

## High performance underlayers with high percentages of re-use as developed in the NR2C-project

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### ABSTRACT

The project “New Road Construction Concepts” (NR2C) is an innovation project of FEHRL supported by the European Commission under the Sixth Framework Programme. NR2C develops long-term perspectives and physical trial projects, in which long-term visions and ideas are linked to short-term action. One of the ideas towards sustainable road construction concerns the development of high performance underlayers with high percentages of re-use materials. High stiffness underlayers are largely used in Europe, but re-use is often very restricted or not used at all because of fear for limited durability. This project aims to optimize the design of such mixes so as to guarantee their long-term performance, even with high percentages of reclaimed asphalt (RA) (including mixes containing 25% and 40% of RA).

The mix designs are made and optimized using BRRC’s PradoWin-software. An extensive laboratory testing program is carried out, with the aim to evaluate, compare and optimize the performance of these mixes, which is related to stiffness, fatigue cracking, durability/adhesion and permanent deformation.

After this laboratory testing phase, three mix designs will be selected and further studied in the full-scale accelerated loading testing (ALT) facility of LAVOC. The sections will be loaded with a heavy traffic simulator, and assessed at subsequent thermal cycles. This study will permit to evaluate the behaviour of the selected solutions in an accelerated way and close to field conditions. The instrumentation (gauges to measure horizontal as well as vertical deformations) in the structure will provide data that are necessary for the assessment of the structural design.

Based on the performance characteristics of the mixtures determined in the laboratory study and on the results of the accelerated loading, the impact on the structural design of the road and on the lifetime of the pavement will be investigated. New construction as well as different repair situations with these solutions will be considered, for different climatic and traffic conditions, representative for Europe.

## 1. Introduction

The NR2C-project (which stands for New Road Construction Concepts) is a project of FEHRL supported by the European Commission under the Sixth Framework Programme. NR2C develops long-term perspectives and specific innovation projects, in which long-term visions and ideas are linked to short-term action [1]. One of the ideas in the framework of sustainable road construction worked out in NR2C concerns the development of high stiffness underlayers with high percentages of re-use materials. Although high stiffness underlayers are already extensively used in some European countries, such as France, the experience with re-use in such mixtures is still very limited. There is indeed a fear for a limited durability of these mixtures because of the combination of a hard binder (which is typical for these mixtures) and re-use material. Because of this, the application of high stiffness underlayers is still limited in countries that normally use high percentages of re-use in their asphalt underlayers.

This project aims to optimize the design of these mixes so as to guarantee their long-term performance, even with high percentages of reclaimed asphalt. This is achieved by both a laboratory and an ALT-study (ALT= accelerated loading testing). The project is carried out by BRRC and LAVOC. BRRC takes care of the material characterization, the mix design and the laboratory performance studies. LAVOC is in charge of the realisation of the experimental ALT-sections. This paper describes the different steps of the project and gives a summary of some of the results of the laboratory study.

## 2. Material characterisation and mix design

High stiffness modulus mixes were prepared with Belgian as well as with Swiss materials. One and the same hard binder 15/25 was used through the whole study. Its characteristics are given in table 1 [2]. The mixes with the Belgian materials were used for extensive laboratory testing. These tests provided information for the designs to be made with the Swiss materials, which will be applied on the LAVOC ALT facility.

Pen (25°C) (1/10 mm)	R & B (°C)	G* (at 1.6 Hz) (MPa)			ZSV – EVT 2 (prEN 15324) (°C)	Temperature for 1 % failure strain (°C)
		50°C	15°C	0°C		
16	70.2	0.273	27.0	152	73.2	-8.1

*Table 1 : Characteristics of the hard binder 15/25.*

The BRRC software PradoWin was used for the development of the mix designs. PradoWin is a user-friendly program, adapted for the volumetric mix design of bituminous mixtures, and with a special feature to facilitate the mix design of mixtures with re-use materials. The required input data are the characteristics of the constituent materials. For both Belgian and Swiss materials the following characteristics were measured in the laboratory of BRRC:

- On the aggregates (sand and stones): grading, density.
- On the filler: grading, density, voids Rigden.
- On the reclaimed asphalt: grading, density, binder content, R&B and pen on recovered binder. The characteristics of the recovered binder are given in table 2.

Type	Pen (1/10mm)	R & B (°C)	%
Belgian RA	17	67.3	5.5
Swiss RA	32	59.4	4.8

*Table 2 : Characteristics of the recovered binder of the reclaimed asphalt*

High stiffness mixtures for underlayers can be achieved by using a high percentage of stones and a hard binder. In general, this combination of a high stone content and a hard binder leads to mixtures that perform less well in terms of workability, compactability, cracking resistance, fatigue and durability. To obtain a good compromise between both conflicting requirements (stiffness and durability), the grading of the asphalt mix shall be optimized in such a way that the volume of voids contained in the mineral aggregate is low as compared to other mixes with a stony skeleton (e.g. SMA or porous asphalt). Together with an increased binder content in comparison with a conventional asphalt composition suitable for underlayers, this allows to design, despite of the high percentage of stones, relatively dense mixtures with a good coating of the aggregates and hence, a good performance in durability.

Although the concept of high stiffness mixtures for underlayers looks simple, the practical design of such mixes is a very secure operation. PradoWin is an ideal tool to perform the mix optimization, because the mix designer can easily adapt the composition of the constituents, while evaluating at once the effect on the voids in the mineral aggregates, the binder content and the filler to binder ratio.

BRRC has made two basic mix designs using PradoWin:

- one mix design with Belgian materials,
- one mix design with the Swiss materials to be used in the ALT study.

Different variants were then defined, based on approximately the same grading curve:

- Variant 1: Design without RA (reference).
- Variant 2: Design with 25 % RA.
- Variant 3: Design with 40 % RA.

The analytical mix design is the initial phase in the mix design procedure. In a next phase, gyratory compaction tests according to EN12697-31 are performed to verify the compactability and the air void content. Depending on the results of the gyratory tests, the analytical mix design is adapted.

Table 3 shows the final mix gradings (obtained after this optimization step) for the various percentages of re-use material. The percentage of RA given in table 3 stands for the percentage of old binder (from RA) on the total binder content.

	Mixes with Belgian materials			Mixes with Swiss materials		
	0	25	40	0	25	40
% RA	0	25	40	0	25	40
% total binder	5.5	5.5	5.5	5.8	5.8	5.8
% RA aggregates	0	24.3	39.4	0	29.5	47.4
% passing on sieve:						
20 mm	100	100	100	100	100	100
14 mm	97.3	96.8	96.4	97.7	97.0	96.7
10 mm	75.4	75.5	74.9	76.4	76.2	79.2
6.3 mm	52.1	53.9	54.1	57.5	55.3	59.5
4 mm	37.9	40.3	41.1	43.8	41.5	45.1
2 mm	30.5	32.0	32.3	33.0	30.3	32.1
1 mm	21.9	24.6	25.8	25.6	22.7	23.2
0.5 mm	16.0	18.9	20.5	21.2	17.9	17.5
0.25 mm	11.1	13.1	14.2	17.5	14.1	13.0
0.063 mm	5.9	6.0	6.1	6.3	6.3	6.4

Table 3: Grading of the different mixtures

### 3. Laboratory performance of the mixes

An extensive laboratory study was performed on all mixtures:

- Stiffness modulus was determined according to EN12697-26 (two-point bending test on trapezoidal samples) for temperatures between -20 °C and 30 °C and for frequencies between 1 and 30 Hz.
- Resistance to fatigue of the different mixes was determined according to EN12697-24 (two point bending test on trapezoidal samples) at 15°C and 10Hz.
- Resistance to permanent deformation is determined according to EN12697-22 (large device in air) at a temperature of 50°C.
- Water sensitivity is determined as the indirect tensile strength according to EN12697-23 before and after conditioning in water according to EN12697-12.

The results on the optimized mixtures are given in table 4. We note that for the Swiss mixtures with RA, some of the tests were performed with a lower binder content (5.7 and 5.6 % for 25 % and 40 % of RA respectively, instead of 5.8 %). The reason for this is that in an asphalt plant, the variations on binder content of RA are usually larger than in the laboratory. With a high percentage of re-use, the impact of this parameter on the total binder content is important. A way to deal with this uncertainty in the phase of mechanical performance testing is to make the tests with the most unfavourable estimation of the binder content. For the mix with 40 % of RA, a variation of 0.5 % on the binder content of the RA would lead to a variation of 0.2 % on the total binder content. By doing the tests with a total binder content of 5.6 % instead of 5.8 %, the laboratory tests will be on the safe side.

It can be observed that a high performance was reached on all aspects:

- All mixes have a very high stiffness around 13000 MPa, except for the Swiss mix with 40 % RA and 5.6 % binder content, which is less stiff.
- The resistance to permanent deformation is very high: always below 5 %.
- The resistance to the action of water is very high: for all mixes above 90 %.
- The resistance to fatigue is very high: above  $1.0 \times 10^6$  cycles at 120 microstrain, except for the Swiss mix with 40 % RA and 5.6 % binder. This is at least a factor seven better than a conventional Belgian mix for underlayers.
- The void content (measured hydrostatically) of the Swiss mixes with 25 % (binder content 5.7%) and 40 % RA (binder content 5.6%) is rather high: 5% respectively 6 %.

	Mixes with Belgian materials			Mixes with Swiss materials		
% RA	0	25	40	0	25	40
% total binder	5.5	5.5	5.5	5.8	5.8	5.8
% voids gyratory (100 gyr.)	3.3	3.8	2.7	3.3	3.2	1.8
Rut depth (%) at 30000 cycles, 50 °C	2.7	-	-	3.0	2.5	2.8
ITS-testing						
Voids (%) (hydrostatic)	3.3	2.8	2.4	3.7	5.0 <sup>(*)</sup>	6.0 <sup>(**)</sup>
Strength before (MPa)	2.5	2.3	2.4	2.3	1.5 <sup>(*)</sup>	1.3 <sup>(**)</sup>
ITS-ratio	98 %	95 %	101%	92 %	104% <sup>(*)</sup>	94 % <sup>(**)</sup>
Stiffness modulus (MPa) 15°C - 10 Hz	12740	-	12830	13900	-	10580 <sup>(**)</sup>
Fatigue (15 °C, 10 Hz) N at 120 microstrain	1.20 X10 <sup>6</sup>	-	1.01 X10 <sup>6</sup>	6.2 X10 <sup>6</sup>	-	0.5X10 <sup>6</sup> <sup>(**)</sup>

<sup>(\*)</sup> determined for 5.7 % binder content instead of 5.8 % to investigate the risk of durability loss

<sup>(\*\*)</sup> determined for 5.6 % binder content instead of 5.8 % to investigate the risk of durability loss

*Table 4: Results of performance tests for the different mixtures*

- Considering also the fact that the stiffness modulus and the fatigue properties of the Swiss mix with 40 % RA and 5.6 % binder are less good than these determined for all other mixes, brought us to the conclusion that the binder content of 5.8 % (that was originally found at the design) cannot be reduced further. Measurements of the stiffness modulus and fatigue properties are planned in the near future on the mixes with 25 % and 40 % RA with 5.8 % of binder also.

It was concluded that the designed mixtures with the Swiss materials can be used for the ALT-study, provided that they are made with a minimum of 5.8 % of binder content.

#### **4. Accelerated loading testing and structural behaviour assessment**

The on-going works are to test the selected solutions in full-scale accelerated loading testing (ALT) facility of LAVOC (Fig.1). They are applied in a full-scale test section. The tested structure is as follows:

- Layer 1: AC MR8 3cm
- Layer 2: High Stiffness Modulus 8cm
- Layer 3: Soil foundation composed by grave 0/60 (40cm), fine Sand (145cm) and concrete.

Four different sections will be studied: a reference without RA, one section with 25% of RA and two sections with 40% of RA of which one doesn't include a wearing course.

The sections will then be loaded with a heavy traffic simulator (axle load of 10 ton, tyre pressure of 0.8MPa), which simulates traffic close to field conditions. The test section behaviour will also be assessed at various temperatures, from 15°C for the fatigue tests down to -15°C. Severe conditions will be applied: temperature ranging from 0 to -15°C and an axle load increased up to 13.5 ton.

This study will permit to evaluate the behaviour of the selected mixes in an accelerated way and close to field conditions. The instrumentation (strain gauges to measure horizontal longitudinal and transverse as well as vertical deformations) in the structure will provide the necessary data for the assessment of the structural and mechanical properties of the design.

The ALT-testing can give us interesting information about the bearing capacity, the fatigue cracking and the rutting behaviour to be used for a proposal of a standard design of HMA with reclaimed asphalt.



*Fig. 1: View of the full-scale accelerated loading testing (ALT) facility*

## **5. Conclusions**

One of the innovations considered in the European NR2C-project aims to optimize the design of high stiffness underlayers with high percentages of reclaimed asphalt, so as to guarantee the long-term performance. Different mixes with different percentages of RA (0%, 25 % and 40 %) and with Belgian as well as Swiss materials, were designed, optimized and compared. For the mix designs use was made of BRRC's PradoWin-software. With the aim to guarantee the performance of the mixes, the different mix designs were studied in the laboratory and optimized further. The performance of these mixes in relation to stiffness, fatigue cracking, water sensitivity and permanent deformation was determined and compared.

High performance mixtures were obtained, provided that an optimization of the mix design is performed based on the analytical mix design study and on the results of the performance tests. The results made us conclude that the designed mixtures can be selected for the ALT-testing, provided that they are made with a minimum of 5.8 % of binder content (for the Swiss materials used in this study). The three selected compositions (without RA, with 25 % and with 40 % of RA) will be further studied in the full-scale accelerated loading testing (ALT) facility of LAVOC. The sections will be loaded with a heavy traffic simulator and will be assessed at various thermal cycles. This study will permit to evaluate the behaviour of the selected solutions in an accelerated way and close to field conditions. The instrumentation (gauges to measure horizontal as well as vertical deformations) in the structure will provide data necessary for the assessment of the structural design in a later phase of the project.

## **6. References**

- [1] NR2C -New Road Construction Concept Work Package 2 – Interurban infrastructures Milestone M2.1 *Comparison of pre-selected innovations with D 2.1 output* by A. Junod and L. Arnaud, February 2006.
- [2] NR2C-report “Summary of results of the new binder”, by A. Vanelstraete and P. Peaureaux, December 2005.