Environmental Science and Pollution Research (2020) 27:4858–4865
https://doi.org/10.1007/s11356-019-06953-7

RESEARCH ARTICLE

Physical–mechanical properties of wood panel composites produced with *Qualea sp*. sawdust and recycled polypropylene

Daiane Cristina Lima[1] · **Rafael Rodolfo de Melo**[2] · **Alexandre Santos Pimenta**[3] · **Talita Dantas Pedrosa**[2] · **Maila Janaína Coelho de Souza**[3] · **Elias Costa de Souza**[3]

Received: 14 August 2019 / Accepted: 4 November 2019

Abstract

Adhesive-free wood-plastic composite panels made with lignocellulosic wastes, and recycled plastics can be a sustainable option for generating useful “green” products. The present work assessed the physical-mechanical properties of adhesive-free panels produced with *Qualea sp*. sawdust and recycled polypropylene (PP). Discarded PP packaging was used. The packages were washed and ground with a laboratory knife mill until particle size of 10 to 14 mesh. *Qualea sp*. sawdust was sieved to select particle size of 14 to 30 mesh. Four experimental treatments were assessed by varying the percentages of PP and sawdust, as follows, 60 and 40%, 70 and 30%, 80 and 20%, and 90 and 10%, in an entirely randomized design with 3 panels per treatment, totaling 12 panels. The mats were hot-pressed at 180 °C during 20 min, the first 10 min under pressure of 1.0 MPa and the remaining 10 min at 42 MPa. Physical-mechanical properties of the panels were obtained as follows: density, moisture content, water absorption, thickness swelling, moduli of elasticity and rupture, and Rockwell hardness. In general, an increase of the percentage of PP provided higher dimensional stability to the panels, but there was no significant influence on mechanical strength.

Keywords Sawmill wastes recycling · Plastics recycling · Qualea sp · Sawdust · Recycled polypropylene · Wood-plastic composites · Physical-mechanical properties

Introduction

Recycling of post-consumer plastics is a major concern in waste management, especially due their extended longevity and recalcitrance in the environment. Although recycling is an obvious solution to avoid accumulation, it faces several difficulties along the plastic value chain, such as polymer cross-contamination, presence of additives, non-polymer impurities, and polymer degradation (Pivnenko et al. 2015). Additionally, the recycling method applied to one type of plastic often cannot be used for other types, which leads to the need to develop specific solutions for every type (Hopewell et al. 2009). Plastics can be recycled by both chemical and mechanical processes, but undoubtedly the latter

---

Responsible editor: Santiago V. Luis

✉ Alexandre Santos Pimenta
aspimenta@ufrnet.br

Daiane Cristina Lima
daiac.lima1@gmail.com

Rafael Rodolfo de Melo
rafael.melo@ufersa.edu.br

Talita Dantas Pedrosa
talita.pedrosa@ufersa.edu.br

Maila Janaína Coelho de Souza
mailajcsouza@gmail.com

Elias Costa de Souza
eliasrem@hotmail.com

[1] Agricultural and Environmental Sciences Institute, Federal University of Mato Grosso – UFMT, Av. Fernando Corrêa da Costa, 2367, Boa Esperança, Cuiabá, MT 78060-900, Brazil

[2] Agricultural Sciences Center, Federal University of Semiarid – UFERSA, Av. Francisco Mota, 572, Costa e Silva, Mossoró, RN 59625-900, Brazil

[3] Agricultural Sciences Academic Unit, Forest Engineering, Federal University of Rio Grande do Norte – UFRN, RN 160, Km 03, District of Jundiaí, Macaíba, RN, Brazil

better established due to its lower cost (Pivnenko et al. 2015; D'Ambrieres 2019). Usually, recycling strategies aim to turn plastics into useful items, while keeping the process steps inexpensive. Whatever the method, waste recycling is promising and is increasingly being applied, as highlighted by Talgatti et al. (2017).

Following the path of low-cost options for plastic recycling, the production of wood-plastic composites (WPCs) has emerged as an interesting solution, since two types of wastes can be recycled at the same time, particularly if industrial wood wastes are used as panel components (Espert et al. 2004; Milagres et al. 2006). WPC consists of a mixture including recycled or virgin thermoplastic resin and wood fibers, more commonly in the form of particles or sawdust, pressed or extruded at high temperatures (Hillig et al. 2011; Benthien and Thoemen 2012; Gozdecki et al. 2012; Horta et al. 2017; Lima et al. 2018). Consolidation between plastic and wood particles confers better chemical and physical-mechanical properties to the final WPCs compared with panels produced with each component alone (Rahman et al. 2013). When properly produced, WPCs have good particle adhesion, low density, high dimensional stability, high temperature resistance, and suitable cracking strength, besides being virtually immune to fungal and insect attack (Leu et al. 2012; Albinante et al. 2013). Due to these properties, WPCs can be employed in several end uses, as decks, tables, walls, and office partitions (Battistelle et al. 2014), to name a few.

Polypropylene (PP) is a type of thermoplastic polymer that has a prominent place in everyday consumption, mainly due to its low production cost associated with its high resistance to impact, high temperatures, and noteworthy impermeability. But these positive characteristics make PP very difficult to decompose as waste through weathering (Webb et al. 2013; Yin et al. 2013), causing increasing accumulation when disposed in the landfills or directly in the environment. Polypropylene does not present stress-cracking problems, and while its properties are similar to those of polyethylene, there are specific differences, including lower density, higher softening point (above 160 °C), and higher rigidity and hardness (British Plastics Federation 2019). Therefore, just like other types of plastics, PP disposal and accumulation in the ground and water bodies is a major problem. Despite being among the most popular plastic packaging materials, as stated by Thomas (2019), only around 1% is recycled, which means to say that most PP is directed to water bodies like oceans as pointed out by Mai et al. (2018), where it can take over 20–30 years to decompose.

In the context of recycling, although wood wastes generated by sawmills do not contain toxic chemicals or dangerous metallic elements, they also have large production, low rate of degradation, and can cause severe environmental impact. Bark, sawdust, trimmings, split wood, sander dust, and offcuts are the commonest wastes derived from sawmilling and woodworking (Ogunbode et al. 2013, Lopes et al. 2015, Carvalho et al. 2018). Unfortunately, this type of waste has limited reuse or recycling, so it is disposed mainly by open dumping or open-air burning, or occasionally taken to landfills. In Brazil, reuses of larger wood pieces from sawmilling can include domestic usage and raw material for making charcoal. Shavings are consumed almost completely as bedding for poultry, but the waste most often cited difficult to reuse or recycle is sawdust (Carvalho et al. 2015). This is case of *Qualea sp.*, which is a wood species of significant economic importance in Mato Grosso state, Brazil, since it has several uses and is found in abundance in areas subject to sustainable forest management. When milled, about 50% of the original log volume is wasted, and sawdust is the most troublesome component to reuse or recycle economically (Melo et al. 2016, 2019), which causes the nuisance of increasing accumulation in sawmill yards (Lima et al. 2018). Several studies have reported the combined recycling of PP and sawdust for the production of WPCs (Milagres et al. 2006; Hillig et al. 2011; Rahman et al. 2013; Horta et al. 2017). However, a wide variation of physical-mechanical parameters of these products can occur by changing the components' percentage and above all the type of wood species. Therefore, since the characteristics found for one type of sawdust and mixture of components in WPCs cannot be generalized from one experiment to another, it is necessary to evaluate each type of sawdust as well as to assess its best proportion in relation to PP.

Therefore, the present work had the goal of assessing the physical-mechanical properties of WPCs produced with different percentages of *Qualea sp.* sawdust and recycled PP.

Material and methods

Collection of materials and production of the WPCs

The experiment was carried out in the Wood Technology and Wood Products Chemical Technology Laboratories of Federal University of Mato Grosso (UFMT, Sinop campus, Mato Grosso state, Brazil). For production of the WPCs, discarded polypropylene was used, mainly from mineral water, yogurt, milkshake, and ice cream cups. The cups were washed and ground in a laboratory knife mill (Retsch Grindomix GM 200) until particle size reached the range of 10 to 14 mesh. *Qualea sp.* sawdust was obtained from a local sawmill and sieved to reach particle size in the range of 14 to 30 mesh, according to the procedure described by Lima et al. (2018). Both materials were oven dried at 60 ± 2 °C for 6 h until PP particles and sawdust reached moisture content of 0 and 8%, respectively. After this, by using a square aluminum frame with dimensions of 17.5 cm length, 17.5 cm width, and 0.5 cm thickness, mats with different proportions of PP and sawdust were prepared. Four experimental treatments were assessed by varying the percentages of PP and sawdust, as follows: 60 to 40%, 70 to 30%, 80 to 20%, and 90 to 10%, in an entirely randomized design with 3 panels per treatment, totaling 12 panels. In each treatment, sawdust and PP particles were placed in a rotary stainless-steel drum (50 cm height × 20 cm diameter) and mixed during 5 min at 80 rpm. For each experimental treatment, the composition of PP and sawdust was considered as having a target final density of 800 kg m^{-3}. The mats were hot-pressed at 180 °C during 20 minutes, the first 10 min under pressure of 1.0 MPa and the remaining 10 min at 42 MPa. No adhesive or agglutinant was added, so the PP was responsible for the particle bonding process. After the hot-pressing step, the panels were cooled by immersion in water at room temperature, according to the procedure described by Lima et al. (2018) and test specimens were prepared for physical-mechanical assessment.

Physical-mechanical properties

The physical- mechanical properties of WPCs were determined according to the routine described in the standard ASTM D638 (ASTM 2002). For physical properties, 6 test specimens per treatment were used with dimensions of 4.0 cm length, 2.0 cm width, and 0.5 cm thickness. The following tests were performed: density, moisture content, water absorption (WA), and thickness swelling (TS), with TS determined after 2, 24, and 72 h of immersion in water. For mechanical assays, test specimens measuring 11.00 cm length, 4.2 cm width, and 0.5 cm thickness were used. The static bending test was carried out with 6 test specimens to obtain both moduli of elasticity and rupture (MOE and MOR) by using a universal testing machine (Emic Instron, São José dos Pinhais, PR, Brazil) equipped with a 20 KN compression/tension load cell. Rockwell hardness test (RHT), also using 6 test specimens but with dimensions of 4.0 cm length, 2.0 cm width, and 0.5 cm thickness, was performed with a Rockwell durometer (Mitutoyo, São Paulo-SP, Brazil). For this test, an initial load of 10 Kgf cm^{-2} and a final of 60 Kgf cm^{-2} were applied by using a ¼” spherical diamond penetrometer.

Experimental data analysis

Initially, a statistical trend analysis by was performed to evaluate the effect of the increasing level of PP in the WPCs after immersion in water, specifically regression analysis with model adjustment. When regression analysis could not be applied, analysis of variance was adopted considering the variation in the composition of panels. If significant statistical differences were detected, the Tukey test at 95% probability was applied.

Results and discussion

Physical properties

Physical characterization of WPCs is shown in Table 1, with the respective properties, density and moisture content. For density, significant differences were observed between the experimental treatments with 60 and 80% PP, with the latter treatment producing denser WPCs. The moisture content of all WPCs was lower than 3.0%. Only the 60% PP treatment showed different behavior from the others, presenting higher moisture exchange with the environment, most likely due to its lower content of PP and consequent lower particle sealing, which did not prevent sawdust from absorbing moisture after ambient exposure. The moisture content values lower than 3.0% reported here are similar to those found in other studies that also employed thermoplastic resins and sawdust to make panels (Leu et al. 2012; Rahman et al. 2013). This behavior is expected in WPCs as a response to the addition of polymers, which when receiving high levels of pressure and temperature melt and bond to the sawdust, resulting in a waterproof structure after cooling. Besides this, hot pressing most likely decreases the number of wood hygroscopic sites able to absorb moisture, so this might be another factor contributing to increase the waterproof character of WPCs (Weber and Iwakiri 2015).

Observed density of the WPCs was in the range of 782.50 to 915.00 kg m^{-3}, not far from the experimentally projected density of 800 kg m^{-3}. The increasing levels of added PP did not lead to significant statistical increase in density, meaning that, as shown in Table 1, there was no statistical difference among experimental treatments regarding that property. Compared with other studies, the values presented here are lower. WPCs composed of 50% PP and 50% *Eucalyptus* sp. sawdust reached density of 930 kg m^{-3}, as reported by Macedo et al. (2015). Likewise, WPCs produced with 70% PP and 30% *Dypterix odorata* sawdust had density of 940 kg m^{-3}, according to Lima et al. (2018). Density values vary according to the combination of particles employed in the production of WPCs. The fact that PP and the *Qualea sp.*

Table 1 Density and moisture content of WPCs produced with different proportions of polypropylene and sawdust

Composition (%)		Density (kg m^{-3})	Moisture content (%)
Polypropylene	Sawdust		
60	40	782.50 ± 23.85^{a}	2.95 ± 0.56^{b}
70	30	842.50 ± 71.55^{ab}	2.35 ± 0.29^{a}
80	20	915.00 ± 57.23^{b}	2.33 ± 0.04^{a}
90	10	847.50 ± 4.33^{ab}	2.32 ± 0.08^{a}

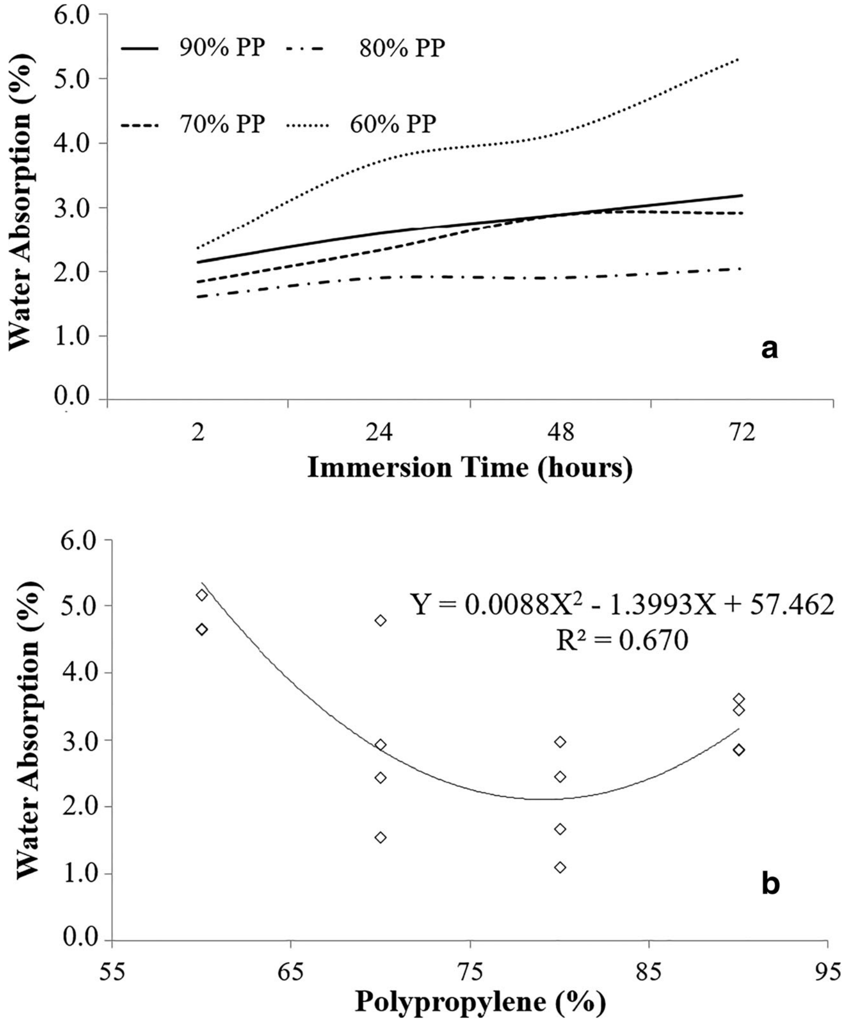
*In the columns, means followed by same letters are equal by the Tukey test at 5% significance wood have, respectively, 910 (Calister 1997) and 680 kg m^{-3} (Nahuz 2013), explains the density values found in our experiments, close to the projected value of 800 kg m^{-3} and lower than those reported in the works cited above. Density is a variable of fundamental importance for WPCs, as pointed out by Rahman et al. (2013) and Lima et al. (2018). The main goal of adding thermoplastic resins in WPCs is to increase their density and improve the mechanical strength of the lignocellulosic fibers (Rahman et al. 2013). Additionally, the latter authors reported that composites achieved higher dimensional stability after PP addition, an important property for production of panels.

Figure 1 depicts, respectively, the water absorption from 2 to 72 h after immersion (graph A) and the quadratic regression model explaining the behavior of that physical property with increasing levels of PP in the WPCs (graph B). For all experimental treatments, water absorption was lower than 6.0%, with 60% PP being the treatment with the highest absorption (4.8%). Water absorption decreased as the PP percentage increased in the WPCs, as also shown in the Fig. 1, graph A. Values for water absorption found in the present work are similar to those reported by Lima et al. (2018), who observed water absorption lower than 1.2% after 24 h of immersion. The authors produced WPCs with *Dipterix odorata* sawdust and PP in the respective proportions of 30 and 70%. Our results are better than those reported by Macedo et al. (2015), who found water absorption lower than 2.0% after 2 h of immersion and 7.6% after 24 h, even with the addition of adhesive in the WPCs.

However, water absorption tended to stabilize after 60 h for the treatments of 70, 80, and 90% PP, most likely due to the saturation of sawdust particles. As indicated by the adjusted model shown in Fig. 1, graph B, as PP addition increased, the water absorption decreased, which was expected due to the hydrophobic character of the polymer. Low water absorption is desirable, since it contributes to better WPC dimensional stability, and also permits defining the practical uses, as commented by Leu et al. (2012) and Battistelle et al. (2014).

For all experimental treatments, as shown in Fig. 2 (graph A), thickness swelling (TS) decreased as the percentage of PP increased. Nevertheless, TS was lower than 14% for all WPCs even after 72 h of immersion, with the minimum value for the

Fig. 1 Water absorption of WPCs after 2 to 72 h of water immersion (**a**) and adjusted model for water absorption as function of polypropylene percentage (**b**)



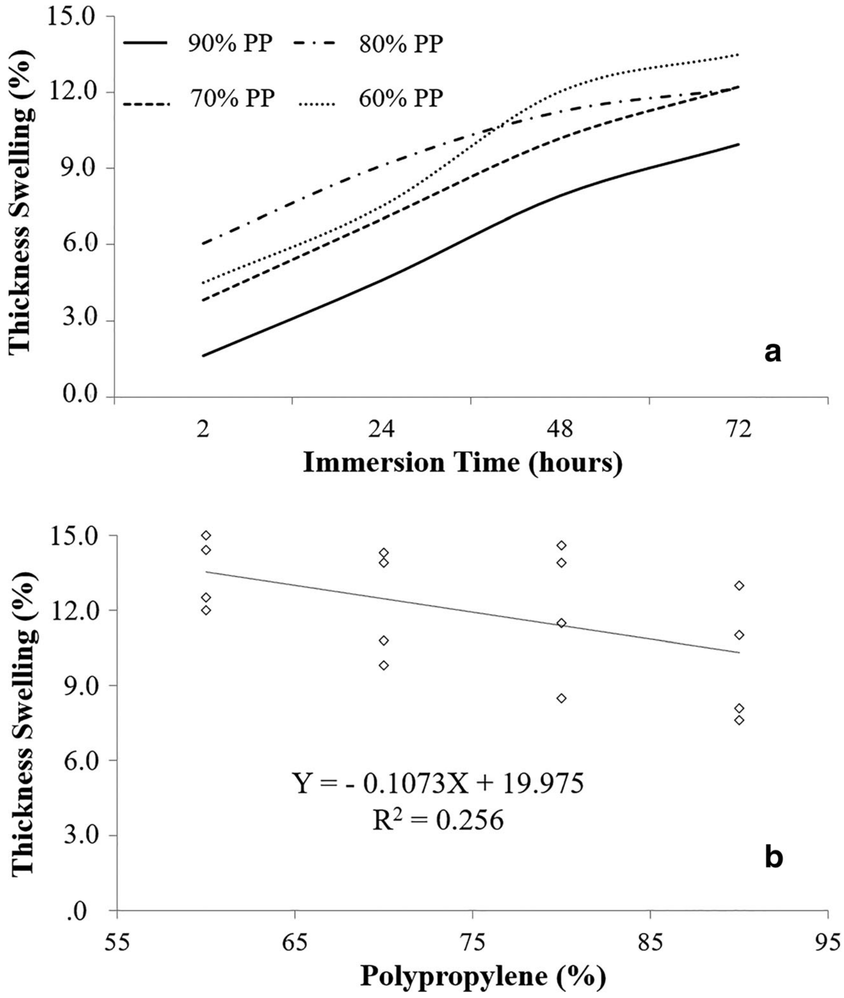


Fig. 2 Thickness swelling of WPCs after 2 to 72 h of water immersion (**a**) and adjusted model for thickness swelling as function of polypropylene percentage (**b**)

90% PP treatment. That behavior was expected since with a higher proportion of plastic in the composite, the wood particles' voids and cracks were better blocked, preventing water penetration, as described by Hillig et al. (2011) reporting results of WPCs produced with sawdust and high-density polyethylene. For the TS after 24 h of immersion for the WPCs produced with 60% PP, the values observed in the present work are close to those found by Rahman et al. (2013), about 6%, for WPCs produced with the same proportions of sawdust and polyethylene terephthalate. Values of TS near the results presented here were reported also by Lima et al. (2018), who determined 1.0 and 6.0% after 2 and 24 h of immersion, respectively, for WPCs produced with sawdust and PP in the proportions of 30 and 70%. When the type of sawdust is considered, the effect of PP addition on the reduction of TS observed in this work was clear. For solid *Qualea sp*. wood (without addition of polymers or adhesives), the TS values after 2 and 24 h of water immersion were, respectively, 4.28 and 10.48% ,as reported by Longo et al. (2015). As expected by comparing these values with the TS of the WPCs produced with sawdust from the same type of wood, the PP addition improved the dimensional stability, as also reported by Espert et al. (2004) and Albinante et al. (2013). The positive effect of increasing PP addition in the WPCs, which was responsible for the reduction in TS, can be observed in the adjusted model, shown in Fig. 2, graph B.

Water absorption and thickness swelling are important parameters to assess the dimensional stability under weathering for outdoor applications, as mentioned by Rahman et al. (2013). According to Lima et al. (2018), the mechanical strength of WPCs with low dimensional stability can be negatively affected by water absorption during weathering, due to loss of integrity caused by alterations in their structure, and further disintegration can occur since swelling breaks the bonds among particles. In this sense, the WPCs produced in the present work reached acceptable dimensional stability values.

Mechanical properties

Mechanical characterization of the WPCs, represented by the results of static bending, is shown in Fig. 3. Modulus of

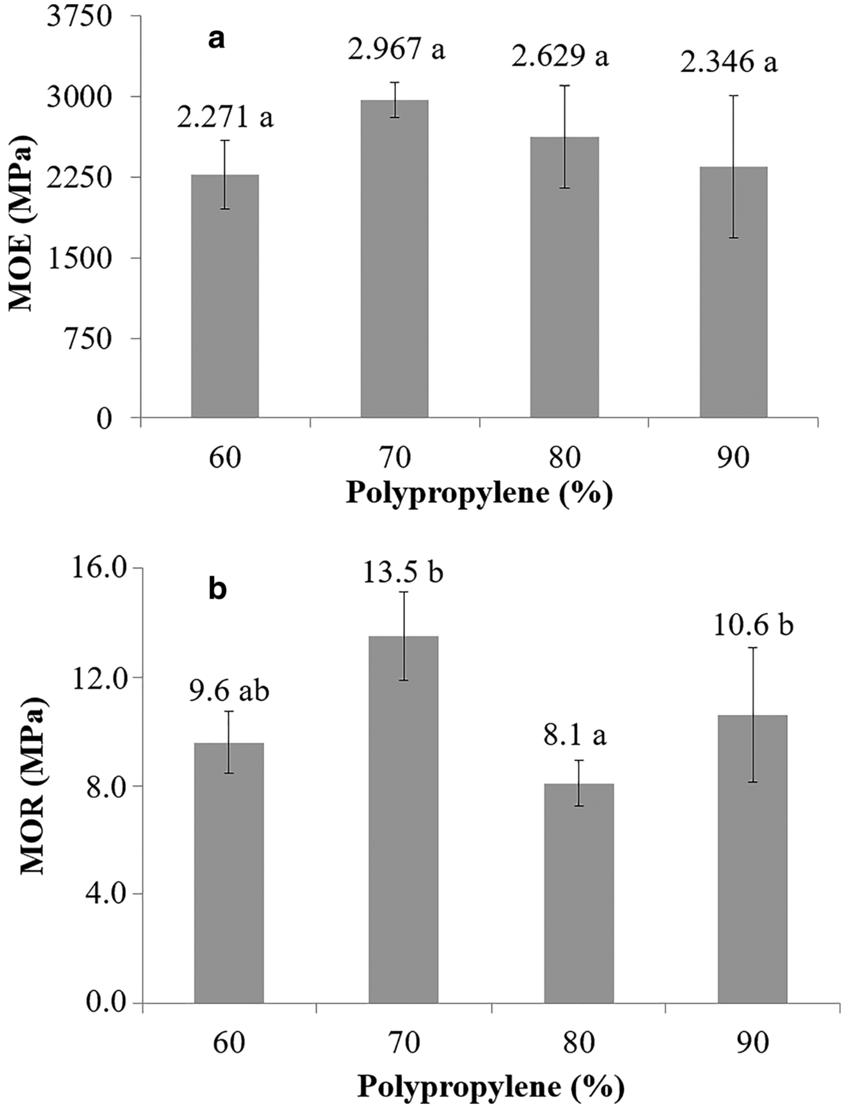
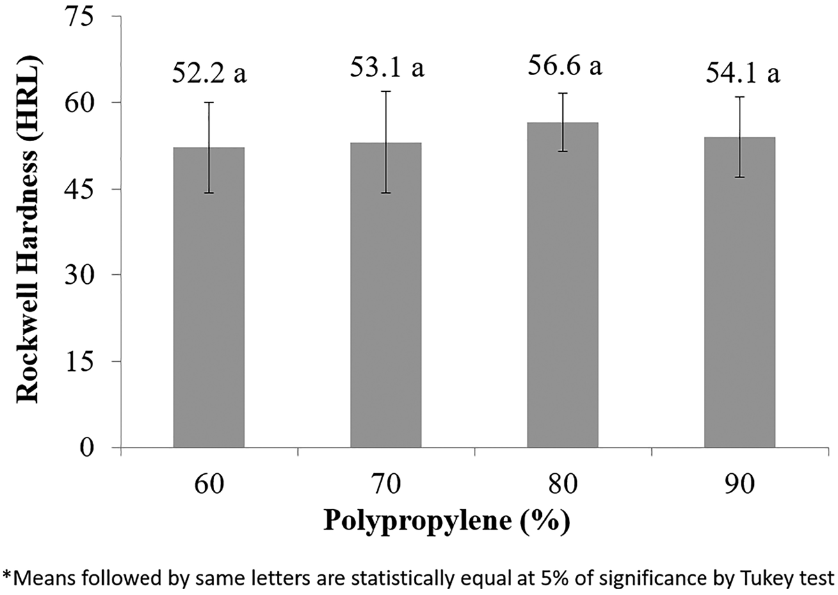


Fig. 3 Statistical comparison of modulus of elasticity (**a**) and modulus of rupture (**b**) as a function of polypropylene percentage (**b**). *Means followed by same letters are statistically equal at 5% significance by the Tukey test

elasticity (MOE), varying from 2271 to 2967 MPa, did not present any statistical difference among treatments. In turn, the modulus of rupture (MOR) varied in the range of 8.1 to 13.5 MPa. Despite the decrease in the 80% PP treatment, there was no statistical difference between it and the treatments with 60 and 90% PP.

For MOE, the values observed in the present work are close to the value of 2213 MPa reported by Battistelle et al. (2014), who produced WPCs with 70 and 30% PP and sawdust, respectively. As shown in Fig. 4, there was no statistical difference among the experimental treatments regarding the MOR as a function of PP addition levels. The MOR values are similar to the 13.0 MPa reported by Milagres et al. (2006), who produced WPCs with 75% PP and 15% wood particles of *Eucalyptus grandis* with adhesive addition. However, the MOR values of the present work are lower than the 20.6 MPa reported by the same authors for WPCs produced with *Pinus* particles and PP with variation in the range of 90 to 70%. The higher values of MOR observed by Milagres et al. (2006) most likely can be attributed to the adhesive addition, although this possible positive effect was not observed by using eucalyptus particles. The MOE and MOR values in this work did not increase greatly as the proportion of PP increased. This behavior can likely be explained by the WPC densities, which also are close to each other, a pattern reported likewise by Iwakiri et al. (2005). Variations in density imply different proportions of voids in the solid structure, which directly affects the technological properties of panels: the higher the number of voids, lower the WPC mechanical strength will be, and vice versa. Besides this, as reported by Murayama et al. (2019), the addition of plastic in higher proportion in relation to lignocellulosic raw material caused a decrease in mechanical strength of WPCs. However, that decrease in strength usually is followed by a decrease in density as well, which was not the case in the present work, where the observed values of MOE and MOR were satisfactory even in

Fig. 4 Statistical comparison of Rockwell hardness as function of polypropylene percentage (**b**)



the treatments with higher proportions of PP, respectively, 80 and 90% PP. Another important point is the fact that even though recycled polymer in the WPCs, the mechanical strength values reported here are higher than those obtained by Mattos et al. (2015) and Lima et al. (2018) using virgin resins.

There was no statistical difference among the experimental treatments for Rockwell hardness, as shown in Fig. 4, even though the property varied from 52.2 to 56.6 HRL. However, the values reported here are higher than that observed by Lima et al. (2018), which was 19.8 HRL. The values of the present work are similar to those reported by Idrus et al. (2011), with sawdust from tropical tree species, respectively *Eugenia* sp., *Artocarpus rigidus*, *Artocarpus elasticus*, and *Koomassia malaccensis*, in the sawdust proportions of 10 to 30%. They observed Rockwell hardness varying from 65.0 to 80.0 HRL among the experimental treatments evaluated.

The mechanical properties obtained in this work indicated the WPCs are suitable for use in floors and decks, for instance, since they presented acceptable values of MOE, MOR, and Rockwell hardness. The suitable mechanical properties combined with good range of density and dimensional stability, reflected by both low water absorption and thickness swelling, complete the requirements for the uses cited above, and are in accordance to the values reported in other studies, as discussed previously.

Conclusions

Sawdust of *Qualea sp*. was successfully used to produce wood-plastic composites having polypropylene as support. There was no need for adhesive addition, since the PP itself was able to keep the particles bonded, generating WPCs with acceptable physical-mechanical properties, similar to products described in the literature. Among the experimental treatments, the best results regarding to physical-mechanical properties were achieved with 70% of PP particles and 30% of sawdust. The production of these WPCs is a good strategy to recycle both waste sawdust and PP cups.

References

Albinante SR, Pacheco EBAV, Visconte LLY (2013) Revisão dos tratamentos químicos da fibra natural para mistura com poliolefinas. Química Nova 36(1):114–122. https://doi.org/10.1590/S0100-40422013000100021

American Society for Testing and Materials – ASTM (2002) D638-02: Standard test method for tensile properties of plastics. West Conshohocken: ASTM International. 13 p.

Battistelle RAG, Viola NM, Bezerra BS, Valarelli ID (2014) Caracterização física e mecânica de um compósito de polipropileno reciclado e farinha de madeira sem aditivos. Revista Matéria 19(1): 07–15. https://doi.org/10.1590/S1517-70762014000100003

Benthien JT, Thoemen H (2012) Effects of raw materials and process parameters on the physical and mechanical properties of flat pressed WPC panels. Composites 43(4):570–576. https://doi.org/10.1016/j.compositesa.2011.12.028

British Plastics Federation – BPF (2019) Polypropylene (PP). Available at https://www.bpf.co.uk/plastipedia/polymers/pp.aspx (access at August 08, 2019)

Calister WD (1997) Materials science and engineering: an introduction, 4th edn. Wiley, Hoboken, p 1000

Carvalho FF, Virgens AP, Aragão MA, Loureiro TC, Cunha DVP (2015) Final provision of solid waste of sawmills – Vitória da Conquista, BA. Enciclopédia Biosfera 11(21):3094–3102

Carvalho DE, Rocha MP, Timofeiczyk R Jr, Klitzke RJ (2018) Rendimento e variedade de produtos no desdobro de toras de Eucalyptus sp. Tecno-Lógica 23(1):08–13. https://doi.org/10.17058/tecnolog.v23i1.12215

D'Ambrieres W (2019) Plastics recycling worldwide: current overview and desirable changes. Field Actions Science Reports, Open Edition Journals, Special Issue 19. Available at http://journals.openedition.org/factsreports/5102 (access in August 8, 2019)

Espert A, Vilaplana F, Karlsso S (2004) Comparison of water absorption in natural cellulosic fibres from wood and one-year crops in polypropylene composites and its influence on their mechanical properties. Composites 35:1267–1276. https://doi.org/10.1016/j.compositesa.2004.04.004

Gozdecki C, Wilczński A, Kociszewski M, Tomaszewska J, Zajchowski S (2012) Mechanical properties of wood-polypropylene composites with industrial wood particles of different sizes. Wood Fiber Sci 44(1):14–21

Hillig E, Iwakiri S, Haselein CR, Bianchi O, Hillig DM (2011) Characterization of composites made of HDPE and furniture industry sawdust, part II – double-screw extrusion. Ciência Florestal 21(2):335–347

Hopewell J, Dvorak R, Kosior E (2009) Plastics recycling: challenges and opportunities. Philos Trans R Soc Lond B Biol Sci 364:2115–2126

Horta JF, Simões FJ, Mateus A (2017) Study of wood-plastic composites with reused high-density polyethylene and wood sawdust. Procedia Manufacturing 12:221–229

Idrus MAMM, Hamdan S, Hamdan MR, Islam MS (2011) Treated tropical wood sawdust-polypropylene polymer composite: mechanical and morphological study. J Biomaterials Nanobiotechnol 2(1):435–444. https://doi.org/10.4236/jbnb.2011.24053

Iwakiri S, Andrade AS, Cardoso AA Jr, Chipanski ER, Prata JG, Adriazola KMO (2005) Produção de painéis aglomerados de alta densificação com uso de resina melamina-ureia-formaldeído. Cerne 11(4):323–328 http://www.cerne.ufla.br/site/index.php/CERNE/article/view/449

Leu SY, Yang TH, Lo SF, Yang TH (2012) Optimized material composition to improve the physical and mechanical properties of extruded wood–plastic composites (WPC). Constr Build Mater 29(1):120–127. https://doi.org/10.1016/j.conbuildmat.2011.09.013

Lima DC, Melo RR, Santana RRC, Botan E, Santana RMC, Stangerlin DM (2018) Wood plastic composites manufactured with sawmill waste and discarded polypropylene packaging. Nativa 8(1):79–84. https://doi.org/10.31413/nativa.v6i1.4432

Longo BL, Cunha AB, Rios PD, Terezo RF, Almeida CCF (2015) Caracterização tecnológica de painéis particulados produzidos com resíduos de cinco espécies tropicais. Scientia Forestalis 43(108):907–917. https://doi.org/10.18671/scifor.v43n108.15

Lopes TR, Fritsch AS, Mees JBR (2015) Metodologias e medidas para a minimização de resíduos em uma indústria moveleira. Tecno-Lógica 19(1):06–17. https://doi.org/10.17058/tecnolog.v19i1.5347

Macedo LB, Ferro FS, Varanda LD, Cavalheiro RS, Christoforo AL, Lahr FAR (2015) Propriedades físicas de painéis aglomerados de madeira produzidos com adição de película de polipropileno biorientado. Revista Brasileira de Engenharia Agrícola e Ambiental 19(7):674–679. https://doi.org/10.1590/1807-1929/agriambi.v19n7p674-679

Mai L, Bao L-J, Wong CS, Zeng EY (2018) Microplastics in the terrestrial environment. In: Microplastic Contamination in Aquatic Environments: an emerging matter of environmental urgency. Elsevier Inc., Chapter 12. https://doi.org/10.1016/B978-0-12-813747-5.00012-6

Mattos BD, Gatto DA, Magalhães WLE (2015) Wood polymer composites prepared by in situ polymerization: concepts, process parameters and properties. Ciência da Madeira 6(3):129–148. https://doi.org/10.15210/cmad.v6i3.7136

Melo RR, Rocha MJ, Rodolfo F Jr, Stangerlin DM (2016) Influence of diameter class on lumber yielding of *Qualea sp*. Pesquisa Florestal Brasileira 36(1):393–398. https://doi.org/10.4336/2016.pfb.36.88.1151

Melo RR, Dacroce JMF, Rodolfo F Jr, Lisboa GS, França LCJ (2019) Lumber yield of four native forest species of the Amazon Region. Floresta e Ambiente 26(1):01–07. https://doi.org/10.1590/2179-8087.031116

Milagres EG, Vital BR, Della Lucia RMD, Pimenta AS (2006) Compósitos de partículas de madeira de Eucalyptus grandis, polipropileno e polietileno de alta e baixa densidades. Revista Árvore 30(3):463–470. https://doi.org/10.1590/S0100-67622006000300017

Murayama K, Ueno T, Kobori H, Kojima Y, Suzuki S, Aoki K, Ito H, Ogoe S, Okamoto M (2019) Mechanical properties of wood/plastic composites formed using wood flour produced by wet ball milling under various milling times and drying methods. J Wood Sci 65(5):1–10. https://doi.org/10.1186/s10086-019-1788-2

Nahuz MAR (2013) Catálogo de madeiras brasileiras para construção civil. IPT, São Paulo, p 103

Ogunbode EB, Fabunmi FO, Ibrahim SM, Jimoh IO, Idowu OO. (2013) Management of sawmill wastes in Nigeria: case of study of Minna, Niger State. Greener Journal of Science, Engineering and Technology Research, 3(2):034–041.

Pivnenko K, Jakobsen LG, Eriksen MK, Damgaard A, Astrup TF (2015) Challenges in plastics recycling. Proceedings Sardinia, 15th International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 5-9 October, 2015, CISA Publisher.

Rahman KS, Islam MN, Rahman MM, Hannan MO, Dungani R, Khalil HPSA (2013) Flat-pressed wood plastic composites from sawdust and recycled polyethylene terephthalate (PET): physical and mechanical properties. SpringerPlus 2(1):669–676. https://doi.org/10.1186/2193-1801-2-629

Talgatti M, Baldin T, Silveira AG, Santini EJ, Vidrano BRA (2017) Compósito madeira-plástico a partir de resíduos de três espécies florestais. Pesquisa Florestal Brasileira 37(91):277–283. https://doi.org/10.4336/2017.pfb.37.91.1385

Thomas GP (2019) Recycling of Polypropylene (PP). AZO Cleantech. Available at https://www.azocleantech.com/article.aspx? ArticleID = 240 (Access at August 8, 2019)

Webb HK, Arnott J, Crawford R, Ivanova EP (2013) Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). Polymers 5(1):01–18. https://doi.org/10.3390/polym5010001

Weber C, Iwakiri S (2015) Utilização de resíduos de compensados, MDF e MDP para produção de painéis aglomerados. Ciência Florestal 25(2):405–413. https://doi.org/10.5902/1980509818460

Yin Y, Zhang Y, Zhen Z, Chub PK, Lv F, Ji J (2013) Thermal degradation and flame retarding characteristics of polypropylene composites incorporated with boron mud. Compos Sci Technol 85(21):131–135. https://doi.org/10.1016/j.compscitech.2013.06.002