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The quest for a sustainable product: An environmental study of tyre recyclates

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ABSTRACT

The main objective of the present study is to assess the environmental advantages of substituting aluminium for a polymer composite in the manufacture of a structural product (a frame to be used as a support for solar panels). The composite was made of polypropylene and a recycled tyres' rubber granulate. Analysis of different composite formulations was performed, to assess the variation of the environmental impact with the percentage of rubber granulate incorporation. The results demonstrate that the decision on which of the two systems (aluminium or composite) has the best life cycle performance is strongly dependent on the End-of Life (EoL) stage of the composite frame. When the EoL is deposition in a landfill, the aluminium frame performs globally better than its composite counterpart. However, when it is incineration with energy recovery or recycling, the composite frame is environmentally preferable. The raw material production stage was found to be responsible for most of the impacts in the two frame systems. In that context, it was shown that various benefits can accrue in several environmental impact categories by recycling rubber tyres and using the resulting materials. This is in a significant part also due to the recycling of the steel in the tyres. The present work illustrates how it is possible to minimize the overall environmental impact of consumer products through the adequate selection of their constitutive materials in the design stage. Additionally it demonstrates how an adequate EoL planning can be an important issue when developing a sustainable product, since it can highly influence its overall life cycle performance.

1. Introduction

The designer of a product has to consider a list of specifications (e.g., mechanical, chemical, haptic, etc.) in order to select the best material which suits its proposed function and application. Currently the designer has more than 160,000 materials available for the task [1,2], from metals and ceramics to polymers. Polymers present a combination of very attractive properties, such as light weight, corrosion resistance, versatility, and easy processing. Moreover, polymers can be combined with other materials (reinforcing elements, such as fibres or particles) creating a composite and promoting a synergic effect on the global properties [3]. Environmental constraints are often added to the list of requirements a product must obey. In that domain, several life cycle studies have shown the benefit of using composites as alternatives to "traditional" materials [4–10]. Some of these studies also concluded that an environmental impact assessment should be performed during the product design phase to enable an adequate selection of the constitutive materials and respective manufacturing processes.

There is, however, a larger framework for this issue. In fact, waste production has increase around the world in the last decades, making waste management an acute challenge [11]. Current European Union (EU) legislation enforces stringent technical requirements for waste and landfills, in order to prevent, or reduce as far as possible, negative environmental effects [12]. The achievement of these objectives, namely minimization of landfill deposition of post-consumer goods, unavoidably implies the joint responsibility of the different actors involved. This clearly applies to tyres. In Portugal, approximately 52.7% of the 90,373 tonnes of used tyres collected in 2011 by the corresponding management system were sent for recycling. The remaining was mostly incinerated with energy recovery or retreaded [13]. In fact, Portuguese legislation that establishes the principles for the management of tyres and used tyres [14] prohibits incineration without energy recovery and landfilling. It also institutes a hierarchy in the management of used tyres, giving priority to prevention followed, in order of preference, by recycling and other forms of valorisation. In

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any case, like in all EU countries, the ultimate aim of the legislation is to promote sustainability, and improve the technological and systemic capacity of recycling and valorisation. This strategy follows the circular economy approach that replaces the open product system by a close loop one, that is, a system in which resources are extracted and used to make products that become waste, to a system which reuses resources and conserves energy [15]. Many studies, namely the recently published World Business Council for Sustainable Development Vision 2050 report [16], which envisages a global population living well and within the limits of the planet by 2050, follow this strategy. It thus in this framework that the incorporation of recycled rubber granulate in composites for subsequent manufacturing of viable higher-value products should be considered.

It is important to point out that there are already in the market a number of products that successfully incorporate rubber granulate from recycled tyres. In particular, recycled rubber granulate can be used as raw material in the production of rubber or plastic products (such as floor mats, dock bumpers, seals, insulators, and fishing and farming equipment) and asphalt paving [17,18]. The main objective of the present study is to evaluate the potential environmental impact of using a composite made with such granulate and virgin polypropylene (PP) in the manufacture of a structural product. The selected product was a frame to function as a support for solar panels. The results obtained were benchmarked with those attained for a solar panel frame made in a traditional material (aluminium). The effect of the End-of-life (EoL) stage on the frame's global environmental performance was also analysed. Finally a study of different composite formulations was performed, to evaluate how the environmental impact varies with the incorporation of rubber granulate.

2. Environmental impact

The potential environmental impact was evaluated by using the Life Cycle Assessment (LCA) methodology, which includes all stages of a product's life [19,20]. The methodology was performed in accordance with the standards from the ISO 14040 series [21,22]. This methodology comprises the definition of goal and scope, life cycle inventory analysis, life cycle impact assessment (LCIA) and interpretation of the results.

2.1. Goal and scope definition

In this study, the LCA methodology was applied to assess the environmental performance of a structural frame (Fig. 1). This frame could be used in the construction of added-value equipments, such as solar panels, where a similar component is currently manufactured from aluminium. A previous technological validation study had already demonstrated the feasibility of substituting aluminium by a composite made with virgin PP and recycled rubber granulate [23], as both materials present similar characteristics (UV and weather resistance, and mechanical properties). In fact, the composite frame presents advantages in that application, namely smaller production cost, higher thermal isolation (and consequently, lower losses of energy during the utilization of the panel), and lower weight. The aluminium frame lifespan is 20 years. The lifespan of the composite frame is yet not known, since until now it has not been applied in solar panels in real conditions of use. However, due to the authors' previous experience with composite materials, a lifespan of 10 years could be foreseen. In this scenario, the composite frame (and thus the solar panel) will need to be replaced after 10 years. Nevertheless, in order to compare the frames, the composite frame lifespan was defined in a first scenario as equal to the aluminium frame. The functional unit was defined accordingly, assuming a frame for application in solar panels, with a lifespan of 20 years. The amount of material needed in both systems (composite and aluminium) was determined on the basis of the geometry, length and thickness of the frames. The LCA was based in a "cradle-to-grave" assessment (Fig. 2) which considers the raw materials production, frame production, EoL treatment and all intermediate transport processes. It is supposed that no maintenance is needed during the use phase. The phases corresponding to the assembly of the frame, use, and dismantling of the solar panel were excluded, because they are considered to be equal in the two systems.

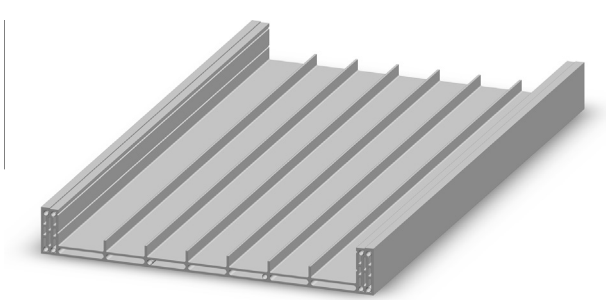

Fig. 1. Schematic of the frame used in this study (functional unit).

2.2. Life cycle inventory analysis

The frame currently in use weights 16 kg and is made solely of aluminium by extrusion. The aluminium production [24] considers a mix of primary (68%) and secondary (32%) aluminium, in accordance with their worldwide production share. The aluminium scrap produced during processing is also considered [24]. At its EoL the current frame is sent to recycling facilities, as aluminium is relatively easy to recycle, being collected and treated in existing process streams without difficulty [25]. The composite frame under analysis, also processed by extrusion, weights 12.5 kg and is made from virgin PP and rubber granulate, with an ethylene propylene diene monomer (EPDM) rubber compatibilizer. Taking into consideration the results of the technological validation performed ex-ante [23], the composite was prepared with 30% of virgin PP. The rubber granulate is obtained by grinding of used tyres at room temperature [26]. The used tyres are collected and sent to the recycling facility and then subjected to a mill (primary and secondary), grinder and calibration processes. During these processes waste, classified as non-hazardous industrial waste, is collected and sent to landfill. Steel is also recovered by magnetic separation and sent to recycling. Textile materials, also recovered during the grinding process are sent for incineration with energy recovery. After the grinding and calibration process, six grades of rubber granulates, with different particle sizes, can be obtained: FBA0008, FB0008, GB0825, GB2540, GB4070 and GB7095 [26]. Of these, FB0008 (20 to 8 mesh, up to 800 μm, nominal size) was selected to be used for the production of the composite.

The environmental load associated with obtaining the rubber granulate can be allocated to the tyre itself or to the recycling process and thus to the composite frame manufactured from it. Consequently, in the former case, no environmental loads need to be allocated to the composite frame. However, in the present study, the latter alternative was selected, in order to make both systems comparable. Thus, the used tyres grinding process should also be included in the life cycle of the composite frame system. This implies accounting for all the environmental burdens, from the reception of the used tyres to granulation and incorporation in the composite. Collection and transport were excluded from the study because they must always exist whether the composite frame is