinite and illite [7] [15] [16]. It was dried, and crushed. The passing of the 63 μm sieve was used for this work (Figure 1(c)).

2.2. Method of Elaboration

The production method is summarized in Figure 2. The base material is made of wood chips (75% by volume) bound by polystyrene resin (25% by volume). To this composition, clay additions were made in proportions of 5%, 10% and 15%. After drying, some of the samples were subjected to thermoforming. To do this, the sample is put between two metal plates; the whole is heated at 150°C for 50 minutes and hot compacted using a manual static press.

Finally, two categories of samples are produced: non-thermoformed samples and thermoformed samples.

2.3. Characterization of Samples

2.3.1. Study of Fire Behaviour: Fire Persistence Test

This test was carried out in accordance with standard NF P 92-504 [17]. The sample is submitted to a heat source consisting of a gas burner. The burner is placed at 4 cm and tilted relative to the sample (that the flame is maintained in contact with the sample) for 5 seconds (Figure 3). For the sample the process is repeated ten times

The duration of flame persistence and phenomena observed are recorded. According to the behaviour, a material can be classified from Table 1.

2.3.2. Mechanical Characterizations

1) Three-point flexural strength test

The three-point flexural strength test was carried out on samples measuring 20 × 10 × 3 cm³ according to the ASTM D 790-81 standard [18]. The samples were placed on two (2) single supports at a distance of “*L*”. A third support is placed on the upper face halfway between the supports. Then a gradual loading is exercised on the sample using the press until it breaks. The load at break “*F*” is noted. The flexural strength is given by Equation (1):

$$R_f = \frac{3FL}{2lh^2} \quad (1)$$

With: *R_f*: flexural strength (MPa), *F*: load at break (N), *L*: the distance between the support supports (mm), *l*: the width of the sample (mm), *h*: the thickness of the sample (mm).

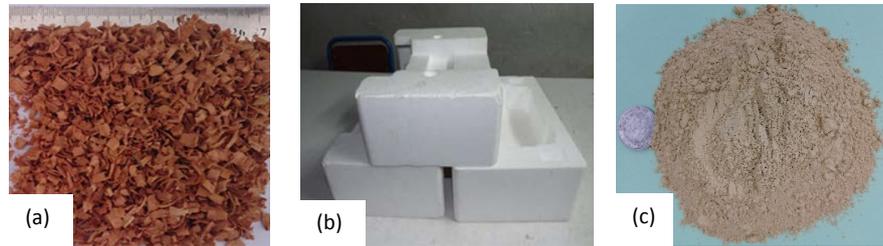


Figure 1. Raw materials; (a) Wood chips; (b) expanded polystyrene (c) Clay.

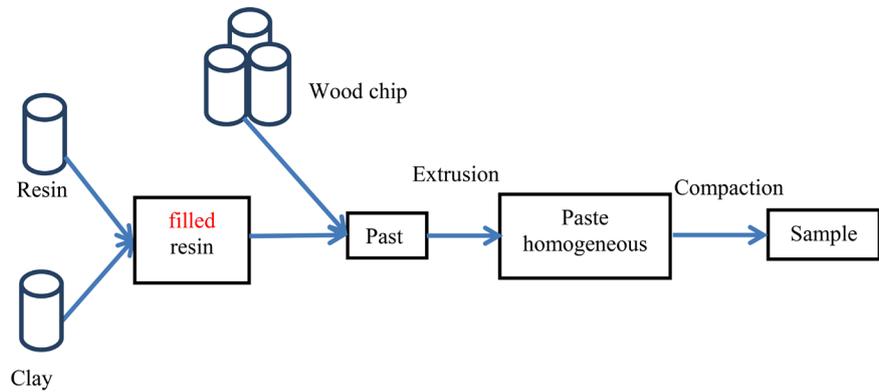


Figure 2. Elaboration methods.



Figure 3. Device of the flame test.

Table 1. M Classification of arrangement and construction products (NF P 92-504).

Raning M	Combustibility	Flammability	Examples
M0	Incombustible	Non-flammable	Bricks, ceramic ...
M1	Combustible	Non-flammable	PVC, mineral tile for false ceiling ...
M2	Combustible	Hardly flammable	Particle boards, wall carpet ...
M3	Combustible	Moderately flammable	Wood, rubber flooring ...
M4	Combustible	Highly flammable	Paper, polypropylene ...
NC	Unclassified	Unclassified	

2) Compressive strength test

For this test, parallelepipedal samples of dimensions $10 \times 5 \times 3 \text{ cm}^3$ were cut from the basic sample. The sample tested is put on its section ($3 \times 5 \text{ cm}^2$) in order to obtain a slenderness of 2 [19]; necessary for an optimal assessment of strength. It is then gradually charged until it breaks. The load at break “ F ” is noted.

$$R_c = \frac{F}{S} \quad (2)$$

With: R_c : Compressive strength (MPa), F load at break (N), S : Loaded section (mm^2).

3. Results and Discussion

3.1. Influence of the Mineral Filler Content on the Fire Behaviour of Composites

The results of the fire persistence test are listed in **Table 2** below. This table shows that samples without mineral addition (0% clay) present combustion with flame. In fact, it is a continuous combustion until their total consumption. However, tastes do not form during their combustion.

After adding mineral filler (5% to 15%), the samples present combustion with a flame for variable duration. The combustion time decreases when mineral filler content increases.

The ignition time is approximately 65 seconds for samples at 5% of filler, for samples at 15% non-thermoformed and thermoformed is respectively about 15 seconds and 11 seconds. Overall, there is no incandescence that persists after the flame is extinguished.

The samples without mineral filler have low fire resistance due to the presence of cellulose (a very flammable material) in the wood and the fact that EPS is a hydrocarbon and therefore an oxidizer by nature. This explains the continuous combustion with flame until the total consumption of these composites.

Table 2. Fire behaviour of composites.

	Clay content (%)	Duration of flammability (seconds)	Average length destroyed (mm)	Formation of tastes	Classification
Non thermoformed	0	total combustion of the samples with flame	≥ 350	No	M3
	5	65.93	25	No	
	10	27.2	21.33	No	M2
	15	15.4	14	No	
Thermoformed	0	total combustion of the samples with flame	33	No	M3
	5	65.12	33	No	
	10	21.57	19.66	No	M2
	15	11.03	18	No	

When the mineral filler is added to the EPS-Wood chips mixture, the clay particles become intercalated into the matrix and hinder the propagation of the flame because clay is not combustible. This discomfort becomes more and more important when clay content increases. This could explain the fact that composites become less flammable. The mineral filler behaves like a flame retardant. Indeed clay particles cover the wood chips by constituting a barrier between the flame and the chips.

Similar results have been reported by [20] [21] on the incorporation of glass silicon carbide and basalt fiber into composites. They explain that these mineral filler reduce the ignition time and the rate of flame propagation considerably. These fillers behave like a barrier layer.

Likewise [22] during their studies on polypropylene composites filled with natural fibers (Kenaf) made the same observations.

For these authors, a carbonized layer is formed at the surface of the polymer during thermal degradation. As an insulating barrier, this carbonized layer reduces; the transfer of the flame to the polymer as well as the diffusion of oxygen into the material.

According to the M classification of construction and arrangement materials (standard NF P 92-504), samples without mineral addition are of class M3, *i.e.* moderately flammable combustible materials while those with mineral filler are of class M2: flame retardant materials such as particle board, wall carpets, etc. Class M2 composites are conform with (French) fire safety legislation [23].

3.2. Influence of the Mineral Filler Content on the Mechanical Properties of Composites

The flexural (three-point) and compressive strength of non-thermoformed and thermoformed composites are shown in **Figure 4**.

When the mineral filler is added to the EPS-Wood shavings mixture, the flexural strength increases up to 10% of filler, beyond that the strength drops (**Figure 4(a)**), both for samples which have sustained thermoforming or not. The flexural strength for thermoformed samples range from 11.73 MPa at 0% of filler to 12.34 MPa at 10% then drop to 9.2 MPa with 15% filler.

For non-thermoformed samples, their flexural strength drop from 5.4 MPa (0% filler) to 7.45 MPa (10%) then drop to 6.28 MPa (15%).

The compressive strength of non-thermoformed samples increases from 14.24 MPa to 15.94 MPa and then drop to 13.32 MPa when filler content goes from 0% to 10% and then to 15%. After thermoforming, the strength range from 18.67 MPa to 21.72 MPa before dropping to 18.13 MPa (**Figure 4(b)**).

This variation can be explained by the fact that when mineral filler is added, during the stress in flexural or in compression, the force which was previously supported only by the EPS matrix and the wood chips, is now supported by these two constituents and by clay. Hence the strength increases as the mineral filler increases.

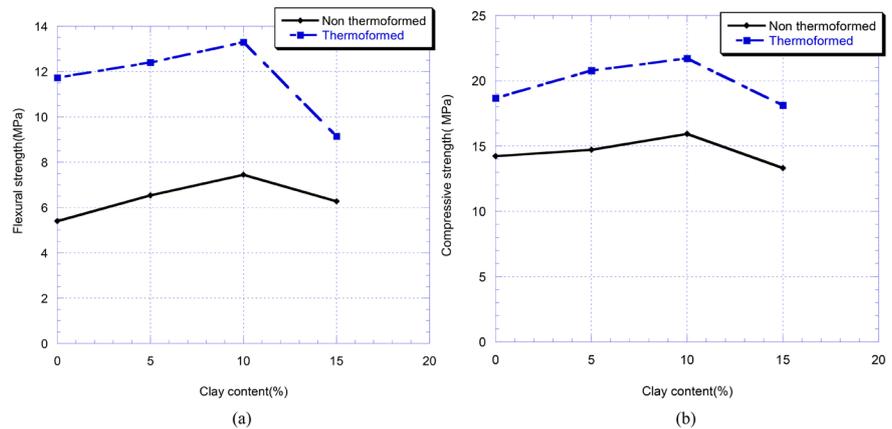


Figure 4. Variations in mechanical properties as a function of mineral load content.

The drop in strength for more than 10% mineral filler would be due to the fact that because of high quantity of mineral filler in the mixture, the action of the binder becomes ineffective. It promotes existence of contacts between clay particles. These contacts weaken the composites, and leading to the drop in mechanical strength.

The same observation was made by [4] in his work on sand-plastic composites filled with clay and by [24] on the incorporation of mineral filler into a biocomposite reinforced with rice husks and sawdust.

Incorporating fibers into a polymer matrix also gives similar results [24] [25]. These authors explain the drop in mechanical strengths after optimal filler rate, by the fact that from this rate, the bringing together of the fibers seem to hinder fluidity of the matrix, and causing weakening of fiber-matrix bonds. This behaviour can reduce mechanical strength of composite materials.

It can be notice that mechanical performance of thermoformed samples is greater than those of non-thermoformed samples. This is explained by the fact that thermoforming ensures a good distribution of the EPS matrix into the composites.

The combined effect of heat and pressure induces reorganization of matrix and wood chips, reducing voids in the mixture while strengthening the bonds between the EPS matrix and the wood chips.

Therefore the optimal rate of mineral filler would be around 10% for these composites.

For some authors [26] [27], this rate depends on kind of polymer in the mixture. For example [25] shows that the optimal filler rate is 5% for polypropylene while [26] place this rate at 20% for corn starch. For the same polymer, this rate may vary when its structure is modified, then the optimal filler rate drops from 5% to 3% for modified propylene [28] [29].

4. Conclusions

The study shows that the addition of mineral filler increases fire resistance of

composites. These pass from moderately flammable combustible materials (class M3) to hardly flammable materials (class M2). The addition of mineral filler can allow easy use of these composites in construction and laying-out.

This mineral filler also increases mechanical performances by addition of 10%.

However, an excessive amount of mineral filler (more than 10%) can alter the mechanical properties even if it allows better resistance to fire. This therefore leads to setting the optimum filler content around 10%.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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