Economic sustainability assessment of a gypsum ceiling tile with polyurethane foam waste

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Abstract. The amount of plastics deposited in the environment is constantly increasing. To improve their circularity, numerous research lines emerge, such as the creation of new construction materials that incorporate polymeric waste. This practice manages to extend the life cycle of the waste, avoids the consumption of limited natural resources and gives the product additional characteristics. The re-use of polyurethane foam waste as a substitute for gypsum in ceiling tiles carries technical improvements such as a decrease in the weight of the material and in its thermal conductivity, maintaining a positive fire reaction performance. The goal of this work is to analyse its economic viability. For this, the financial assessments of the PU-Gypsum product and its standard alternative are compared. The results show that the Life Cycle Cost Analysis (LCCA) of the new precast is 6% cheaper. Despite the fact that the waste processing entails an extra cost, this is widely offset by the increase in the factory's production capacity due to its shorter drying time. The manufacturing stage represents 3/5 of the total cost for both materials. The PU-Gypsum precast is an ideal market alternative to the traditional gypsum one with improved properties and proficient in an economic level.

1 Introduction

The worldwide plastic production has experienced a great growing of 230% since the second half of the 20th century [1]. The cumulative global production is 9.5 billion tonnes of polymers [2]. China and North America manufacture more than the 50% while Japan and Latin America do not arrive to the 5% each in the recent years [3]. Polyurethane is a thermoset polymer that represents almost 8% of the demand of the total amount of plastic in Europe [4]. Almost the half of those polymers became waste in less than one month [5]. The 65% of plastic waste are out of the circular economy in Europe in 2020, energy recovery or landfill are their end of life [6].

Linear model (take, produce, use and dispose) is arriving at its limits, primary resources are finite and they are running out, so its price rises progressively and volatility [7]. Besides, the plastic waste levels are higher than ever and it is demonstrated its connection with the

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environmental pollution and health problems in human beings [8]. Sustainable alternatives are needed to address the plastic challenge towards the circular economy (CE) and improve the stage of decision-making.

CE is closely linked to sustainable development since the last one allows quantifying the effects of different circularity strategies [9]. Environment, economy and society are its three pillars. There are different tools to analyse each aspect, adding all of them a sustainability score is obtained [10]. Life Cycle Cost Analysis (LCCA) is one of the methods used to evaluate the economic performance [11]. Promoting the reuse of the resources as long as possible and its economic viability accelerates the circularity of the waste. This research studies the CE strategy of polyurethane foam waste valorization into a construction material and the financial profitability of its development.

2 Materials and methodology

This section describes the materials under study and the method used to assess the economic performance of the materials.

2.1 Materials

Two different gypsum ceiling tiles are evaluated. They both have the same composition, with the exception that new one also includes polyurethane (PU) foam waste and additive. The incorporation of the polymer provides extra properties to the construction material and benefits the reuse of this subproduct and the lengthening of its life cycle. Besides, its inclusion as aggregate in substitution of part of the gypsum allows to reduce the amount of this raw material.

A valorisation waste process should be carried out before its reuse (Fig. 1.(a)). For that, the polyurethane waste is crushed, with the help of a grinder (Fig. 1.(b)). The particle size that has the best performance inside the gypsum mortars is the one that is smaller than 2 mm (Fig.1.(c)).

(a) (b) (c)

Fig. 1. Polyurethane foam waste processing.

The precast includes the maximum amount of PU that guarantees a good technical behaviour and the compliance of the regulations applicable in that field [12]. An in-depth composition and main properties of both ceiling tiles are described in a previous research [13]. The ceiling tiles have a square shape and they take up an area of 0.35 m^2. Fig. 2 includes the standard product on the left of the pictures and PU-gypsum product on the right. The exposed and hidden faces are shown in Fig. 2.(a) and (b), respectively.

(a) (b)

Fig. 2. Standard and PU-gypsum precast.

2.2 Methodology

The goal of this research is to quantify the economic sustainability of the new construction material with PU foam waste. In order to achieve the main objective, the standard and the PU-gypsum precast are both evaluated. The results obtained are compared to get the final conclusions.

The method used consists in analysing and adding the costs of each life cycle stage. The Life Cycle Cost Analysis (LCCA) is the tool used. Standards ISO 14040:2006 [14], ISO 14044:2006 [15] and ISO 15868-5:2017 [16] have also been considered. The study has different boundaries: the geographic limit is Spain, the temporary limit is 2018 and 2019, and the system limits are cradle to grave.

The costs included in the analysis refer to:

- The raw materials supply and transport to the factory where the precast are produced. The resources needed to the ceiling tiles manufacturing and packaging are considered.
- All the incurred costs necessary to make the construction materials in the plant such as energy, equipment, labour, etc.
- The final transport in the end of life stage.

No cost has been considered for the precast placing due to the variety of options regarding the installation systems and the place to be installed. The usage stage costs have not been taking into account because the products are projected in order to no need maintenance, repair, replacement or refurbishment during their estimated life. Besides, part of the end of life has not been measured because there are also multiples choices. Avoiding those stages has a low relevance for the research since their impact is minimum and in both materials the process or treatment would be the same.

The financial category evaluated is the currency, therefore the economic data used are the costs provided by the factory where both ceiling tiles are produced. All the costs are referred to the reference unit that is 1 m^2 of precast.

3 Results and discussion

Fig. 3 shows the results obtained from the economic assessment comparing both models. Different stages of the product life cycle are included in order to analyse those that have the most impact in the total life cycle cost. The stages included are raw materials supply and transport, production, placement, utilisation and end of life. The two last columns concern to the whole life cycle cost. The results are presented as percentages to better understand the comparison of models.

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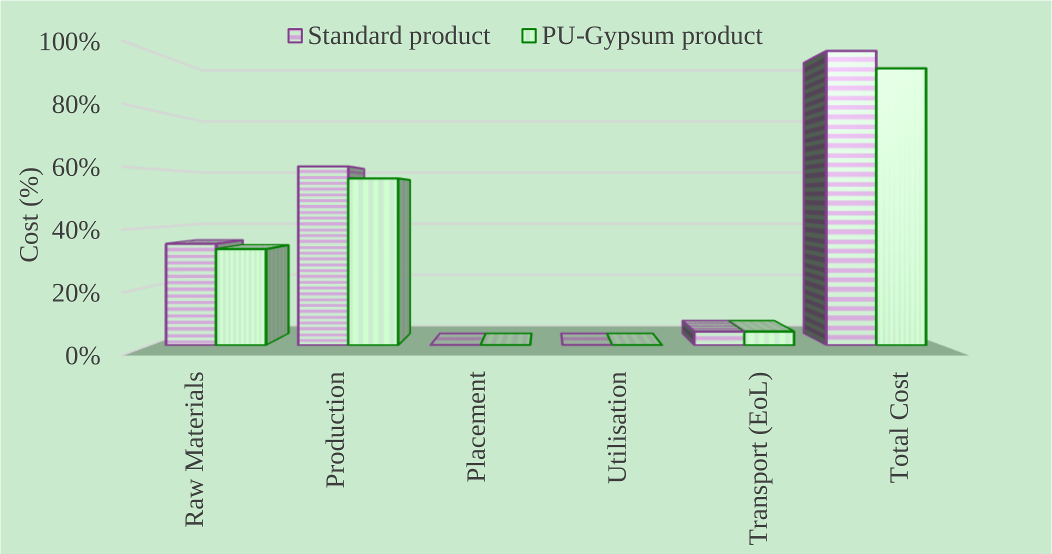

Fig. 3. Cost results of the Standard and PU-gypsum precast.

The raw materials supply and transport represents around 35% of the total cost. The new precast is 3% cheaper in this stage due to the difference in the composition of the products and in the amount of gypsum, additive and polyurethane. The packaging is also considered, but its cost is the same for both construction materials.

The production becomes approximately the 60%. The PU-Gypsum product has an extra cost in this stage regarding the crushing process and the crusher needed, however the production capacity increases for that model. Taking everything into account, the cost data express that the sustainable sample is lower-cost, the savings in these stages are around 7%. Placement and utilisation have not been taking into account therefore no influence in the cost is noticed.

The last phase is the transport of the ceiling tiles after its removing. It represents only the 5% of the cost. The PU-gypsum sample is a bit more inexpensive, but the difference is minimum. The key for the transport process cost is the weight of the materials and the new product is lighter.

The total cost is obtained adding the cost of each stage analysed. Considering the discounts mentioned before, it is concluded that the ceiling tile that includes PU foam waste in its composition is more affordable. The final cost reduction is estimated in 6% per m^2 of ceiling tile.

4 Conclusions

The positive development of a gypsum ceiling tile that incorporates polyurethane foam waste contributes to the plastic transition towards the circular economy. It implies a reduction in the number of polymeric waste and the reused and valorisation of resources. Besides, it reduces the consumption of gypsum, since the polyurethane is introduced in its substitution.

The comparative assessment of the economic performance of each precast allows knowing the viability of the new solution in the market. The results show that the PU-Gypsum ceiling tile is 6% cheaper that the traditional one. The discount in due to the fact that the cost of the materials introduced is less than the cost of the raw materials avoided. Besides, the properties of the new product allow increasing the production capacity of the factory therefore the fix costs per each m^2 of ceiling tile are reduced. This saving is higher than the cost because of the polyurethane processing and equipment.

Evaluating the cost data in each phase, raw materials supply and transport, and manufacturing are the ones that have more economic impact in the final result, they suppose 95% of the total cost. To improve the results, an action plan should be addressed and developed in those stages.

To sum up, it could be confirmed the success of the economic assessment for the new construction material and the improvement of the polyurethane foam waste circularity.

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