A Laboratory Procedure for Improving the Design of Road Rehabilitation Actions: Study of a Real Case in a Highway Pavement

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Abstract Pavement rehabilitation has become an issue of major concern for road administrations. In the coming years, the development of more effective strategies for improving these actions will be crucial. On some occasions, traditional methods used to define pavement rehabilitation solutions are not able to select the best alternative from a sustainable, technical and economical point of view. Given these challenges, a new methodology was developed for use as a complementary tool for optimizing road pavement rehabilitation actions. This methodology is based on a comparative analysis of the structural behaviour of different types of materials and the subsequent selection of the best alternative based on the results obtained. The present paper describes the methodology and summarises its application during the rehabilitation of a highway pavement. The results of this study indicate that the use of this procedure could optimize the consumption of natural and economical resources in rehabilitation actions, offering more competitive alternatives when the available budget cannot cover the costs associated with traditional solutions.

Keywords Pavement · Asphalt · UGR-FACT · Bituminous mixtures · Road

1 Introduction

In the last decades, pavement rehabilitation has become one of the main concerns for road administrations. Nonetheless, the majority of the tools available for selecting rehabilitation solutions were developed on the basis of experimental observations made several decades ago [1–3] or are based on linear-elastic mechanics [4, 5], and they do not take into account the advantages offered by the latest developments in asphalt materials (high performance modified bitumens, fibres, rejuvenators, interlayer structural reinforcement systems, etc.) and they are not able to integrate

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the accumulation and propagation of damage suffered by the materials during their service life (thus some discrepancies could appear between the stresses and strains calculated and those that actually occur in the pavement).

Consequently, in many cases the solutions selected to conduct rehabilitations are not the optimal alternative available (in terms of costs and mechanical performance). In addition, the use of these tools limits the application of non-traditional materials (crumb rubber modified binders, high RAP content, warm-mix asphalts, etc.), since they consider these to be structurally more expensive. In this regard, this paper presents a novel methodology (based on structural performance) to select the optimal thickness and type of materials to be used in pavement rehabilitation actions.

2 Description of the Laboratory Procedure

The test procedure can be conducted within the time frame of executing the rehabilitation action (it can be implemented easily and rapidly) and at a laboratory scale (with reduced costs). As data input (advisable, but not strictly necessary), it uses the deflection of the pavement to be rehabilitated, as well as the traffic and climatic conditions to withstand. Then, based on the solution proposed by traditional tools (reference solution), other alternatives can be studied at laboratory level using UGR-FACT (University of Granada-Fatigue Asphalt Cracking Test) [6]. Unlike other common tests that evaluate bituminous materials individually, UGR-FACT allows for evaluating specimens composed of more than one layer (including or not include interlayer reinforcement systems) and different qualities of foundations (or defects) can be simulated by varying the stiffness of its spring (Fig. 1).

Specimens of at least 3 different thicknesses are manufactured with all the solutions to be studied (reference and the different alternatives to be considered). Then, they are tested using stresses comparable to those to be suffered during their service life (and adapting the stiffness of the spring to simulate the characteristics of the existing structure) and similar environmental conditions (test temperature and specimen moisture contents). Based on the results obtained, design laws (which relates thicknesses and deflections produced in the layer) and fatigue laws (which relates deflections and number of load cycles that cause a complete crack propagation through the layer) are defined, and the equivalent thicknesses of the studied alternatives with respect to that used by the reference solution are determined. For this purpose, horizontal displacements in the bottom of the layer and vertical displacements in the top of the layer (initial displacement) are related to the number of load cycles supported by the specimens (fatigue laws), and to the thickness of the layer (design laws). The displacements produced with the thickness of the reference solution (Fig. 2a) are introducing into the fatigue law to determine its life span (Fig. 2b). Using an inverse process, the associated displacements to this life span in the alternative solutions are defined (Fig. 2c) and finally, the equivalent thicknesses calculated (Fig. 2d).

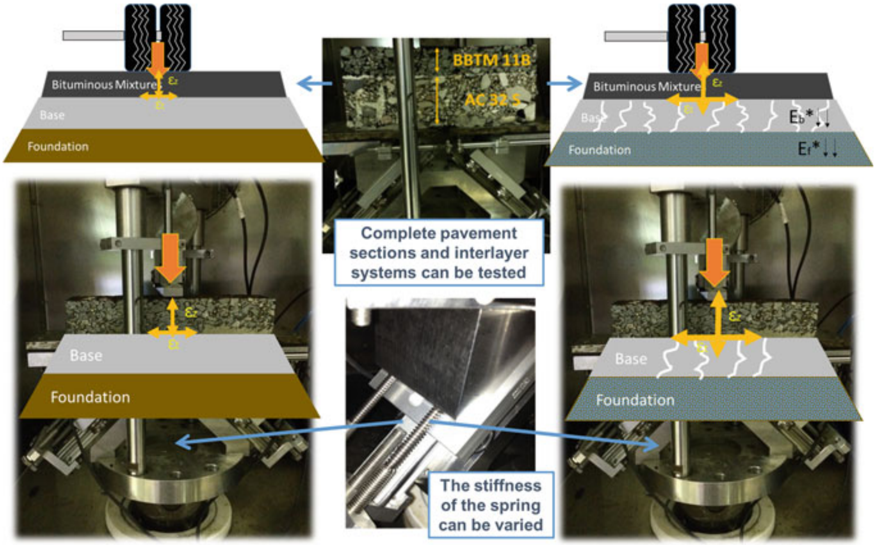

Fig. 1 Sketch of the test procedure presented

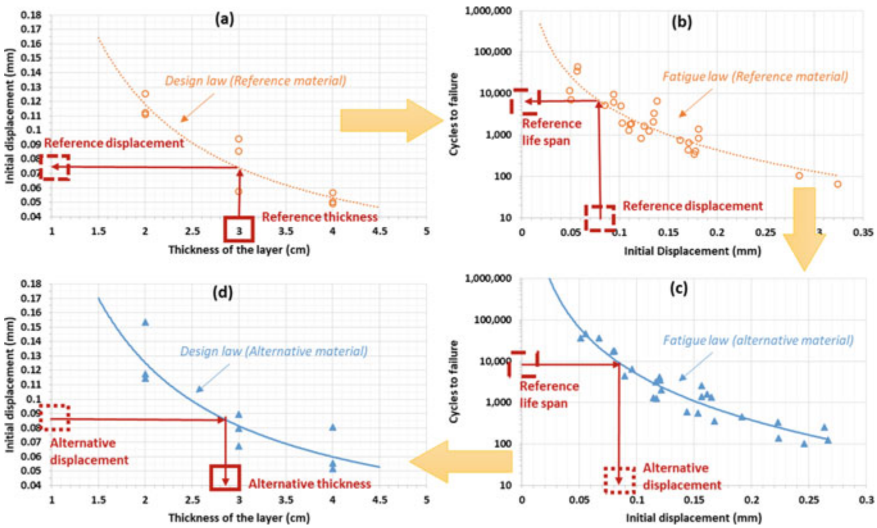

Fig. 2 Summary of the process carried out to determine the equivalent thickness to the solution propose

3 Application Example: Study of a Real Case in a Highway Pavement

As an example, this section summarises an application of the presented methodology to a rehabilitation action on the A-92 highway in south Spain. Based on the study of deflections carried out in the existing pavement, as well as the Spanish catalogue for pavement rehabilitation design [3], the proposed reference solutions were: a regrowth of the pavement using an overlay with a thickness of 3 cm (in the areas where the deflections measured were less than 40 mm/100); partial removal of the deteriorated layers and subsequent replacement with 10 cm of new asphalt mixtures (in the areas where the deflections measured were between 40 and 51 mm/100).

The bituminous mixtures selected for the reference rehabilitation were: a BBTM 11 (EN 13108-2) manufactured with a modified binder PMB 45/80-65 in the case of the regrowth with an overlay of 3 cm; and an AC 22 (EN 13108-1) manufactured with a conventional binder B 35/50 and the same BBTM 11 manufactured with PMB 45/80-65 in the case of the partial removal and replacement with 10 cm of new mixtures (7 cm of AC 22 + 3 cm of BBTM 11). As an alternative to these two mixtures, additional BBTM 11 and AC 22 mixtures were designed using a crumb rubber (CR) modified binder, in order to evaluate the efficiency of substituting traditional mixture with other more sustainable mixtures manufactured with crumb rubber from end-of-use tyres. Table 1 summarises the main characteristics of the mixtures studied.

Figure 3a and b shows the fatigue and design laws obtained for the BBTM 11 mixtures tested at 20 °C. Taking the thickness defined for the reference solution in the Spanish design catalogue (3 cm, Step 1), the displacement associated with the reference material BBTM 11 was determined (Step 2). Following this, the number of load cycles supported (life span) by the reference material under this displacement was calculated (Steps 3 and 4). After that, the displacement associated with this life span in the alternative material BBTM 11 CR is determined (Steps 5 and 6) and using it, the equivalent thickness for the reference materials is calculated (Steps 7 and 8). Based on the results obtained, it was observed that using the alternative material BBTM 11 CR it is possible to reduce the thickness of the surface layer by approximately 7%. Following a similar process, it was observed that using the

Table 1 Properties of the mixtures studied

Mixture ID	BBTM 11	BBTM 11 CR	AC 22	AC 22 CR
Apparent density (mg/m^3), EN 12697-6	2146	2134	2478	2450
Voids in mixture (%), EN 12697-8	16.5	18.0	4.3	4.0
ITS at 15 °C (kPa), EN 12697-23	1287	1161	1720	1389
ITSR (%), EN 12697-12	91.9	90.7	87.3	96.9
WTS ($mm/10^3$ cycles), EN 12697-22	0.056	0.054	0.072	0.063

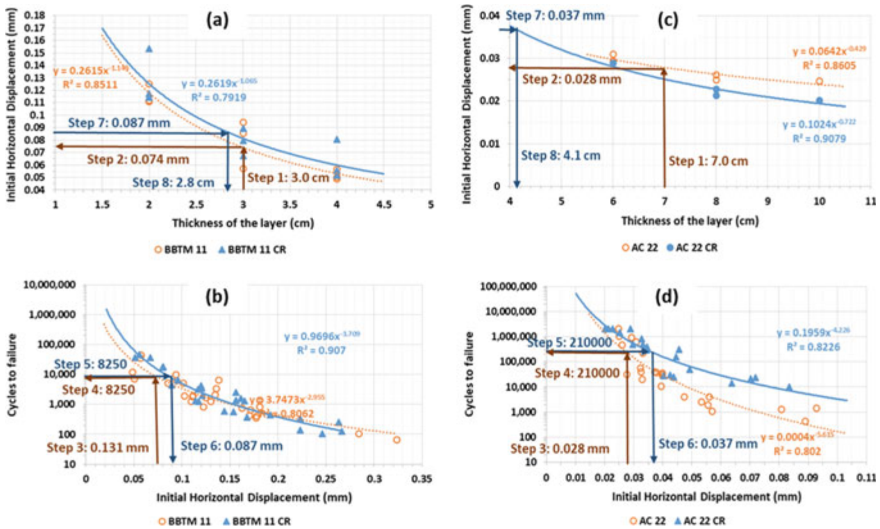

Fig. 3 Results obtained during the study of BBTM 11 and AC 22 mixtures: **a**, **c** design laws; **b**, **d** fatigue laws

alternative material AC 22 CR it is possible to reduce the thickness of the binder layer by approximately 35% (Fig. 3c and d).

Based on the information obtained in the laboratory, a cost analysis was conducted for the different solutions (Table 2). It was observed that using the alternative materials (BBTM 11 CR and AC 22 CR) and taking into consideration the reduction of the thicknesses of the layers (from 3 to 2.8 cm in surface layer; and from 7 to 5 cm in binder layer) it is possible to produce an overall saving of around 40,000 € (more than 11% of the original budget).

Table 2 Properties of the mixtures studied

	Regrowth with overlay		Removal and replacement	
	BBTM11	BBTM11 CR	AC22	AC22 CR
Bituminous mixture cost (€/t)	28.05	28.52	15.44	20.64
Bituminous mixture density (kg/m^3)	2146	2134	2478	2450
Thickness of the layer (m)	0.030	0.028	0.07	0.05
Bituminous mixture per m^2 (kg)	64.4	59.8	173.4	122.5
Cost per m^2 of rehabilitation (€)	1.81	1.70	2.68	2.53
Surface (m^2)	135,000		99,000	
Solution cost (€)	243,769.24	230,077.32	443,908.12	419,034.97
Saving (€)	–	**13,691.92**	–	**24,873.16**
Saving (%)	–	**5.62**	–	**5.60**

Fig. 4 Detail of the trial section before opening to traffic

Based on the results obtained in this study, a trial section was constructed during the rehabilitation action conducted in the A-92 highway in September 2017 (Fig. 4). Currently, this trial section is under evaluation to assess the development of these materials under real environmental and service conditions (and to compare the results with those obtained in the laboratory during the solution design).

4 Conclusions

This article presents a novel methodology developed to optimize the resources used in road rehabilitation actions, and to select the most competitive solutions in terms of costs. This laboratory procedure can be carried out at both the project and construction stages (which can be helpful for decision-making). The results obtained in real experiences where this procedure has been applied have demonstrated that it is sensitive to the changes produced in the composition of the materials (such as type and content of binder, and the presence of interlayer reinforcements) in terms of the design of the pavement (thickness of the layers) and the external conditions (load stress applied and temperatures).

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