DURABROADS - Towards a more durable and resilient road pavement

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ABSTRACT

Nowadays, traditional road materials, procedures and techniques are expected to deliver a minimum performance but unexpected new challenges have a negative impact reducing their lifetime. In addition, each kilometre of road requires a large amount of materials and energy for its construction, maintenance and rehabilitation which are not viable according to new environmental patterns. Hence, the search of more cost-effective and eco-friendly practices in the road sector represents a priority for the industry.

In this sense, the DURABROADS EU Project aims at providing a sustainable solution through the design, development and demonstration of cost-effective, eco-friendly and optimized long-life pavements, more adapted to freight corridors and climate change through innovative designs and the use of greener materials improved by nanotechnology.

Throughout the Project lifetime, an analysis, selection and characterization of the most suitable nanomaterials will be carried out to create different nanotechnology-enhanced binders. Accordingly, various Warm Mix Asphalts (WMA) will be tested incorporating nanomaterial-modified bituminous binders as well as Reclaimed Asphalt Pavement (RAP) and by-products. Based on the results of these tests, better performance pavement sections for different climate conditions and traffic loads will be constructed on a real case scenario.

DURABROADS represents also a formal collaboration in road infrastructure research between the US Federal Highways Administration and the European Union.

The Project is financed by the EU FP7 scheme. The consortium is composed of a multi-disciplinary partnership formed by 9 partners including academia, industry, SMEs and research centers: University of Cantabria, Acciona Infraestructuras S.A., Fraunhofer, Institute for Transport Science, European Road Federation, Tecnalia Research and Innovation, Norwegian Graphite, BSRIA and Inzenierbuve Ltd.

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1. Rationale

Public finances in EU member states have been seriously touched during the last years by the financial crisis. Funding strength has been dramatically lessened especially in some strategic sectors (i.e. road infrastructure). Consequently, a development of new technologies and materials is needed in order to provide more affordable, durable, greener and cost-effective road network (1), (2).

In addition, negative effects of changing weather conditions due to climate change, the significant increase of traffic flow in certain motorways due to the opening of freight corridors and the technical limitation of current materials and procedures are expecting to have a considerable impact on the asphalt pavements in coming years reducing its lifetime.

According to the *Research and Innovation Roadmap* (3), the vulnerability of roads to expected extreme weather conditions will be visible very soon. An increase of 70% until 2030 (4) of the freight volume transported on roads, together with a higher frequency of extreme weather events (i.e. flooding, heavy rainfall, etc) will lead to a clear early road infrastructure deterioration.

As consequence, this deterioration will bring more often maintenance, intervention and rehabilitation operations, having as immediate consequence the reduction of the network availability and, clearly, a need for additional and costly extra investment (5).

In this sense, the DURABROADS Project aims at facing these difficulties while supporting economic growth and promoting a more durable, competitive and greener material for road construction and rehabilitation.

From the political perspective, the current *White Paper on Transport* seeks to achieve a more sustainable and efficient transport for Europe. In the same line, the EU flagship initiative *"A resource-efficient Europe"* under the Europe 2020 Strategy (1) encourages the achievement of a sustainable growth by increasing the efficiency of our resources. As well, the Directive 2008/98/EC on Waste (6), lays down the waste management hierarchy (i.e. prevention, preparing for re-use, recycling, energy recovery, and disposal), encourages waste prevention. Above all, a main political priority for the EU specially after the COP21 is to reduce Greenhouse Gas emissions progressively to 80 by 2050 compared to percentages dated in 1990 (7).

2. BACKGROUND

In this institutional, social and economic framework, the DURABROADS consortium seeks to develop innovative, cost-efficient and more durable designs of pavements as well to optimize road construction and rehabilitation procedures while minimizing the negative impact on the environment.

The development of innovative nanotechnology-enhanced binders will be carried out to improve resilience and durability of asphalt mixes. Moreover, the deployment of Warm Mix Asphalt technologies and the substitution of natural aggregates with by-products will be researched in order to minimize environmental impacts.

The project will then complete various tests in several aspects: analysis of the influence of climate change on roads, development of modified-asphalt binders, application in new warm asphalt mixes and the use of by-products and RAP in these new asphalt mixes.

2.1. Influence of climate change on road infrastructure

Existing highway construction and maintenance patterns and standards are normally based on historical climate data records. However, future predictions need also to be taken into consideration. Road Authorities are starting to realise about the importance to adapt their strategies to the impact of climate change on their networks in order to minimise disruption and costs. (5)

Several countries are already implementing adaptation strategies. The UK Highways Agency has assessed the potential risks that climate change poses to the ongoing operation, maintenance and improvement of the strategic road network (8). In the same way, Finland's National Strategy for Adaptation to Climate Change (9) and the Guideline for the Transport Sector until 2010 were issued in 2005. These documents contain action lists for the administrative sector to minimize CO2 emissions from traffic, estimated costs of these activities and targets concerning the use of renewable energy sources and the emissions reductions by 2020. The US Department of Transportation has also developed a Transportation Climate Adaptation Plan (10) with the information about the effects of transportation on climate change, as well as the impacts of climate change on transportation.

Another three projects dealing with the impacts of the climate change effects on the transport network have been mentioned as a good example of EU-US co-operation in the area of transportation research: WEATHER, EWENT and ECONET. Physical and economic impacts of the climate change, including a risk management approach, were studied by these projects.

In addition, the UK's first National Infrastructure Plan (11) launched in 2010, underlines the importance of maintaining transport, water and energy systems in the face of climate impacts.

2.2. Asphalt Binder Modifications: Use of Polymers and Nanoparticles

The addition of polymers has been employed for many years to increase the viscosity of the bitumen and to improve its temperature susceptibility (12). The inclusion of Polymer Modified Bitumen (PMB) in asphalt pavements provides then higher resistance to rutting and thermal cracking, as well as lower fatigue damage and aging.

An important polymer commonly used to modify bitumen is Polystyrene-Polybutadiene-Polystyrene (SBS). SBS was developed in the early 1960's and has been commercialised for the first time in 1976 (13). However, several drawbacks resulting from the immiscibility of SBS and bitumen, and the tendency of SBS to degrade when it is exposed to heat UV light and oxygen (14), have leaded to ongoing research.

Recent studies have investigated the influence of the inclusion of clay or *organophillic montmorillonite* (OMMT) as a third component to the polymer (SBS)-modified bitumen to improve its performance. According to the latest results obtained, the inclusion of OMMT increases softening point, viscosity and penetration index. On the other hand, it decreases penetration of bitumen (15). Previous research also showed how the addition of graphite powder can transform more free asphalt to structure asphalt improving this way its high-temperature thermal properties (16).

Concerning the use of nanotechnology in asphalt pavements, it might lead to improved properties of these materials, including resistance to damage from moisture, durability or saving on maintenance costs. Key properties as compressive strength, tensile strength, stability to tolerate loads at high temperatures and noise reduction from traffic would also be improved. More precisely, the use of nanotechnology in asphalt pavements means the use of nanoscaled additives/fillers. Several of these fillers have already been tested in polymer matrices, where they can improve the performance of the matrix material, often in a dramatic way.

Consequently, the addition of Multi-Walled Carbon Nanotubes (MWNT) to a SBS matrix have been studied showing the following features: the MWNT were homogeneously dispersed in the SBS matrix and better thermal and mechanical properties were observed (17).

Other interesting nanomaterial, the exfoliated graphite nanoplates (xGnPs), has attracted the interest of the researchers. Apart from its properties, this material is perceived as promising inexpensive nanofiller. Some studies in which xGnPs and Polystyrene-(Polyethylene Butylene-Polystyrene (SEBS) have been tested as matrix material show that compared with pure SEBS, the tensile modulus and the tensile strength of the nanocomposite were improved by adding xGnPs at a significant high loading amount (18).

Finally, during the last three years ternary mixtures of asphalt, SBS and carbon nanotubes have been also investigated (19) and the following features can be mentioned: SBS can be a suitable link between asphalt and Carbon Nanotubes (CNTs), but CNTs by themselves can hardly modify the asphalt mix characteristics. Thus, ternary mixtures of bitumen, polymers and carbon nanomaterials seem to be promising objects of research.

2.3. Warm Mix Asphalts

Conventional asphalt mixtures are usually produced at a temperature between 150 and 170 ºC. As an alternative, according to definitions from the International Road Association (PIARC) and the European Asphalt Pavement Association (EAPA), WMA are produced in a temperature range from 100 to 140 ºC whereas Half-Warm Mix Asphalt (HWMA) is manufactured from 70 to 100 ºC (20).

Such temperature reductions are aimed at reducing the carbon footprint of asphalt, as demanded by the last COP21. For instance: among others, WMA allows emission reductions from 30 to 40% of carbon and sulphur dioxides (CO_2 and SO_2), 50% for volatile organic compounds (VOC), 10 to 30% for carbon monoxide (CO), 60 to 70% for nitrous oxides (NO_x)

and 25 to 55% for dust. Moreover, reductions in harmful asphalt fumes and polycyclic aromatic hydrocarbons can reach up to 50% (21).

Apart from the advantages in emissions, the use of warm mix asphalts allows longer haulage distances, reduces the appearance of compaction troubles and requires less time before opening the road to traffic or applying the next asphalt layer. Last but not least, energy consumption required for producing WMA can be reduced up to 35% or more, which is a major economic and environmental benefit at the same time.

2.4. The Use of Reclaimed Asphalt Pavement (RAP) in WMA

Reclaimed Asphalt Pavement is the term given to removed and re-processed asphalt pavements containing asphalt and aggregates. These materials are mixed with virgin materials and reused in road construction. Using RAP has several advantages, mainly economic and environmental: it needs a lower consumption of aggregates and binders, lower transportation distances and prevent asphalt from being disposed of.

Nowadays the recycling of RAP in Hot Mix Asphalt (HMA) is a common technique in Europe: 57% of European reclaimed asphalt was recycled in HMA in 2008. However, the use of RAP for producing new asphalt means the blending of old asphalt which generally is harder and more brittle. This can result in a stiffening effect that can increase fatigue and cracking of asphalt mixtures in service. Moreover, a higher mixing temperature is needed to produce a homogeneous final blend with virgin materials. For this reason, there is a limitation regarding the maximum RAP allowed in HMA in most of the countries, generally under 30%.

Nevertheless, the decreased aging of the binder as a result of the lower production temperatures of WMA can compensate the stiffness of the binder within the RAP fraction (22) Therefore, higher amounts of RAP can be used with WMA technologies, decreasing the environmental impact by using less virgin material and reducing CO_2 emissions.

3. TECHNICAL DESCRIPTION

Changing technology, changing properties of construction materials, increasing traffic, higher permitted load on pavements and changing environmental conditions need to be considered when designing pavements. Maintaining design methods that were working well in the past are not enough anymore. In this project the identification of the best practices from different research studies in different countries and the optimization of the road-related procedures will be performed to provide to road managers with more affordable, safer and environment-friendly practices to manage their infrastructures. To do this, optimization criteria defined using life-time engineering concepts will be considered. This new discipline forecasts and optimizes the technical, economic, environmental, cultural and human features of a structure throughout its whole life since the design phase (21).

As traffic demand increases and funding becomes more limited, efficient design of more durable materials and pavement sections is of major importance. In this project, different carbon nanomaterials will be analysed, characterized and selected regarding their size, quality and shape in order to find the most suitable ones for binders and polymers modification. The characterization of carbon nanomaterials will include scanning electron microscopy (SEM), thermo-analytical methods, such as thermo-gravimetric analysis and differential scanning calorimetry (TGA and DSC respectively), and X-ray diffraction.

In addition, the bonding interaction between the selected nanomaterial and the most common polymers used in asphalt production will be researched in order to produce a polymer/nanofiller composite to be used as high-performing bitumen additive as well.

Composites developed following these procedures will be subjected to interfacial adhesion studies, in order to find out the most favourable polymer-nanomaterial systems. Hereby, impact tests will provide an effective measurement of the cohesive energy, and thus adhesion quality of the mixture. Tensile and flexural tests will be also performed to evaluate the evolution of mechanical properties (strength and Young modulus) upon addition of the nanomaterial.

Concretely, three enhanced-modified-bitumen with increased softening point and decreased penetration index are expected to be produced from the research:

- Traditional bitumen modified with nanoparticles.
- Traditional PMB modified with nanoparticles.
- Traditional bitumen modified with nanomaterial/polymer composites.

Several asphalt mixes incorporating the modified-binders will be designed, evaluated and characterized in order to control the performance changes introduced by the new binders. Modified mixtures are expected to present better mechanical properties than conventional ones due to the incorporation of these additives. Furthermore, the maximum amount of Reclaimed Asphalt Pavement (RAP) and by-products in substitution of natural resources will be incorporated to these mixtures taking advantage of the improved properties enabled by the DURABROADS-modified bitumen and WMA additives. Considering that the main technical parameters to design asphalt pavements are the elastic module and the resistance to fatigue, the indirect tensile test and the four point bending test, will be deemed key. The objective is to develop a number of novel sustainable and enhanced mixes with good environmental profiles to use as the asphalt layers in long-life and eco-friendly asphalt pavements.

Long-life pavement sections including DURABROADS advanced WMA will be calculated using the finite element method. Several WMA pavement sections will be designed with different characteristics in order to cover different climate conditions and traffic loads.

Afterwards, two DURABROADS pavement sections will be implemented for validation in a real case scenario. Furthermore a LCA study (Life Cycle Analysis) and LCC study (Life Cycle Cost Analysis) will be performed for DURABROADS WMA Pavements, and will be compared with conventional ones at environmental, technical and economical level. While the LCA will be used for comparing the environmental effects between conventional and DURABROADS pavements, LCC will be used for calculating the worth costs for pavement alternatives as it is the primary tool used for economic comparisons.

Finally, guidelines and recommendations of the best practices identified during DURABROADS project will be elaborated. In addition, a guideline for introducing DURABROADS in Green Public Procurement processes in the European scenario and recommendations about the next steps for the future standardization of DURABROADS products will be performed.

4. CONCLUSIONS

Positive impacts on innovation, growth and sustainability in the asphalt sector are expected as a consequence of the implementation of DURABROADS actions:

- Research and innovation of DURABROADS will aim at better technical and functional durability of asphalt pavements in road structures. DURABROADS asphalts are expected to present better physical and mechanical properties than conventional ones, such as improvement of stiffness under high temperature while maintaining elastic behaviour satisfactory under low temperature, meaning important resistance and structural performance for higher durability of pavement construction.

- Increase in durability and resilience, and even the eco-friendly aspects of DURABROADS asphalts and pavements will have a positive impact in the road infrastructure funding aspects by: reducing rehabilitation and maintenance costs, traffic disruption, energy consumption and resources consumption.

- The reduction of energy consumption as well as Greenhouse Gas emissions (GHG) along with the decrease of resource intensity are benefits of the project also in accordance with the aims of Europe 2020 flagship *"Resource-efficient Europe"* that intends to support the shift towards a resource-efficient, low-carbon economy.

- The adoption by decision makers and road authorities of the best practices identified during the project regarding the construction, maintenance and rehabilitation of the road could bring cost and environmental benefits due to the advantages of using new technologies and systems.

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