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Review

Are functional fillers improving environmental behavior of plastics? A review on LCA studies

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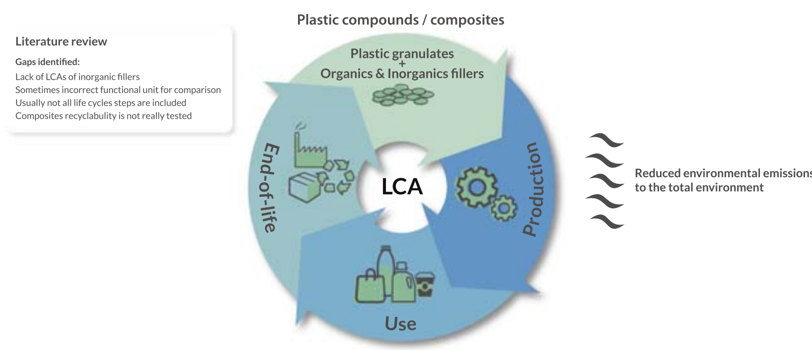
HIGHLIGHTS

- Functional fillers help improving plastics' environmental impact.
- Mineral fillers in plastics provide better performances and sustainable options.
- The growing market of plastics with fillers needs further environmental research.
- Life cycle assessment studies show that using fillers reduces impact on resources.
- LCA methodology for composites should be developed to include multifunctionality.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of functional fillers can be advantageous in terms of cost reduction and improved properties in plastics. There are many types of fillers used in industry, organic and inorganic, with a wide application area. As a response to the growing concerns about environmental damage that plastics cause, recently fillers have started to be considered as a way to reduce it by decreasing the need for petrochemical resources. Life cycle assessment (LCA) is identified as a proper tool to evaluate potential environmental impacts of products or systems. Therefore, in this study, the literature regarding LCA of plastics with functional fillers was reviewed in order to see if the use of fillers in plastics could be environmentally helpful. It was interesting to find out that environmental impacts of functional fillers in plastics had not been studied too often, especially in the case of inorganic fillers. Therefore, a gap in the literature was identified for the future works. Results of the study showed that, although there were not many and some differences exist among the LCA studies, the use of fillers in plastics industry may help to reduce environmental emissions. In addition, how LCA methodology was applied to these materials was also investigated.

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Contents

1. Introduction

1.1. Plastics with fillers

Because of their optimal cost and high performance, thermoplastics have been used in many different kinds of applications during the last few decades; and they have been even replacing other conventional materials like glass, metal, and wood (DeArmitt, 2011). Because of the increasing demand for thermoplastics, people started to look for ways to reduce their cost. That was the initial reason behind the introduction of fillers to plastics. Primarily, the term "fillers" corresponded to cheap diluents introduced into plastics to reduce the overall cost. However, they were found to be more than this. Recently, the term "functional fillers" is used, because they can provide other properties in addition to cost reduction (Rothon, 2001). The addition of fillers creates multiphase systems composed of micro/macrostructures giving characteristics to the material (DeArmitt, 2011). Improvement in processing, density, thermal expansion, thermal conductivity, flame retardancy, optical changes, electrical and magnetic properties, and mechanical properties like stiffness are examples of properties that can be changed through the addition of functional fillers to plastics (DeArmitt, 2011; Rothon, 2001).

In 2003, the global demand for fillers in plastics industry was predicted to be 15 million tons and their main markets were transportation and construction, later consumer products like furniture, industry and machinery, electrical appliances and electronics, and packaging were also important markets (Xanthos, 2010). In 2015, the global polymer filler market was more than USD 45 billion (Grand View Research, 2016). According to DeArmitt (2011), carbon black, $CaCO_3$, silica, $Al(OH)_3$, talc and kaolin are the major fillers contributing to a multi-billion euro/year market. Recently, an increased interest in environmental protection has led to using fillers to reduce environmental impacts of products by replacing petrochemical materials (Murphy, 2001).

Any particulate material added to plastics would serve as a filler (DeArmitt, 2011). Polymer composites with fillers are defined as mixtures of polymers with inorganic or organic additives with certain geometries; thus, consist of two or more components and phases (Xanthos, 2010). In this paper, in addition to polymer composites, polymer systems which are the mixture of polymer and additives will be subject to research. This kind of mixtures is referred as compounds.

Fillers can be grouped into two main categories: inorganic or organic ones. Then, they can be even further subdivided based on their chemical family as shown in Table 1, which includes some commonly known examples as well. According to the market research performed, in 2015 inorganic fillers were found to lead the filler market with 78.9% share (Grand View Research, 2016).

Ground calcium carbonate (GCC) is easily found on earth, mostly in the form of limestone and chalk, which are formed from fossils (Maier and Calafut, 1998). With a market share of 34%, GCC is the most commonly used inorganic filler in plastics because it is a common and inexpensive material with superior functions like increasing stiffness, impact strength and flexural modulus of the plastic to which it is added. The demand is even expected to increase by 2.7% between 2015 and 2023 (Ceresana, 2016). Hydrated magnesium silicate, known as talc, provides better rigidity and impact strength to plastics, especially to polypropylene (PP), when it is added. Thanks to the advanced milling technology, higher purity provides thermal stability; therefore, it is a good choice to use in packaging (Murphy, 2001). Among other inorganic fillers, silicates like mica, kaolin, and wollastonite can modify some mechanical properties of plastics. For example, the

Table 1
Chemical grouping of fillers (Xanthos, 2010).

Groups	Examples
Inorganics	
Oxides	Glass, SiO_2, ZnO, Al_2O_3, Sb_2O_3 and MgO
Hydroxides	$Mg(OH)_2$ and $Al(OH)_3$
Salts	$CaCO_3$, $CaSO_4$, $BaSO_4$, hydrotalcite and phosphates
Silicates	Talc, kaolin, mica, montmorillonite, wollastonite, a sbestos and feldspar
Metals	Steel and boron
Organics	
Carbon, graphite	Carbon fibers and nanotubes, carbon black, graphite fibers and flakes
Natural polymers	Cellulose and wood fibers, starch, cotton, sisal and flax,
Synthetic polymers	Polyester, aramid, polyamide and polyvinyl alcohol fibers

Table 2
NFs as fillers (Bos, 2004).

Natural fibers	Examples
Straw fibers	Wheat, corn, and rice
Bast	Hemp, jute, kenaf, lax
Leaf	Sisal, henequen, pineapple leaf fibers
Seed/fruit	Cotton, coir
Grass fibers	China reed, bamboo, grass
Wood fiber	