RILEM RESEARCH ACTIVITIES ON PERFORMANCE TESTING AND EVALUATION OF BITUMINOUS MATERIALS

Manfred N. Partl

EMPA Swiss Federal Laboratories for Materials Testing and Research

Überlandstrasse 129, CH-8600 Dübendorf – Switzerland

Tel.. +41 1 823 5511 - Fax. + 41 1 821 6244 - e-mail: manfred.partl@empa.ch

Dariusz Sybilski

IBDiM, ul. Jagiellonska 80, PL - 03 - 301 Warszawa – Poland

Tel. +48 22 8 11 03 83 – Fax. +48 22 8 11 17 92 - e-mail: sybilski@ibdim.edu.pl

Hervé di Benedetto

ENTPE, rue Maurice Audin, F - 69518 VAULX-en-VELIN Cedex – France

Tel. +33 472 04 70 65 – Fax. +33 472 04 71 56 - e-mail: herve.dibenedetto@entpe.fr

Herald Piber

Amt der Kärntner Landesregierung, Josef Gruberstrasse 13 H, A - 9020 Klagenfurt – Austria

Tel. +43 463 25 601 – Fax. +43 463 230 100 – e-mail: 4piber@netway.at

Chantal de La Roche

LCPC, F - 44340 Bouguenais Nantes – France

Tel.. +33 2 40 84 59 23 – Fax. +33 2 40 84 59 94 - e-mail: Chantal.De-La-Roche@lcpc.fr

Ann Vanelstraete

BRRC, Boulevard de la Woluwe, 42, B-1200 - Brussels, Belgium

Tel. +32 2 766 0402 - Fax. +32 2 767 17 80 – e-mail: a.vanelstraete@brrc.be

Actual Members of RILEM TC 182-PEB:

Manfred N. Partl, CH (Chairman); Chantal de La Roche, FR (Secretary); Hussein Bahia, USA; Leif Bakløkk, NO; Yves Brosseaud, FR; Mike Butcher, AU; William Buttlar, USA; Morris De Beer, ZA; Hervé Di Benedetto, FR; Bernard Eckmann, BE; Remy Gubler, CH; Rob Hofman; Hans E. Höppel, GE; Martin Hugener, CH; Ulf Isacsson, SE; Ilan Ishai, IL; Burgard Koenders, FR; Didier Léonard; BE; Marcello Luminari, IT; Antonio Paez, ES; Andreas Pfeiler, AT; Herald Piber, AT; Ad C. Pronk, NL; Christiane Raab, CH; Geoffrey Rowe, USA; Safwat Said, SE; Emanuelle Sauger; FR; Shakir Shatnawi, USA; Milorad Smiljanic; YU; Hilde Soenen, SE; Jorge B. Sousa, PT; Dariusz Sybilski, PL; Lijun Sun, CN; Gregory Svechinsky, IL; Sandor Toth, HU; Ann Vanelstraete¸ BE; Matt W. Witczak, USA; Ludovit Zanzotto, CA

ABSTRACT

An overview on current research activities of the task groups within the RILEM Technical Committee "Performance Testing and Evaluation of Bituminous Materials" TC 182-PEB is presented:

Task group TG1 on "Bituminous Binder" (D. Sybilski) has recently accomplished a 2nd Round Robin Test on Binder Rheology on rheometers for different binders in order to determine the repeatability and reproducibility of these test methods. It is now preparing a recommendation based on these test results.

Task group TG3 on "Mechanical Testing of Mixtures" (H. Di Benedetto) has recently produced a recommendation on stiffness testing and is now evaluating the results of an inter-laboratory test program with different types of fatigue tests in order to separate fatigue material properties from test-type induced artifacts.

Task group TG4 on "PPPE Pavement Performance Prediction and Evaluation" (H. Piber) is conducting an inter-laboratory PPPE study on heavy loaded roads to compare performance predictions by different laboratories with long term performance field observations. Test results and predictions of different laboratories have been evaluated and analyzed. A report on this first phase of the PPPE studies is in preparation.

1 INTRODUCTION

The International Union for Testing and Research Laboratories for Materials and Structures RILEM (**R**éunion **I**nternationale des **L**aboratoires d'**E**ssais et de Recherches sur les **M**atériaux et les Constructions) is an organization of researchers from all over the world who devote their expertise and time voluntarily in order to advance scientific knowledge on testing and modelling of building materials. RILEM has a long tradition in dealing with bituminous materials dating back to the sixties. The actual RILEM Technical Committee TC 182-PEB on "Performance Testing and Evaluation of Bituminous Materials" [5, 6, 7, 8, 9, 10] succeeds the former RILEM TC 152-PBM "Performance of Bituminous Materials" [1, 2, 3, 4]. It was created in 1999 and concentrates on fundamental aspects of performance related problems of asphalt materials testing and modelling. This paper focuses on the activities and achievements of the following three task groups

- TG1 "Bituminous Binders" (D. Sybilski, PL) is evaluating binder properties with respect to aging and other factors relevant to performance and application.

- TG3 "Mechanical Testing of Mixtures" (H. Di Benedetto, FR) is evaluating mechanical tests for subjects such as fatigue, stiffness and permanent deformation.
- TG4 "Pavement Performance Prediction Evaluation, PPPE" (H. Piber, AT) is conducting an inter-laboratory PPPE study to compare performance predictions by different laboratories with long-term performance field observations.

In addition there is also TG2 on mix design which is still in an early conceptual stage. The role of the different task groups within the methodology for bituminous pavement materials according to [3] is shown in Figure 1. It demonstrates that RILEM TC 182-PEB extends its activities on most areas where testing of bituminous materials is of practical concern.

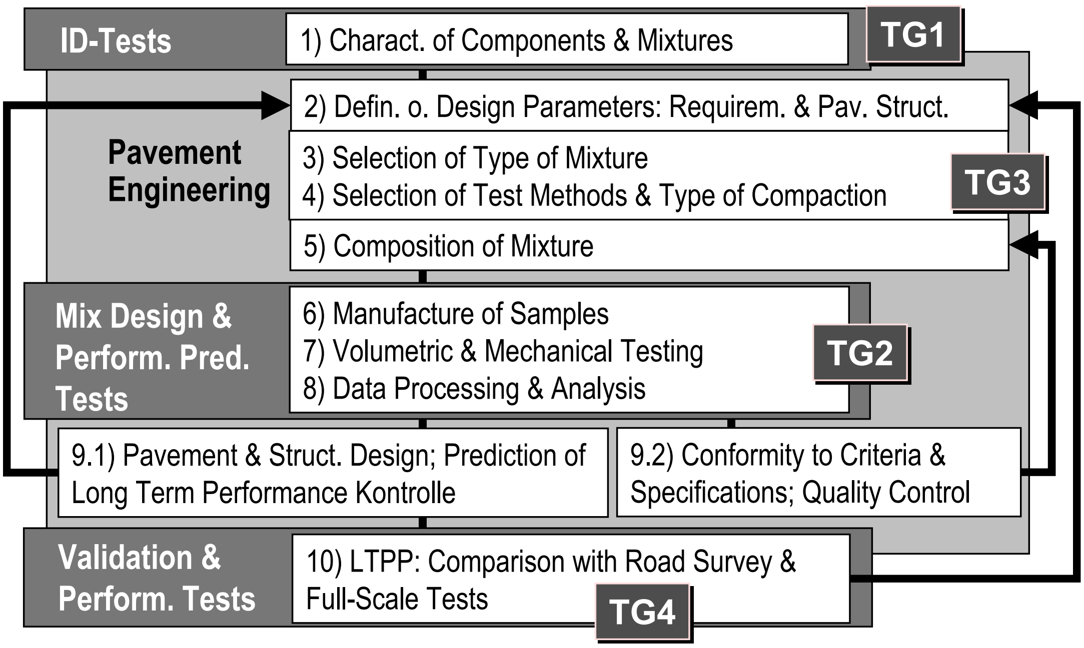


Figure 1. Basic elements of a methodology for bituminous pavement mixtures according to [3]

2 BITUMINOUS BINDERS (TG1)

This task group has recently accomplished an inter-laboratory test program on repeatability and reproducibility of dynamic rheometer (DSR or equivalent) and bending beam rheometer (BBR) tests [6, 10]. Tests were performed on the following four different binders in the original state as well as after RTFOT and RTFOT + PAV at 100°C aging following the procedures described in EN 12607-1 and AASHTO-PP1-97:

- Binder #1: Straight run bitumen used in the PPPE section in Portugal (see TG 4)
- Binder #2: SBS polymer modified binder (low modification)
- Binder #3: SBS polymer modified binder (high modification)
- Binder #4: EVA polymer modified binder

The differences of the binder characteristics are depicted in Figure 2. It can be seen that binder #1 clearly tends towards a linear viscous behavior with decreasing modulus whereas the binder No 3 with high modification clearly has non-Newtonian properties. Binder #2 and #4 with low SBS or EVA modification show an intermediate behavior and follow both a very similar curve.

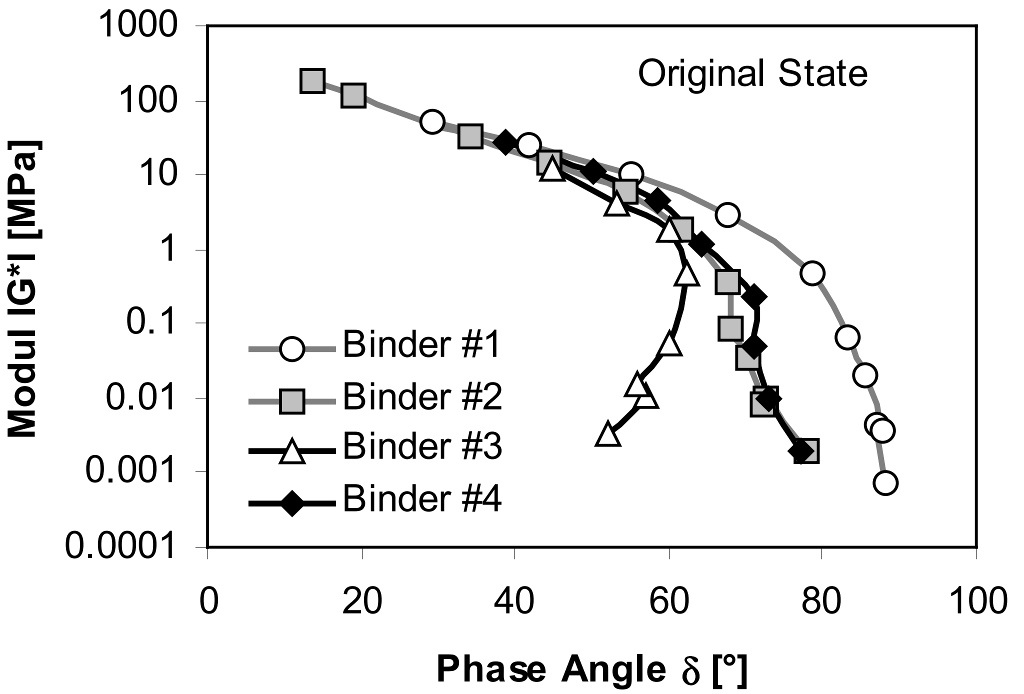


Figure 2. Black diagram for different binders in the original state for mean G-values and mean phase angles δ, obtained from the DSR-results of eighteen laboratories (data taken from [6]).*

Laboratories from nine different countries (AT, BE, CH, ES, FR, GB, HU, NO, NL, SE and US) participated in this investigation. The original binders were tested by eighteen and the aged binders by sixteen laboratories. Coordination of the program was carried out by the Belgian Road Research Center (BRRC). As shown in Figure 3 different types of dynamic shear rheometers were used. Measurements of G* and δ on the four binders were performed if possible at - 24, -18, -12, -6, 2, 10, 16, 22, 28, 34, 40, 46, 52, 58, 64,

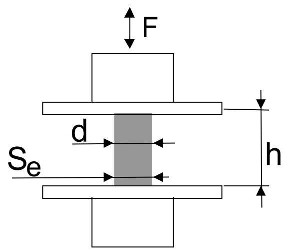
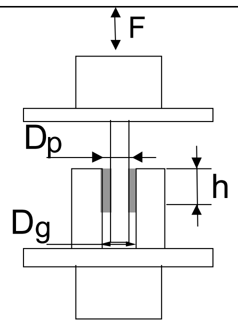
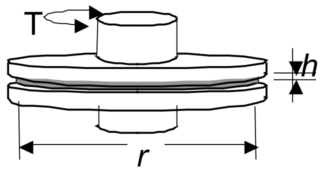
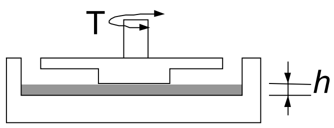
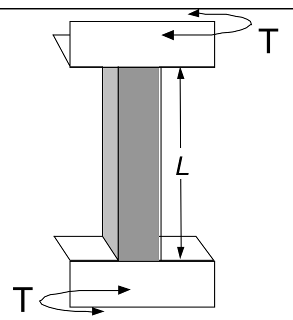
Notation	Test Geometry	Type of loading	No of Labs
L-TC-CY		Linear Tension-Compression	2
L-SH-AN		Linear Annular Shear	2
R-SH-PP		Rotational Shear Parallel Plates	15
R-SH-CP		Rotational Shear Cup & Plate	1
R-TO-PR		Torsional Shear	1

Figure 3. Overview on DSR equipment used by different laboratories [6]

70, 76 °C and at 0.1, 1.6, 5, 10, 20, 50 Hz. In case of one of the binders three repetitions were performed whereas on the others 1 measurement was carried out. As for BBR, three temperatures per binder and three repetitions per temperature were taken into account.

The results, recommendations and practical conclusions of the DSR and BBR measurements on the original binders and on the binders after aging were published in [6] and [10].

The DSR results on binders in the original state showed that

- large improvements were made compared to the earlier RILEM round robin on binder rheology by RILEM TC PBM [3]. The standard deviation for most of the experimental conditions lies between 15 and 30 % for G* and is less than 10 % for the phase angle.
- for stiffness values larger than about 10 MPa (temperatures of about 10°C or lower), the results were very scattered mainly because of limitations of the experimental devices. Therefore, emphasis was put on this item for the tests after aging.
- the most important reason for outlying results and for the larger standard deviations obtained appears to be compliance problems, related to the sample geometries being used.
- the reproducibility standard deviation is believed to be sufficient to determine the Performance Grade of the binder for what concerns the G*/sinφ - criterion at high temperatures.

From the DSR results on binders after RTFOT and RTFOT + PAV aging the following statements were made:

- For standardization purposes it is recommended to limit DSR rheometers to SHRP-equipment and geometries. Other equipment/geometries can also lead to correct results, but with higher risks
- For standardization purposes the temperatures should range between 10 to 76 °C
- The reproducibility standard deviation for G* is 10 % and for the phase angle 5%
- The AASHTO TP5 is reasonable
- Precision of test does not significantly depend from stage of binder: original or aged (RTFOT or PAV)

The BBR results on binders in the original state showed that

- a high reproducibility standard deviation was obtained with the used draft ASTM test method : 5 to 12 % on the S-value and 2 to 7 % on the m-value.
- the reproducibility of this BBR-test method is found sufficient to determine the Performance Grade of a binder according to Superpave with adequate accuracy. The temperature corresponding to the S-value of 300 MPa can be determined with an accuracy of about 1.5°C; the temperature corresponding to the m-value of 0.3 can be determined with an accuracy of about 2°C.

From the BBR results on binders after aging follows that

- the reproducibility standard deviation for S (60s) was 5 % and for m (60s) it ranged from 3 to 5 %
- the Performance Grade according to SHRP can be determined with a precision of about 1 °C (3 measurements per temperature)

3 MECHANICAL TESTING OF MIXTURES (TG3)

3.1 Recommendation for stiffness testing

Based on the results from the interlaboratory test program with 15 laboratories as reported in [3], the group recently released a RILEM recommendation on how to determine linear viscoelastic properties of bituminous mixtures by means of sinusoidal cyclic stiffness tests [8]. Some main statements of this recommendation read as follows:

Test and specimen selection

- **Non-homogeneous tests** (e.g. bending) for complex modulus determination can be used only for linear viscoelastic materials otherwise a large error may be introduced.
- For bending tests both **trapezoidal** and **prismatic** specimens can be recommended.

- The **minimal dimensions** of bending test specimens should not be smaller than about a factor 2.5 of the maximum aggregate size of the mix. For **homogeneous test** samples (e.g. compression) a factor of 5 appears safer.
- To achieve **standard deviations** of the complex modulus of 5 % statistical procedures for specimen selection on the basis of bulk densities and dimensions should be used
- Accuracy of the **test equipment** for force measurements at high temperatures and displacement measurements at low temperatures must be in accordance with the range of values to be measured.
- **Specimen installation** must have negligible effect on the measurements.
- **Stiffness of the testing machine** should high enough to be neglected even in cases when high specimen stiffnesses are measured.

Testing

- **Material linearity** tests should be performed to define the maximum acceptable stress and strain levels for complex modulus measurement. To avoid errors due to material non-linearity, testing strains should be lower than $100 \cdot 10^{-6}$ m/m.
- Amplitudes and the number of load cycles should be small to avoid **thermomechanic effects** on complex modulus measurement. Therefore it is recommended to apply less than 100 cycles for a modulus determination and to consider the frequency and temperature sweep procedure under that respect.
- To evaluate the temperature-frequency dependency of the stiffness properties, **testing condition** should be chosen in a reasonably broad range. A minimal temperature and frequency range of -10°C to 40°C and 0.5 Hz to 30 Hz is recommended.

Output and Analysis

- Not only the norm of the **complex modulus**, but also the **phase angle** should be determined**.**
- The complex modulus can be used as a good indicator of **constancy and quality** of the material composition.
- An Arrhenius type of equation may be used to determine **master curves** at least for a temperature range higher than 10°C. The WLF formula seems to be accurate on a larger temperature range.

- To determine the **purely elastic** component of the complex modulus (very high frequency and/or very low temperature) the plot of Black diagrams (|E*| versus phase angle φ) is recommended.

3.2 Fatigue testing

.

Fatigue behavior is very sensitive to boundary and loading conditions, which explains the considerable scatter of the results. Tests are generally performed assuming simple stress/strain and temperature distributions without considering the effect of load induced temperature change and densification. Fatigue laws are often expressed as simple functions of number of load cycles implying that fast and slow traffic have the same effect. Problems with the classical approaches for fatigue are related to the situation that no link between stress and strain controlled test exists and that no link between different types of tests could be established, so far.

The first RILEM inter-laboratory test program [2] [3] clearly demonstrated that comparable results between different laboratories can only be obtained if the test procedures and conditions are strictly standardized. Even then, a correlation to real behavior can only be expected to give a prediction within the right order of magnitude. It was concluded, that fatigue is not understood clearly in its physical principles and that further fundamental research is desperately needed.

Hence, a new RILEM inter-laboratory test program has been initiated by TG3 to study and characterize the fatigue phenomenon from a fundamental point of view and to separate fatigue material properties from test-type induced artifacts. Different types of fatigue tests were performed and applied to specimens which were all produced by the French Laboratoire Central des Ponts et Chaussées (LCPC) in Nantes in order to minimize the influence of specimen variation. The stiffness materials properties determined by LCPC in terms of complex modulus and phase angle are given in the black diagram in *Figure 4*.

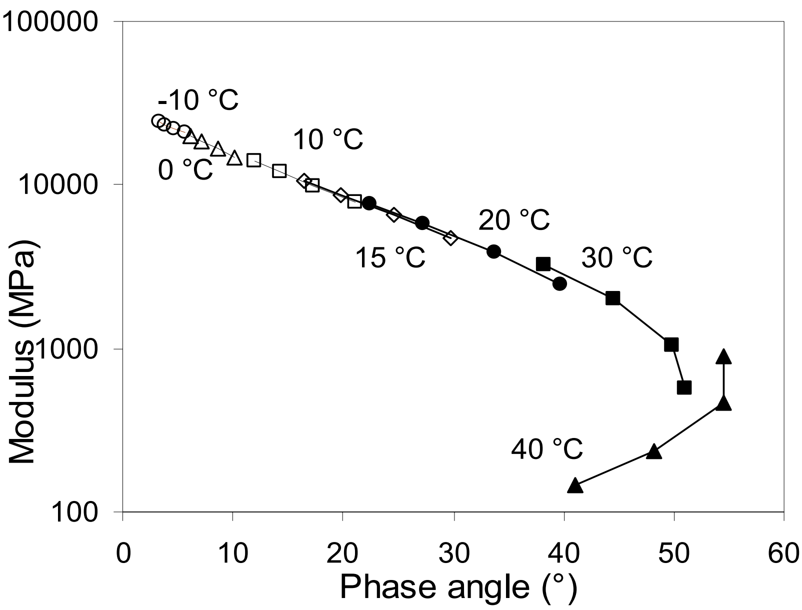


Figure 4. Black diagram by LCPC from sinusoidal complex modulus bending test

Eleven labs have agreed to participate (Figure 5). Fatigue tests in 2 point-, 3 point-, 4 point-bending beam (PB) mode as well as indirect tensile (IDT), tension/compression (T/C) and different shear (SH) fatigue tests on cylindrical specimens are conducted (including the LCPC shear and Superpave shear tests). Tests are performed at 10°C and as close to 10Hz as possible, using sinusoidal loading without any rest period. With the exception of the IDT, the half peak to peak strain amplitudes of 140 µstr and 180 µstr are kept the same for all tests. In addition, either amplitudes of 100 µstr or 220 µstr are chosen depending on the type of test. As for the IDT which can only be conducted in stress controlled way, stress amplitudes of 0.9 and 1.4 MPa are applied corresponding to an initial strain amplitude that is half the chosen strain amplitude for the other types of tests.

It is the intention of the program not to determine and predict the fatigue life only, but to perform a detailed analysis, focusing on the evolution of parameters such as modulus, phase angle, dissipated energy with the number of cycles. *Table 1* presents the set of output parameters currently considered by the task group. For data evaluation, three intervals “i” were considered (40 000 to 80 000 cycles, 50 000 to 150 000 cycles and 150 000 to 300 000 cycles). The non-linearity correction factors are 4/5, 3/4, 2/3 for interval 0, 1 and 2 respectively. Note, however, that these output parameters are still open to changes, depending of the findings during data evaluation.

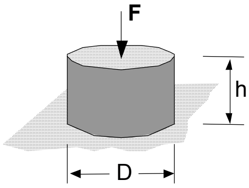
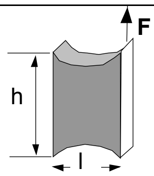
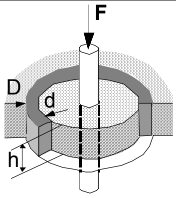
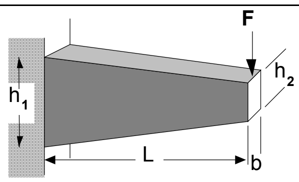
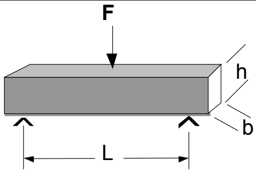
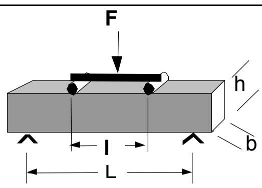
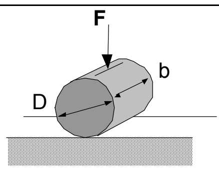
Notation	Test Geometry	Type of Test	Type of loading	No of Labs
T/C		Homo-geneous	Tension-Compression	2
SH		Homo-geneous	Simple Shear Test	1
SH-BE		Depending on d/D ratio	Co-Axial Shear Test	1
2PB		Non-Homog.	Two Point Bending	2
3PB		Non-Homog.	Three Point Bending	1
4PB		Non-Homog.	Four Point Bending	4
IDT		Non-Homog.	Indirect Tensile Test	1

Figure 5. Fatigue tests used by different laboratories

ε_0; E_0; φ_0	strain level; modulus; phase angle (at 100 cycles),
N_{f50}; N_1	fatigue life at 50%; defined from energy curve according to DWW
N^*_1; N^*_2	characteristic number of cycles at sharp changes in the fatigue curve
εi_0; εi_1; εi_2	average strain in interval i (from regression curve in the intervals i=0; 1; 2)
ε_{40000}; ε_{50000}; ε_{150000}	strain at cycle 40000; 50000; 150000 (from regression curve in the intervals i=0; 1; 2)
E_{00i}; φ_{00i}; W_{00i}	modulus; phase angle; dissipated energy per cycle extrapolated at N=0 for interval i=0; 1; 2)
a_{Ti}; a_{wi}; a_{Fi}	experimental E/E_{00i} slope; normalized energy slope; fatigue damage slope corrected of artifacts in interval i=0; 1; 2)

Table 1. Output parameters considered in the RILEM inter-laboratory fatigue tests

Data analysis and testing is still under way. So far, it appears that

- the obtained stiffness and phase angle values at 10°C and 10Hz are rather close for the different laboratories (between 10 500 and 12 000 MPa, and around 16°),
- the fatigue life is very different between the different tests methods,
- fatigue life on the same type of samples determined by different laboratories may be very different (factor of 2 to 3),
- small samples seem to enjoy a longer fatigue life in bending tests.
- there are suggestions to calculate 4PB test results from T/C test results

Examples of fatigue test results are presented in *Figure 6.* Complex modulus at 10°C vs. the number of cycles and dissipated energy under a mean strain of 110 µstr at 10°C from a 10 Hz tension/compression test by ENTPE is shown together with another test by ENTPE where dissipated energy under stress and strain control conditions were determined as a function of load cycles. It clearly depicts the three characteristic phases of the fatigue behavior [2]. Similar relationships between the different parameters are now in the process of being evaluated, verified and discussed before being ready for presentation in detail by the task group. The project is progressing in an encouraging way and will certainly contribute to clarify the fatigue testing subject on a fundamental basis.

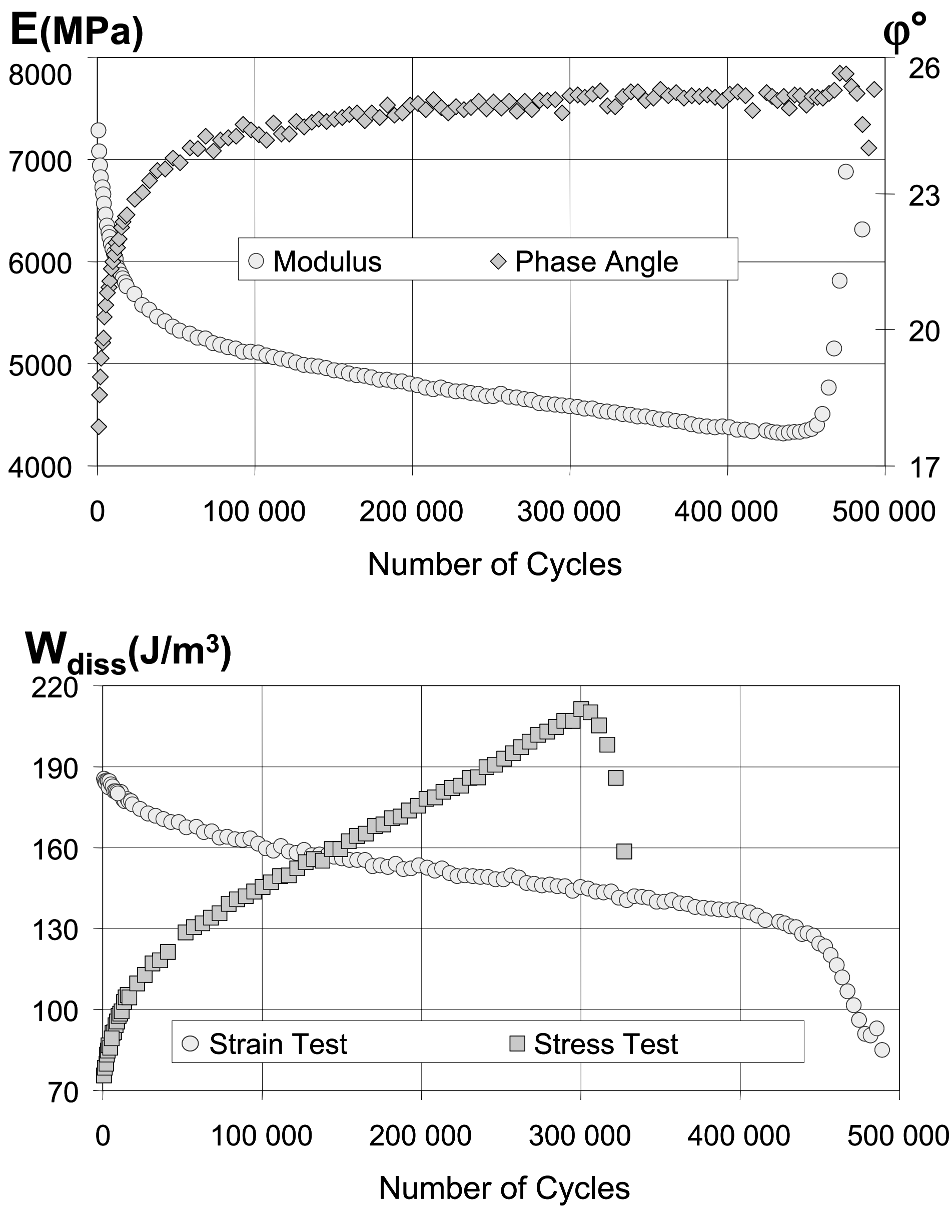


Figure 6. *<u>top:</u> Modulus vs. number of cycles under a mean strain of 110 μstr at 10°C from a 10 Hz tension/compression test by ENTPE; <u>bottom:</u> Dissipated energy versus number of cycles in a test performed by ENTPE.*

4 PAVEMENT PERFORMANCE PREDICTION EVALUATION, PPPE (TG4)

This task group is conducting an inter-laboratory Pavement Performance Prediction Evaluation PPPE study on heavy loaded roads under two different climatic conditions relevant to many of the densely populated parts in Europe and other industrialized regions of the world. The aim is to compare performance test results and predictions by different laboratories with long-term performance field observations on the same test sections. A short paper on the interim findings was recently published [9].

Relying on their own tests results and methodology and based on a standard set of input data on climate, traffic condition, sub-base and sub-soil properties from the road section operator the laboratories were asked to predict permanent deformation (rutting), cracking (fatigue cracking, thermal cracking) and surface defects (loss of material) at each test site over a period of about 10 years. The prediction of distresses was to classify according to *Table 2*.

No	**Type of damage**	**Dimension**	**Class of distress**			
			A	**B**	**C**	**D**
1	Rutting [1)]	mm	< 5	≤ 5 ... < 10	10 ... < 20	≥ 20
2	Single cracks (thermal cracking)	m/100 m	< 4	≥ 4		
3	Net cracks (fatigue cracking)	% of 100 m²	< 5	≤ 5 ... < 10	10 ... < 20	≥ 20
4	surface defects [2)]	% of 100 m²	< 2	≥ 2		

[1)] Rutting in surface course & deformation of each asphalt course, (max. depth & thickness change)

[2)] Loss of material and/or raveling

Table 2 Performance prediction classification table [9]

In this PPPE study two test sections with newly laid asphalt courses were considered:

- one section in Austria near Villach about 40km to the west of Klagenfurt (capital of Carinthia), representing an alpine region with large temperature changes and the risk of thermal cracking, called CCRIPPPE (Cold Climate RILEM Interlaboratory Pavement Performance Evaluation) and
- one section in Portugal near Mindelo which about 20 km north of Porto representing a warm coastal region with risk of permanent deformation, called WWRIPPPE (Warm Weather RILEM Interlaboratory Pavement Performance Evaluation).

Details on the selected test sections are summarized in *Table 3*.

The test program consisted of two main parts:

1. *Test section operator part (in situ):* Providing the field samples for testing and basic input data as well as conducting long term pavement performance monitoring of the test sections over a period of 10 years.
2. *Laboratory part (ex situ):* Performing laboratory tests on field samples and prediction of long-term pavement performance.

Name of test section:	**WWRIPPPE: Mindelo**	**CCRIPPPE: Villach**
Name & number of the road:	IC 1 (E 01); Valença/Lisboa, Sublanço Perafita/Mindelo	A 10 (E 55) Tauernautobahn
Sea level [m]	35	500
Horizontal alignment:	straight	bend - radius = 2.5km
Gradient [%]:	0.5	0.5
Cross fall [%]:	-	3.4
Layers top-down:	40mm PA (1997)	35mm SMA 11 (1997)
PA: Porous asphalt	110mm AC Caltrans (1996)	80+80mm; BT I 22 HS (1997)
AC: Asphalt concrete	110mm AC Arizona (1996)	65+65 mm BTS I 22 (1988)
SMA: Stone mastic asph.	200 mm unbound (1996)	200 mm unbound. (1988)
BT(S): bitum. road base	300 mm unbound (1996)	300 mm unbound (1988)
Earthwork:	cutting (1996)	embankment (1987)
Bearing capacity	Falling Weight Deflect.:	Load plate (ÖNORM B 4417):
Test values during construction time	road base and subbase: 245 ± 65 MPa subgrade: 85 ± 15 MPa	road base: 111 ± 20 MN/m² subbase: 79 ± 14 MN/m² subgrade: 115 ± 60 MN/m²
Traffic census (year, type):	1996; automatically	1995; by hand
Avg. annual dail. traffic:	9405	16.200
Avg. annual dail. heavy traff.	971	2.350
Traffic forecast [% p.a.]	+ 4 %	+ 3 %
Traffic restriction [km/h]:	120	100
Weather station:	Porto – Pedras Rubras (70m)	Villach - Seebach (492 m)
Days max. T >25°C:	32	46
Days min. T < 0 °C:	2	128
Days with snow:	0	33
Annual avg. rainfall [mm]:	98	1232
Avg. 7d max. air T[°C]:	30.04 ± 2.46	30.7 ± 1.8
Avg. min. air T p.a. [°C]:	0.44 ± 2.01	-19.3 ± 3.7 °C

Table 3 Basic data of the PPPE test sections [9]

Thirteen laboratories participated actively in this study, producing fourteen different predictions in case of rutting and nine results on fatigue. Only very few laboratories offered a distress prediction for thermal cracking (single cracks) and for surface defects. Most of the laboratories based their prediction on mechanical tests on the materials in the original state, i.e. as delivered. Only one participant considered the long term ageing effect. *Figure 7* and *Figure 8* respectively provide an overview on the test methods used for rutting and fatigue prediction.

All laboratories used a sample of the top layer of the base course for rutting prediction. Some laboratories did not consider the surface course and only few participants considered all pavement courses. Most laboratories preferred compression and wheel tracking tests and used load-controlled procedures. Test temperatures for the materials of the two test sections were equal with the exception of the shear test.

As for fatigue, the majority of laboratories used specimens from the lowest layer of the base course (BC1) for fatigue prediction. Most laboratories preferred bending beam tests and used deformation or strain controlled methods. With two exceptions, fatigue test temperatures for the materials of the two sections were equal.

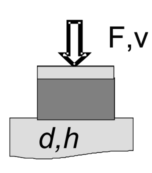
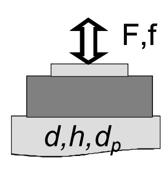
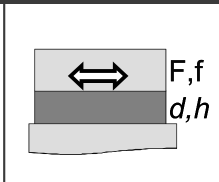
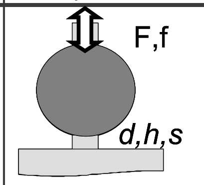
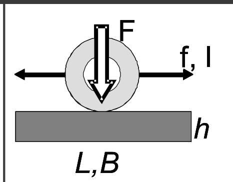
Test-Type	Compression CO		Simple Shear SH	Ind. Tensile IT	Wheel Tracking WT
Loading	Static S	Cyclic C	Cyclic C	Cyclic C	Cyclic C
Set-Up, Geometry					
Input	Deform.	Load	Load	Load	Load
Temp. °C	50	-15...50	43...52	25...44	20...60
Cyclinder CY	S-CO-CY	C-CO-CY	C-SH-CY	C-IT-CY (horiz. Cores)	C-WT-CY
Prisma PR		C-CO-PR			C-WT-PR
Number of Labs	1	3(CY),1(PR)	2	1	1(CY),5(PR)

Figure 7. Test methods used for rutting prediction

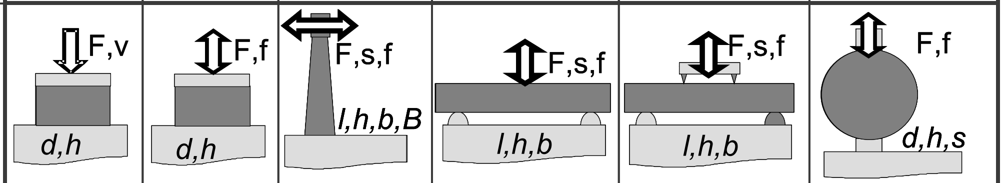
Test-Type	Compression CO		2, 3, 4 Point Bending (PB)			Ind. Tensile IT
Loading	Static S	Cyclic C	Cyclic C	Cyclic C	Cyclic C	Cyclic C
Set-up, Geometry 	F,v d,h	F,f d,h	F,s,f l,h,b,B	F,s,f l,h,b	F,s,f l,h,b	F,f d,h,s
Input	Deform.	Load	Load, Str.	Deform.	Strain	Load
Temp. °C	-20...30	15	-20...30	18, 20	5...20	10
Cyclinder CY	S-CO-CY	C-CO-CY				C-IT-CY
Prisma PR			C-2PB-TR	C-3PB-PR	C-4PB-PR	
Number of Labs	1	1	2	1	3	(1)

Figure 8. Test methods for fatigue prediction

The first results of the predictions are summarized in *Table 4*. Note however, that the data evaluation and interpretation of this RILEM inter-laboratory test program is still ongoing and a comparison with the in field behavior of the two sections is not possible yet. Hence, the following findings from [9] deal only with the pavement performance prediction by the laboratories:

- None of the laboratories followed a procedure and methodology, which was directly comparable to one of the others.
- The rut depths predicted by different laboratories using their own test methods and prediction models varied over a wide range.

- In those cases where the curve of rut depth development was determined exactly, generally the larger permanent deformations were predicted for the CCRIPPPE than for the WWRIPPPE section. The values of the CCRIPPPE section were more scattered.
- Some laboratories compared their rutting results with requirements, which are fixed in regulations or national standards and came partly to contradicting conclusions. Hence, in some cases, the CCRIPPPE section and in other cases, the WWRIPPPE section did not pass the requirements.
- It was generally agreed, that rutting will probably not exceed 20 mm in both sections. As compared to the other methods, the predictions based on the wheel-tracking test were extremely unfavorable for the WWRIPPPE section.

No	Type of Damage	Class of Distress			
		A	B	C	D
1	**Rutting [mm]**	**<5**	**5...<10**	**10...<20**	**≥ 20**
	CCRIPPPE Villach	5	3	4	-
	WWRIPPPE Mindelo	4	4	3	-
2	**Single Cracks [m/100m]**	**<4**	**≥ 4**		
	CCRIPPPE Villach	4	-		
	WWRIPPPE Mindelo	4	-		
3	**Net Cracks [% of 100m^2]**	**<5**	**5...<10**	**10...<20**	**≥ 20**
	CCRIPPPE Villach	9	-	-	-
	WWRIPPPE Mindelo	6	1	-	1
4	**Surface Defects [% of 100m^2]**	**<2**	**≥ 2**		
	CCRIPPPE Villach	2	-		
	WWRIPPPE Mindelo	-	1		

Table 4. Performance prediction classification table with number of predictions

- Compared to rutting, the fatigue predictions were in better agreement. However due to the fact that the prediction period was only about half of the design period, it can not be concluded that the fatigue models are more accurate than the permanent deformation models.
- With one exception the remaining life after 10 years of the CCRIPPPE section is predicted to be higher. For the WWRIPPPE section the prediction showed less

agreement. Fatigue life prediction by all laboratories in terms of net cracking confirmed this finding.

- In summary, the findings clearly demonstrate that further exchange and co-ordination of research efforts is extremely necessary.

REFERENCES

[1] Partl M.N., Francken L.: *RILEM Interlaboratory Tests on Stiffness Properties of Bituminous Mixtures.* Proc. of 5th Int. RILEM Sympos. on Mechanical Tests for Bituminous Materials MTBM '97, Lyon, France, 14-16. May, pp9-14, ISBN 90 541 0876 2 (1997).

[2] Di Benedetto H., De La Roche C., Francken L.: *Fatigue of Bituminous Mixtures: Different Approaches and RILEM Interlaboratory Tests.* Proc. of 5th Int. RILEM Sympos. on Mechanical Tests for Bituminous Materials MTBM '97, Lyon, France, 14-16. May, pp15-25, ISBN 90 541 0876 2 (1997).

[3] Francken L. (Editor): *"Bituminous Binders and Mixes", State-of-the-Art and Interlaboratory Tests on Mechanical Behaviour and Mix Design.* RILEM Rep. N°17, E&FN Spon, ISBN 0 419 22870 5, (1998).

[4] Raab C., Partl M.N., Eustacchio E.: *RILEM Interlaboratory Test Program: Part 1, Mix-Design. Vergleichende Untersuchung der "optimalen" Mischungen der Laboratorien.* Bitumen 2+3/99, pp70-77, (1999)

[5] Partl M.N., Sybilski D., Sousa J.B., Di Benedetto H., Piber H.*: Current Research Projects of the New RILEM TC PEB (Performance Testing and Evaluation of Bituminous Materials), 20-22. Sept.* Proc. of 2nd Eurobitume & Eurasphalt Congress 20-22. September, Barcelona, Book I, pp 605...613, (2000)

[6] Vanelstraete A., Sybilski D. and other members of RILEM TC PEB – TG1 "Bituminous Binders": *Results of the RILEM Round Robin Test on Binder Rheology.* Proc. of 2nd Eurobitume & Eurasphalt Congress, 20-22. September, Barcelona (2000).

[7] Sybilski D., Luminari M., Hopman P.: *„Functional Aspects of Bituminous Mixture Design".* Proc. of 2nd Eurobitume & Eurasphalt Congress, 20-22. September, Barcelona (2000).

[8] Di Benedetto H., Partl M.N., Francken L., De La Roche C.: *Stiffness Testing for Bituminous Mixtures. Recommendation.* J. of Materials and Structures, Vol.34, pp66 –70, (2001)

[9] Partl M.N., Piber H.: *RILEM – Interlaboratory Tests on Performance Prediction of Pavements.* Proceedings of 9th international Conference on Asphalt Pavements, ISAP, 17..22. August, Copenhagen (2002)

[10] Vanelstraete A., Sybilski D.: *Results of the RILEM Round Robin Test on Binder Rheology.* Proceedings of 9th International Conference on Asphalt Pavements, ISAP, 17...22. August, Copenhagen (2002)

RECYCLED MATERIALS: RESEARCH AND SPECIFICATIONS

Jeffrey S. Melton
Recycled Materials Resource Center
338 Environmental Technology Building
University of New Hampshire
Durham, NH 03824 U.S.A
Tel: 603.862.2107 – Fax: 603.862.3957 – Email: jmelton@rmrc.unh.edu

ABSTRACT

The Recycled Materials Resource Center (RMRC) is a National Center working in partnership with the Federal Highway Administration to encourage the appropriate use of recycled materials in the highway environment. Since its inception in 1998, the RMRC has developed vigorous research and outreach programs to support its mission. A total of 20 research projects have been funded to date, with two projects extended and three projects completed. The results generated by the research program are developed into new protocols, recommendations for specifications, computer models and composite recycled materials. The outreach program of the Center takes these products and works with government agencies, universities and private companies to transfer appropriate technology and make information available to the highway community. In addition, the Center sponsored the international conference on "Beneficial Use of Recycled Materials in Transportation Applications" in Washington, D.C. last November. Research and outreach activities of interest to the SIIV audience are summarized.

1. INTRODUCTION

The Recycled Materials Resource Center (RMRC) was formally established on September 4, 1998 in close partnership with the Federal Highway Administration (FWHA) and in coordination with the FHWA Pavement Management Coordination Group. The Center was realized through authorization in the Transportation Equity Act for the 2lst Century (TEA-21) with funding for six years and potential reauthorization for an additional six years. It is part of the Environmental Research Group (ERG) at the University of New Hampshire (UNH). The mission of the Center is to develop and pursue strategies to overcome barriers to the appropriate use of recycled materials in the highway environment. In this sense, recycled materials are broadly defined as recycled pavement materials, secondary materials, byproduct materials, and waste materials.

The RMRC has developed active research and outreach programs to support its mission. The research program is primarily focused on the long-term physical and environmental performance of recycled materials in the highway environment, though other topics such as cost-benefit analysis of recycled materials are addressed as well. One key component of the research program is the requirement that the research result in some kind of tangible product such as a computer model, a new testing protocol or a recommendation for a new specification. The outreach program then works with State and Federal agencies, universities and private companies to encourage the use or implementation of the final products.

2. RESEARCH PROGRAM

The RMRC supports recycled materials research across the United States through competitive and non-competitive grants. The research program is product oriented, meaning investigators are encouraged to develop their results into new protocols, specifications or other guidance documents. Specific technical issues such as evaluating the potential use of a recycled material for a given application may qualify for a Technical Problem Solving grant. These grants are small, less than 20,000 USD, and generally last only a year. Larger, multiyear grants are available through a peer review process. Most large grants involve State Departments of Transportation (State DOTs) or State Environmental Protection Agencies (State EPAs) working with universities or industry as a team. All large grants have a 20% cost sharing requirement that encourages cooperation among researchers and preserves RMRC funds. All investigators are required to submit quarterly progress reports and a final report as well as develop their final products. The reports and results of each project are posted on the RMRC website.

3. SPECIFICATIONS AND PRODUCTS

The final products can take many forms, with the most common being a recommendation to the American Association of State Highway and Transportation Officials (AASHTO). There are currently 15 recommendations to AASHTO that are planned, being processed or completed. There are two recommendations to the American Society for Testing and Materials (ASTM) expected as well. Additional planned final products include two new computer models and three new testing and evaluation protocols for State DOTs, State EPAs and the US EPA. Two new composite materials created from Coal Fly Ash have already been developed. Lastly, plans for a mobile Portland Cement Concrete recycling plant are being review for technical feasibility.

4. EXAMPLES OF RESEARCH AND PRODUCTS

4.1 Introduction

The RMRC supports research on a wide range of physical and environmental topics related to recycled materials in the highway environment. The following projects provide examples of the types of research being conducted and also the types of products that result from the research.

4.2 Mitigating Alkali Silicate Reaction in Recycled Concrete

Throughout the United States there exists an enormous amount of Portland Cement Concrete (PCC) infrastructure that is nearing the end of its working life and will have to be replaced. Disposal of this material is problematic since landfill space is dwindling and disposal costs are rising. One possible option is to recycle the PCC as an aggregate in new concrete construction. However, recycled concrete aggregate (RCA) can potentially contribute to Alkali-Silica Reaction (ASR), a destructive chemical reaction that causes premature concrete degradation. This project is using test methods developed at the University of New Hampshire to evaluate the potential for ASR in concrete mixes that use RCA. The research has two distinct components; one component is focused on determining the effectiveness of various ASR mitigation strategies to control and/or eliminate ASR in RCA concrete while the other will confirm that the test procedures developed at UNH can be used with the above mitigation strategies.

Current research is investigating the mitigation properties of low-alkali cement, class F fly ash, ground granulated blast furnace slag, silica fume blended cement and lithium nitrate on RCA concrete under laboratory conditions. The RCA came from a section of PCC pavement that used Blue Rock, an igneous fine-grained quartzite rock, as an aggregate. Concrete made with Blue Rock and with limestone aggregates are being tested as well for comparison to concrete made with Blue Rock RCA.

One focus area of the this project is to evaluate modifications to ASTM C 1293 and ASTM C 1260, standard tests for evaluating potential ASR in concrete. In their current form the standards are not truly applicable to concrete that uses recycled concrete aggregate. For example, the ASTM C 1260 mortar bar test requires crushing the aggregate, which would destroy the RCA since it is composed of aggregate and paste. The test procedure has been modified to use larger specimens in the form of cubes and prisms, with promising initial results. Additional modifications to the ASTM C 1293 test have succeeded in cutting the test period from a year to three months while maintaining sensitivity to ASR. It is expected that the experience gained from these modifications will be combined into a new ASTM or AASHTO specification that will be applicable to both virgin aggregate and RCA concrete. Guidelines will also be developed to allow DOTs to evaluate a given RCA for recycling in concrete. Numerous State DOTs and industry are involved in this project.

4.3 Environmental Weathering of Granular Waste Materials

The primary hypothesis of this research project is that weathering reactions in industrial byproducts will change the environmental and physical behavior of the byproduct materials. It is expected that weathering reactions will improve the environmental performance of the material; although it remains unclear in what way the physical performance will be changed. Initial research concentrated on artificially aging Municipal Solid Waste Incinerator (MSWI) bottom ash using heat and water, and then analyzing the structural integrity, mineral components and leaching behavior of the weathered material. The artificially aged ash was also compared to naturally weathered ash to determine what, if any, differences existed between the two materials. It was determined that aging with heat and water alone did not improve the leaching characteristics of the ash. Current research is using carbonation with heat and water as a means of aging.

The principle objective of this research is to more completely understand the chemical and physical behavior of byproduct materials in the environment over the long term. Improved understanding will lead to the satisfaction of three goals: to be able to predict the long-term environmental performance of the byproduct material; to be able to predict the long-term physical performance of a particular application using byproduct materials; and to be able to devise beneficiation strategies to improve the environmental performance of the material prior to its use in the highway environment.

4.4 Development of a Risk Analysis Framework for Beneficial Use of Secondary Materials

One of the barriers to wide spread use of recycled materials is the confusing and sometimes contradictory information that is available to regulators who need to evaluate the possible risks of using secondary materials. This project will address this problem in two ways: First, standards and practices for beneficial uses of recycled materials in both the U.S. and abroad will be reviewed and synthesized into a set of rational, straightforward tools that will allow regulators to predict the environmental impact of secondary materials. Second, a simplified hydrogeologic transport model is being developed that will incorporate source term behavior and environmental fate. The model will help regulators assess potential ground water issues that arise from leaching of contaminants from recycled materials. A comprehensive literature survey to identify ground water issues was recently completed and these results will be combined with information gathered from the international workshop held at UNH in April 2000 to define what capabilities the model must have to be useful. The proposed end products of this project are a (i) mechanistic source term/fate/transport model for inorganic contaminants that will be field-verified and (ii) a simplified model or approach that embodies the principles of the source term/fate/transport model for use by regulators.

4.5 Leaching from Granular Materials Used in Highway Construction During Intermittent Wetting.

Many secondary materials are being considered for use as aggregate substitutes in unbound highway construction applications (embankments, sound barriers, fill, base course). It is reasonable to assume that these materials will be subjected to intermittent wetting and perhaps even constant flow, in which case leaching of contaminants becomes a concern. The goal of this project is to develop standardized testing methods to estimate constituent leaching from granular waste materials that are utilized in highway construction applications. The initial focus was on developing a mathematical framework to model long-term performance from short-term laboratory results. The model has been finished and verified, with documentation in progress. Percolation tests are underway on municipal solid waste incinerator ash, and percolation tests on foundry sands are expected to start soon. During testing the primary focus is on leaching conditions that occur as a consequence of intermittent infiltration (wetting and drying, CO_2 uptake, O_2 uptake) into the granular material. These tests are also looking at the effects of aging on leaching characteristics.

In the end, the resulting test methods, interpretation protocols, mathematical models will be available for evaluating the environmental impacts of specific secondary material utilization applications through the leaching pathway. Motivation for end-users to adopt the protocols will be based on the need to evaluate potential environmental impacts for both liability and regulatory assessment. State DOTs, State EPAs, industry and the US EPA are all involved in this project.

4.6 Development and Preparation of Specifications for Recycled Materials in Transportation Applications

In this project a Technical Advisory Group (TAG) was organized with members from the DOTs of California, Florida, Illinois, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York State, North Carolina, Ohio, Pennsylvania, Texas, and Wisconsin to develop specifications for using recycled materials in highway projects. The lack of appropriate specifications for the use of recycled materials in highway projects is often a significant barrier to acceptance of these materials. A survey of TAG members had them rank different recycled materials in terms of usefulness in the highway environment. They then began to develop common specifications for the top six combinations. The material-application combinations they chose are listed below:

- Reclaimed Concrete in Portland Cement Concrete
- Reclaimed Concrete in Granular Base
- Reclaimed Asphalt Pavement in Asphalt Concrete
- Waste Glass in Granular Base
- Coal Fly Ash in Embankments
- Tear-off Asphalt Scrap Shingles

Two specifications have been developed and approved by AASHTO. One was on the use of crushed glass (glass cullet) as a soil aggregate base course and one on the use recycled concrete as an aggregate base course. A specification on recycled concrete as an aggregate in concrete and a specification on coal fly ash in embankments are currently being considered by AASHTO. Draft specifications for the scrap shingles and reclaimed asphalt are currently being prepared.

4.7 Development of a Rational and Practical Mix Design System for Full Depth Reclamation (FDR)

This project aims to develop a rational and practical mix design system for full depth reclamation (FDR) of asphalt pavements. The objective is to develop methods for determining curing periods and the number of gyrations required in the Superpave gyratory compactor to produce in-place densities. The resulting mix design system should be able to produce mixtures with consistently good performance, thereby enhancing confidence in the use of FDR and encouraging the increased use of recycled materials. Contractors are not always willing to consider FDR because they do not want to assume the risk of producing a defective product until they have more experience and guidance with FDR. Mix design specifications will lessen their exposure to risk and encourage contractors to use FDR. To date, a preliminary mix design, construction of test sections, and testing of materials obtained during construction have been accomplished. The preliminary mix design was conducted by compacting in-place materials, along with additives at different proportions, with the Superpave gyratory compactor. The samples were made by combining unbound base course and asphalt bound materials, which were obtained from the test sections, in the proportion in which subsequent full depth reclamation was planned. Based on the results of this study, several conclusions have been made regarding the N_{design} mixture and curing times. Current work is focused on comparing the effectiveness of four different types of additives used for FDR at a specific location in the state of Maine. By extending the time frame of this project, work will concentrate on making the developed methodologies applicable to not only New England, but also all 50 states.

4.8 Specifications for Erosion Control of Composted Materials

When people think of recycled materials, they usually think of glass, plastics, construction materials, etc. However, organic materials can be recycled as well, being turned into compost or mulch. This project seeks to promote using organic recycled materials for erosion and sedimentation control in construction areas by developing necessary AASHTO specifications. A specification would accelerate acceptance of organic recycled materials by state DOTs, which have been using techniques such as silt fences, hay bales and straw matting for erosion control. Two recommendations for AASHTO specifications are being developed to provide guidance on the use of composted material (recycled organic material) for erosion control in highway projects. The first is titled *Standard Specification for Compost for Erosion/Sediment Control (Compost Blankets)*. It describes the use of composted material as ground cover to prevent erosion from runoff. The second is titled *Standard Specification for Compost for Erosion/Sediment Control (Filter Berms)*. It details the construction of small berms using composted material to reduce erosion and control sedimentation. Both recommendations were recently accepted as provisional specifications by AASHTO.

4.9 Life-Cycle Analysis and Decision Support Tools for Recycled Versus Virgin Materials

One of the challenges designers face when trying to use recycled materials is choosing the appropriate material for a given application. The objective of this project is to develop a computer based life-cycle analysis (LCA) tool and model that uses environmental and economic parameters to assist decision-makers in evaluating the use of recycled materials in highway construction applications. The tool will compare the properties of traditional materials such sand, gravel and crushed rock to those of recycled aggregates (concrete and asphalt), coal combustion byproducts (fly ash, bottom ash, bottom slag), crumb rubber (from tires), blast furnace slag, and recycled glass. Bound applications (pavement, stabilized bases, flowable fill) will be considered as well as unbound applications (base course, structural fill). The ultimate goal is to provide users with a simple yet powerful tool to help them determine if recycled materials can provide a safe and cost effective alternative to traditional materials in highway applications.

5. OUTREACH

Outreach activities take several different forms, though the most popular is our website at www.rmrc.unh.edu. The website provides a venue for all the RMRC news, reports and updates on the research projects. The Internet also allows great flexibility as well. For instance, there is the Virtual Demonstration Sites area that contains multimedia presentations on different recycled materials technologies. The idea is that the reader can virtually visit a demonstration site in the field, even if the site is in another country. The RMRC website also lists all of the abstracts from the Beneficial Use of Recycled Materials in Transportation Applications conference as well as the most up-to-date drafts of specifications that are being developed with RMRC funding. A visitor can also sign up at the website to receive the RMRC Quarterly Newsletter, a short letter that announces new funding, new projects or important events related to recycling in the highway environment.

6. CONCLUSIONS

In four years the RMRC has made great strides in promoting the wise use of recycled materials in the highway environment. The research and outreach programs continue to thrive, and the request for proposals due out in February will provide for another half-dozen research projects. In the future, the RMRC will continue to develop new ways of promoting recycled materials, such as a joint training program with FHWA for FHWA staff and AASHTO members. Please contact the RMRC if you have any questions or would like to be on our mailing list.