LIFE CYCLE ASSESSMENT OF A FIBRE-REINFORCED POLYMER MADE OF GLASS FIBRE AND PHENOLIC RESIN WITH BROMINATED FLAME RETARDANT

Moliner E.[1], Fabregat J.[1], Cseh M.[2], Vidal R.[1]
[1]*Engineering Design Group, Department of Mechanical Engineering and Construction, Universitat Jaume I, Av. SosBaynat s/n, 12071 Castellón, Spain, +34 964729252, kike.moliner@gmail.com (Moliner E.), www.gid.uji.es*
[2]*Denkstatt Hungary Kft., Vörösmarty u. 64., 1064 Budapest, Hungary, +36 12391206, cseh.m@denkstatt.hu (Cseh M.), www.denkstatt.hu*

Abstract

A life cycle assessment (LCA) for fibre-reinforced polymers consisting on glass fibre and phenolic resin with a brominated flame retardant additive is presented. Due to its toxicity and difficulties in recycling, new environmental friendly materials are being designed. It is intended that this LCA, which is based on new data life cycle inventory (LCI) serves as a benchmark.LCA results obtained with these new LCI are compared with results from LCI of commercial database. The environmental impacts associated with energy consumption and air emissions were assessed, as well as other environmental impacts resulting from the extraction and processing of materials and fibre-reinforced polymers manufacturing. End-of-life scenarios for recycling, incineration and landfilling,including the environmental impacts of brominated flame retardants,were also compared for this material.

Keywords:*life cycle assessment; fibre-reinforced polymer; glass fibre; phenolic resin; brominated flame retardant*

Resumen

Se presenta el análisis del ciclo de vida (ACV) para un polímero de resina fenólica reforzado con fibras de vidrio y con retardante de llama bromados como aditivo. Debido a su toxicidad y dificultades en el reciclaje, se están buscando nuevos materiales alternativos. Se pretende que este ACV, que está basado en datos de nuevos inventarios del ciclo de vida (ICV) sirva como base de comparación. Los resultados del ACV obtenidos con estos nuevos ICV se comparan con los resultados de ICV de bases de datos comerciales. Se han evaluado los impactos ambientales asociados al consumo de energía y emisiones al aire, así como otros impactos resultantes de la extracción y procesado de los materiales y fabricación de los polímeros.Además, se han comparado tres escenarios de fin de vida: reciclaje, incineración y disposición en vertedero, incluyendo en todos ellos los impactos ambientales de los retardantes de llama bromados.

Palabras clave: *análisis del ciclo de vida; polímero reforzado con fibras; fibra de vidrio; resina fenólica; retardante de llama bromado*

1. Introduction

Fibre-reinforced polymer (FRP) materials are commonly used in the aerospace, automotive, marine, and construction industries. FRP is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, basalt or aramid, although other fibres such as paper, wood or asbestos can also be used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, or phenol formaldehyde resins. The FRP considered in this research comprise glass fibre, phenolic resin and Deca-BDE as flame-retardant additive. These are noxious materials and this composite is not easily recyclable.

Deca-BDE is a brominated flame retardant used in polymers and composites for applications that demand high fire resistance. Deca-BDE belongs to the group of polybrominated diphenyl ethers (PBDEs). PBDEs are persistent, bioaccumulative, and toxic to both humans and the environment. Human exposure to PBDEs may occur through occupations that manufacture flame retardants or products that contain flame retardants, as well as in end-of-life operations.

The European Community and the United States government have expressed concern about the use of PBDEs as flame retardants. The EU Directive restricting the use of hazardous substances in electrical and electronic equipment (RoHS Directive or Directive 2002/95/EC) prohibits the use of Deca-BDE since July 2006. In December 2012, the European Chemicals Agency announced the inclusion of the flame retardant Deca-BDE in the Candidate List of Substances of Very High Concern (SVHCs) for Authorization under REACH regulation. The authorization procedure aims to assure that the risks from SVHCs are properly controlled and that these substances are progressively replaced by suitable alternatives while ensuring the good functioning of the EU internal market. In June 2013, Norway announced that it submitted a proposal to consider the listing of Deca-BDE under the Stockholm Convention as a persistent organic pollutant (POP). The Stockholm Convention aims for the elimination of POPs and requires that they are disposed of in such a way that the POP content is 'destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs'. It also permits to dispose of POPs in an environmentally sound manner 'when destruction or irreversible transformation does not represent the environmentally preferable option' or 'when the POP content is low'. If the proposal of Norway is finally adopted, the inclusion of Deca-BDE in the Candidate List of SVHCs will cease to be valid and the use of Deca-BDE will be definitively prohibited as previously happened with other PBDEs listed as POPs in the Stockholm Convention (e.g., Penta-DBE and Octa-BDE).

Furthermore, the question of how to dispose of end-of-life thermoset composite parts is growing in importance. Traditional disposal routes such as landfill and incineration are becoming increasingly restricted, and composites companies and their customers are looking for more sustainable solutions.

A life cycle assessment (LCA) has been carried out for FRP made of glass fibre and phenolic resin with a brominated flame retardant additive to be used for future comparative assessments with other environmental friendly substitutes. Besides gaining knowledge about the environmental impact of FRP by the results of LCA, one additional aim of the study was to obtain new life cycle inventories, which environmental results are compared to LCI of commercial databases.

The LCA was further extended by the consideration of flame retardants at the end-of-life calculations. As a result of LCA, environmental impacts by life-cycle stages and by FRP components furthermore the end-of-life impacts by incineration, mechanical recycling and landfilling is discussed in the paper.

2. Materials and methods

The LCA methodology was used in this study to calculate the environmental impacts of a FRP made of glass fibre and phenolic resin and a brominated flame retardant additive. LCA was applied according to the guidelines provided by the International Organization for Standardization (ISO, 2006a, 2006b). The LCA software application SimaPro® was used to tackle the development of the study more effectively. The ReCiPe method (Goedkoop et al., 2009) was then used to assess the environmental impacts according to two sets of impact categories: midpoint categories and endpoint categories. Midpoint impact categories are climate change, fossil depletion, and another sixteen impact categories. Endpoint impact categories are damage to human health, damage to ecosystem diversity, and damage to resource availability. The Cumulative Energy Demand method was also used to assess the total energy.

2.1 Goal and scope definition

The present study aimed to calculate the environmental impacts of a FRP made of glass fibre and phenolic resin with flame retardant. One kilogram of FRP is assumed here as the functional unit, which is a reference unit to which the results of the LCA are related. These results will serve as a baseline for comparison with novel FRP materials made from renewable polymers and natural fibre reinforcements, which will be assessed in further studies.

The scope of this study includes all processes from raw material extraction until delivery of the FRP at plant (cradle-to-gate analysis). The end-of-life of the FRP is also considered in the study to compare the environmental impacts of different treatments that can be applied to FRP products when these become waste. The life cycle of the FRP being studied can thus be divided into these major stages or sub-systems: (1) materials, (2) manufacturing, and (3) end-of-life.

2.2 Inventory analysis

2.2.1 Materials

The FRP being studied is composed of glass fibres and phenolic resin modified with a halogenated flame-retardant additive (decabromodiphenyl ether or Deca-BDE). Table 1 shows the composition of the finished FRP and the total amount of each material required for manufacturing one kilogram of FRP, including rejects and waste.

Table 1: Materials required for manufacturing 1 kg of FRP

Material	Composition of FRP (% by weight)	Total amount, including waste (kg)
Phenolic resin	34.4	0.406
Glass fibre	60.0	0.708
Deca-DBE	5.6	0.066

Phenolic resins are synthetic polymers obtained by reaction of phenol with formaldehyde. The phenolic resin used in the FRP studied is composed of 95% phenol and 5 % formaldehyde. The LCI of formaldehyde was taken from the Ecoinvent® database (Althaus et al., 2007) and includes data for all processes from raw material extraction until delivery of formaldehyde at plant. The LCI of phenol was based onthe Eco-profiles of the European Plastics Industry (Boustead, 2005) and it also includes data for all processes from raw material extraction until delivery of phenol at plant. Additional data for the production of phenolic resin were also taken from the Ecoinvent® database (Althaus et al., 2007), including transport of materials to the manufacturing plant, infrastructure of the plant, water consumption, process energy demand, and emissions to air and water from production.

Glass fibres are prepared from a mixture of the so-called E-glass in the form of continuous strands with a size coating and a binder. A LCI of glass fibres was available from the Ecoinvent® database (Kellenberger et al., 2007), which includes data for all processes from raw material extraction until delivery of glass fibres at plant. An alternative LCI of glass fibres was developed here based on the reference document on best available techniques for the manufacture of glass (Joint Research Centre, 2013), which includes a specific section for glass fibre products. This inventory includes the resources, raw materials and chemicals used for production (silica sand, limestone, dolomite, aluminium oxide, and so forth); process energy demand (light fuel