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EVALUATION OF POST-CONSUMER RECYCLED POLYPROPYLENE-BASED COMPOSITE MATERIALS REINFORCED WITH RICE HUSK FIBERS

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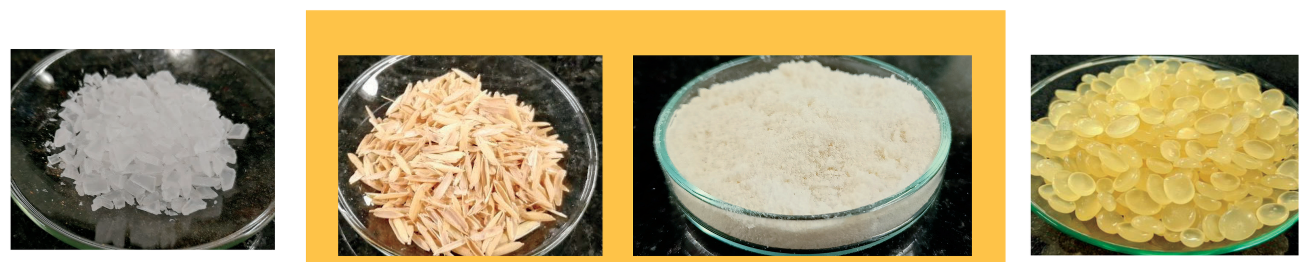
INTRODUCTION

The Circular Economy is a consumption model based on intelligent waste management, which has been steadily growing over the last two decades. The use and management of agro-industrial waste is an integral part of the generation of closed-cycle materials that support the pillars of a society based on sustainable development [1]. One of the most produced agro-industrial waste in the world is rice husk (RH) with about 180 million ton/year [1]. It is a by-product limited mainly to energy generation by burning, but it could instead find applications in composite materials [2].
On the other hand, although plastic consumption has increased worldwide, recycling rates are often not higher than 5% in many countries including the United States [3]. Therefore, the development of novel products based on recycled plastics, such as post-consumer polypropylene (rPP), and RH fibers becomes a great alternative to contribute to waste reduction and the adoption of a circular economy model.

The present work aims to evaluate the potential of RH-based fibers implementation as fillers in composites based on post-consumer recycled polypropylene. A design of experiments was used to study the influence of the type of filler (Untreated rice husk – RH and isolated cellulose extracted from rice husk – RHC) and the use of coupling agent (with and without polypropylene-grafted-maleic anhydride – MAPP) on mechanical, physical, and thermal properties of the recycled polypropylene biocomposites.

MATERIALS AND METHODS

1. Materials



2. Experimental design

Factorial 2^2
- Type of filler (10%)
  - Rice husk (**RH**)
  - Rice husk cellulose (**RHC**)
- PP-grafted maleic anhydride (4%) (**MAPP**)
  - Yes
  - No

3. Manufacturing

4. Characterization methods

Thermal characterization

Thermogravimetric Analysis (TGA):
- ASTM E1131
- Ramp: 10°C/min at 100 mL/min nitrogen flow rate

Differential Scanning Calorimetry (DSC):
- ASTM D3418
- Ramp: 5°C/min at 400 mL/min nitrogen flow rate

Mechanical characterization

Tensile test:
- ASTM D790 (5 specimens)
- Universal Machine Instron 3367
- Load Cell: 30 kN
- Crosshead Speed: 5 mm/min

Izod impact test:
- ASTM D256 (5 unnotched specimens)
- TMI 43-1 impact machine
- 2.7J max. impact energy pendulum

RESULTS

TGA

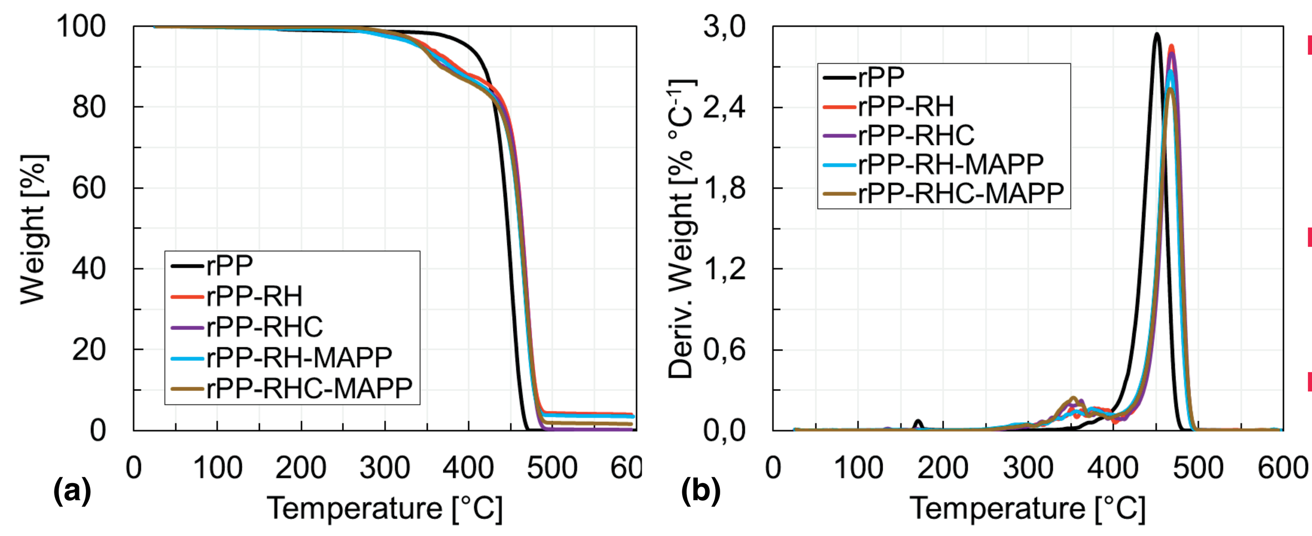


Fig. 1. **(a)** TGA and **(b)** DTGA for rPP and rPP-based composites reinforced-infill with RH and RHC.

- 250 – 350°C: mainly lignocellulosic RH and RHC (6%).
- 350 – 500°C: Mainly degradation of rPP.
- Composites residues (fiber ash at 600°C): 1 - 5%.

- RHC produces lower residues than RH.
- The degradation process of the composites started in a similar temperature range as the neat rPP due to the low fiber and additive (MAPP) fractions.

DSC

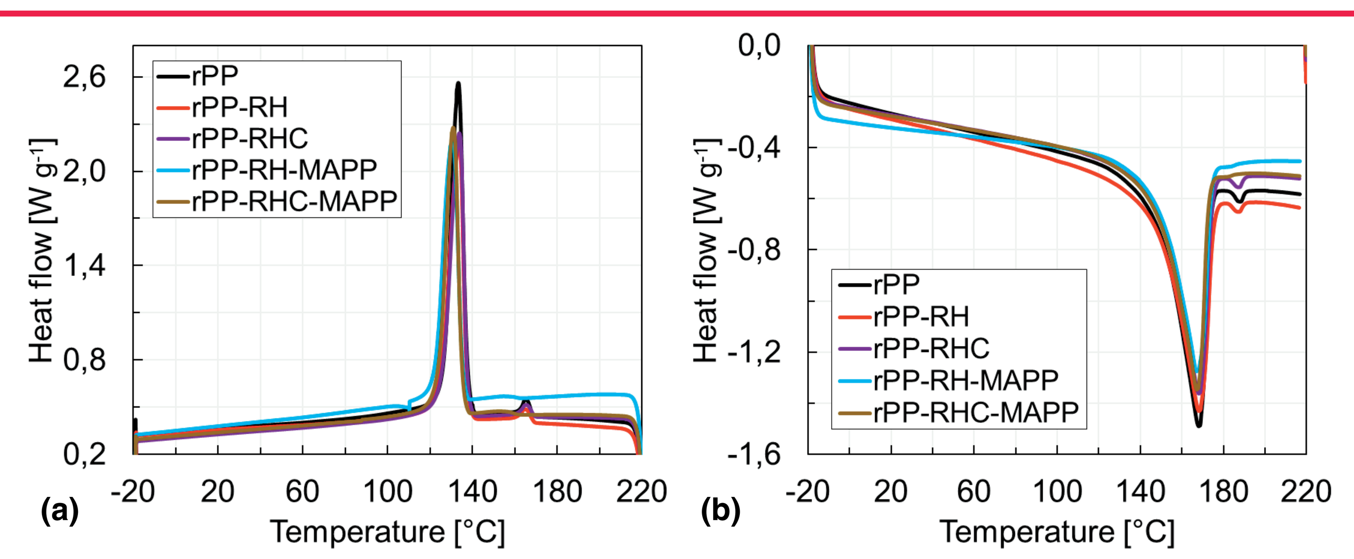


Fig. 2. **(a)** DSC crystallization and **(b)** melting for rPP and rPP-based composites.

Table 1. Temperatures and enthalpies of melting and crystallization of rPP and composites.

Formulation	Tc (°C)	ΔHc (J/g)	Tm (°C)	ΔHm (J/g)	% Crystallinity
rPP	132,72 ± 0,82	98,38 ± 0,74	168,44 ± 0,35	84,23 ± 0,45	40,69 ± 0,22
rPP–RH	133,17 ± 0,77	91,16 ± 2,32	168,03 ± 0,16	76,45 ± 0,81	36,93 ± 0,39
rPP–RHC	133,33 ± 0,73	89,24 ± 1,82	168,04 ± 0,28	77,58 ± 2,05	37,48 ± 0,99
rPP–RH–MAPP	130,12 ± 0,50	79,41 ± 6,56	167,24 ± 0,14	78,29 ± 2,70	37,82 ± 1,30
rPP–RHC–MAPP	130,81 ± 0,18	84,39 ± 6,04	167,65 ± 0,12	80,42 ± 0,27	38,85 ± 0,13

- All the materials have a melting temperature of 167-169°C and a crystallization point above 130°C.
- The composite's crystallinity (36-38%) is lower than the matrix (~41%) because the MAPP and reinforcement incorporation inhibit early nucleation, thus reducing crystallinity.

Mechanical performance

Table 2. Mechanical properties of rPP-based materials.

Formulation	Tensile strength [MPa]	Young's modulus [GPa]	Tensile strain at maximum load [%]	Impact strength [kJ m⁻²]
rPP	32.06 ± 0.18	2.19 ± 0.05	4.96 ± 0.27	18.28 ± 1.89
rPP–RH	27.11 ± 0.56	2.40 ± 0.07	3.36 ± 0.10	8.77 ± 0.86
rPP–RHC	27.10 ± 0.41	2.73 ± 0.07	2.64 ± 0.11	7.61 ± 0.78
rPP–RH–MAPP	31.97 ± 0.16	2.55 ± 0.05	3.05 ± 0.14	9.89 ± 1.34
rPP–RHC–MAPP	32.17 ± 0.62	2.33 ± 0.06	3.92 ± 0.11	15.06 ± 1.49

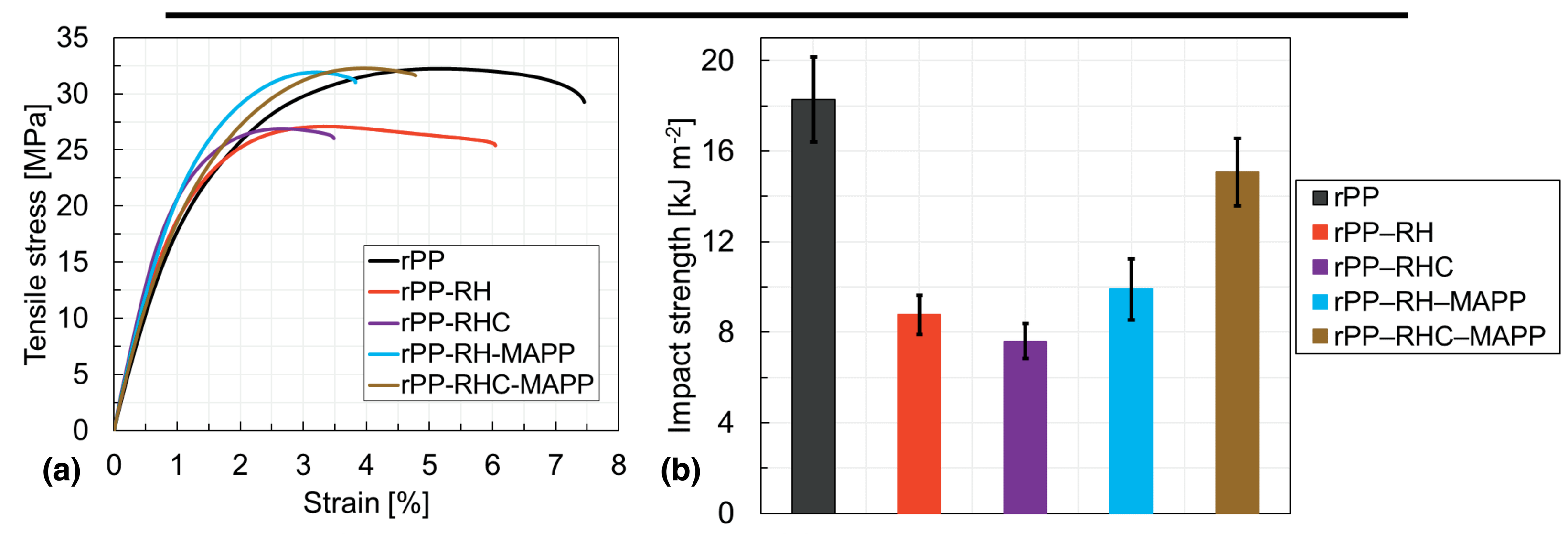


Fig. 3. **(a)** Tensile stress-strain curve and **(b)** impact strength for rPP and composites.

- The impact strength of the rPP–RHC–MAPP formulation is only 17.6% lower than that of the neat rPP. The other formulations show lower values between 46 and 58%.
- In rPP–RH–MAPP and rPP–RHC–MAPP composites, tensile strength is not significantly different from neat rPP, and Young's modulus is improved by 16.43% and 6.39%, respectively. rPP–RH and rPP–RHC (MAPP-free composites) also increased Young's modulus by 9.5% and 24.7%, respectively.

CONCLUSIONS

Composites based on post-consumer polypropylene filled with rice husk were produced using compression molding. The mechanical and thermal properties of the improved formulation (rPP–RHC–MAPP) showed the great potential of rice husk as a filler for post-consumer recycled polypropylene composites. The results also show the importance of adding a coupling agent between natural fibers and a hydrophobic matrix. Finally, this study illustrates an opportunity to generate added value for agro-industrial waste and recycled polymers by developing sustainable, eco-friendly products that contribute to a circular economy.

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