

An environmental tour along the life cycle of the asphaltic roads.

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In the framework of the Spanish FENIX project and with the collaboration of companies belonging to the civil engineering sector, several studies have been carried out to obtain an environmental profile of the road, taking into account all the stages within its life cycle (excluding the indirect effect of the use stage). The potential technical and environmental improvements have been evaluated by means of the Life Cycle Assessment (LCA) tool. In this way, the environmental behaviour of the road section S122 (Spanish regulation) was obtained, identifying the most impacting stages of the life cycle of the road: the extraction/production of raw materials and maintenance operations. This fact allows the research of new strategies to reduce the impact on the roads, boosting areas of Eco-innovation as long life pavements and recycling techniques.

1 Introduction

One of the most important concerns in today's society is the protection of the environment, which has become a very important factor in business competitiveness. The civil engineering industry is no stranger to this trend, being constantly interested about the environmental improvement of their processes, looking for greater sustainability in their activities. Over 90% of the total road network in Europe has an asphalt surface. There are around 4.000 production sites

in Europe and about 10.000 companies are devoted to production and/or laying of asphalt.

These statistics, along with the importance of the sector in the actual society, lead many companies to try to improve their services to obtain products with a distinctly environmental profile.

The use of raw materials in road construction implies a great effort in resources availability, due to the amount of material needed and, in addition, some of the components have an important environmental impact, in particular binders (cement, bitumen). The opportunity offered by the maintenance operations, in which several parts of the pavement (bitumen and aggregates) are milled, can be exploited incorporating this milled material to new recycled asphalt mixtures, in different ratios, taking into account the new formulations and processes involved. In the framework of the FENIX Project, that represents the greatest effort in Research & Development carried out in Europe about road paving, a Life Cycle Assessment of a Spanish section (S122) has been carried out, taking into account potential improvements in the main life cycle stages.

2 Methodology and functional unit of the study

The functional unit (F.U.) of the studied system is “one meter long of a two-lane road (3,5 m each of them), including left (1 m) and right (2,5 m) shoulder, during 30 years”. The pavement consists of 25 cm of soil-cement base and 20 cm of asphalt mixture divided in three layers with different formulations (known as road section S122 according to the Spanish regulation) as it can be seen in the figure 1. Layers description can be seen in table 1.

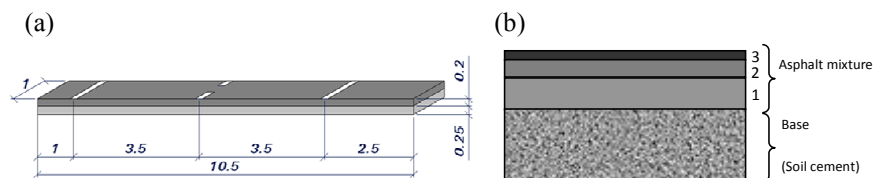


Fig.1: Functional unit definition (a) and S122 section profile (b)

The soil-cement base is performed mixing cement with soil from the quarry. This mixture is transported to the work site and extended over the platform. During construction works, two emulsions are incorporated (curing and pre-cracking emulsions). The soil cement is then compacted and in a few hours it is ready for the asphalt mixture incorporation. The asphalt mixture manufacturing process consists of the mixture of inert filler (aggregate) and a binder matrix (bitumen).

Tab.1: Section S122 description

Layer type	Composition	Nomenclature
Soil-cement	25 cm thickness 3% cement	SC
Asphalt layer 1	11 cm thickness 3,6% bitumen, limestone aggregate	G20 mixture
Asphalt layer 2	6 cm thickness 4,6% bitumen limestone aggregate	S20 mixture
Asphalt layer 3	Rolling surface layer 3 cm thickness 4,8% bitumen porfidic aggregate	M10 mixture

To ensure the correct asphalt agglomerate manufacturing, the aggregates need to be dried and reach a temperature around 160°C, so after the transportation from the quarry, aggregates are collected using a loader and they are put in the conveyor belts. The belts take the aggregates to the drier drum, which uses natural gas combustion to provide the aggregates the right processing temperature. Then, the aggregates are elevated using the lifts to the storage deposits, and after that they are weighted and screened to be introduced into the mixer.

The other asphalt mixture component, bitumen, is pumped from the tanks to the mixer. There is a heating oil circuit in the tanks and in the conductions from the tanks to the mixer, which heats the bitumen to obtain the appropriate fluidity, in order to obtain a better homogenisation process.

In the mixing unit, the aggregates are mixed with the bitumen and the mixture is collected in the trolley ready to be loaded on the truck to the construction site. The mixture reaches a temperature that allows it to be transported from the plant to the work site with the optimum temperature to be properly extended and compacted. In the figure 2 the life cycle stages included in the study can be seen.

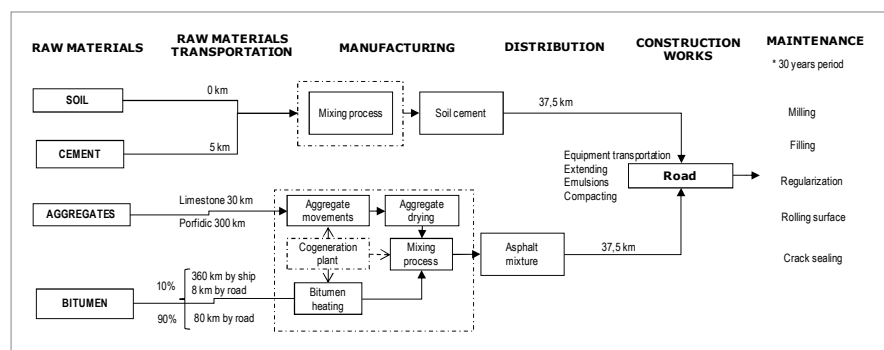


Fig.2: Life cycle stages in section S122.

The impact evaluation of the identified environmental loads has been developed following the methodological structure proposed in the international Standard ISO 14040:2006 [1]. SimaPro 7.1 was the software used in this study [2]. The impact assessment method selected was the Eco-indicator '99 E/E [3] that gathers the different assessment categories in three categories of damage:

- Human Health, devised as DALYs (Disability Adjusted Life Years). This damage category aggregates Carcinogenic effects, the Organic and Inorganic breathed particles, Climatic change, Radiation and Ozone Layer Depletion.
- Ecosystem Quality, related to the lost species in an area during a time period. Ecotoxicity, Acidification/Eutrophication and Land Use are included.
- Resources damages, according to the necessary energy for the future minerals mining and fuels extractions.

3 Results and discussion

The results, expressed by impact category, can be seen in the figure 3.

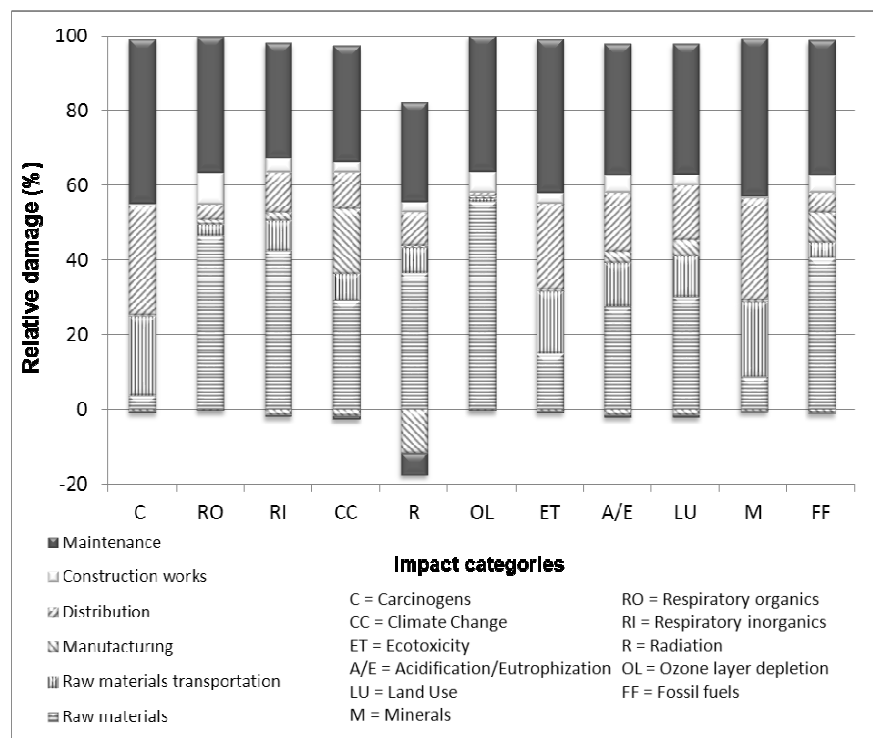


Fig.3: Impact category characterization of the Section S122 functional unit

Maintenance stage presents the higher values in Carcinogens (C), Climate change (CC), Ecotoxicity (ET), Acidification/Eutrophization (A/E), Land use (LU), and Minerals (M) impact categories. Raw materials is the stage with higher impact in Respiratory organics (RO), Respiratory inorganics (RI), Radiation (R), Ozone layer depletion (OL) and Fossil fuels (FF).

Raw materials transportation processes have relevance in Carcinogens, Ecotoxicity and Minerals impact categories.

Manufacturing stage presents a high value in the Climate Change category, mainly due to the CO₂ emissions produced in the aggregate drying process during asphalt mixture manufacturing. Avoided burdens can be seen due to the cogeneration plant. It exports electricity to the Spanish grid.

Construction works stage does not present high values in any category.

It can be seen clearly how Raw materials and Maintenance are the stages with the most important relative damage in all the impact categories.

The damages in the Human Health category can be seen in figure 4, showing the results per impact category and stage. The respiratory inorganics impact category is the most important one in this damage category and it can be checked again the importance of raw materials and maintenance stages.

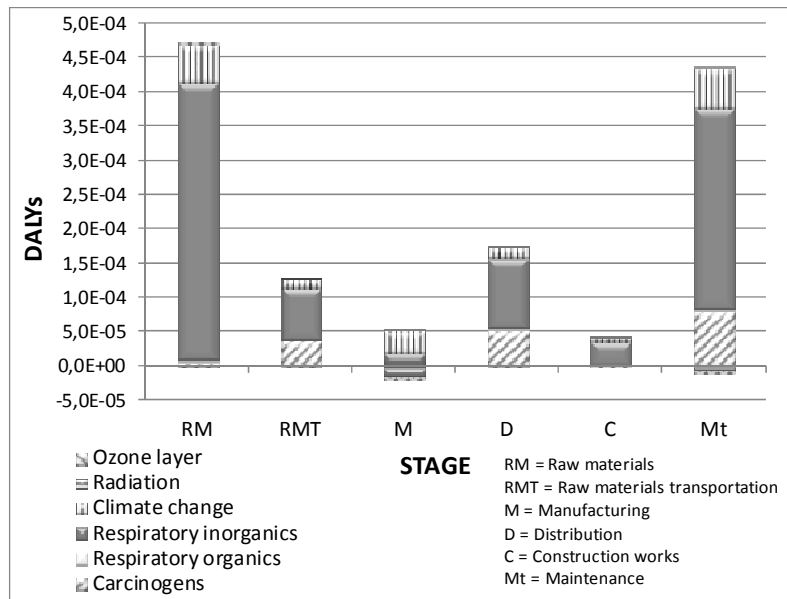


Fig.4: Human health damage in the road life cycle per functional unit

In the figure 5 the Ecosystem quality damage is represented. It can be seen how the Acidification/Eutrophization impact category presents the highest values, especially in the bitumen and cement contribution within the raw materials and maintenance operations in the rolling surface. High Ecotoxicity values in the Maintenance operations are also related to the rolling layer maintenance

operations. Rolling layer replacement has proved to be the most impacting maintenance process in the road.

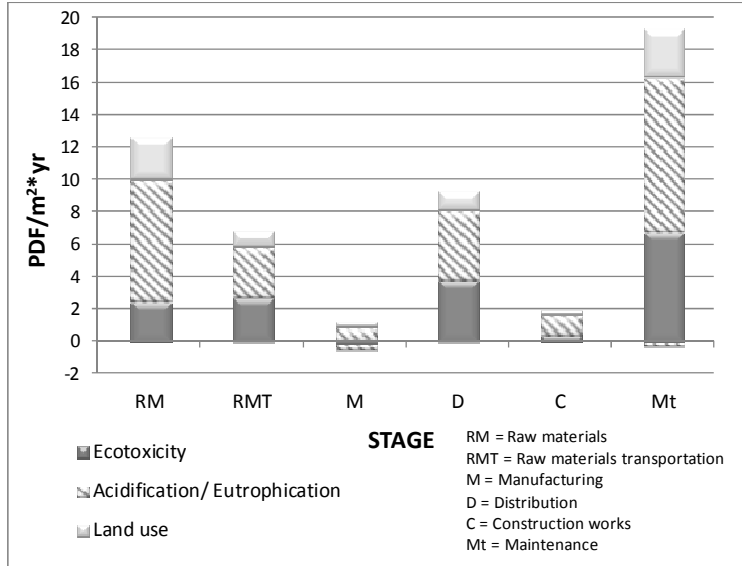


Fig.5: Ecosystem quality damage in the road life cycle per functional unit

Figure 6 shows the resources damage category.

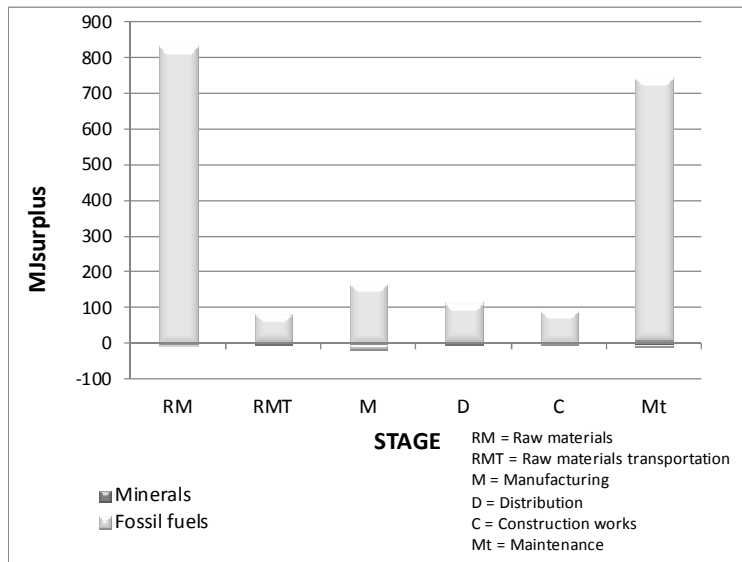


Fig.6: Resources damage in the road life cycle per functional unit

Raw materials stage presents again the highest impact, being Fossil fuels the main impact category. It is obvious, regarding the figures 3, 4, 5 y 6, how the impacts along the life cycle of the road provide from mainly two stages: raw materials and maintenance. So, the damage in these two main stages has been studied in detail.

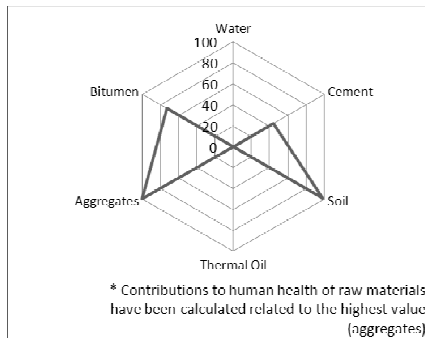


Fig.7: Contributions to human health damage of raw materials

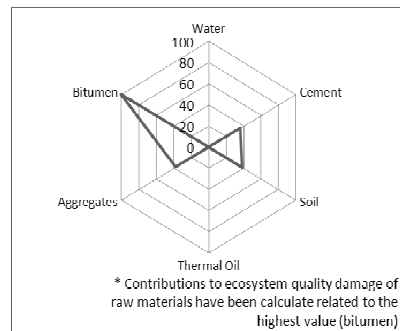


Fig.8: Contributions to ecosystem quality damage of raw materials

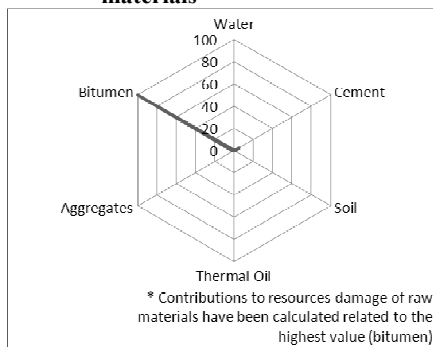


Fig.9: Contributions to resources damage of raw materials

The raw materials stage includes the extraction and conditioning of soil, cement, aggregates and bitumen (it is expressed in figure 2) and the contribution of each one is represented in figures 7, 8 and 9: The inorganic filler (aggregates and soil) is decisive in the Human health category, as bitumen is in Ecosystem quality and Resources.

Maintenance stage includes, for the assessment, five fundamental operations in the life cycle of the road: milling, filling, regularization, rolling surface and crack sealing.

- Milling operations are related to remove part of the asphalt mixture once it does not present the right properties to be used. The operation is quite simple, and it involves the use of a milling equipment and the transport to landfill or plant. Usually milled asphalt is used as fill material in roads and areas next to the road, to avoid transportation processes. According to the experience of some companies in the civil work sector, the scenario proposed for the milling operations was 9% of the heavy vehicles lane and 20 cm depth of milling. This operation is carried out once every ten years.

- Filling involves several operations. New raw materials extraction, transportation, manufacturing, distribution and construction works to fulfill the previously milled material. It only involves new asphalt mixture (the soil cement base does not suffer any maintenance operation). As it has been reported before, this process is developed only in the heavy vehicles lane.
 - Regularization is related to the contribution of new asphalt mixture in the 5% of the road (including the two principal lanes and the shoulders). The average depth of this adjustment is 4 cm.
 - Rolling surface implies the incorporation of a new rolling layer over the two principal lanes and shoulders (100% of the road surface). It implies, as filling and regularization, the five previous stages (raw materials, transportation, manufacturing, distribution and construction works) for a 3 cm depth new rolling surface.
 - Crack sealing is related to the fissures filling operations. For the S122, one meter of crack is supposed to be sealed.
- As it can be expected, rolling surface is the most important of the five operations carried out during maintenance stage.

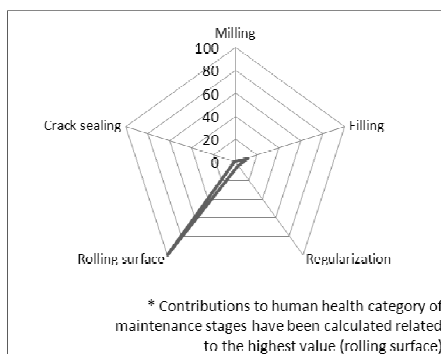


Fig.10: Contribution to human health of maintenance stage

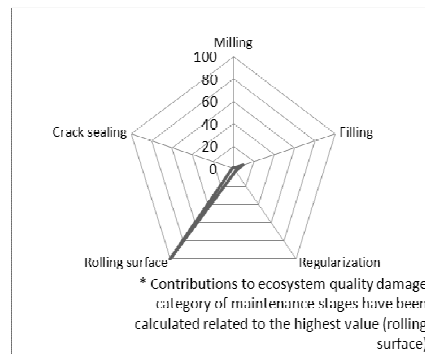


Fig. 11: Contributions to ecosystem quality damage of maintenance stage

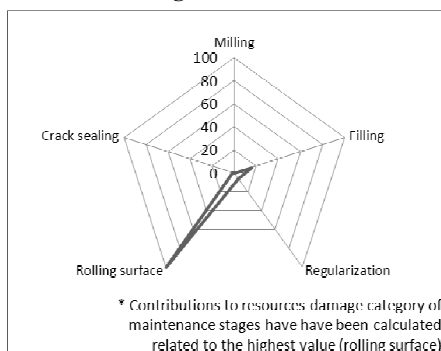


Fig.12: Contributions to resources damage of maintenance stages

The contribution of each operation to the three categories of damage is shown in figures 10, 11 and 12 and undoubtedly the problematic stage is rolling surface maintenance. It is responsible of a high percentage of the damages related to this stage and that is the reason why it becomes critical in terms of impacts on the life cycle of the road.

Therefore, from an environmental point of view, it is a key point to give priority to actions associated with raw materials for the bituminous mixture and with rolling surface maintenance operations, in order to contribute to the reduction of impacts on the life cycle of the road. These improvements are widely developed in the framework of the Fenix project.

4 Best practices proposed

As it has been reported in the previous section, the raw materials and Maintenance stages provide the highest values in the three damage categories.

The efforts made in this study were focused on environmental improvements in these two key stages, without putting the technical characteristics of the road at risk. To obtain a better environmental profile in the Raw materials stage, recycling processes have been included. 30% of asphalt mixture from milling has been included in the asphalt mixture performing (only in the G20 and S20 mixtures, M10 is the same as in the traditional scenario). This recycling technique implies a slightly increase in fuel consumption in the manufacturing process and some changes in the transportation of raw materials. The recycled fraction (composed by aggregates and bitumen) replaced virgin aggregate and virgin bitumen, with the help of an additive that improves recycled bitumen binder properties.

In the other hand, during the design process of roads, several technical specifications for construction and maintenance plans for conservation must be met. The incorporation of surface layers of special features (higher percentage of bitumen) offers greater pavement durability, making maintenance operations decrease. In this case, the incorporation of SMA rolling layer (instead of M10) can diminish the rolling layer maintenance operations (rolling surface and crack sealing), and a scenario of 50% diminished has been selected.

Three scenarios have been compared, taking into account all these considerations (table 2).

Tab.2: Studied scenarios of section S122

Scenario	Description
0	Traditional S122 section
1	30% recycled S122 section
2	SMA rolling layer S122 section

The results of the three studied scenarios can be seen in the figure 13, where the three damage categories has been assessed and represented to verify the final environmental results of the potential improvements chosen.

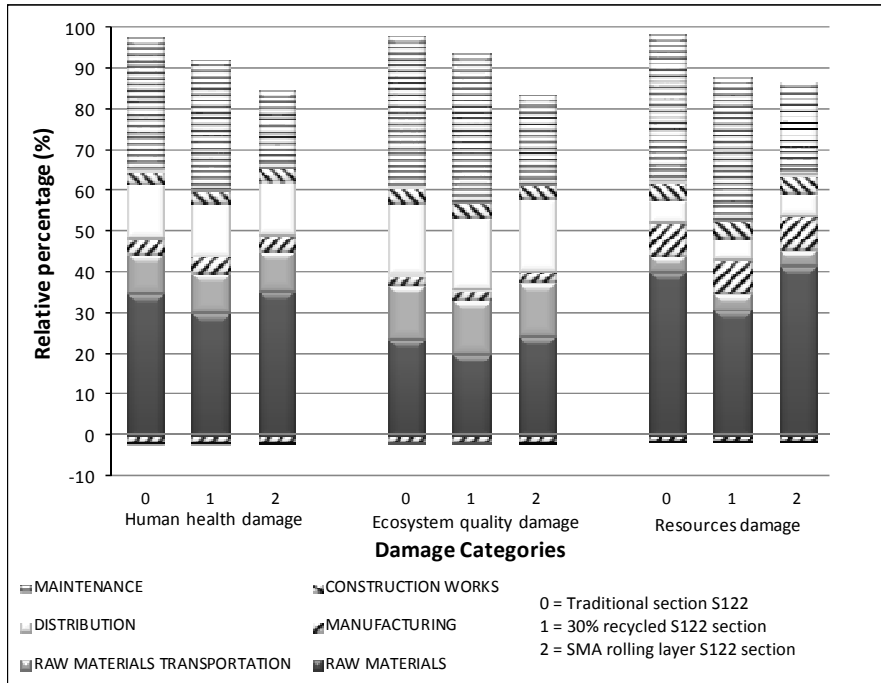


Fig.13: Comparison in the three damage categories between a traditional section of a road and two improvements studied in the Fenix Project (recycled material and SMA rolling layer)

Evaluating the results per stage, it can be seen an important improvement in the Raw materials stage in the recycling scenario 1 in the three damage categories over the traditional scenario 0. However, the inclusion of higher content of bitumen and fibres in scenario 2 (SMA rolling layer S122 section) implies higher damage the three damage categories in the raw materials stage.

There no relevant differences in the three scenarios in the transportation of raw materials, distribution and construction works stages. A slight increase in the manufacturing stage in the scenario 1, due to higher energy needs in the aggregates temperature, but is almost negligible.

In the Maintenance operations, the best results appear in the scenario 2, due to the lower maintenance operations needed.

There is also a slight decrease in the recycled scenario 1 comparing to traditional one. The new asphalt mixture needed in the maintenance operations is also manufactured with a 30% recycling ratio, which diminish damages.

5 Conclusions

In this paper, the environmental behavior of a road section S122 (according to the Spanish regulation) has been reported, identifying the worst environmentally friendly stages in the life cycle of this road product (Raw materials and Maintenance). This fact allows the research of new strategies to reduce their impact, boosting areas of improvement such as long life pavements, able to diminish maintenance stage.

The use of 30 % recycling ratios appears to be a good option in the global damage reduction, as it decreases the contribution of the two main stages with no relevant damage migration between stages.

Small improvements made in the design stage, as it is the incorporation of long life surface layers (SMA rolling layers), have provided the road better environmental properties, thanks to the significant reduction of impact on the maintenance phase. Although section including SMA surface layers presents higher damage at the stage of raw materials, these are largely offset due to the decrease in maintenance.

LCA from the design stage, taking into account the whole life cycle of the product, proves to be a very important tool in order to obtain good results from the environmental, economic and even security point of view in the operations related to roads and pavements.

6 Acknowledgments

The authors would like to thank all organizations and companies involved in the project FENIX: CIESM, Centro Zaragoza, Collosa, Ditecpesa, Elsan, Inrame, Pavasal, Repsol YPF, Sacyr, Servia Cantó, Sorigué, CARTIF, CEDEX, CIDAUT, CSIC (IIQAB) GIASA, INTROMAC, Labein, Universidad de Alcalá de Henares, Universidad Carlos III de Madrid, Universidad de Castilla La Mancha, Universidad de Huelva, Universidad de Cantabria, Universidad Politécnica de Catalunya, Universidad Politécnica de Madrid, and the many collaborators whose working capacity is enabling the development of this project in a cooperative atmosphere.

Funded by CDTI (MICINN). Spanish Government [4].

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