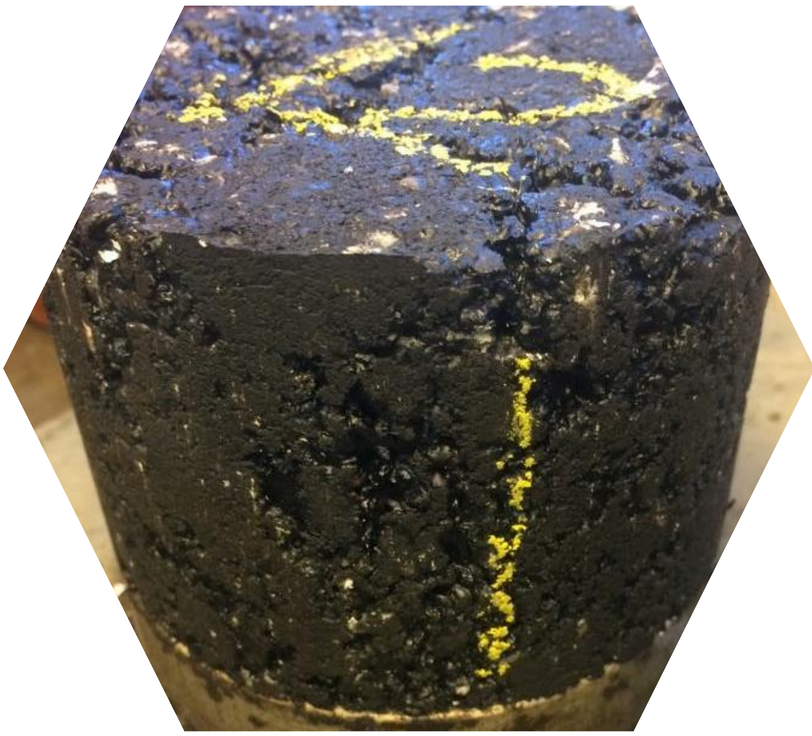
Literature review

Plastic Utilization in Road Base Course

Plast í Burðarlög - Verkþáttur fyrir Slitlög



About the report

Title:

Plastic Utilization in Road Base Course

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Efnisyfirlit

1 Introduction

It is estimated that 32 000 tons of plastic were produced in Iceland in 2019, of which 55.3% was packaging plastic. 68.4% ended up in a landfill or did not undergo waste processing (Desjardins, 2021; Hagstofa Íslands, 2021). Therefore, there is still a need to find a method to reuse or recycle non-packaging plastics as they are not being valorised.

For the past years, asphalt mixes with plastic waste have been studied in Iceland (Guðrún Fjóla Guðmundsdóttir, 2021). A positive correlation between the percentage of plastic waste and Marshall stability has been demonstrated and the results of the rutting tests showed excellent resistance to rutting. Also, the results of adhesion tests, Marshall sigs, porosity, Prall and water sensitivity were within normal limits. However, the formation of microplastics from road wear is a definite problem, whether it is recycled or new plastics.

Since base course asphalt is not in direct contact with traffic, such as pavement, it is proposed to assess the effect of plastic waste as an additive in base course asphalt and whether it presents technical and environmental benefits for road construction.

1.1 Goal and scope

Due to lack of resources, it was not possible to fulfil within this project a laboratory testing campaign to test the use of plastic waste in the base layer of road construction. Instead, it was proposed to work on a literature review and describe the necessary steps to further investigate the potential of such application.

The purpose of the study is to describe how plastic waste can be used in base course asphalt. Initially the research aimed at answering the following questions:

- What are the environmental impacts of using plastics in the base course?
- How can plastic waste be mixed into the base layer asphalt?
- What type of plastics are the most desirable to reinforce the asphalt in the base course?

The expected result is that the analysis supports knowledge regarding the use of plastic waste in structural layer asphalt. If successful, the research may result in increased plastic recycling in Iceland and support the development of the circular economy concept applied to road construction.

2 Background

2.1 Road structure

A typical road structure is composed of multiple layers, with each having a specific role in insuring structural stability and traffic safety over the lifetime of the road. An overview is given below in Figure 1 (Vegagerðin, 2022a).

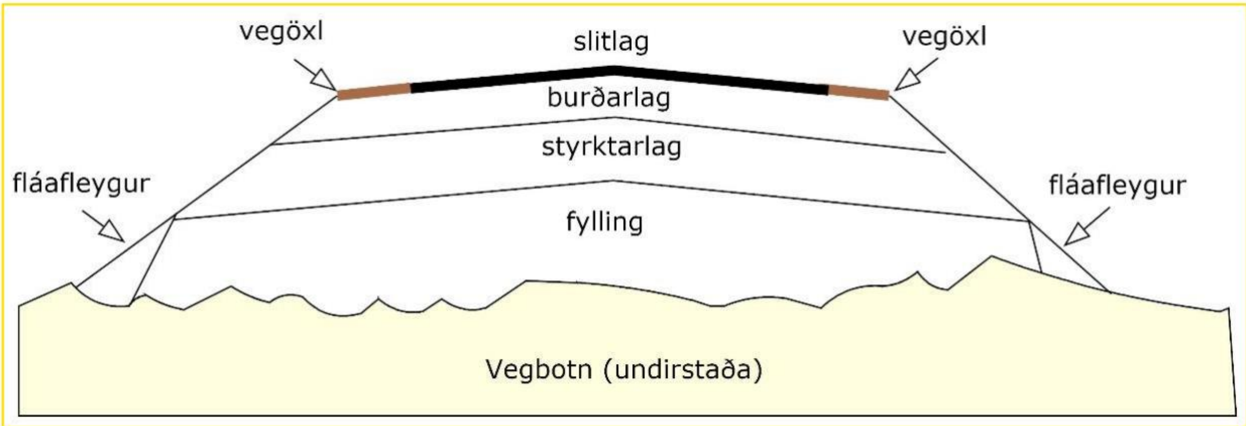

Figure 1 - Road layers of a typical road in Iceland

The **Subgrade ("Vegbotn")** is the soil already existing at each location and is compacted. The **Subbase ("Fylling")** is made from material existing in the surrounding area which is pressed to even out the surface of the subgrade and obtain the right height for the road.

On top of the Sub-base course comes the Base course. There are two categories of base courses

- The **lower base course** ("Styrktarlag")
- The **higher base course** ("Burðarlag")

Both are used to transfer the load from traffic to the lower layers. The base course is made stronger compared to the subbase and prevents the deformation of the surface course.

Finally, the **Surface course ("Slitlag" or Pavement)** ensures a firm and even layer for vehicles and should minimize skidding and withstand tears for example from spiked tires. It must function in all weather conditions (frost, snow, rain, sun, etc.). It can be non-bound or bound depending on the traffic conditions.

All layers are made out of material that must let water drain, so it does not accumulate over time except for the wearing course that has to be as tight and non-permeable as possible to avoid water going into the lower layers. All courses must be resistant to frost that may occur.

Different amounts of road material are used in each layer. To give an example of the different magnitudes of aggregate used in each layer, in Iceland in 2008 the total amount of material used for road construction was

5 million cubic meters of which approximately 77% was used for the sub-base layer, 21% for the base course and 2% for the wearing course (Vegagerðin, 2022a).

2.2 Asphalt production

Description of the Asphalt mixture and production are not included in this report as they are considered common knowledge in the field. Only specific aspects of asphalt production are presented in this background section to help the reader to understand the challenges to use plastic additives.

2.2.1 Production temperature

Most widely used asphalt mix is Hot Mix Asphalt (HMA- 140-190°C). The HMA has superior performance and lower initial cost compared to other asphalt mixture temperatures. However, it requires more heating and has therefore a bigger environmental impact with higher Greenhouse gas (GHG) emissions during production.

The second category is Warm Mix Asphalt (WMA – 100-140°C) which has gained in popularity the last two decades. With temperature lower by 20-40°C compared to HMA, it makes it possible to use organic and chemical additives and water foaming techniques. If the manufacturing temperature is below 100°C, we talk about Half Warm Mix Asphalt (HWMA – 70-100°C). HWMA is found to have performance as good as HMA and even better in some cases.

The third category is Cold Mix Asphalt with manufacturing temperature 0-40°C. CMA is used in minor construction and repair works. Because of its low temperature, CMA requires significantly less energy for production and less investment in equipment. On the other hand CMA have lower early life strength, higher voids and higher moisture susceptibility (Jain & Bhupendra, 2021).

2.2.2 Types of plastic additives

Low-grade waste plastics in asphalt have been rapidly developing and notably used in India, Iran and China (Polacco et al., 2005). Different types of plastics have been investigated individually as enhancers for asphalt (Tuncan et al., 2003).

The addition of Polyethylene (PE) to asphalt has been researched in the range of 0-12% of the weight of bitumen, heated to temperatures well above the typical softening point of HDPE and LDPE. The results of using PE are promising with decreased pavement deformation and increased Marshall stability, where HDPE is responsible for the increased impact resistance and LDPE for good abrasion resistance (Huang et al., 2007; Polacco et al., 2005; Vasudevan et al., 2007; Yildirim, 2007).

Polypropylene (PP) has notably higher softening temperatures than the other five polymers. This fact has the complications that the size of the PP particulates needs to be small enough (3-4 mm), the aggregates hot enough (170-190°C), or the mixture mixed long enough (additional 1-30 sec) for the polymer to melt, all solutions requiring more energy. However, the research results made with PP give a good adhesion between bitumen and aggregates and increased Marshall stability (Vasudevan et al., 2007;

Yildirim, 2007). Polyvinyl chloride is non-applicable to asphalt because PVC releases hydrogen chloride (HCl) upon combustion coupled with the risk of exposure during the laying of asphalt (Verma, 2008).

One study was found on the use of plastic bottles (polyethylene terephthalate, PET) in asphalt using 6% plastic to the weight of bitumen (Sangita et al., 2011) which found an increased Marshall stability and increased void. Only one study was found. Similarly, one study of polystyrene (PS) in asphalt (Polacco et al., 2005) found increased Marshall stability using less than 15% of plastic to the weight of the bitumen.

2.3 Waste-polymer enhanced asphalt in Iceland

A major research project was carried out by ReSource International in Iceland during 2018-2020. The project included literature review, laboratory test campaign and road laying in pilot scale of waste-polymer enhanced asphalt in Iceland. Major results from the laboratory testing campaign are presented in this section (Guðrún Fjóla Guðmundsdóttir, 2021).

2.3.1 Asphalt composition

The asphalt tests were conducted in laboratories owned by private and public operators. Choice of material, mixing, density measurements, Marshall compaction and Marshall compression test were all performed according to standards ÍST EN 12697-1, -5, -6, -22, -30, -33, -34, and -35.

The types of waste plastics used were determined by examining the composition of Icelandic based nonrecyclable mixed waste-plastics, containing; **10% high-density polyethylene (HDPE), 35% low-density polyethylene (LDPE), 40% polypropylene (PP) and 15% polystyrene (PS)**. These plastics were shredded to 3-5 mm size pieces and mixed in with hot aggregate before adding bitumen to the mixture. The method is referred to as the polymer-coated aggregate (PCA) method (Vasudevan et al., 2007). It differs from the polymer-modified bitumen method in that the plastics are not melted together with the bitumen before mixing.

The starting temperature of the aggregate was between 150 to 170°C, plastic particles at room temperature (19-24°C) and bitumen between 150-170°C, mixed for around 300 seconds in a stand mixer in an asphalt research facility. Tests were chosen in accordance with the demands of the Icelandic Road and Costal Administration (IRCA) and include void content, Marshall test, wheel-track performance test, Prall abrasion test and water sensitivity. In addition to the standard tests, a microplastics test was performed using fluorescence counting.

2.3.2 Results and conclusions

The addition of waste polymers can be used as enhancers for bound asphalt. Despite the increased void content, the rut resistance of the asphalt was stable, the Marshall flow of the replicates did not increase, and the stability increased by up to 85%. The waste-polymer enhanced asphalt also passed tests regarding water sensitivity and adhesion test. These results indicate that a waste-polymer enhanced wearing course will have good water drainage, low noise pollution, durable tire wear, and a high breaking threshold. In conclusion, local waste plastic can be sampled, sorted, and analysed, cleaned and shredded to 4 mm pieces, and used for asphalt using traditional machinery and methods. Using waste polymers in asphalt helps to:

- Reduce the need of bitumen in asphalt
- Increase performance and strength of asphalt
- Avoid incineration, landfilling and non-proper treatment of plastic waste
- Increase value of plastic waste
- Promote clean-up in plastic-polluted areas
- Develop the circular economy model.

2.4 Plastic waste in Iceland

A flow analysis carried out for the past decade indicated that 31,644 tons of plastic were produced in Iceland in 2019, of which 55.3% was packaging plastic. 68.4% ended up in a landfill or did not undergo waste processing (Desjardins, 2021; Hagstofa Íslands, 2021). It is estimated that around 35-40 thousand tons of plastic are produced as waste per year in Iceland. The majority of this is plastic packaging (~98%), but in 2018 around 9 thousand tons of plastic packaging and 540 tons of non-wrapping plastic were collected. Plastic waste that is not packaging is of particular interest because it is less likely to be recycled.

3 Results

3.1 Waste polymer sourcing

To offer a recycling or even upcycling alternative, the method developed should consider fractions of plastics that are not recycled today in Iceland. Furthermore, the selected fractions must be chemically compatible with asphalt production.

There are several reasons why plastic waste might not be recycled in Iceland. Plastic recycling requires proper source sorting to increase quality of the fraction and washing/shredding/drying/pelleting steps so that fractions can be further processed by the plastic industry (Giustozzi & Boom, 2021).Furthermore, there is only one known plastic recycling facility that recovers and transforms into pellets some type of hard plastics (*Pure North - Endurvinnslan*, n.d.). The situation forces waste management companies or waste producers to export their plastic waste abroad. However, increasing costs will likely make it non-economically or technically feasible to export, thus landfilling or incineration might become a preferred choice (Umhverfisstofnun, n.d.)

If an industry in Iceland such as road construction would need a stable supply of plastic waste of a specific type, it will allow waste companies to develop a new stream and business.

For small scale recycling markets, plastic recycling as virgin plastics requires that plastics have kept their mechanical and chemical properties (Giustozzi & Boom, 2021). The proposal to use plastic waste in waste polymer enhanced asphalt, reduces this barrier as the waste plastic is considered for its properties at the chemical (polymer) level and not as a commercial plastic.

As previous work from ReSource International indicated, the proposed fractions of waste polymer should fit with the nonrecycled waste-plastics available in Iceland i.e. non packaging plastics such as:

1. High-density polyethylene (HDPE)
2. Low-density polyethylene (LDPE)
3. Polypropylene (PP)
4. Polystyrene (PS)

PVC is excluded due to too high toxicity during the melting process.

3.2 Plastic addition into asphalt

There are mainly two approaches to incorporate recycled plastics in asphalt mixtures (Mushtaq et al., 2022).

1. Polymer-coated aggregate (PCA) method (Vasudevan et al., 2007) where aggregates are mixed with plastics before being mixed with asphalt, also called dry process. This method fits all types of plastics and enhances the rutting and moisture resistance of asphalt pavements (Ma et al., 2021).
2. Polymer-modified bitumen (PMB) method where plastics are melted together with the bitumen before mixing with aggregate, also called wet process. Plastics must be shredded into powders and mixed with hot asphalt binder. Plastics with relatively low melting points, especially PE are considered suitable for wet processing (Ma et al., 2021)

3.2.1 Wet method

When recycled plastic-modified binder is used to prepare asphalt, the addition does not have an adverse impact on the compactability and moisture resistance of the asphalt mixes, which improves both in cracking and rut resistance. Wet method however requires other additives to be used to provide storage stability and reduce viscosity (Ma et al., 2021).

3.2.2 Dry method

The compactability of the plastic-modified asphalt mixes with the dry method is affected by the amount of recycled plastic used and its size and shape. The moisture resistance is not affected by adding plastics. The cracking and rutting resistance of the mixes is slightly enhanced with plastics (Ma et al., 2021).

3.2.3 Melting temperatures of plastics

The use of waste-polymer requires that the plastic waste is melted, whether it is applied with the aggregates, mixed with the bitumen or melted with solvent. General melting temperature for the proposed plastics is given below (Xu et al., 2021):

Table 1 - Melting point range of different plastics waste

Materials	Melting Point Range (°C)
HDPE – High-Density Polyethylene	130
LDPE – Low-Density Polyethylene	110-120
Polypropylene	145-165
Polystyrene	210-249

3.3 Application to base course

There are two categories of base courses

- The **lower base course** ("Styrktarlag")
- The **higher base course** ("Burðarlag")

The lower base course is made of fine aggregate and compacted. In some cases, the higher base course ("Burðarlag") is bound with asphalt or concrete. This study focuses on the use of asphalt in the higher base course.

Literature on plastic additive in asphalt focuses usually on asphalt and the impact on its properties. It is therefore important to understand the difference between requirements between the surface course and the asphalt bound base course.

British standards for road asphalt mixture are different for Stone Mastic Asphalt (BS EN 13108-5:2016) i.e. surface course and Asphalt Concrete (BS EN 13108-1:2016) i.e. base course. Furthermore, the criteria of the road performances for the course base are defined by the traffic density the road will be under. A description of the tests required by the Icelandic Road Authorities is given for asphalt bound base course (Vegagerðin, 2018).

Addition of plastic waste into asphalt for the production of the base course is reported possible (White & Reid, 2018) but is widely dependent on the material used by the local industry. Therefore, laboratory testing using Icelandic production standards is required to assess the final performance of the base course. Technical feasibility of mixing plastic waste during production has already been proved (Guðrún Fjóla Guðmundsdóttir, 2021).

3.4 Environmental benefits

3.4.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a versatile and standardized tool to investigate the environmental aspect of a product or service. It usually includes the so-called life cycle i.e. from cradle (raw material extraction) to grave (disposal). In some cases the methodology is applied only to certain steps of the life cycle. For example, in road making, some studies include results from raw material extraction to laying down the road, focusing on different production scenarios but omitting effect on the use phase of the road or the disposal phase (Butt, 2014).

After the scope definition and the life cycle modelling using real data or extrapolated data as input, it is possible to quantify the environmental impact of the product within several impact categories and for each of the different life stages. LCA is used to identify the environmental hotspots within a system and support designers taking decisions in product development.

The earliest study of using LCA in pavements was in the 1990's. Since then, a lot of knowledge and data have been developed and reviewed. Literature compares different types of pavement/road structures e.g. concrete vs. asphalt or different recipes such e.g. different asphalt mixtures (Butt, 2014).

From the literature, LCA on road pavement present different depths, quality and conclusions because they use data sources which differ significantly in quality. It is therefore important when considering LCA results for comparison to use similar scenarios from the reference.

3.4.2 LCA framework and scope

In order to assess the environmental impact of the road, it is important to clarify the scope of the LCA framework. As this study focuses on asphalt road construction, it was chosen to look at LCA application for asphalt roads only. The figure below shows an example of LCA framework developed for decision support with a focus on energy and GHG emissions for the environmental impact category (Butt, 2014).

Considering for the whole life of the road, the fuel, electricity, constructions materials, recycled materials and pavement life prediction and design will affect the outputs of the study. Main outputs of the LCA framework are quantification of airborne emissions, waste, recyclable materials and energy use.

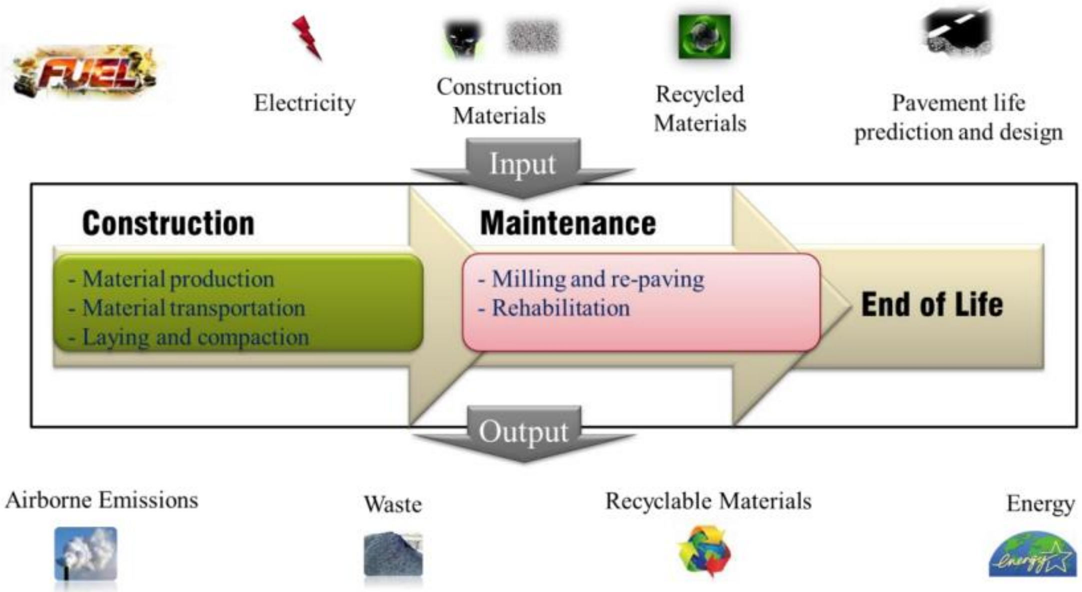

Figure 2 - LCA Framework for apshalt road

3.4.3 Conclusions from LCA

Following the LCA framework proposed (Butt, 2014), it is proposed that the following aspects should be considered when using plastic waste into the base course:

System boundaries: if additives are to impact the durability of the road, then the whole life cycle of the road should be considered i.e. including use phase.

Production: Within the material production, asphalt production is found to be the most energy consuming process as high temperatures are required to dry the aggregates, melt the bitumen and additives and for mixing and storing. If plastic waste is to be added in the base course asphalt, the increase in energy use as to be compensated by other environmental benefits.

Transportations of material: Sourcing as local material as possible is key for reducing emissions related to transport. This is relevant for all material input such as aggregates but also for transport of the prepared asphalt to the road construction site.

3.4.4 Other impacts

Even though LCA is a strong and holistic tool helping with quantification of environmental impacts, it does not include all potential impacts.

A particular one has increasing interest for the last past years is microplastics. As plastics are degrading into smaller and smaller pieces over time they tend to decrease in size (macro plastics and then microplastics) to accumulate in the food chain and the environment. Therefore, plastic recycling is not only important for resource depletion and energy use but also finding ways to use plastics in short circuit will help avoiding plastic littering during transport or landfilling.

Furthermore if plastic are sent to landfills, as they hardly degrade, they take up land and create a long term issue with the biodiversity but also local community and economics related to land utilisation (Castro, 2014).

3.5 Cost benefit

In order for the method to be developed and sustained, the performances of the asphalt should be equivalent at lower cost or improved for similar cost. Therefore, processing plastic waste and using it in asphalt production must compete against comparably performing technologies.

In their study, White & Reid discussed the use of plastic waste imported from the UK in Australian roads. They found that using 6% plastic additive would decrease the need for regular binder. In addition of looking at physical properties of the asphalt, they also looked at the economic impact. Results are shown in the table below:

Table 2 - Estimated saving per tonne of asphalt binder using waste plastic at 6%. A20E is the asphalt mixture used for base course in Australia. (White & Reid, 2018)

Saving for 6% replacement	MR6 for A35P	MR6 for M1000	MR10 for A20E
Binder supply (per tonne)	$470	$130	$410
Binder supply	35%	12%	30%
Asphalt raw materials	12%	4%	10%
Produced asphalt ex-bin	9%	3%	8%
Paved and finished asphalt	5%	2%	4%

The direct cost benefits of the plastic waste is the reduction of other expensive additives or binders at similar road performances. The study also emphasized the shipment costs of some products. As Iceland depends largely on imported materials it is likely that the cost of local plastic waste is lower than imported binders. However no sufficient local plastic waste stream is commercially available at the moment in Iceland, and a comparison is hard to do at this stage.

4 Conclusions

4.1 Technical feasibility

In a similar fashion that plastic waste addition was studied for asphalt pavement production (Guðrún Fjóla Guðmundsdóttir, 2021), it is proposed that plastic waste addition is tested on asphalt base course based on the same conditions the industry is using in Iceland.

Asphalt testing should include the addition of different amount and/or composition of plastic waste in the asphalt mixture. Test will be carried out based on industry standard and the properties should be assessed against the Icelandic Road Authority's criteria (Vegagerðin, 2022b).

4.2 Environmental impact

In this study several environmental aspects were pointed out regarding the use of plastic waste into asphalt mixture and how they are affecting LCA results and the environmental impacts. However, LCA results are mainly dependant on the scope definition.

In order to correctly assess the benefits of using plastic additive, it is proposed that a comparative LCA is done using Icelandic conditions between a regular asphalt paved road and an asphalt road using plastic additive in the base course higher layer.

4.3 Economic impact

Plastic waste is produced within Iceland from already imported plastic products. By using plastic waste in structural layers, and if the additive can replace asphalt material or increase life expectancy of the road, currency could be saved. It also makes road construction less sensitive to shortages of raw materials from abroad, which in recent years markets have seen shortages or inflation of goods and fuel due to epidemics and wars.

An economic impact assessment should be carried out on the use of plastic in the road industry in Iceland in order to properly assess the benefits of these additives from the economical point of view.

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