Determining the Environmental Effects of Recycled Polypropylene Reinforced with Wood flour and Glass Fibers via a Life Cycle Assessment

Maryam Al-Ejji*§, Noora Al-Qahtani*
*Center for Advanced Materials (CAM), Qatar University, Doha 2713, Qatar
§Correspondence: maryam.alejji@qu.edu.qa

***Abstract*— The aim of this study was to investigate the environmental impacts of recycled polypropylene (RPP) reinforced with date palm wood flour (WF) and glass fibers (GFs). Hybrid composites with different weight ratios of WF and GFs were prepared on a lab scale. These composites consisting of 70 wt% RPP reinforced with WF, GF, and WF/GFs were prepared on a lab scale. An extruder machine was used to mix the composites. This work aimed to study the environmental impact of new composites developed and prepared on a lab scale and compared to the tensile modulus values of the hybrid composites. A life cycle assessment analysis (LCA) of the entire process, from the materials before extruding and after mixing were performed. The environmental impacts of the prepared composites in terms of the GWP, AP, FAEP, and HTP were conducted. The environmental impact was reached between the tensile modulus of the composites and the effect of the global warming potential (GWP). As shown by the LCA, that an increase in the GFs content improved the tensile modulus but increased the GWP. In addition, increasing the GF loading increased the marine aquatic ecotoxicity potential (MAEP). The environmental effects of the hybrid composites reinforced with palm WFs were lower than those of the composites reinforced with different amounts of GFs.**

Keywords—Environment impact; Natural wood flour;Recycled polypropylene; Lifecycle assessment

I. INTRODUCTION

Many recent studies have focused on the quantity of accumulated waste and the demand for new composites to prevent negative impacts in the future [1–4]. The fibre-reinforced polymer composites have been utilized in automobile applications [5]. The global market of automobile materials was estimated to reach $9.4 billion by 2020 and predicted to approximately reach $19.4 billion by 2027 with a yearly increase of 10.9% [6]. Most fiber-reinforced composites are hybrids that comprise a matrix composed of two fillers, the ratio of which may differ, but balanced with a matrix of material. They are formulated in such a way that the fibers support the load, and the matrix provides adhesion and adequate load transfer [7,8]. The need for the development of new hybrid composites stems from increasing awareness of environmental concerns, which has prompted the utilization of natural rather than synthetic resources [9,10]. Using natural fibers and nanofillers within the matrix can produce hybrid composites with improved mechanical properties and low water absorption properties [11]. In terms of natural fillers and synthetic solutions, such as glass, the environmental performance of natural fillers is better due to their lower weights and lower energy requirements during production [12,13]. Unlike composites produced using natural fillers, synthetic fiber manufacturing can have severe ecological and health consequences [14]. The major concerns about increasing waste production and resource consumption have led to a reevaluation of recycling and reuse strategies. A life cycle assessment (LCA) is a useful tool that can be used to assess the environmental consequences of a production system over its lifetime. Due to increasing awareness of environmental issues, LCA is commonly used in various industries to evaluate the environmental consequences of manufacturing processes and materials and aid the selection of processes and materials [15]. The LCA approach can be used to determine whether composites can be improved to meet target properties (e.g., lightweight, low water absorption) in different industries [16]. In this study, we investigated the environmental impact of RPP composites reinforced with WF, GF, and WF/GF. To assess the environmental impact of each production process, 1 kg of material produced was used as a functional unit. The values of tensile modulus were compared with their global warming potential (GWP) impacts for the composites.

II. Methods

A. Materials

This study builds on previous work, where recycled PP (RPP) was produced by Qatar Polymers Company in the form of pellets and then mixed with WF and GFs. The source of the WF was date palm from a waste landfill in Qatar, without further treatment. The GFs used were E-Glass commercially available in local market, which has an average length of 4.55 ± 1 mm and an average density of 2.9 g/cm [17]. For mixing these materials, a Brabender twin screw extruder was used. After mixing, the composites were allowed to cool and granulated and then prepared for mechanical testing in an injection molding machine. Hybrid composites were prepared with different weight ratios of RPP reinforced with WF and GFs. In all the composites, the RPP content was kept constant at 70% by weight, and only the amounts of fibers in the reinforced composites were changed as shown in (Table 1).

TABLE 1. Compositions of the composites (Adopted and reprinted with permission from [17]).

Sample ID	RPP (w%)	GF (w%)	WF (w%)
RPP	100	0	0
WFRPP	70	0	30
RPPGW1	70	5	25
RPPGW2	70	10	20
RPPGW3	70	15	15
RPPGW4	70	20	10
RPPGW5	70	25	5
GFRPP	70	30	0

B. Mechanical Testing

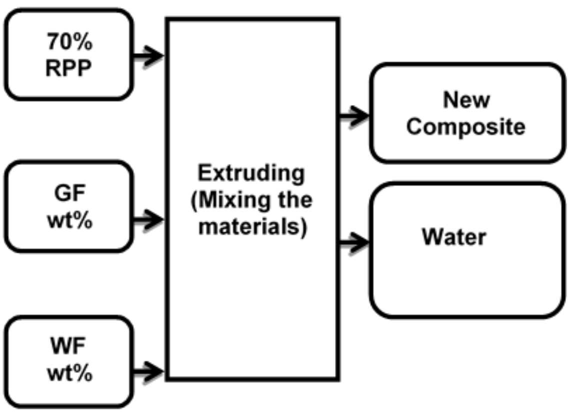
For mechanical testing, 1 kg of each product produced was defined as the functional unit for calculations and comparative purposes. In the mechanical test, tensile modulus was determined as described in the previous work [17] and compared with the highest environmental impacts. The mechanical testing was carried according to the guidelines of ASTM D638-02 using a Universal Testing Machine at a cross- head speed of 10 mm/min [17].

C. LCA

The LCA in this study was conducted in accordance with the guidelines of the International Organization for Standardization ISO 14040 series of standards. Based on these guidelines, an LCA measures the environmental performance of a product throughout its life cycle, from the “cradle,” where the raw materials are extracted, to the “grave,” where the product is finally disposed. The outcome of an LCA, known as an “eco-profile,” includes all compiled measurements of indicators of environmental issues. The environmental aspects and potential impacts associated with a product are assessed by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with these inputs and outputs, and interpreting the results of the inventory analysis, followed by impact assessment stages.

In this study, the LCA consisted of four phases: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation (ISO, 2006). The goal and scope stage of this study was to identify the environmental impacts of hybrid composites of RPP reinforced with different weight ratios of WF and GF. In this work, it is assumed that each sample will produce 1 kg of new material for assessment, and the data on RCC are from Europe. For Lifecycle inventory analysis, an LCA was carried out for newly developed composites to compare natural and artificial fiber-reinforced recycled plastics using GaBi LCA software. The data required for constructing the inventory were obtained from various supporting databases found in GaBi impact assessment software, with a modification for Qatar. The LCA was accomplished for composite material that was developed by mixing thermoplastic polymer with fiber. The mix design is presented in Table 1.

The reference scenario was for mixing 1 kg of the composite, including 70% RPP reinforced with 30% different ratios of fibers, taken into extruding, which mixed the materials to produce the new composite material. Electricity uses during extrusion, and water for cooling purposes, were all considered during the LCA analysis. Figure 1 shows the design process in the production of the hybrid composites.



Figure

Fig.1. The design process in the production of the hybrid composites

Generally, the impact assessment stage of an LCA has several mandatory elements, such as selecting an appropriate methodology and impact category indicators, calculating the indicators to convert that into a collection of indicators of different impact categories

In the present study, the methodology used for the impact assessment was CML 2001, which was developed by the Institute of Environmental Sciences, Leiden, the Netherlands. The environmental impacts investigated in the present study were as follows: the acidification potential (AP), freshwater aquatic ecotoxicity potential (FAEP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAEP), and GWP, which were compared with the tensile modulus of the composites.

In the interpretation phase, we identified significant issues based on the results of the LCA system and presented them to meet the requirements described in the goal and scope stage of the LCA.

III. RESULTS AND DISCUSSION

A. *Abbreviations LCA and Interpretation*

An LCA was carried out to determine the environmental impacts associated with the production of the different composites, including WF-reinforced RPP, GF-reinforced RPP, and WF/GF-reinforced RPP. The materials were mixed by extrusion methods. The impacts of the different composites throughout their life cycles were the focus of the study. The impact of the prepared composites on climate change was represented by the GWP. Figure 2 shows the GWP and tensile modulus values of the different composites. GWP was related to greenhouse emissions from electricity production and that considered for over a time horizon of 100 years. Both electricity production and transportation were excluded from this study that are mainly considered as a background system, which are also important for environmental evaluation [18]. The tensile properties of the composites containing different fiber loadings were tested. Previous research reported improved adhesion between fibers and RPP [17,19]. The tensile modulus of the RPP reinforced with WF increased by 32% and was better than that of the RPP reinforced with the GFs [17]. The tensile modulus of the RPP reinforced with WF fibers showed an improvement within the increases of GF contents [20]. The GWP of the RPP was higher than that of the GF loading of the hybrid composites due to more greenhouse emissions. The WF-reinforced composite had the lowest GWP impact among all the composites. According to these results, in terms of their environmental impacts, the performance of the natural fiber-reinforced composites with plastics was better than that of the GF-reinforced composites because of the reduced weight and energy demands of the former [12].

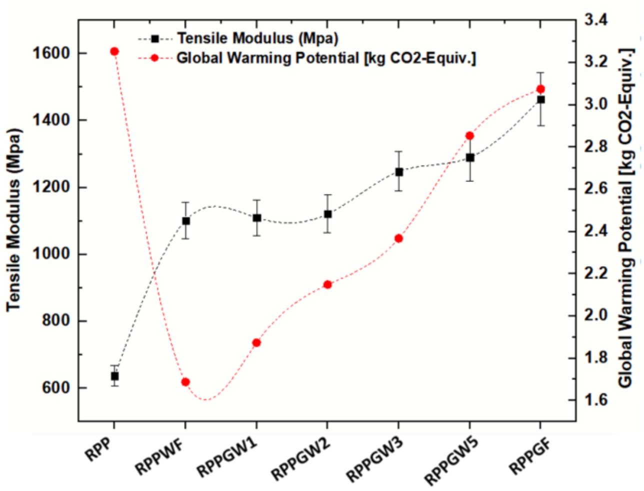


Fig. 1. A comparison of the global warming potential and tensile modulus values of the different composites (Tensile modulus adopted and reprinted with permission from [17]).

Figure 3 shows the results of the environmental impacts of the different composites. An increase in the GF loading was associated with an increase in the AP. The AP of the composite containing 15 wt% filler of WF and GW (RPPGW3) was about the same as that of the composite RPP. The 30 wt% WF-reinforced RPP had the lowest AP. The energy used in composite manufacturing can lead to arsenic and hydrogen fluoride emissions, which are related to the HTP of a product [21]. In the present study, the RPP had the highest HTP, whereas the whole composites decreased emissions of HTP. In terms of the environmental impact of FAEP of the prepared composites, it was similar range, with a slight increase in emissions associated with an increase in the GF loading. As compared to the other LCA categories, all the composites had a very high MAEP due to the use of water for the cooling stage after extrusion.

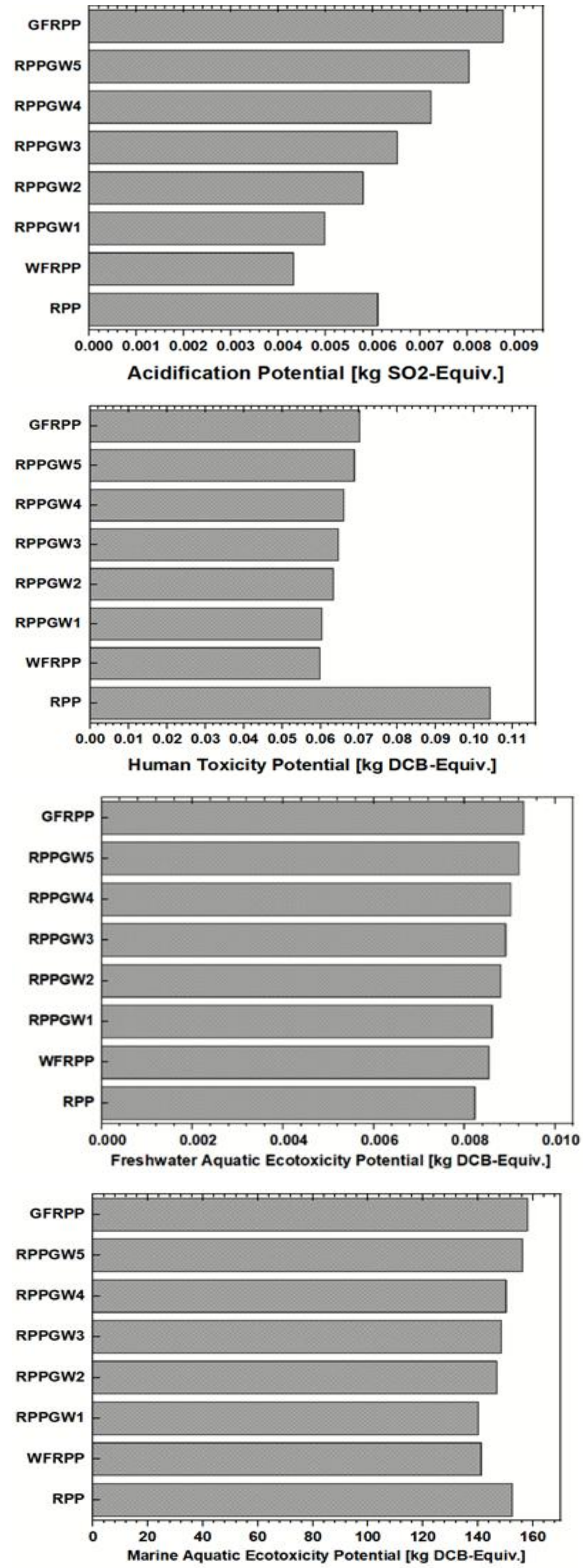


Fig. 3.The results of the life cycle impact assessment of the composites.

IV. Conclusion

In this study, new composite materials were developed by reinforcing RPP with WF and GFs. An LCA was performed to compare their environmental impacts, including their GWP, HTP, ADP, and AP during extrusion in a lab-scale experiment. The GWP of the composites was compared with the tensile modulus values to specify the amount of greenhouse emissions of GWP for producing stronger composites. We also compared the tensile modulus values of the different composites. The results revealed that the hybrid composites produced from a recycled matrix containing greater amounts of WF had fewer environmental impacts than those containing greater amounts of GF, as clearly shown by the GWP and AP of the composites. Thus, natural fiber reinforced RPP products are superior to RPP mixed with GFs, which has the worst environmental effects.

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