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#### **Research Article**

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# Study and fire test of banana fibre reinforced composites with flame retardance properties

https://doi.org/10.1515/chem-2020-0025 received April 2, 2019; accepted January 9, 2020.

Abstract: The interest in natural fibre reinforced composites is growing in industrial applications due to natural fibres being an attractive alternative to synthetic fibres. However, it is necessary to improve the fire behaviour of the material because natural fibres have a high combustibility. The objective of this work is to evaluate the fire resistance of polymer composites reinforced with natural fibre fabric, using magnesium hydroxide as flame retardant for the polymeric matrix and alkali treatment for the fibre. The types of fabric are banana, banana with cotton and linen; and long banana fibre has been used for the formation of a nonwoven. The fire test is carried out based on ISO 9773 standard and the effect of the additive has been studied, chemical treatment, type of fabric and number of layers. Through statistical analysis, it is concluded that the flame propagation speed has a decreasing relation with respect to the percentage, but it decreases the mechanical properties considerably. In addition, the number of layers and type of fabric influence the fire properties. Finally, it is concluded that composites reinforced with linen fabric have the best mechanical properties, but banana nonwoven with 60% additive has the best fire behaviour.

**Keywords:** Natural fibre composites; Magnesium hydroxide; Mechanical properties; Flame retardancy.

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## 1 Introduction

Among the many environmental problems that exist nowadays, several studies improve the sustainability of industrial process and the management of the huge amount of polymer waste [1] produced in the world. Thanks to its renewable origin, recycling possibilities and biodegradability of its derivatives, natural fibres are suitable as reinforcement of polymeric materials in the industrial sector [2]. Natural fibres show as main advantages their low density, low cost and biodegradability; their main drawbacks in the polymer sector are related to their poor compatibility with polymer matrix, limited processing temperature and a high moisture sorption, among others [3]. In addition, it is necessary to know the interaction of these materials with fire because natural fibres have a high combustibility [4], not only to ensure its use in industries, but more importantly the protection of lives from the derived risks associated with fire. To improve the fire resistance in composites a number of strategies can be followed, from the reduction of the flammability of the matrix, the fibre reinforcement and/or the composite as a whole [5].

For the matrix, a wide number of papers about flame retardants and mineral fillers for polymers [5-14] can be easily found. Flame retardants (FR) are substances that are added to combustible materials, such as plastic, to prevent fire or reduce the spread of fire to provide additional escape time. Therefore, the term "flame retardant" refers to a function, not a family of chemicals. These substances can be separated into several classes: halogenated, phosphorus based, nitrogen based, intumescent systems, boron based, silicon derivatives, inorganic substances and natural substances [12]. The additives based on halogenated compounds have been the most used ones as flame retardants for thermoplastics until the entry of new environmental regulations that restrict their use. This is due to these flame retardants being found at increasing levels in household dust, human blood and breast milk, and wild animals [15-17]. All these circumstances have led to the development of regulations in Europe such as

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REACH, WEE or ROHS that limit and even prevent the use of many of these substances [12]. Nevertheless, these substances have been the most effective solutions to improve the behaviour of thermoplastic materials to fire; therefore, finding alternatives is a great challenge for the industry of flame retardants.

This work focuses on the assessment of flame retardants based on inorganic substances, specifically magnesium hydroxide, as a more sustainable and safer compound than halogenated ones. These retardants are the best-selling group of flame retardant additives, reaching 50% of commercially available flame retardants [12]. The main reasons for its high consumption are low price compared to other additives, low toxicity and low corrosion. In addition, smoke emissions in the presence of these additives are often reduced compared to other retardants [18]. Among the inorganic additives, aluminium hydroxide stands out as the most sold additive, with application in multiple thermoplastics, thermosets and elastomers with a process temperature below 200°C [19]. For applications where higher temperatures are required, such as in technical plastics, the use of magnesium hydroxide is very widespread due to its greater thermal stability.

The fireproofing action of the hydroxides is based on their thermal decomposition showed below [20]:

2Al(OH)<sub>3</sub> à Al<sub>2</sub>O<sub>3</sub> + 3H<sub>2</sub>O 
$$\Delta$$
h=-1051 J/g Al(OH)<sub>3</sub>  
Mg(OH)<sub>3</sub> à MgO + H<sub>3</sub>O  $\Delta$ h=-1316 J/g Mg(OH)<sub>3</sub>

The flame retardant action of hydroxides is, therefore, due to three different processes:

- The absorption of combustion energy as a result of the endothermic reaction.
- The dilution of combustible gases by the water vapor released
- The formation of an oxide layer which isolates the material from heat and oxygen.

The aluminium or magnesium hydroxides have the great advantage of entering in action before the thermal decomposition of the polymeric material, which occurs between 350°C and 400°C for the most common thermoplastics [21], but high percentages of additive are necessary to obtain a fireproof material. In the case of magnesium hydroxide, percentages between 60 and 65% are necessary, hence the mechanical properties of the material are remarkably reduced [20,22].

As mentioned before, the flammability of composites can be reduced by fibre surface modification instead of incorporating FRs in the composites. The fire behaviour of natural fibres depends on fibre constituents, weight percentage and morphology of the fibre [23]. The main constituents of natural fibres that control their flammability are lignin and cellulose [24]. The decomposition of cellulose, between 260°C and 350°C, results in the formation of flammable volatiles and gases, non-combustible gases, tars and some char [25]. Hemicellulose decomposes between 200°C and 260°C but forms more non-combustible gases and less tar than cellulose [5]. Lignin starts decomposing from about 160°C until around 400°C; during thermal decomposition of lignin, relatively weak bonds break at lower temperature, whereas the cleavage of stronger bonds in the aromatic rings takes places at higher temperature [26]. In addition, Kozlowski observed using cone calorimetry technique that heat release rate (HRR) from bast fibres (flax, hemp) is considerably lower than from leaf fibres (abaca, cabuya) [27]. Fibres orientation is an important aspect to consider, because it results in less oxygen permeability through fibres and, as a consequence, in improved flame resistance [23]. The common FRs applied to natural fibres are ammonium phosphates, such as mono- or diammonium phosphates (DAP), ammonium bromide (where allowed), borax and boric acid, ammonium sulphamate, and sulphates [28]. The surface treatment apart from influencing mechanical properties of the fibre, has an impact on the thermal properties too. In this work the alkali treatment has been used because it improves the thermal stability of the fibre [29,30]. This process reduces the fibre diameter by removing the amorphous materials, such as hemicellulose, lignin and other waxy materials; from the fibre surface and increases its surface roughness. Thus, the removal of amorphous materials exposes cellulose and its hydroxyl groups, and leads to more hydroxyl bonding between fibre surface and polymer matrix thereby enhancing the mechanical and thermal properties of the fibre reinforced polymer composites [31].

This paper aims to study the effect of magnesium hydroxide and alkali treatment on the mechanical and fire properties of natural fibre reinforced composites. The mechanical and fire properties of all composites were investigated using standard procedures such as tensile, flexural, impact and UL-94 methods. Finally, the objective was to obtain a composite with good fire behaviour reinforced with natural fibre, which is highly combustible.

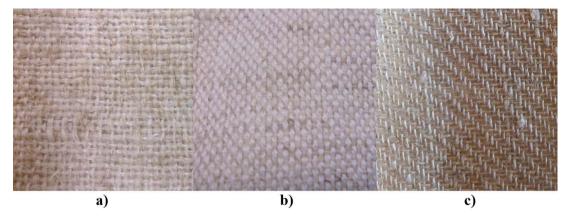


Figure 1: Natural fibre fabric: (a) Banana (b) Banana with cotton (c) Linen.

# 2 Material and methods

#### 2.1 Materials

The polymeric matrix used is a homopolymer polypropylene (PPH 9069) in pellets kindly supplied by Total Polymers. The density in the solid state is 905 kg/m<sup>3</sup> and the melt flow rate (230°C, 2.16 kg) is 25 g/10 min. The flame retardant used is magnesium hydroxide in powder purchased from VWR Chemicals with 99% assay and density (20°C) 2.34 g/cm<sup>3</sup>.

The fabrics of natural fibre used have been the result of the research project BANTEX (MAT2013-47393-C2-1-R). Banana fibres were extracted mechanically from banana tree pseudostems with a patented system by the University of Las Palmas de Gran Canaria (ULPGC) [32]. Subsequently, long fibre is chopped in a developed machine according to the requirements of the enzymatic treatment (45 mm). The conditions of enzymatic treatment and varn and fabric obtaining have been optimized and performed as shown in previously published papers [33,34]. In summary, the varn used had a linear mass density of 157 tex, with an average diameter of the banana yarn of 0.24 mm and the one twisted with multifilament of PP 0.36 mm. One of the fabrics was obtained with the banana/wool/PP yarn in the warp and the weft and the other one with a banana/wool/ PP weft and cotton warp and the textile structures plain, basket and twill. The structure employed in this work is plain and the weight of the fabric is 279 g/m<sup>2</sup> in banana plain, and 337 g/m<sup>2</sup> banana/cotton plain [34]. In order to compare the fabrics developed in BANTEX project, it is used a commercial linen fabric LINEO FLAXPLY BT with a density of 200g/m<sup>2</sup>. In summary, the three types of fabric employed are banana, banana with cotton and linen (Figure 1). In addition, long banana fibre has been used for the formation of a nonwoven.

## 2.2 Samples preparation

In order to make a good mixture between the polypropylene and the flame retardant, the plastic must be grinded. The equipment used is the Ultra Centrifugal Mill ZM200 of Retsch able to reduce particles to sizes below 500µm. This procedure is rather complicated because the material tends to melt. Therefore, it is necessary to freeze the material for 24 hours, select low rotation speeds and feed the material slowly.

Plastic parts were manufactured by compression moulding, in a Collin hot plate press model P200 P/M in an aluminium mould with male and female parts and a cavity of 190x190 mm. The weight of the plate is 80g and the additive percentages used are 45 and 60% to determine the trendy of the flame propagation speed with the retardant load. The procedure consists of mixing the PP powder and the additive manually and then introduce them inside of the mould, but during the trials, it was observed that the distribution of the flame retardant additive worsen with the increase in the additive ration. For this reason, the compression moulding process conditions vary depending on the percentage used to improve the distribution. In the case of the parts without additives, a pressure of 10 bar is applied, for 45% 35 bar and for 60% 100 bar; the processing temperature is kept to 220°C for all the plates.

Regarding to the natural fibre fabric, the textiles showed in Figure 1 are cut at 190x190mm<sup>2</sup> and then dried in an oven at 100°C for 24 hours. The nonwoven was obtained from banana fibres with about 40 cm length. The procedure consists of separating and adapting the fibres to the mould dimensions, then by wetting them with distilled water and finally pressed and dried in a stove to keep their shape (Figure 2).



Figure 2: Banana nonwoven.



Figure 3: PP and linen fabric placed in the hot plate press for moulding.

To increase the degradation temperature and improve the adhesion fibre-matrix, the fibre has been treated. The treatment used has been alkaline and it consists of immersing the fibre in a 1 N sodium hydroxide solution for 1 hour. Subsequently, the fibres are washed with distilled water and dried in an oven for 24 hours.

The linen composites made with linen fabric have two layers, one of plastic and one of fibre, and the manufacturing is carried out without mould. The layers are stacked and placed on the plate of the hot plate press between Teflon sheets, as it is shown in Figure 3, and the process conditions are 190°C and 35 bar.

On the other hand, the parts with banana nonwoven have four layers, two of plastic and two of fibres. In this case the mould is used to avoid the deformation of the nonwoven and the process conditions are 200°C and 100bar. In addition to the specimens manufactured in this work, there have been added specimens from BANTEX project to observe the differences among fabrics and number of layers. The manufacturing and process

conditions are shown in a previously published paper [35]. Table 1 summarizes the different formulations of composites that have been tested.

#### 2.3 Measurements

The plates were characterized under an Olympus BX51 optical microscope, to observe the additive distribution and the adhesion fibre-matrix.

Then, parts were mechanically characterised by tensile, flexural and impact tests, following ISO standards. Standardized test specimens were obtained by CNC machining. Tensile tests were conducted according to ISO 527 using a load cell PCE-FG1k Model YZC-516 500kg and a strain rate of 20 mm/min. Flexural testing was performed following ISO 178 standard, using the load cell PCE-FG1k and a test rate of 20 mm/min. Finally, Izod impact tests were conducted according to ISO 180 using an IZOD&CHARPY Impact Tester from LIYI-tech and a pendulum force of 5.5I.

The fire tests were based on ISO 9773 standard, using lab - made equipment (Figure 4). It consists of a combustion chamber equipped with a gas extraction device in the upper part. Inside there is a sample holder with a Hoffman clamp and a Bunsen burner. The lighter can be placed at 45 degrees to avoid the drops which are collected in a removable tray. In the test the residual flame time and the propagation speed were quantified. Also, a video recording device has been introduced inside the chamber and marks have been made to the specimens every 2 cm, for the calculation of the propagation speed.

Finally, the data obtained in the mechanical and fire tests have been subjected to a statistical study to find the effect of the flame retardant additive and the treatment of the fibres, among others. Analysis of variance, multi-rank test and Kruskal-Wallis have been carried out.

Ethical approval: The conducted research is not related to either human or animal use.

## 3 Results and discussion

#### 3.1 Optical microscopy

As a consequence of the chemical treatment shrinkage in the fabric is observed, which may hinder the introduction of the plastic and the additive inside the mesh. In the images of the microscope (Figure 5), it is confirmed that there is a reduction of the space between threads. This

Table 1: Formulations included in the study.

Fabric type	% additive	% fibre	Number of fibre layers	Treatment	Sample code
Without reinforcement	0	0	0	No	PP
	45	0	0	No	PP-45%
	60	0	0	No	PP-60%
Linen fabric	0	33	1	No	LN200-01
	0	36	2	No	LN200-02
	0	41.8	2	Yes	LN200-T-02
	0	39.7	3	No	LN200-04
	45	15.5	1	No	LN200-45%
	45	18.2	1	Yes	LN200-T-45%
	60	8.8	1	No	LN200-60%
	60	10.3	1	Yes	LN200-T-60%
Banana nonwoven	0	9	2	No	NOTE
	0	8	2	Yes	NOTE-T
	45	8.5	2	No	NOTE-45%
	45	8.8	2	Yes	NOTE-T-45%
	60	9.2	2	No	NOTE-60%
	60	9.4	2	Yes	NOTE-T-60%
Banana fabric	0	39.1	1	No	PL-01
	0	50.6	2	No	PL-02
	0	50	3	No	PL-03
Banana with cotton fabric	0	39	1	No	PL+AL-01
	0	46.7	2	No	PL+AL-02
	0	44.8	3	No	PL+AL-03

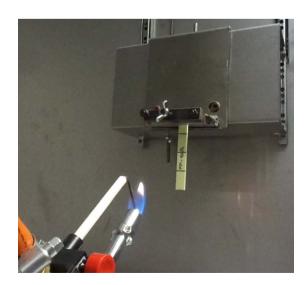


Figure 4: Fire test equipment.

causes for the plastic to be more difficult to flow through the tissue, which leads to a worse adhesion between fibre and matrix.

In the case of the nonwoven, there are no visual differences due to the treatment, apart from a decrease in the fibre diameter (Figure 6).

## 3.2 Mechanical tests

### 3.2.1 Composites with flame retardant additive

The results obtained in the mechanical tests are shown below. The data have been subjected to a statistical study to observe if the flame retardant and the chemical treatment applied to the fabrics have a statistically significant

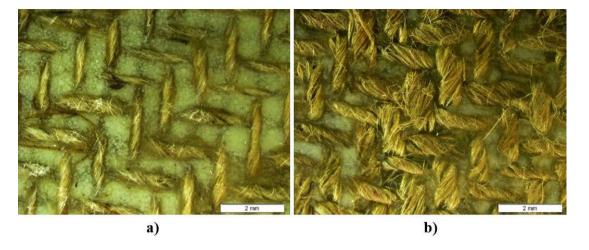


Figure 5: Polypropylene with linen fabric and 60% additive: (a) Without treatment (b) With alkali treatment.

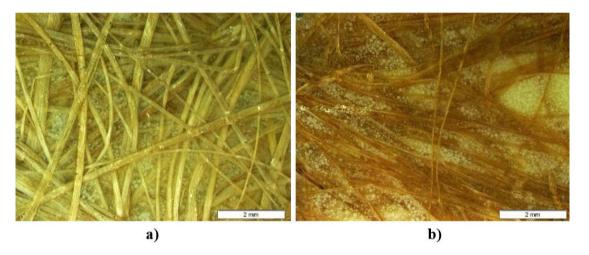


Figure 6: Polypropylene with banana nonwoven and 45% additive: (a) Without treatment (b) With alkali treatment.

effect in the mechanical properties. The analysis of each property has been carried out separately and the samples have been divided into three groups: pieces without reinforcement, linen fabric and banana nonwoven.

Figure 7 shows the tensile specific properties of the samples. Firstly, it is observed that the percentage of additive influences the elastic modulus and the maximum tensile strength. In the case of parts without reinforcement, the elastic modulus increases in relation to the percentage of additive, but the maximum tension decreases. The value of the elastic modulus increases with the filler percentage due to the greater rigidity of the additive particles. The reduction of the tensile strength with the percentage of magnesium hydroxide is mainly due to the bad adhesion between the particles and the matrix, which causes the interface to take off. The effective section is therefore reduced and the value of the maximum tension decreases

[20]. In consequence, the additive provides rigidity to the material, but it is fragile. In relation to linen fabric, there is a decreasing relation in the elastic modulus and tensile strength with the amount of flame retardant. Linen fabric improves the elastic modulus of net polypropylene by 130%, but the effect of the reinforcement is lost when adding the flame retardant. This fact is due to the additive increases the viscosity of the polymer [36], so it is more difficult to flow through the threads of the fabric and the fibre-matrix adhesion is worse. Regarding the treatment, a decrease in mechanical properties is found when the fabrics used are previously alkali - treated, because of the shrinkage of the linen. In relation to banana nonwoven, the additive worsens the tensile properties as in the other samples. The nonwoven improves the elastic modulus by 54%, but the additive decreases the tensile properties as the percentage increase, except for 60% additive

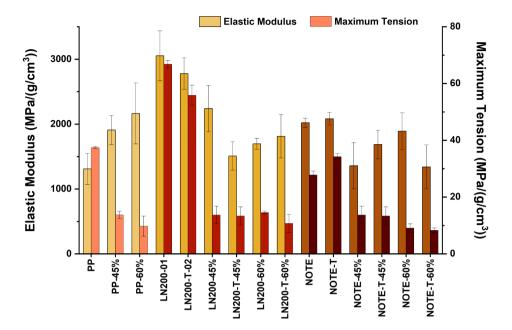


Figure 7: Tensile specific properties.

without treatment. Analysing the chemical treatment, it is obtained a slight improvement of the elastic modulus in the nonwoven without additive and at 45% and no effect in the maximum tension, therefore, it is not possible to conclude that the alkali treatment improves the tensile properties. As a summary, the highest value in the elastic modulus and maximum tension is obtained in the plate with linen fabric without additive, 3052.1 MPa and 66.8 MPa, respectively. The lowest value of elastics modulus is obtained with net PP (1309.7 MPa) and maximum tension in banana nonwoven with 60% of additive (8.3 MPa). In the ANOVA analysis it is observed that the additive has a statistically significant effect for all the samples because it is obtained a p-value lower than 0.05. However, the treatment has no significant effect, and only has influence on the maximum tension.

In the case of the flexural properties (Figure 8), it is observed an increasing relation of the modulus with respect to the percentage of additive because it provides stiffness to the material due to the greater rigidity of the magnesium hydroxide. The alkali treatment improves slightly the flexural modulus, except in the banana nonwoven without additive, but the effect is not significant. The highest value in the flexural modulus is obtained in the plate with linen fabric at 60% with alkali treatment (4305.44 MPa) and the lowest value is obtained with banana nonwoven with 60% of additive (2069.6 MPa), but the difference with respect to the value that precedes them is not notable. From the statistical analysis it is concluded that the amount of flame retardant additive has a significant effect in the flexural properties because it is obtained a p-value lower than 0.05, while the chemical treatment of the fabrics has not.

Figure 9 shows the impact specific properties of the samples; the conclusions obtained from these tests are similar to those obtained for tensile and flexural tests. The percentage of additive decrease the impact strength of the sample due to the reduction of the effective section by the bad adhesion between particles and the matrix. The effect of the additive is more prominent in the banana nonwoven, where the difference is around 20 kJ/m<sup>2</sup>. The alkali treatment shows no effect in the resistance of the material, except in the linen fabric (LN200-T-02) where it improves the impact strength by 58%. As a summary, the higher values are obtained in the plates with banana nonwoven without additive (around 22 kJ/m<sup>2</sup>) and the lowest value is obtained for net PP with 60% of additive (0.96 kI/m<sup>2</sup>), but the other samples have values similar to this plate. From the ANOVA analysis it is concluded again that the additive has a statistically significant effect in the impact properties, but the treatment has no influence.

#### 3.2.2 Composites with natural fibre fabric

The results obtained in the mechanical tests for BANTEX composites are shown in Table 2. In this case the different configurations of banana and banana with cotton fabric

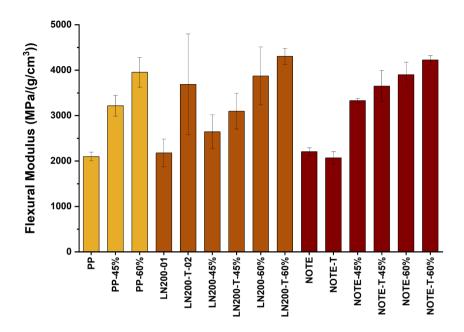


Figure 8: Flexural specific properties.

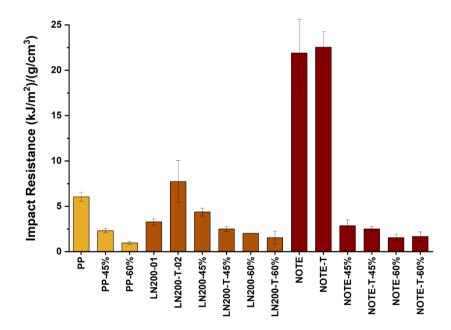


Figure 9: Impact specific properties.

are compared with net PP and commercial linen textile. Firstly, it is observed that linen is clearly better than the banana fibre textiles, principally in the tensile test. Linen fabric (LN200) improves the elastic modulus of net polypropylene up to 100% and the max stress up to 78%. Regarding to banana fabric (PL), a reduction of the tensile properties, especially the max stress, is obtained due to the

fabric having a 50% of wool, which has low mechanical properties. The reason of using wool to obtain the yarn was the difficulty to obtain pure banana yarn with the available equipment, therefore it is necessary to improve the process to achieve almost 100% of pure banana fibre [35]. On the other hand, when it is added cotton in the warp of the textile (PL+AL), a slightly increase in the

Table 2: Mechanical properties of BANTEX composites.

Sample	Tensile test				Flexural test	Flexural test		Impact test	
	Modulus (MPa)	SD	Max Stress (MPa)	SD	Modulus (MPa)	SD	kJ/m²	SD	
PP	1309.73	240.11	37.45	0.38	2098.54	95.81	6.04	0.5	
LN200-01*	3052.31	385.18	66.80	1.35	2069.22	290.47	3.12	0.32	
LN200-02*	2642.47	438.09	69.41	2.82	4256.92	346.93	10.29	0.33	
LN200-04*	2951.48	314.84	70.81	2.02	4837.44	416.90	17.26	2,43	
PL-01*	1322.64	222.95	23.82	1.45	1489.10	231.01	3.66	0.49	
PL-02*	1623.68	181.43	25.85	0.35	2089.88	56.72	6.28	0.53	
PL-04*	1307.23	405.00	25.27	4.01	2182.89	96.36	7.86	3.68	
PL+AL-01	1428.76	422.99	54.27	2.97	1844.50	463.90	4.64	0.77	
PL+AL-02	1479.93	227.19	60.60	1.78	2629.15	617.02	9.95	2.00	
PL+AL-04	1553.54	306.16	61.57	1.85	2803.66	608.21	19.10	3.51	

<sup>\*</sup>Data extracted from the reference [35]

elastic modulus and a considerably improvement of the max stress is observed. In the case of the flexural test, the conclusions obtained are similar to those obtained for tensile test: linen composites are superior to banana and cotton, and followed by the banana and wool composites. Lastly, the impact strength is improved when the composites have 2 or 3 layers of fabric, being the best result with banana and cotton fabric. To conclude, in the ANOVA analysis it is observed that the fabric type has a statistically significant effect for the tensile and flexural test because it is obtained a p-value lower than 0.05. Otherwise, the number of layers affects the impact strength and the max stress.

#### 3.3 Flame resistance test

In the case of fire tests, the samples have been divided into four groups: parts without reinforcement, linen fabric, banana nonwoven and type of fibre. Figure 10 shows the propagation speed of the samples with flame retardant additive. Firstly, it is observed a decreasing tendency of the propagation speed with respect to the percentage of additive and the difference with the plate without retardant is noticeable. The best results are obtained in the plates reinforced with banana nonwoven and 60% of magnesium hydroxide with a propagation speed nearly to 0 mm/min. However, the greater reduction of the flame propagation speed is observed in the untreated linen samples, obtaining an improvement of 90%.

In the case of specimens with different types of fabrics and number of layers (Figure 11), the lowest propagation speed is obtained for the linen and the highest for the banana fibre. The lowest propagation speed of linen can be justified because linen is a bast fibre and the lower lignin content as Kozlowski reported [27]. Comparing the banana and banana with cotton fabric, a slight improvement with the fabric with cotton is obtained due to its composition. The composition of cotton fibre is mainly cellulose (85-90%), followed by hemicellulose (1-3%), ash (0.8-2%) and lignin (0.7-1.6%) [37]. The higher content of cellulose improves the flammability due to the degradation begins at a higher temperature [27]. Finally, it is concluded that the propagation speed decreases as the number of layers increases because there is more material to be burned and the fibre percentage is higher (Table 1).

The results of the p-value in the ANOVA analysis are shown in the Table 3. It is obtained that the additive has a statistically significant effect on the propagation speed and the residual flame time for all the samples. The effect of the chemical treatment of the fabrics does not show any clear trend. Finally, in the study of the type of tissue it is observed that both the type of tissue and the number of layers influence the result.

As a summary, the best results in terms of fire protection were obtained for the sample of banana nonwoven with 60% additive because the combustion of any of the test samples does not occur (Figure 11). This fact is because these plates have two layers of plastic with additive, so if one of them does not have a good

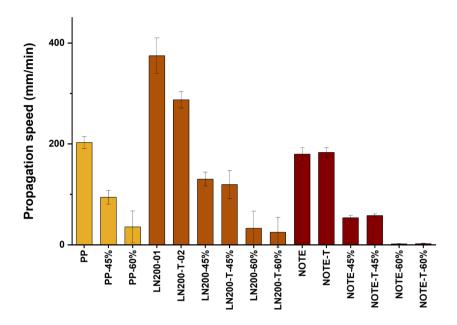


Figure 10: Propagation speed of composites with additive.

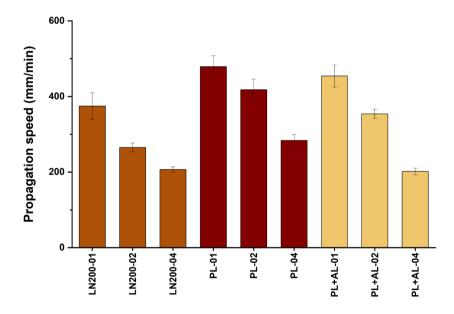


Figure 11: Propagation speed of composites with different fabric types.

distribution of the additive, the next layer compensates it, but it is necessary to improve the mechanical properties. In addition, the fibre percentage is around 9% (Table 1), therefore, the combustibility of the fibre doesn't have a high influence.

# 4 Conclusions

In this study the effect of the magnesium hydroxide and alkali treatment in mechanical and fire properties have been studied. Alkali treatment applied to the fabrics produces shrinkage and consequently, an increase in density of the linen fabric. In the statistical analysis, it is

Table 3: P-value in the ANOVA analysis of fire properties.

		Propagation speed (mm/min)	Residual flame (s)
Without reinforcement	Additive	0.0000	0.0135
Linen fabric	Additive	0.0000	0.0358
	Treatment	0.0081	0.7667
	Interaction	0.0255	0.1953
Banana	Additive	0.0000	0.0000
nonwoven	Treatment	0.3843	0.9698
	Interaction	0.8621	0.0407
Different	Fabric type	0.0000	0.0000
fabrics	Nº of layers	0.0000	0.0000
	Interaction	0.0061	0.0904



Figure 12: Samples of banana nonwoven with 60% magnesium hydroxide after fire test.

confirmed that the additive has a statistically significant effect on the mechanical properties. The elastic modulus, tensile strength and impact resistance have a decreasing relationship with respect to the percentage of additive, while the flexural modulus increases with the additive content. In relation to the alkali treatment, it is concluded that it has only a significant effect in the maximum tensile strength, not affecting the rest of studied mechanical

properties. In conclusion, the piece with the best mechanical properties is polypropylene with linen fabric.

Regarding fire properties, magnesium hydroxide decreases the propagation speed of the flame, showing a higher effect (lower propagation speed) with the increase of the additive content. The number of layers influences the properties of fire resistance because the thickness of the sample is greater, more material to be burned and higher percentage of fibre. Regarding the type of fabric, the linen fabric has the slowest propagation speed and the banana fabric the highest, due to linen fabric is made of a bast fibre with a HRR considerably lower than that from leaf fibres like banana. Finally, a part with banana nonwoven and 60% of magnesium hydroxide with fireproof character has been produced, but due to its fragility, it would be necessary to improve the mechanical properties of the composite.

Acknowledgments: The authors acknowledge the Spanish Ministry of Economy and Competitiveness, as well as Fondo Europeo de Desarrollo Regional (FEDER) funds, as research was conducted under the BANTEX project (code: MAT2013-47393-C2-1-R).

Thesis/work co-financed by Agencia Canaria de Investigación, Innovación y Sociedad de la Información de la Consejería de Economía, Industria, Comercio y Conocimiento and by the European Social Fund (ESF) Integrated Operational Program of Canary Islands 2014-2020, Axis 3 Priority Theme 74 (85%).

Conflict of interest: Authors declare no conflict of interest.

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