

3rd International Conference on Natural Fibres: Advanced Materials for a Greener World

ICNF 2017, 21-23 June 2017, Braga, Portugal

Influence of different thermoplastic polymer/wood ratios on the mechanical and thermal properties of composite materials

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Abstract

This work compares the influence of different thermoplastic polymer/wood powder ratios on the mechanical and thermal properties of composite materials. These mass ratios were varied between 70:30 and 50:50, respectively. Moreover, the effect of a coupling agent incorporation, namely maleic anhydride polypropylene (MAPP), to promote better adhesion between both components, on these properties was evaluated. The composite materials were obtained by compression moulding process. The mechanical tests were subsequently performed to evaluate the tensile, flexural and impact properties. Besides that, the thermal properties were obtained using an Alambeta testing device. The experimental results show that the wood powder has the capacity to reinforce the thermoplastic polymer used, polypropylene (PP). The increase of mass fraction of wood powder on the final composite materials allows better mechanical properties, such as Young's and flexural modulus. Comparing the composite materials with 70:30 and 50:50 ratios, it was verified the improvement of Young's modulus by 1773 MPa to 2808 MPa, and flexural modulus by 1569 MPa to 1739 MPa. In the other hand, it was also verified that this trend contributes to the slight decrease on the thermal conductivity, namely from $0.145 \text{ W m}^{-1} \text{ K}^{-1}$ to $0.141 \text{ W m}^{-1} \text{ K}^{-1}$, respectively. The 2% MAPP incorporation leads to an even higher increase of the mechanical properties, namely in the Young's modulus to 3320MPa, with 50:50 ratio. However, despite this trend, the same was not verified on the thermal conductivity, which increases to $0.145 \text{ W m}^{-1} \text{ K}^{-1}$. These results allow to conclude that the increase of wood powder can increase the mechanical properties of the PP composites, and the MAPP incorporation contributes to the better compatibility between both materials, increasing also these properties.

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Peer-review under responsibility of the scientific committee of the 3rd International Conference on Natural Fibers: Advanced Materials for a Greener World.

Keywords: Wood powder; Composites; Mechanical properties; Thermal properties.

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1. Introduction

The recent world population growth has been one of the main factors for the technological development and innovation. In fact, exponential growth has taken place in the world population, being expected to reach 9 billion in 2042, compared to 3 billion in 1960 [1]. This has led to the use and development of new materials and products, which can respond to these increasing needs and trends. Consequently, an increase in composite materials use has been noticed mainly in construction and automotive areas, replacing conventional materials. In addition to the costs and weight reduction of components, these materials also allow to increase some mechanical properties and corrosion resistance. Actually, the most used materials as reinforcement have been synthetic fibres such as carbon and glass. The use of these materials has effectively allowed the positioning of the composite materials in higher level of the value chains. However, in an era dominated by concerns about environmental sustainability, the use of natural and recyclable materials on composites has gained paramount importance. Several scientific groups and researchers have been looking for development of composites with natural materials as reinforcement and the replacement of thermosetting matrices to thermoplastic ones. In this context, for instance, natural fibres have been the most popular compounds as reinforcement of composite materials.

However, the combination of natural fibres with polymeric materials presents some constraints related to the adhesion of both materials at the interface. Typically, this type of natural materials has a partial hydrophobic surface, due the presence of lignin, unlike polymer materials, which have a hydrophilic surface. This causes poor wettability of this type of natural materials by polymers and, consequently, weak compatibility and adhesion at the interface between both materials [2] [3]. Therefore, the combination of hydrophilic natural fibrous materials with hydrophobic polymer matrices often requires the use of coupling agents to improve the adhesion between these materials at the interface [4].

This study intended to evaluate the combination between a thermoplastic polymer, PP, and wood powder, at different weight percentages. Besides that, the effect of coupling agent incorporation in the mixture, namely maleic anhydride polypropylene (MAPP) was investigated. The composite materials were produced by compression moulding and subsequently were characterized by mechanical tests, such as tensile, flexural and impact ones, and thermal tests.

Nomenclature

PP	polypropylene
MAPP	maleic anhydride polypropylene
MFI	melt flow index

2. Experimental

2.1. Materials

One of the most important factors to take into account on this study was the similarity of densities of the different materials, in order to guarantee a good and homogeneous mixture before the processing. All materials are presented in Fig. 1. Then, the wood powder used is coming of mahogany tree, *Swietenia macrophylla*, which presents a density between 0.85 – 0.95 g cm⁻³. The polymer material used was purchased from Resinex, Portugal, with a RXP 2101 commercial reference. This polymer has a melt flow index (MFI) of 100 g/10 min and a density of 0.9 g cm⁻³, which is similar to that of mahogany wood.

The MAPP was supplied by BYK Additives & Instruments, with the commercial reference Scona TPPP 8112 FA. This polypropylene highly functionalized with maleic anhydride, in powder form, has a MFI higher than 80 g/10 min and a maleic anhydride content of 1.4% approximately.



Fig. 1: Raw-materials, namely PP, wood powder and MAPP, respectively

2.2. Composite Materials Production

The composite materials were produced by compression moulding, Fig. 2. Firstly, the powder form of several compounds were manually mixed, according to mass fractions referred in Table 1. After the mixture, the processing occurs in a specific mould, to obtain composite materials with 25×25 cm dimensions. This process was performed at 210°C and using 20 ton pressure, for 20 minutes. After this heating step, the samples were cooled down in the same equipment, using cold water circulation to hot plates, and using 20 ton pressure, during 5 minutes. Finally, the final composites, Fig. 3, were extracted after the pressure withdrawal.



Fig. 2: Moulding compression equipment and mould used

Table 1: Composite materials produced

Sample	PP/Wood ratio	% MAPP
1	70:30	0
2	60:40	0
3	50:50	0
4	50:50	2



Fig. 3: Wood powder/PP Composite

2.3. Characterization Tests

The obtained samples were subsequently subjected to several characterization tests. The mechanical tests performed included tensile, flexural and impact tests, Fig. 4. The tensile tests were performed according to EN ISO 527-2 standard, using 10 samples of 2 cm width and at least 150 cm overall length. The test parameters used were a crosshead speed of 2 mm min^{-1} and 115 cm as initial distance between grips. The flexural tests were performed in accordance to EN ISO 178 standard, using 10 samples of 10 mm width, 80 mm length and 4 mm thickness. These specimens were tested at a crosshead speed of 5 mm min^{-1} . The impact resistance of the material composites obtained was measured according to ASTM D256-04 standard.

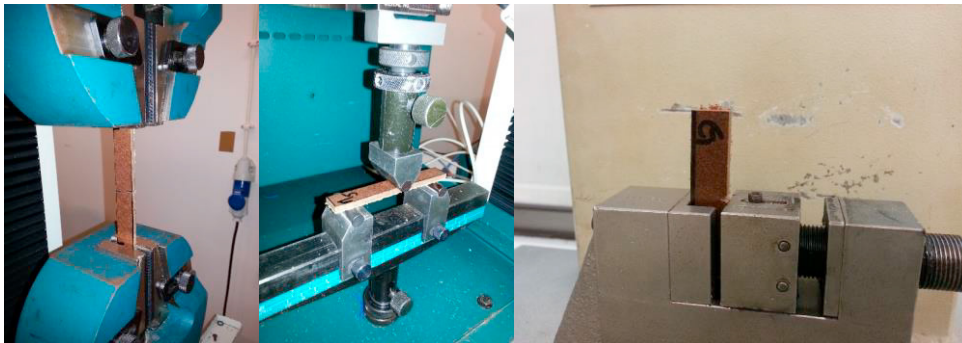


Fig. 4: Specimen in a tensile, flexural and impact tests, respectively

The thermal tests were performed by Alambeta device with 55 mm radius circular samples, and the thermal conductivity was determined. Finally, the moisture absorption test, with an analytical balance, allowed to measure the moisture content absorbed after 24 hours. The used equipments in both tests are presented in Fig. 5.



Fig. 5: Alambeta device and analytical balance for thermal and moisture absorption tests, respectively

3. Results and Discussion

The summary of results of the several tests performed is presented in Table 2 and Table 3. Table 2 shows the properties obtained in the mechanical tests, namely Young's modulus, flexural modulus and impact resistance. From these results, it is possible to verify that the increase of wood powder in the mixture allows better mechanical properties of the composite materials. Comparing samples 1, 2 and 3, the tensile and flexural modulus increased from 1773 MPa to 2808 MPa and 1569 MPa to 1739 MPa, respectively. Consequently, the impact strength demonstrated slight variations. On the other hand, it is also possible to conclude that the coupling agent incorporation improved these mechanical properties, as well as the impact strength of composite materials. Comparing samples 3 and 4, it can be observed that an increase from 2808 MPa to 3320 MPa in Young's modulus and from 1739 MPa to 2022 MPa in flexural modulus. Besides that, the incorporation of MAPP causes also an increase of impact strength from 1.68 kJ m^{-2} to 1.76 kJ m^{-2} .

Table 2: Mechanical properties of thermoplastic composites produced with wood powder

Sample	PP/Wood ratio	% MAPP	Young's Modulus (MPa)	Flexural Modulus (MPa)	Impact Resistance (kJ m^{-2})
1	70:30	0	1773.91 ± 2.03	1569.60 ± 3.71	1.85 ± 0.33
2	60:40	0	2662.16 ± 4.06	1687.72 ± 8.63	1.45 ± 0.09
3	50:50	0	2808.48 ± 8.21	1739.61 ± 7.12	1.68 ± 0.26
4	50:50	2	3320.44 ± 7.42	2022.71 ± 11.24	1.76 ± 0.42

In terms of thermal conductivity and moisture absorption, Table 3, small variations between the samples were observed. A decreasing trend was verified with the increase of wood mass fraction, between samples 3, 5 and 7, by $0.145 \text{ W m}^{-1} \text{ K}^{-1}$ to $0.138 \text{ W m}^{-1} \text{ K}^{-1}$. However, with MAPP incorporation, sample 7, this parameter increases again to $0.145 \text{ W m}^{-1} \text{ K}^{-1}$.

Moreover, an increasing trend of moisture absorption with increasing wood powder ratio was clearly noticed. Comparing samples 1 and 3, it is verified and increased by 0.97% to 1.34% on moisture absorption. This fact is probably related to the wood's morphology, which is a porous structure. Then, despite of hydrophobic surface, wood has the capacity to absorb moisture through these pores, once the interior is constituted by hydrophilic compounds.

Table 3: Thermal and absorption properties of thermoplastic composites produced with wood powder

Sample	PP/Wood ratio	% MAPP	Thermal Conductivity ($\text{W m}^{-1} \text{ K}^{-1}$)	Moisture absorption (%)
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1	70:30	0	0.145 ± 0.02	0.97 ± 0.13
2	60:40	0	0.141 ± 0.03	1.15 ± 0.17
3	50:50	0	0.138 ± 0.02	1.34 ± 0.19
4	50:50	2	0.145 ± 0.02	1.08 ± 0.15

In Fig. 6 is presented the influence of wood mass fraction on the several studied properties, namely mechanical, thermal and moisture absorption ones. As it can be observed, there is a trend to improve the mechanical properties of Young's and flexural modulus with increasing the wood mass fraction. Opposite to this, it is confirmed the trend to decrease the thermal conductivity of the samples, with the increase of wood mass fraction. In this context, both conclusions are positively important for the desired properties. However, the trend to moisture absorption is also verified with increasing of wood mass fraction, which is not so positive such as the previous properties.

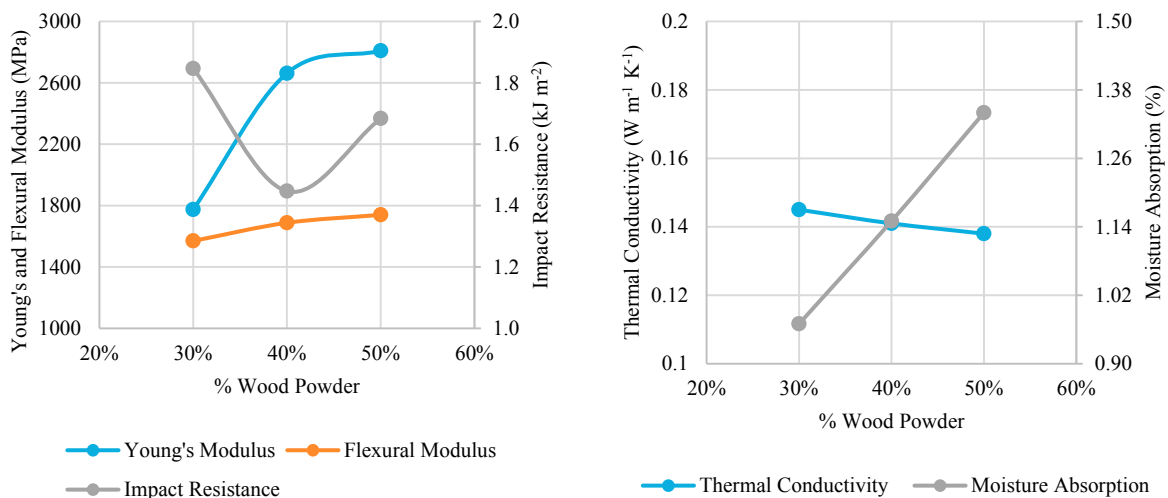


Fig. 6: Influence of wood mass fraction on several studied properties of composite materials

4. Conclusions

This study shows that the use of natural materials, such as wood powder, allows the reinforcement of thermoplastic polymers and increase of mechanical properties of composite materials. Tensile tests showed an increase of approximately 37% on Young's modulus, between samples with 70:30 and 50:50 ratios. Flexural tests showed an increase of approximately 10% on flexural modulus, between samples with 70:30 and 50:50 ratios. In addition to this, it is also demonstrated that the use of coupling agents, such as MAPP, can improve the adhesion at the interface between both components. With the use of MAPP, the Young's and flexural modulus increased approximately 15% and 14%, respectively, comparing to the sample without this coupling agent, in the same mass fractions.

Moreover, it was also demonstrated that the increase of wood's mass fraction can slightly improve the thermal properties, such as thermal conductivity, once this property decrease approximately 3%, between 70:30 and 50:50 ratios. Then, decreasing the thermal conductivity of the composite materials, the thermal insulation is improved.

Thus, from this study, it can be concluded that the increase of wood's mass fraction on the final composite materials can improve their mechanical properties and contributes to the slight increase of thermal insulation. Therefore, these conclusions are of paramount importance for some applications, namely in the automotive or building sectors.

Acknowledgements

The authors gratefully acknowledge to project “*Fibrenamics Green - Platform for the development of innovative waste-based products*”, code NORTE-46-2015-03, which is co-financed by the European Union, through the European Regional Development Fund (ERDF) under the NORTE 2020 - North Portugal Regional Operational Program 2014–2020.

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