Study concerning the conception and construction of Long-Lasting Flexible Pavements

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Abstract. The paper presents the current state of Long Lasting Flexible road pavement design, which is characterized by permanent development, both in terms of the calculation scheme that can reproduce as accurately as possible the actual operating behaviour and also in terms of more efficient materials usage. The research has shown that these types of flexible, well-designed and executed road pavements could have a longer lifetime than classical ones. In the same context, the energy performances and the Global Warming Potential, related to the construction and maintenance of Long-Lasting Flexible Pavements, calculated using a Life Cycle Assessment approach, are given, in order to substantiate their ecological advantages compared with a classical road pavement. This paper emphasizes the necessity to adopt appropriate constructions alternatives for road pavements, also within the initial construction phase, as well as within their maintenance and intervention stages, in order to have a sustainable build environment. In conclusion, roadwork and recent research have shown that Sustainable road pavements, known also as Long Lasting Pavements could be designed and built, resulting in significant material savings and, therefore, low maintenance costs with high performance and significantly longer service life compared to classical road pavements.

1. Introduction

The transportation system represents a significant key component of the current development process. Besides the positive effects correlated with the continuous development of transport system a wide diversity of, mostly negative impacts are also produced. Taking into account the actual high levels of pollutions worldwide, the current goal is to achieve a sustainable development for the transport systems. Given the accelerated increase of vehicle fleet and the extensive development of the road network, the paper concentrates on the construction of road transport infrastructure. The development processes within this area implies the productions of a wide range of externalities. These refer to ecological impact, lithographic materials depletion, energy and fuel consumption or ecosystem equilibrium disruption, social and economic impact [1]. In order to tackle these externalities, sustainable and eco-friendly transportation policies and practices have to be promoted worldwide. Recent research has shown a direct link between transport development and climate change, high levels of pollution and depletion of lithographic resources. In this context, it is essential to make changes, take appropriate measures and promote low carbon mobility, given that these are fundamental features for a sustainable future and competitive urban areas. Taking into account the actual high levels of pollution and the fact that, based on the studies performed by the European Commission, transport activities have been proved to be
responsible for almost 32% of Europe’s energy consumption and 28% of total CO\textsubscript{2} emissions [2], the development of sustainable road construction technologies and processes has become more and more important.

In addition to the initial construction of the road pavement, the maintenance and rehabilitation phases, are major factors in the increase of greenhouse effect. The aim of this paper is to study the approaches, which could be taken for the transition to low carbon mobility, in regards with the new technologies, which support this transition, namely the construction of Long-Lasting Flexible Pavement. The results obtained are envisaged to be assimilated and implemented in the actual policies and strategies adopted for the North East Region of Romania.

Low carbon mobility is characterized through specific actions correlated to the transportation system, which results in significantly reduced consumption of non-renewable materials and smaller quantities of pollutant emissions released in atmosphere and also, to an increased service life. These actions or measures refer to the new technologies and processes encouraging this transition, specific policies developed for their implementation, as well as the human behaviour and daily personal choices [3].

Thus, the paper presents the new developments correlated to the transport infrastructure towards low carbon mobility, which consist in designing and construction of Long-Lasting Pavements, road pavements characterized by an initial service life of forty or more years. These road pavements are a safer, an efficient and more environmentally friendly road structures alternatives and are capable to withstand unusual actions without suffering major faults and without losing functionality [3]. Furthermore, they are characterized by low maintenance costs with high performance and significantly longer service life compared to classical road pavements. These new concepts and construction technologies, developed recently, in the frame of Technical University Gheorghe Asachi of Iasi, such as Long Lasting Flexible Pavements (LLFP) [4], [5] involving new concepts of road pavements, will extend the life of asphalt roads from twenty-five to fifty years, thus contributing to significantly reduced costs and emissions, during the construction and maintenance processes. In Romania, the design and the construction of durable pavements, started with the direct involvement the Strategic Highway Research Program [6] designed to evaluate the performance of Romanian pavements and to enhance its pavement performance prediction models, being over 30 LTPP test section in the Romanian program, including asphalt and concrete pavements situated in specific rural and urban locations. One of such RO-LTPP sector, considered as a typical Romanian pavement with extended life, its envisaged design life being of forty to fifty years, is localized on the national road DN 12A – Miercurea Ciuc – Onesti, km. 30+000 – 30+150 and it has been built twenty-seven years ago [7]. Another example of a Long-Lasting Pavement constructed in the North East Region of Romania is represented by the sector build on the national road DN 17 Suceava – Vatra Dornei using a sustainable rigid pavement reinforced with steel fibers, recovered from post-consumed tires, as a part of the EU collaborative research project EcoLanes [3].

As a response to the actual ecologic and economic problems arisen from the use of fossil fuel and lithographic materials, the Long-Lasting Flexible Pavements contributes to the following:

- An efficient and effective transport network to make the North East Region of Romania internationally competitive;
- Urban congestion solutions;
- Increased service life and low costs for maintenance in addition to materials saving and overall a smaller carbon footprint.

The implementation of Long-Lasting Flexible Pavement could be achieved progressively starting with research and experimental road pavement construction (end user) and moving forward to the regional level. This could be performed based on appropriate management decisions through close collaboration between research institutes, technology progress, decision-makers and people, the development of norms and regulations, and training courses regarding the design, construction and maintenance of these types of road pavements. At regional level, the low carbon mobility can be implemented through research programmes, standards and accreditation for carbon reduction products and services regulations, experimental road pavement construction, planning guidance and incentives.
2. The design of Long-Lasting Flexible Pavements

The current state of flexible road pavement design is characterized by permanent development, both in terms of calculation scheme that can reproduce as accurately as possible the actual operating behaviour and in terms of more efficient usage of materials.

The main role of road pavements is to support the traffic loads and to transmit them to the foundation soil without suffering irreversible deformations during their exploitation period, followed by distresses that affect their functionality. Consequently, the road pavement design requires to establish the stresses and strains of the actions to which the structure is subjected in exploitation in order to assess the structural response and to ensure high reliability. Compared to other types of construction, road pavements have the particularity of being designed to fail after a certain period of operation of the road. Nowadays, due to the possibilities offered by automated methods of road pavement design, a number of simplifications can be used. The calculation objectives are to determine the strains and displacements in a spatial computing model, taking into account both the non-linear behaviour of the materials determined by experimental tests and the degree of cooperation/adhesion between the component layers of the road pavement. It also takes into account the dynamic loads, the optimization of the road pavement as a whole and its component elements [8].

Sustainable road pavement ("Long Lasting" or "Perpetual Pavements") have been designed since the 1960s. Research has shown that these types of flexible, well-designed and executed road pavements, can have a longer lifespan than conventional ones [9]. Many of these road pavements are the product of "full-depth" design of asphalt pavement that are built directly on foundation or "deep-strength" soil that are placed on a layer of natural aggregates and it is very important to know that they carry a very high traffic [10]. One of the main advantages of this road pavement is that the whole section of the structure is smaller than those commonly used, hence, the material consumption is significantly reduced. Recent advances in material selection, mix design, performance testing, and road pavement design have enabled the development of an appropriate methodology for sustainable road pavements with an increased technical performance and a lifetime of about 50 years [11], [12], [13].

3. Composition of flexible road structures

Flexible road pavements are road structures in which there are no layers containing hydraulic or puzzolanic binders, and the road wearing course is bituminous. The composition of the road pavement will be determined taking into account the following factors:

- the minimum thicknesses of the different layers of the road pavement;
- the maximum thicknesses of the different road layers, taking into consideration certain constraints specific to the execution technologies;
- reducing the number of layers and interfaces, in order to minimize the risk of adhesion layers failures;
- establishing the shape of the layer so that its thickness can be taken into account in the road pavement design regarding the action at the freeze-thaw phenomenon.

4. Case study 1. Sustainable road pavement design. Intermediate solutions made from asphalt macadam, respectively, asphalt mix AB2

4.1. Scheme of the research program

The following types of road pavements have been studied, as follows:

A) The Alternative 1 takes into consideration the design of a sustainable road pavement having as an intermediate layer, the asphalt macadam, which has the asphalt courses as shown in figure 1.

According Alternative 1, the Sustainable road pavement is composed of a stone matrix asphalt with the maximum size of aggregates of 16 mm (SMA16) and an asphalt macadam course laid on another stone matrix asphalt layer, supported by a ballast foundation course, which is designed on an improved subgrade course, as shown in figure 1.
B) The Alternative 2 analyses a sustainable road pavement with an intermediate layer of asphalt mix AB2, as shown in figure 1, presented below.

According Alternative 2, in this case, the Sustainable road pavement is composed of a stone matrix asphalt and an asphalt mix AB2 course laid on another stone matrix asphalt layer, supported by a ballast foundation course, which is designed on an improved subgrade course, as shown in figure 1.

**Figure 1.** Sustainable road pavements with: A) asphalt macadam as an intermediate layer and B) asphalt mix AB2 as an intermediate layer

### 4.2. Assessment of the ecological impact associated with a Long-Lasting Flexible Pavement

In order to assess the ecological performances of Long-Lasting Flexible Pavement, a Life Cycle Assessment Analysis, incorporated in the asPECT software, developed by TRL Laboratories U.K., has been performed on the Alternatives previously presented.

asPECT software, Version 3.1, developed by Transport Research Laboratory - TRL UK, gives a methodology for computing greenhouse gas emissions on the pavement life cycle correlated with using asphalt materials on roads construction. The asPECT software enables the assessment of pollutant emissions based on data collected concerning materials, transport and mixture plant characteristics [14]. The software database contains the necessary formulas and emission factors for calculating CO₂e emissions associated with the production, laying and maintenance of bituminous layers by taking into consideration all the stages of materials and energy production and all the processes from raw material extraction, production, transport and use phase of the asphaltic mixture to the end of their life, shown in figure 2.

The process for calculating the carbon footprint associated with flexible road pavement consists in three main phases [3], namely:

- The introduction of raw materials used in the asphalt mixture (total annual energy consumption for the acquisition, broken down by type of fuel and operation);
- Data introduction regarding the asphalt mixes plant characteristics (plant type, annual production, energy consumption and asphalt mix composition);
- Data introduction regarding installation of bituminous mix and visualization of the results.

**Figure 2.** The life cycle stages of asphalt mixtures Cradle to Grave [14]
The Life Cycle Assessment Analysis has been conducted on a built section of 1000 ml long and 7.0 m wide based a CRADLE TO GRAVE perspective, presented above, in figure 2.

4.3. Results obtained
A) Alternative 1. Sustainable road pavement with intermediate layer - Asphalt Macadam
For this assumption, it is found that the two verification criteria, namely the admissible horizontal tensile stress at the bottom of the bituminous layers and the vertical strain at the level of subgrade are met for medium and heavy traffic categories. For these criteria to be fulfilled for the other types of computational traffic categories, such as very heavy and exceptional traffic, it would be necessary to modify the proposed sustainable road structure by increasing the total thickness of the asphalt layers from 30 cm to higher values, namely 34 cm, either retaining the initial thicknesses for the SMA layers and increasing the thickness of the intermediate layer to 24 cm, either by retaining the thickness of the intermediate layer and correspondingly increasing the thickness of the SMA layers. Another change leading to the verification of the two criteria for the very heavy and exceptional categories of traffic could be the use of materials characterized by a high elasticity (SMA asphalt mixes for the upper and lower layers of the durable road pavement with bitumen modified with polymers).

In terms of ecological impact associated with the construction of a Long-Lasting Flexible Pavement, using Alternative 1, the results of the quantitative assessment of greenhouse gas emissions, are presented in Table 1.

**Table 1.** CO2e emissions associated with Alternative 1: Sustainable road pavements with asphalt macadam as an intermediate layer

| No. | Life Cycle Stage                        | kg CO2e/t | Total kg CO2e  |
|-----|----------------------------------------|-----------|----------------|
| 1-3 | Material extraction and processing     | 14.91     | 75152.93       |
| 4   | Transport to plant                     | 28.08     | 141515.24      |
| 5   | Asphalt production                     | 42.28     | 213081.12      |
| 6   | Transport to site                      | 40.23     | 202748.00      |
| 7   | Laying and compacting                  | 4.70      | 23688.00       |
| 8   | Project works                          | 106.46    | 15969.64       |
| 9   | Maintenance                            | 34.00     | 5100.00        |
| 10  | Reconstruction                         | 14.80     | 74607.00       |
|     | **Project results summary (5340.00 t material)** | 141.79 | 751861.93 |

B) Alternative 2 - Sustainable road pavement with the intermediate layer of an asphalt mix AB2
For this alternative, given their modulus of deformation significantly greater than the asphalt macadam, the study has been conducted in a similar manner. For the subgrade type P2, as expected, given the higher elasticity modulus of the asphalt mix AB2 it has been found that the two verification criteria are met.

From an ecological perspective, the results of the quantitative assessment of greenhouse gas emissions associated with Alternative 2, are presented in Table 2.
Table 2. CO₂e emissions associated with Alternative 2 - Sustainable road pavements with asphalt mix AB2 as an intermediate layer

| No. | Life Cycle Stage                  | kg CO₂e/t | Total kg CO₂e |
|-----|----------------------------------|-----------|---------------|
| 1-3 | Material extraction and processing | 49.50     | 232178.28     |
| 4   | Transport to plant               | 36.49     | 171120.49     |
| 5   | Asphalt production               | 42.28     | 198283.82     |
| 6   | Transport to site                | 30.17     | 141501.21     |
| 7   | Laying and compacting            | 4.70      | 22043.00      |
| 8   | Project works                    | 106.46    | 15969.64      |
| 9   | Maintenance                      | 34.00     | 5100.00       |
| 10  | Reconstruction                   | 16.76     | 78623.00      |

Project results summary (4990.00 t material) 175.38 864819.44

In order to justify the ecological benefits associated with the construction of Long-Lasting Flexible Pavements, a classical road pavement has been properly analysed, taking into consideration the same assumptions defined for the two alternatives studied above. The difference between the classical road pavement and the sustainable versions consist in the fact that the classical ones are usually designed over an initial service life of 15 years. In this regard, a flexible road pavement consisting in the following layers, has been analysed:

- Wearing course (asphalt concrete with the maximum size of the aggregate of 16 mm, 4 cm);
- Binder course (asphalt concrete with the maximum size of the aggregate of 25 mm, 6 cm);
- Base course (asphalt base, 15 cm);
- Foundation layer (ballast, 20 cm);
- Subgrade (20 cm).

The results of the quantitative assessment of greenhouse gas emissions associated with road construction using a classical alternative are given in Table 3.

Table 3. CO₂e emissions associated with a classical road pavement over its initial service life

| No. | Life Cycle Stage               | kg CO₂e/t | Total kg CO₂e |
|-----|--------------------------------|-----------|---------------|
| 1-3 | Material extraction and processing | 52.88     | 203434.62     |
| 4   | Transport to plant             | 36.52     | 140500.34     |
| 5   | Asphalt production             | 48.28     | 162643.47     |
| 6   | Transport to site              | 6.48      | 24946.30      |
| 7   | Laying and compacting          | 4.70      | 18080.90      |
| 8   | Project works                  | 241.23    | 36184.10      |
| 9   | Maintenance                    | 34.27     | 5140.00       |
| 10  | Reconstruction                 | 15.89     | 61120.78      |

Project results summary (4147.00 t mixture) 154.08 652050.51

In order to be properly compared these case studies, both from an ecological and technical perspectives, a structural overlay has been taken into account, which is envisaged to be applied at the end of initial service life of the classical road pavement, which will extend the service life of the road pavement and increase its mechanical resistance. Structural overlays represent a current road repair work which is meant to increase the pavement load bearing capacity. The bituminous road pavement is composed from two asphalt layers with a minimum thickness of 8 cm. This reinforcement strategy can be performed using two alternatives, namely: two-layer bituminous road pavement with a thickness of less than 13 cm or a road pavement with two-layer bituminous wearing course and an asphalt base course with a thickness greater than 13 cm, but not exceeding 18 cm. For the assessment of the ecological impact associated with the structural overlays, the reinforcement layers have been designed using the first assumptions (asphalt wearing course of 4 cm and a binder course of 5 cm) and the associated
quantities of CO₂e are presented in Table 4. Also, the final results, calculated over the same service life as a Long Fasting Flexible Pavement, are given in Table 5.

**Table 4. CO₂e emissions associated with structural overlays**

| No. | Life Cycle Stage                          | kg CO₂e/t | Total kg CO₂e |
|-----|-------------------------------------------|-----------|---------------|
| 1-3 | Material extraction and processing        | 44.76     | 64070.37      |
| 4   | Transport to plant                        | 35.41     | 50687.96      |
| 5   | Asphalt production                        | 42.28     | 60520.96      |
| 6   | Transport to site                         | 30.17     | 43189.55      |
| 7   | Laying and compacting                     | 4.70      | 6728.05       |
| 8   | Project works                             | 0.00      | 0.00          |
| 9   | Maintenance                               | 34.27     | 5140.00       |
| 10  | Reconstruction                            | 16.91     | 24206.05      |
|     | **Project results summary (1581.50 t mixture)** | **160.95** | **254542.93** |

**Table 5. Final results of CO₂e emissions associated with a classical road pavement over its total service life**

| No. | Life Cycle Stage                          | kg CO₂e/t | Total kg CO₂e |
|-----|-------------------------------------------|-----------|---------------|
| 1-3 | Material extraction and processing        | 97.64     | 267504.99     |
| 4   | Transport to plant                        | 71.93     | 191188.30     |
| 5   | Asphalt production                        | 90.11     | 144518.35     |
| 6   | Transport to site                         | 36.65     | 68135.85      |
| 7   | Laying and compacting                     | 9.40      | 24808.95      |
| 8   | Project works                             | 241.23    | 36184.10      |
| 9   | Maintenance                               | 68.54     | 10280.00      |
| 10  | Reconstruction                            | 32.80     | 85326.83      |
|     | **Project results summary (5718.50 t mixture)** | **315.03** | **906593.44** |

5. Conclusions
The most challenging environmental issue facing mankind nowadays is represented by the acceleration of global warming and climate change associated with this phenomenon as a direct result of an increase quantities of pollutants emanated in the atmosphere. In this context, the paper presents the results of recent research undertaken for the assessment of the environmental indicators, associated with the construction and maintaining of an asphalt road pavement, based on a Cradle to Grave perspective, which takes into account all the stages of materials and energy production and also all the processes from lithographic material extraction, production, transportation and use phase of the products to their end of life. The Life Cycle Assessment Analysis has been conducted on a built road section of 1000 ml long and 7.0 m wide using a Cradle to Grave approach, incorporated in the asPECT software.

Within this paper two specific alternatives for the construction of a Long Lasting Flexible Pavement using different materials, have been analysed in an environmental perspective as well as a technical approach. These type as well-designed structures are characterized by an initial service life of forty or more years. The Long Lasting Flexible Pavements are safer, more efficient and environmentally friendly road pavements alternatives and are capable to withstand unusual actions without suffering major faults and without losing functionality [3].

The first alternative deals with the construction of a durable pavement, composed by a stone matrix asphalt wearing course and an asphalt macadam layer laid on another stone matrix asphalt layer, supported by a ballast foundation course, which is designed on an improved subgrade course. The alternative 2 analyses a sustainable road pavement with an intermediate layer of asphalt mix AB2. From a technical point of view both alternatives met the verification criteria used in the design phase. In terms of environmental perspective, the first alternative represents a more sustainable choice for the construction of the road pavement, with a reduction of the total quantities of CO₂e emissions of 15.02%,
given the fact that the asphalt macadam requires smaller quantities of bitumen in the mix, while providing an increased bearing capacity.

When comparing the most ecological alternative of Long Lasting Flexible Pavement, namely Alternative 1, with a classical road pavement, one may notice that, in this case, Alternative 1 has an increased value of pollutant emission, with 15.31% higher than the classical version of road pavement. The difference is explained through the fact that Long Lasting Flexible Pavements are designed with an initial service life of forty or more years, compared with the classical one, where its service life is 15 years. In order to properly compare these two technical solutions, specific strategies for regular maintenance and structural reinforcement of the classical road flexible pavement have to be performed. In this context, a structural overlay, meant to extend the road service life, has been taken into account within the study. When the total service life is considered, one may notice that a Long Lasting Flexible Pavements, besides low maintenance costs and works, represents a more sustainable alternative for the construction, rehabilitation and modernisation of road transport infrastructure, with a total reduction of CO2 emissions of 20.58%.

Therefore, looking at the results under an engineering and ecological consideration, the optimal construction strategy to be applied, consists in a sustainable road pavement with intermediate layer - asphalt macadam. The worst-case scenario studied in the frame of this research is represented by the construction of a classical pavement, where the specific intervention strategies ought to be applied when the pavement condition of the road is poor and the user’s safety is endangered. In this case the only viable solution is reinforcing the pavement, the ecological impact being significantly higher.

In the context of improving the regions sustainably, the Long-Lasting Flexible Pavement represents a step forward achieving low carbon mobility based on their initial service life of forty or more years, low maintenance costs and reduced energy and materials consumptions. These road pavements represent a safer, an efficient and a more environmentally friendly alternatives of road structures and are capable to withstand unusual actions without suffering major faults and without losing their functionality. Moreover, it is imperative for the decision-making factors to have a decisive role in implementing these technologies in practice for fulfilling the sustainability criteria.

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