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Technische Universität Braunschweig
ISBS
Institut für Straßenwesen
TU Braunschweig
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Experimental Investigation on Double Recycling of Asphalt Mixture for Pavement Applications

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Outline

- Introduction
- Materials and Experimentation
- Results and Analysis
- Summary and Conclusions

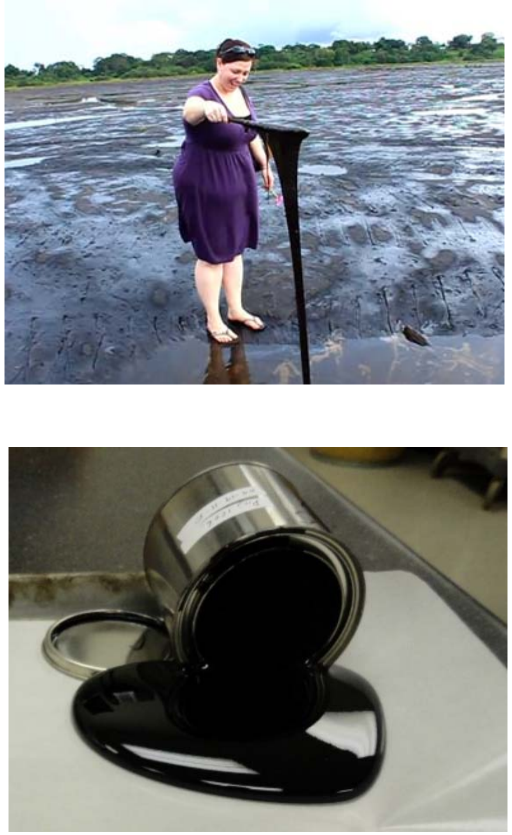
Introduction

- **Asphalt mixture** is the main road paving material
- In **Europe** and **north America** more than **90%** of roads are surfaced with asphalt mixture (NAPA & EAPA, 2011)

Asphalt mixtures:

- a particulate composites that contain **aggregate particles** of various sizes and shapes randomly distributed in a matrix made of **asphalt bitumen/binder.**

Introduction



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Asphalt
Bitumen/Binder

Aggregates

Asphalt
Mixture

Introduction

REUSE AND RECYCLING

RECYCLING IN 2015

Country	All available Reclaimed Asphalt in tonnes	% of available reclaimed asphalt used in							Applied area in m² of hot reuse of existing asphalt pavement material in-situ / on the road (Remixing,	The amount of "only" reheated (reused) asphalt material in-situ / on the road (Remixing, Repaving, ing, Road c.) in metric nnes
		Hot Mix Asphalt Production	Warm Mix Asphalt Production	Half Warm Mix Asphalt Production	Cold Recycling**	Unbound Road Layers	Other Civil Engineering	Put to Landfill / Other Applications/		
Austria	1.350.000	45	no data	no data	no data					data
Belgium	1.553.994	64	no data	no data	no data					data
Czech Republic	2.000.000									data
Croatia	no data									data
Denmark	1.300.000									data
Finland	1.160.000									data
France	7.000.000	68	no data	no data	no data					7.172
Germany	11.000.000	90	0	0	0					data
Great Britain	3.5									data
Hungary	1									data
Iceland	1									data
Italy	9.									data
Lithuania	no									data
Luxembourg	200.000	90	0	0	10					data
Netherlands	4.500.000	70	0	0	10					data
Norway	932.049	38	no data	no data	no data					data
Romania	no data	no data	no data	no data	no data					data
Slovakia	75.000	98	0	0	1					4.700
Slovenia	37.000									data
Spain	410.000									data
Sweden	1.600.000									0.000
Switzerland	no data									data
Turkey	1.520.000	2	0	0	0	98	0	0	no data	no data
USA	69.700.000	91		no data	0	6	2	1	no data	no data

47 million tons

97.3% of the RAP

70 million tons

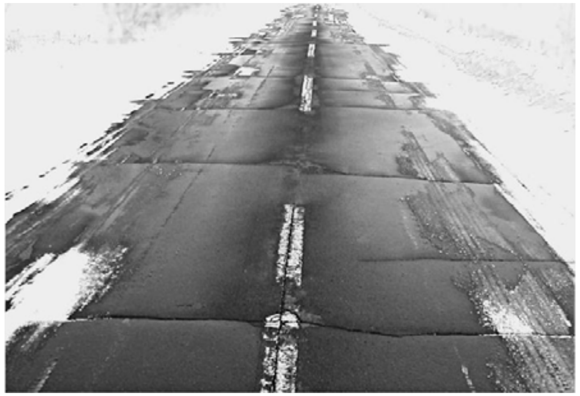
** Cold recycling includes stabilisation with bitumen emulsion, foamed bitumen and/or cement.

*** no data, but all recycled

EAPA (Asphalt in Figures, 2015)

Introduction

Asphalt bitumen/binders and asphalt mixtures are **temperature susceptible** materials. **Thermal cracking** is a significant distress in asphalt pavements built in cold climates.



Low T
Thermal
Cracking

Intermediate T
Fatigue
Cracking

High T
Permanent
Deformation

After field aged or laboratory aged, the asphalt binders are getting harder and more stiffness; hence, the low temperature properties of asphalt mixture should be studied.

Introduction

Research Objective

Evaluate the effect of adding different amounts of **re-recycled (double recycled)** RAP on low temperature creep property and fracture property of asphalt mixture.

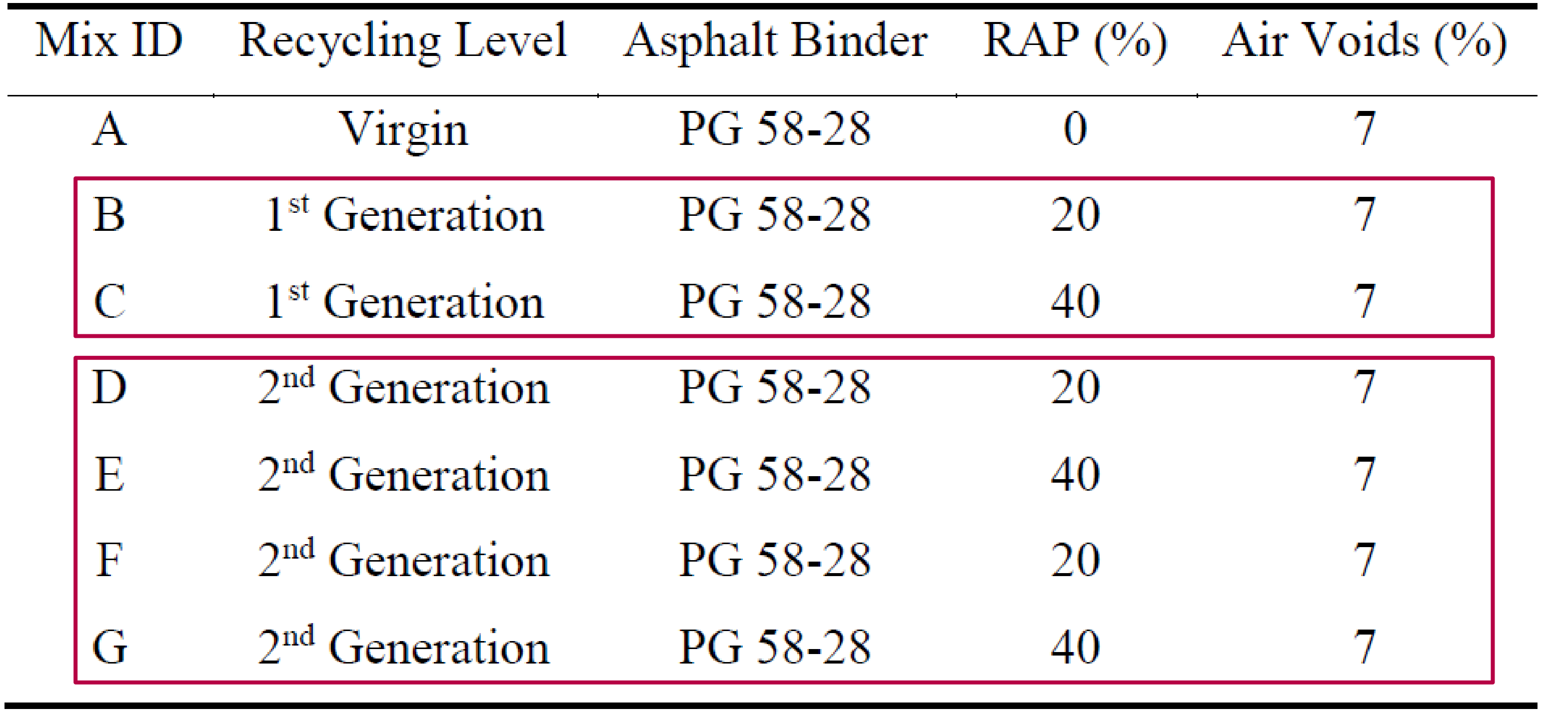
Based on:

- Bending Beam Rheometer (**BBR**) Test on asphalt mixture
- Semi-Circular Bending (**SCB**) tests

Materials and Experimentation

Materials

Table 1. Asphalt mixtures



Mix ID	Recycling Level	Asphalt Binder	RAP (%)	Air Voids (%)
A	Virgin	PG 58-28	0	7
B	1st Generation	PG 58-28	20	7
C	1st Generation	PG 58-28	40	7
D	2nd Generation	PG 58-28	20	7
E	2nd Generation	PG 58-28	40	7
F	2nd Generation	PG 58-28	20	7
G	2nd Generation	PG 58-28	40	7

PG: Performance Grade

PG 58-28: the materials is suitable for the temperature between -28℃ and 58 ℃.

Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing

- A small asphalt mixture beams (*l*=102mm, *b*=12.5mm, and *h*=6.25mm) with the BBR equipment.
- A higher constant load *P*=4,000mN and extend time of *t*=1,000s were used for BBR asphalt mixture testing.

Figure 2. BBR Pro Device

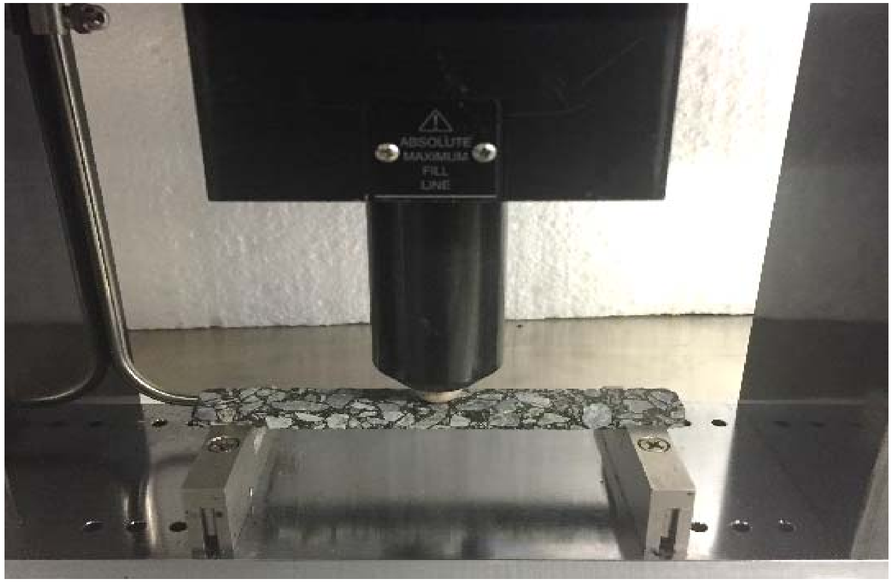


Figure 3. BBR Mixture Sample

Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing

creep stiffness:

$$S(t) = \frac{\sigma}{\varepsilon(t)} = \frac{Pl^3}{4bh^3\delta(t)} = \frac{1}{D(t)}$$

σ	the maximum bending stress,
$\varepsilon(t)$	the bending strain,
P	4,000mN,
$\delta(t)$	the mid-span deflection
t	time (0~1,000 seconds).

The relaxation parameter ***m*-value** is also computed.

$$m(t) = \left| \frac{d \log S(t)}{d \log t} \right|$$

Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing

Based on the conventional Hopkins and Hammings algorithm (1967) and the CAM model (Marasteanu and Anderson, 1999), the **thermal stress** can be calculated:

$$\sigma(\xi)=\int_{-\infty}^{\xi}\frac{d\varepsilon(\xi')}{d\xi'}\cdot E(\xi-\xi')d\xi'=\int_{-\infty}^{t}\frac{d(\alpha\Delta T)}{dt'}\cdot E(\xi(t)-\xi'(t))dt'$$

where,

$\xi = t / a_T$ the reduced time,

α the coefficient of thermal contraction of asphalt mixture assumed to be equal to $30.28\times10^{-6}/^{o}C$.

Materials and Experimentation

Bending Beam Rheometer (BBR) – creep testing

critical cracking temperature, ***T_{cr}***:

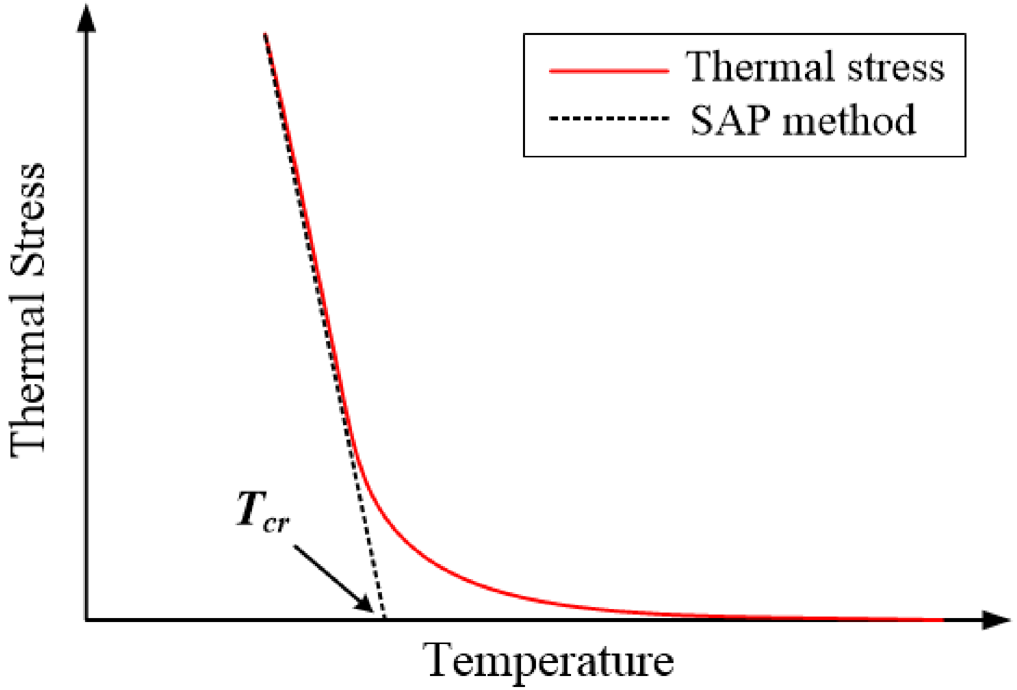


Figure 4. Schematic of the Shenoy (SAP) method for computing T_{cr}

Single Asymptote Procedure (SAP): T_{cr} is determined as the intersection with the x axis (temperature) of the asymptotic line to the highest stress value in the thermal stress curve.

Materials and Experimentation

Semi-Circular Bending (SCB) – fracture testing

- A semi-circular shape with a diameter of almost 150mm, a thickness of 25mm and a straight vertical central notch of 15mm in length.
- The sample is placed on a frame consisting of two fixed rollers and having a span of 120mm.

The fracture energy, G_f:

$$G_f = \frac{W_f}{A_{lig}}$$

where,

W_f the work of fracture,

A_{lig} the area of ligament.

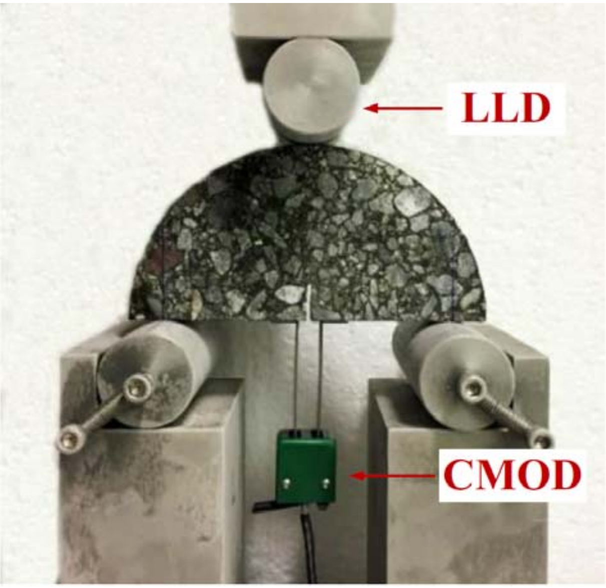


Figure 5. SCB Device

Materials and Experimentation

Semi-Circular Bending (SCB) – fracture testing

The **fracture toughness** (stress intensity factor), $\boldsymbol{K_I}$:

$$K_I = \sigma_0 \sqrt{\pi a}\left[Y_{I(S_0/r)} + \frac{\Delta s_0}{r} B \right] = \sigma_0 \sqrt{\pi a}\left[Y_{I(S_0/r)} + \left(\frac{s_a}{r} - \frac{s_0}{r} \right) B \right]$$

where,

K_I	Mode I stress intensity factor, $\sigma_0 = P/(2rt)$;
r	radius; t thickness;
Y_1	the normalized stress intensity factor (Li X. J. & Marasteanu, 2009 and 2010);
a	the notch length;
s_a/r	the actual span ratio;
s_0/r	the nearest span ratio;
B	a parameter depending on a and r .

Results and Analysis – BBR tests

Creep Tests

Thermal Stress

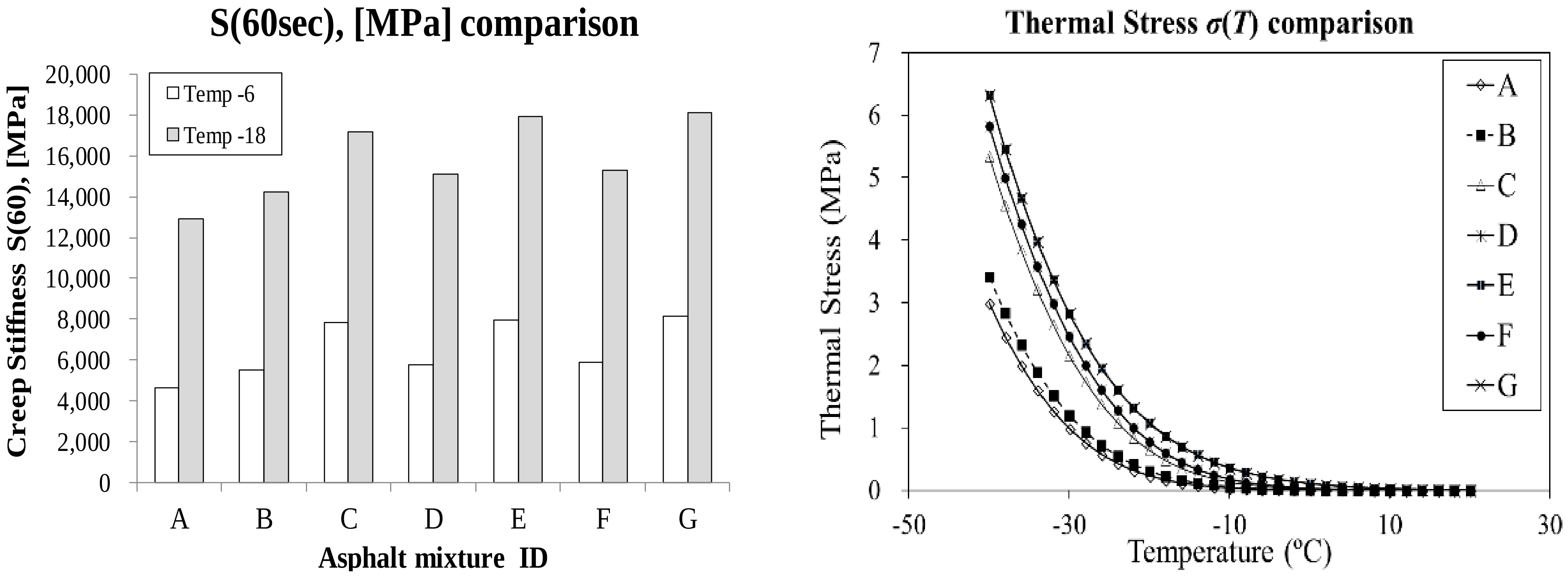
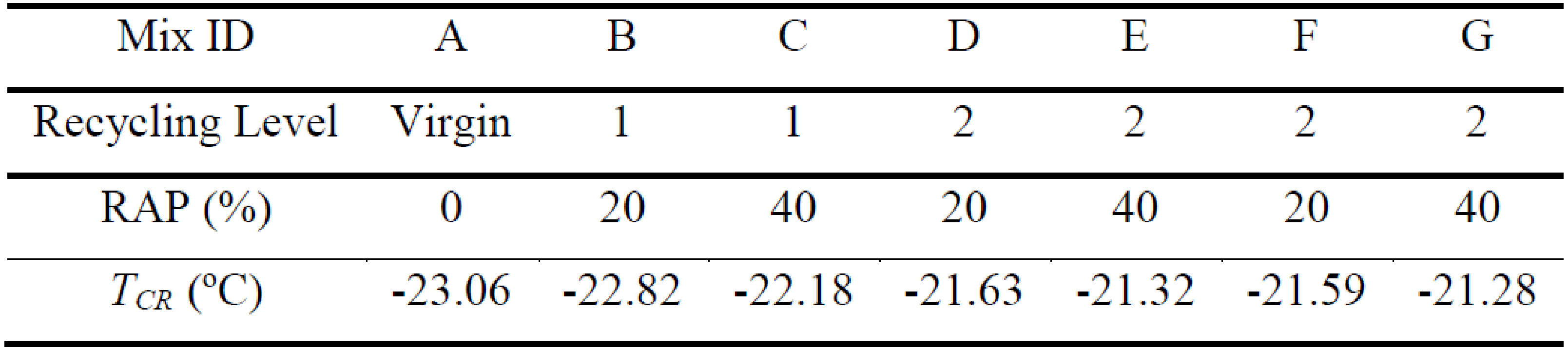


Figure 6. BBR results: (a) creep stiffness at *t*=60s; (b) *σ*(*T*) comparison of different mixture at 20℃/h.

Results and Analysis – BBR tests

Critical Cracking Temperature

Table 2. Critical cracking temperature, T_{CR}, comparison



Mix ID	A	B	C	D	E	F	G
Recycling Level	Virgin	1	1	2	2	2	2
RAP (%)	0	20	40	20	40	20	40
T_{CR} (°C)	-23.06	-22.82	-22.18	-21.63	-21.32	-21.59	-21.28

Only slightly higher T_{CR} were found in mixtures prepared with RAP compared to virgin mixtures, where a higher percentage of RAP leads to a higher T_{CR}.

The mixture prepare with double recycled RAP indicate a very close response to the mixtures prepared with RAP.

Results and Analysis – SCB tests

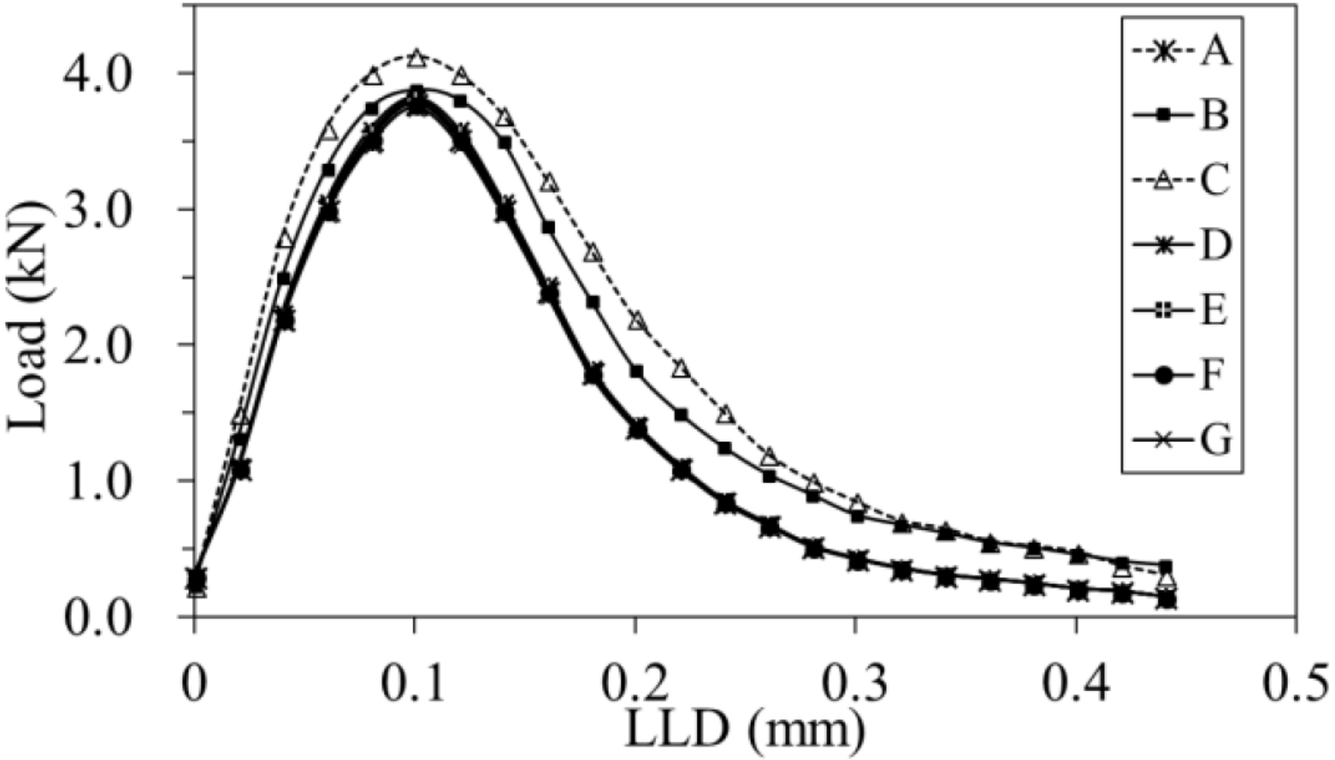


Figure 7. Load vs. LLD curves from SCB tests.

A substantial increase in the peak load and stress is found in the case of recycled asphalt mixtures of first generation (B and C), while a decreasing trend is experienced for the mixture containing RAP of second generation.

Results and Analysis – SCB tests

Table 3. SCB results comparison

Mix ID	Recycling Level	RAP (%)	RAP Mixture Origin	P_N (kN)	G_F (kN/m)	σ_n (kPa)	K_I (MPa*m$^{0.5}$)
A	Virgin	0	-	3.78	0.411	988	1.119
B	1st Generation	20	A	3.88	0.422	1,175	1.122
C	1st Generation	40	A	4.13	0.484	1,351	1.168
D	2nd Generation	20	B	3.82	0.420	1,211	1.118
E	2nd Generation	40	B	3.81	0.401	994	1.115
F	2nd Generation	20	C	3.78	0.415	1,105	1.110
G	2nd Generation	40	C	3.75	0.392	977	1.108

This overall trend suggests that the presence of the first generation of RAP is surprisingly improving the fracture response of the mixture. However, the fracture response of double recycled RAP is similar to the virgin mixture.

Summary and Conclusions

The effect of different amount of double recycled RAP on low temperature properties of mixture is experimentally investigated in this study.

- Low temperature creep tests indicate that mixtures prepared with double recycled RAP have similar response to that of mixtures designed with recycled RAP.

- Fracture performances tests found that the mixture prepared with double recycled RAP have similar behavior with the fresh mixture.

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RILEM 252-CMB-SYMPOSIUM
BRAUNSCHWEIG, GERMANY
SEPTEMBER 17 – 18, 2018

CHEMO MECHANICAL CHARACTERIZATION OF BITUMINOUS MATERIALS

Important Dates

Sept. 17-18th, 2018	RILEM 252-CMB Symposium
Sept. 19-20th, 2018	RILEM Cluster F Annual Meeting

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Thank you
Questions?