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USE OF RECYCLED PLASTICS AS A SECOND RAW MATERIAL IN THE PRODUCTION OF ROAD PAVEMENTS: AN EXAMPLE OF CIRCULAR ECONOMY EVALUATED WITH LCA METHODOLOGY*

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Abstract

The road pavement sector contributes significantly to Europe-wide climate-altering gas emissions. Emissions related to road pavement are mainly due to the production of bituminous conglomerate (asphalt), which represents the main contribution to roads construction and maintenance activities. The aim of this work is to assess the extent of potential environmental impacts mitigation due the use of newly formulated bitumen modifiers, containing recycled non-recyclable hard plastics. The considered new additives containing hard plastics substantially improve the performance and durability of road pavements, which allows reducing material amount required to obtain the same functionality. This opens up two different application scenarios addressed in this work which provide an alternative to the conventional road pavement design and management. Given the same service time frame, the first scenario considers the extension of the asphalt maintenance-free operating periods (MFOP) of each pavement layer. The second scenario considers the possible reduction of the pavement asphalt layers thickness. The new bitumen modifier also allows implementing a circular model for hard plastics alternative to their incineration at end-of-life. In the circular model hard plastics are given a second life by incorporating them into the modifier as a raw material, thus entering the closed-loop of periodic pavement maintenance cycles. This study compares the environmental performance of the innovative road pavements life cycle by considering production-, use-, and maintenance phases with respect to conventional pavements. The results show that the asphalt production represents the major environmental impact source within the whole functional system considered. The overall reduction of

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required material in the first scenario is obtained by MFOP extension along the whole pavement life cycle, while in the second scenario by the reduced thickness of each asphalt layer since first paving. These enhanced performance-driven effects due to the hard plastic-based new modifier determine an overall environmental impact reduction.

Keywords: circular economy, environmental impact, LCA, plastic waste, road pavements

1. Introduction

Several researchers have studied the effects on the environment due to construction, maintenance and disposal of road pavements (Birgisdottir et al., 2007; Huang et al., 2009; Muench, 2010; Santero et al., 2011a, 2011b; Stripple, 2001).

In Europe 400 million tons of asphalt are produced annually (EAPA and NAPA, 2011). In road construction, GHG emissions represent 5-10% of total GHG emissions produced by the transport sector, but they are growing rapidly, especially in developing countries (World Bank, 2011). Therefore, it is necessary to introduce new technological solutions to mitigate the impacts. In the road industry innovative technologies have been developed in order to reduce the environmental impact, such as the use of recycled asphalt, temperature reduction during asphalt production, and additives that extend the pavement’s service life. In order to achieve this aim, the Life Cycle Assessment (LCA) methodology is increasingly used for determining the environmental benefits and for finding out solutions to minimize direct and indirect impacts.

This plastics circularity model is an interesting “case study” in accordance with the European Plastics Strategy and it highlights how the most sustainable destiny of these polymers is as a second raw material. The plastics circular economy is a model for a closed system that promotes the reuse of plastic products, generates value from waste and avoids sending recoverable plastics to landfill or to incineration. Plastic waste is a valuable resource that can be used to produce new plastic raw materials and manufacture plastic parts and products, or to generate energy when recycling is not viable. In fact, hard plastics are generally hardly recoverable and a circularity model for them is difficult to be implemented. On the contrary, the circular solution considered in this LCA case study allows assessing the sustainability of employing hard plastics as raw materials by their incorporation in new products for road paving, thus avoiding hard plastics incineration at end of life. The conversion of waste hard plastics into raw material for asphalt modifiers includes their separate collection in ecological platforms and transports the treatment plants. At the treatment plant they are manually separated from metal parts. At the end of treatment process a fraction of “polyolefin plastics” is obtained and finally properly ground and additivated, to obtain a granulated blend with dimensions less than 3 mm used as an additive suitable for modifying bitumen and road bituminous conglomerates (BCs). The incorporation of the obtained granulated blend, also containing graphene, in the BC allows enhancing the asphalt performance. This allows considering two possible scenarios: the first one (i) allows the extension of the service life for each layer (base, binder and ware bed), determining the extension of the asphalt maintenance-free operating periods (MFOP), within the road pavement identified service time-frame. The second (ii) considers reduced asphalt layers thickness having the same BC performance of the standard asphalt.

The aim of this study is to compare standard road pavements (with neat bitumen) and pavements built with the asphalt recycled-plastic-based-modifier along their life cycle and to assess potential environmental impacts mitigations.

2. Material and methods

The analysis of the impacts was carried out using the LCA methodology according to ISO 14040 and ISO 14044 (ISO, 2006a, 2006b), comprising four phases, which affect one another: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment and (iv) interpretation. Data needed for this LCA study are primary data obtained by the bitumenous conglomerate modifier manufacturer. The secondary data source is from literature (Eurobitume, 2012). The impact assessment has been made by using *OpenLCA* 1.10 software, *Ecoinvent 3.5* database, with the impact methodology CML-IA baseline.

2.1. Functional unit and system boundaries

The functional unit is a measure of the performance of the analyzed product system. For road pavements, physical dimension and service descriptors allow defining the functional unit. In the present study two scenarios are considered, in which suitable functional units are defined.

i) In the first scenario comparison between road pavements with same thickness are considered. In this case the functional unit is defined as 1 km of road, 15 m wide, considering standard thickness, as described in Table 1. The service parameters are defined by the traffic intensity of 4.000.000 vehicles per year and by considering a service time over a period of 20 years. Within the service time-frame, road pavement layers standard maintenance is included.

Table 1. Pavement with same thickness have the different useful life

Type of pavements	*Layer*	*Thickness (cm)*	*Useful life*	*Bituminous mixture (t) for 1 km laying*
Standard pavements	Surface	5	5	1785
	Binder	6	10	2142
	Base	14	20	4998
Pavement with modifier	Surface	5	15	1785
	Binder	6	30	2142
	Base	14	90	4999

ii) In the second scenario roads with different thickness and with same overall performance are compared, as described in Table 2. In this case the functional unit employed is defined as 1 km of road, 15 m wide, used over a period of 20 years, whose layers thickness are computed by equating the structural number (SN) of the two road pavements solutions, which are determined by the material structural parameters (which measure the relative strength of the construction materials in the layer) and by the layer thickness. The SN is an index providing an indication of the strength of the pavement layers and of the total pavement structure. The SN determines the total number of ESAL (Equivalent Single Axle Loads) that a particular pavement can support, and is connected to the layer thickness, calculated according to AASHTO 1993 Design Factors.

In both first and second scenarios, two extended functional systems (FS) are compared. Both FS provide the same functional output, defined by the functional road pavement and by the equivalent amount of electrical and thermal energy obtained by incineration of a defined amount of hard plastics.

The first FS is based on the model of neat bitumen conglomerate production and by the functional system extension, including collection of waste hard plastic, which are sent to incineration. Connected to the incineration process are: emissions to the environment and the production of defined amount of electrical and thermal energy. The amount of plastics considered is determined by the amount of plastics needed in the second FS to produce the BC with modifier.

Table 2. Pavement with different thickness but the same useful life

Type of pavements	*Layer*	*Thickness (cm)*	*Useful life*	*Bituminous mixture (t) for 1 km laying*
Standard pavements	Surface	5	5	1785
	Binder	6	10	2142
	Base	14	20	4998
Pavement with modifier	Surface	3.8	5	1356.6
	Binder	4.8	10	1713.6
	Base	11	20	3927

The second FS is based on the model of asphalt production with modifier, including the collection of waste plastics, their conversion and incorporation into the modifier. The second FS extension includes the generation of the amounts of electrical and thermal energy as output, which are equivalent to those obtained in the first FS by the defined amount of plastic incineration.

Standard pavement (neat asphalt, as per the first FS analyzed) is formed by aggregates and bitumen, while pavement with modifier incorporates polyolefin by recycled waste plastic and graphene. In the second FS the modifier is added to the BCs in the proportion of 0.5%wt/wt to each batch of produced BC.

The extension of the two functional systems allowed to intrinsically comparing the two models for plastic management: the linear model of plastic incineration and the circular model of plastic incorporation in to the BC modifier.

The system boundaries comprise all the steps in the pavement life cycle. The assessment has been carried out according to the “cradle to cradle” life cycle analysis, considering the road pavement entire life cycle, from the extraction of raw materials to BC production and maintenance cycles within the defined service time and to the final reuse of the predefined portion of the reclaimed asphalt.

The reclaimed asphalt from each maintenance cycle is reintroduced in the BC production process in the proportion of 20% for wear layer and of 30% for binder and base layers with respect to the total BC produced in each batch.

The amount of reclaimed asphalt that is not entering the circular model is considered as stored for other secondary uses, which are not accounted for in this analysis.

The analysis has been carried out according to the modular approach for each FS considered, as reported in the boxes of the diagram shown in Fig. 1; the system boundaries are represented by the line encompassing all modules boxes.

3. Results and discussion

The results of the impact assessment are a function of the inventory analysis, classified as confidential.

With reference to the first scenario, Fig. 2 shows the potential environmental impacts between the two BCs with the same thickness (Table 1). The solution employing asphalt with the modifier incorporating the converted hard plastics yields a strong impact reduction for all impact categories obtained in the order of 70%.

With reference to the second scenario, Fig. 3 shows the results obtained by reducing the thickness of the pavement layers (Table 2) by keeping the same structural performance and durability. Also in this case the BCs added with plastic and grapheme based modifier show a better environmental performance along the life cycle with an average reduction of about 30% in all impact categories.

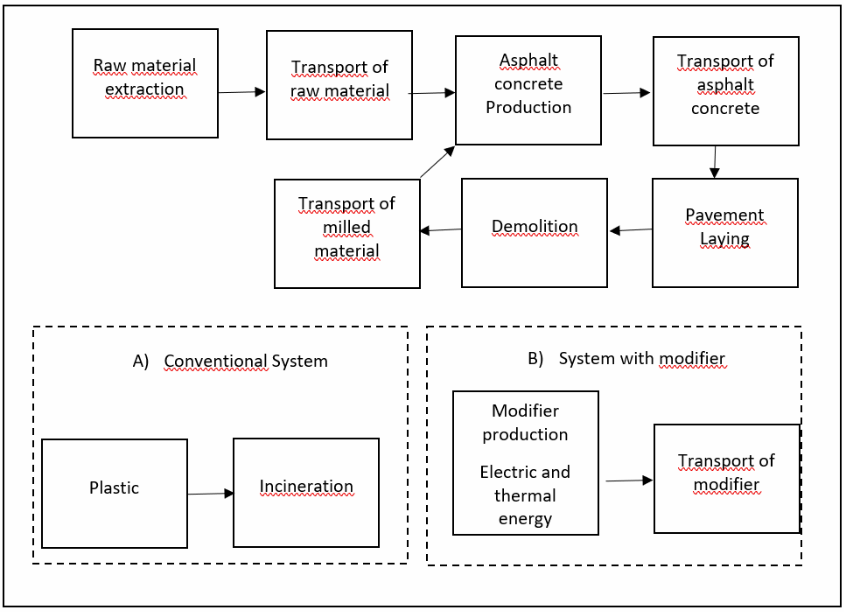

Fig. 1. System boundaries of the LCA study. Dotted boxes concern two functional system: A) Conventional system consider the standard asphalt concrete with the extension of the system to the hard plastics incineration process and B) System with the modifier

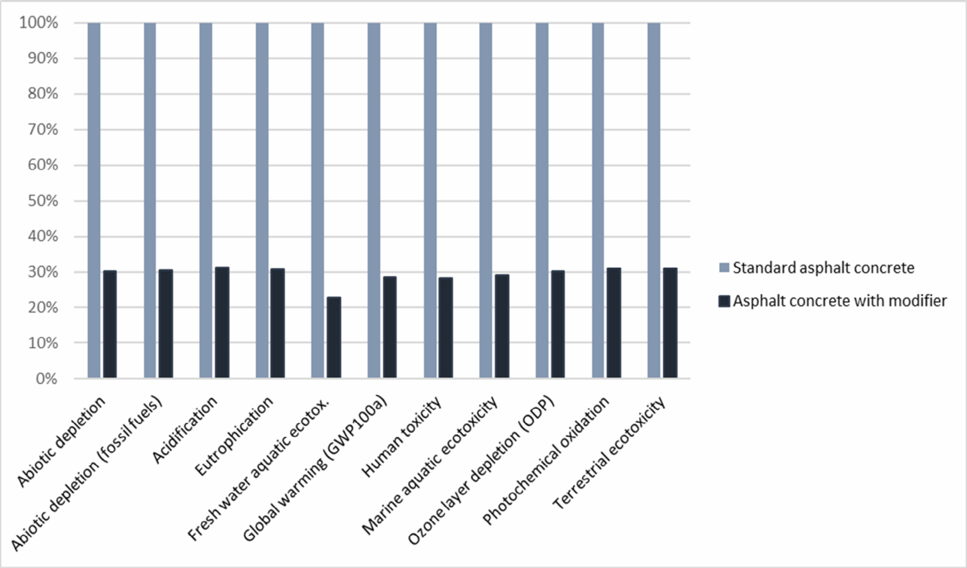

Fig. 2. Potential environmental impacts by comparing the standard asphalt concrete with asphalt with the modifier, with the same thicknesses (CML methodology)

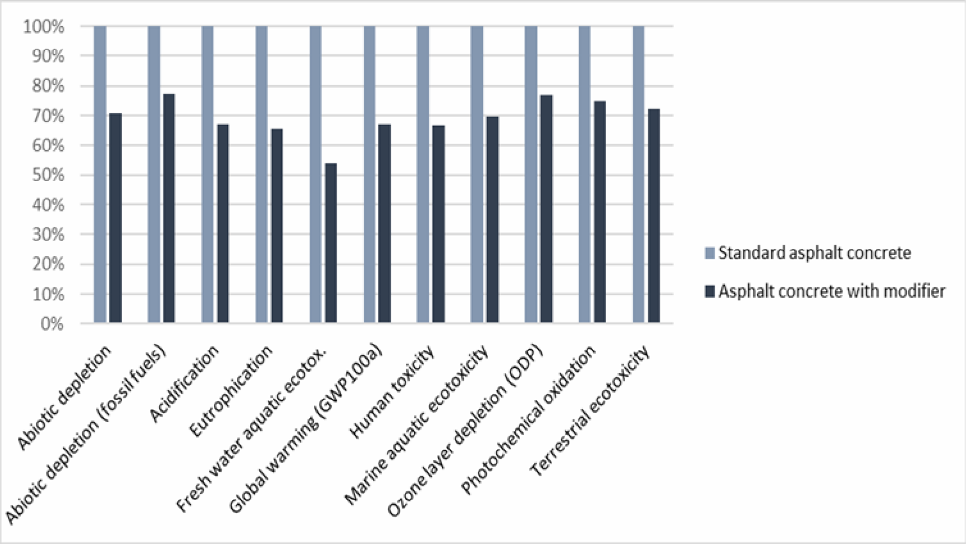

Fig. 3. Potential environmental impacts by comparing the standard asphalt concrete with asphalt with the modifier, with the reduction of thicknesses (CML methodology)

The analysis showed that the production of bituminous conglomerate represents the main source of environmental impact in the considered functional systems. In both scenarios the modifier added BCs determine a better performance either expressed by a longer life cycle of each single layer (first scenario), or by the theoretical possibility of reducing the thickness of each pavement layer (second scenario).

For the identified service time frame of 20 years the first scenario highlights how the extended durability of each layer (of BC with modifier) determines an extension of the asphalt maintenance-free operating periods (MFOP), which turns into a strongly reduced number of asphalt reclaiming an re-paving operations and therefore into a reduced BC material demand to guarantee the road service. This effect is strong and it is seen through the whole service time-frame. In the first scenario no beneficial effect would have been seen at the first paving cycle due to the fact that the BC material amount used in the two solutions with modifier- and with neat asphalt are comparable. On the contrary, in the second scenario a beneficial effect is seen at the first paving cycle since a considerable material reduction is obtained by the paved layers reduction. This effect is smoothed along the selected time frame of 20 years, since at each maintenance cycle the material saving, which is the main responsible of the environmental reduction, is limited due to the reduced amount of BC to be used for paving at each maintenance cycle.

In synthesis the two cases analyzed show that:

- With standard thickness there is an improvement in the medium and long term in the asphalt concrete with modifier in all impact categories of about 70% because in 20 years less material is used due to lesser number of road repairs.
- With reduced thickness there is an economic and environmental gain at first laying, and along the service life for the least amount of material, in all impact categories of about 30%.
- Whatever would be the scenario possibly implemented in a real case study this approach shows that the circularity model hard plastics for the recycling enables the production of a CB modifier that allows strongly improving the asphalt performance and durability with consequent environmental impacts mitigations in connection to road paving.

4. Conclusions

Road paving represent a relevant portion of the transport environmental impact in Europe. The investigated paving solution based on waste hard plastic recycling to produce a high performance asphalt modifier according to a circular model shows potential mitigation of the environmental impacts in all impact categories up to 70% average reduction. This is due to the performance driven effect of the plastic and grapheme based modifier-added bituminous conglomerate, which, according to the scenarios considered allows reducing the maintenance cycles and thus of material needed for road paving along the service time frame, or a material reduction proportional to the decrease of layers thickness.

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