Transportation Research Board
97th Annual Meeting

January 7–11, 2018 ▪ Washington, D.C.

ISAP Day

Asphalt Pavements and Environment (APE) Technical Committee

Sunday, January 07, 2018

FIELD PERFORMANCE OF COLD IN-PLANT RECYCLED ASPHALT MIXTURES

Alessandro Marradi
University of Pisa
Italy

OVERVIEW

- Need for field evaluation of materials performances;
- Short term performances and Long term performances;
- Instruments currently used for field structural performances evaluation of cold recycled mixtures: LWD and FWD;
- Evaluation of cold recycled temperature sensitivity by means of field tests;
- Possibility to investigate the long term durability of the materials with a new model of FWD: Fast FWD.

NEED FOR FIELD PERFORMANCE EVALUATION?

ASSES LAYERS STIFFNESS FOR *QC* ACTIVITIES

LAYER ELASTIC MODULI

GENERALLY THE VALUE OF ELASTIC MODULUS IS REQUIRED FOR EACH LAYERS USED IN PAVEMENT DESIGN AND CONSTRUCTION PROCEDURE.

MODULI ESTIMATED WITH FWD DEFLECTION MEASUREMENT MUST MATCH THE ONE ADOPTED DURING THE DESIGN PROCESS.

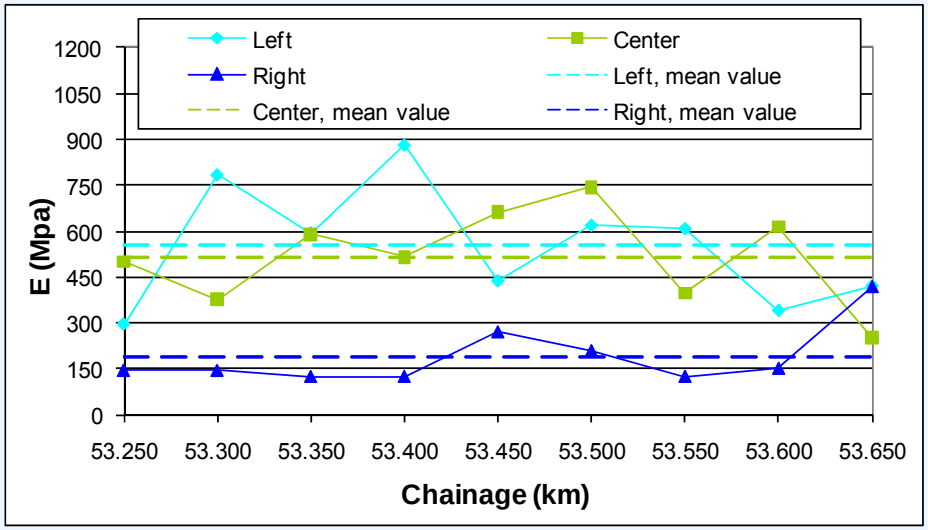
ESTIMATE PAVEMENT RESIDUAL LIFE

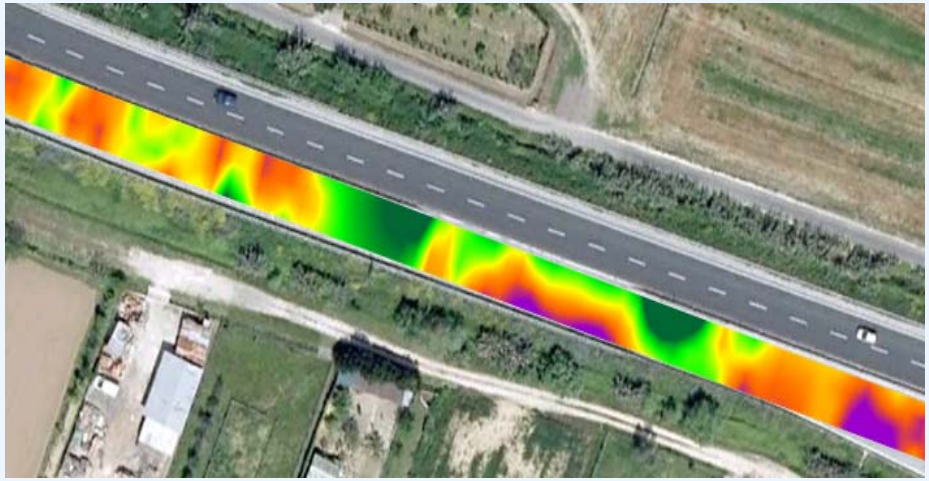
IDENTIFY THE CRITICAL LAYER AND FIND THE BEST MAINTENANCE ALTERNATIVE

NEED FOR A SPECIFIC PERFORMANCE CRITERIA FOR EACH LAYER (DAMAGE)

LAYERS STIFFNESS ASSESSMENT *QC* ACTIVITIES

LAYERS BUILT USING BSM (with foamed asphal or bitumen emulsion) CAN BE EVALUATED DURING CONSTRUCTION WITH **LWD *LIGHT WEIGHT DEFLECTOMETER***





Example of «heat map» (spatial interpolation) of LWD results on foam bitumen stabilized layers.

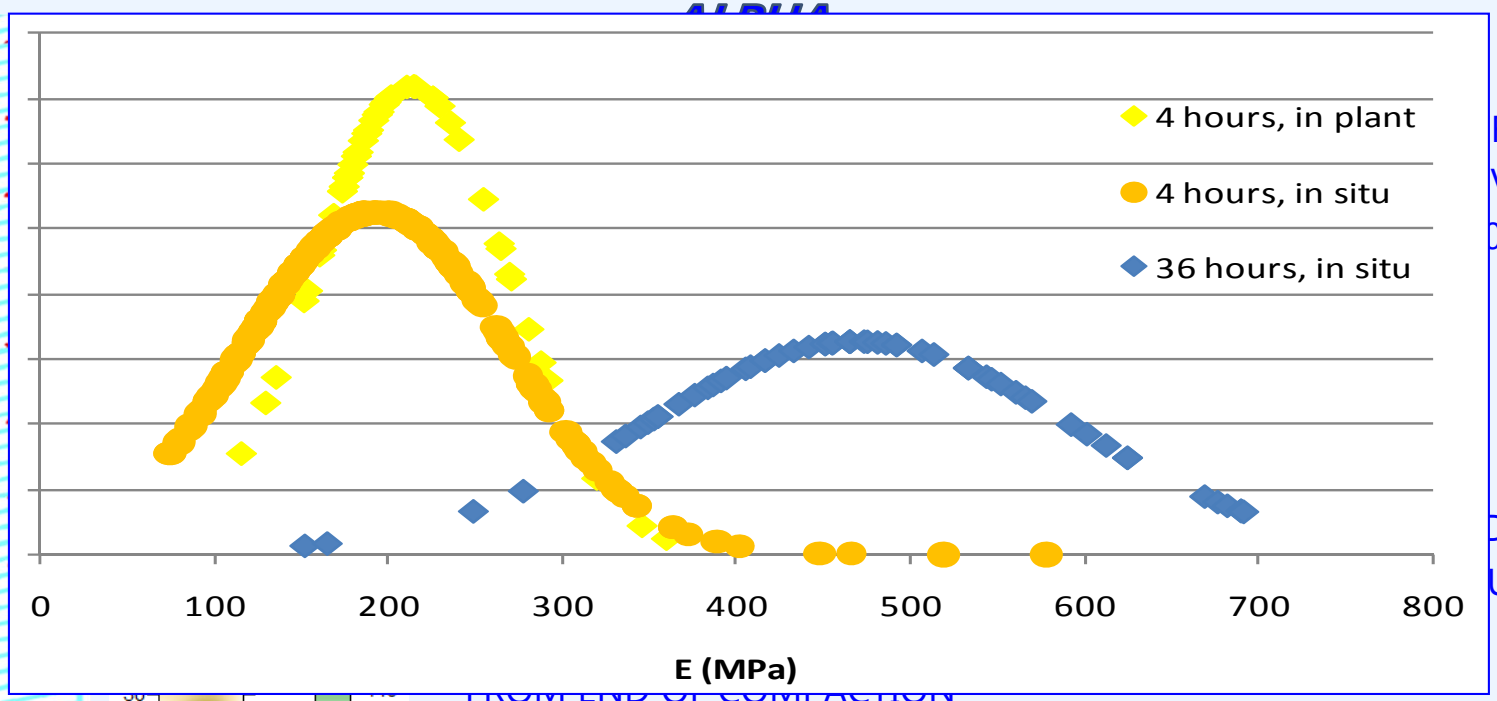
LAYERS STIFFNESS ASSESSMENT
***QC* ACTIVITIES**

USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME

CASE HISTORIES:

IN SITU PLANT COLD RECYCLING

G.B. PASTINE CIAMPINO (ROME) INTERNATIONAL AIRPORT - TAXIWAY ALPHA



FERENT
VERSAL
0 M

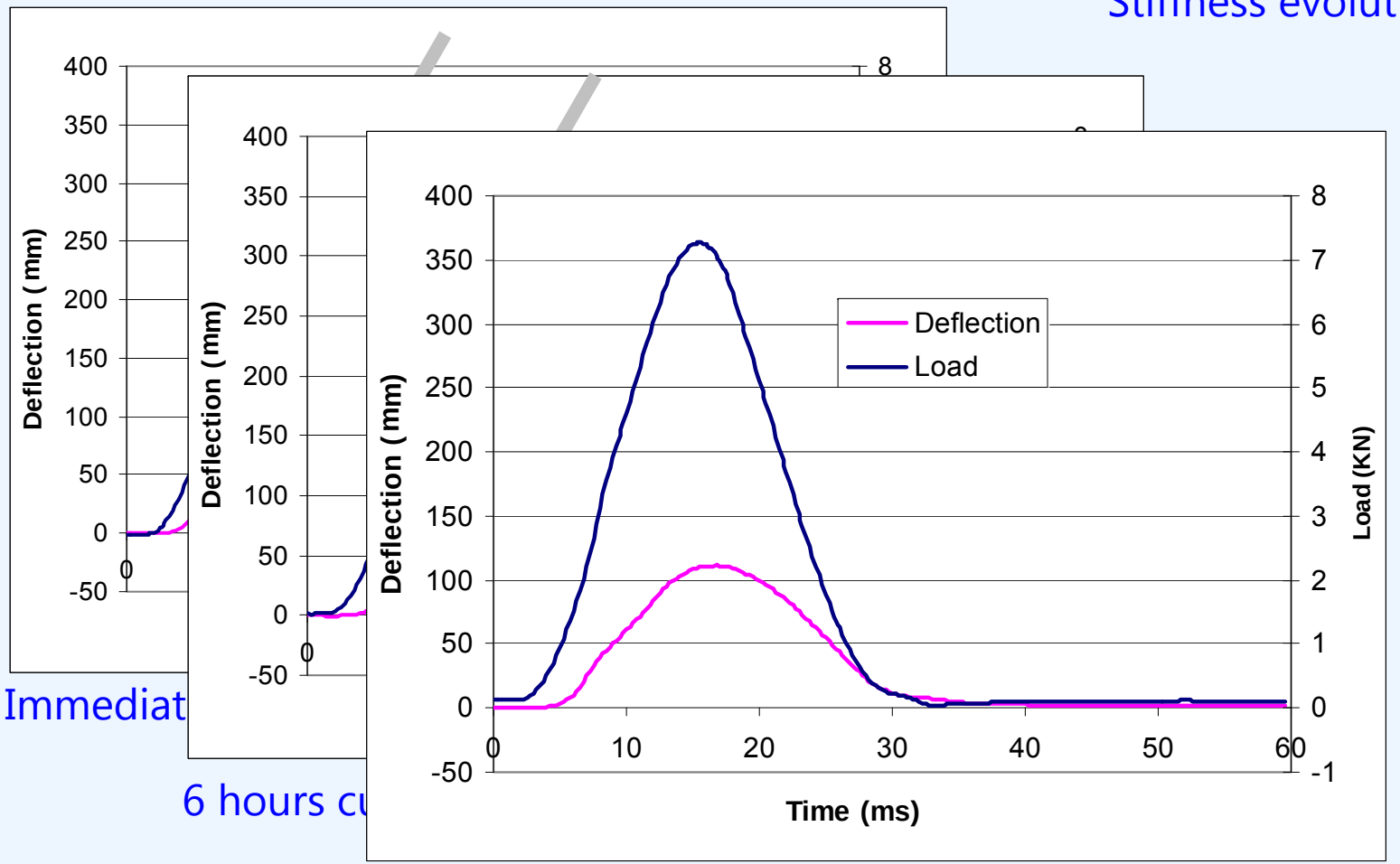
D THAT
ULUS IS
HOURS

ADOPTING A NORMAL DISTRIBUTION FOR LWD DATA REGISTERED FOR TWO DIFFERENT COLD-RECYCLING TECHNIQUES (IN PLANT AND IN SITU) AFTER 4 HOURS FROM COMPACTION, IT CAN BE SEEN THAT, AS EXPECTED, DISPERSION OF RESULTS IS HIGHER FOR IN SITU RECYCLED MATERIAL. THIS RESULTS CONFIRM THAT IN PLANT RECYCLING ALLOW A MORE SELECTION OF MATERIAL AND A SIGNIFICANTLY HIGHER HOMOGENEITY OF STIFFNESS VALUES

LAYERS STIFFNESS ASSESSMENT *QC* ACTIVITIES

USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME

Stiffness evolution



Immediat

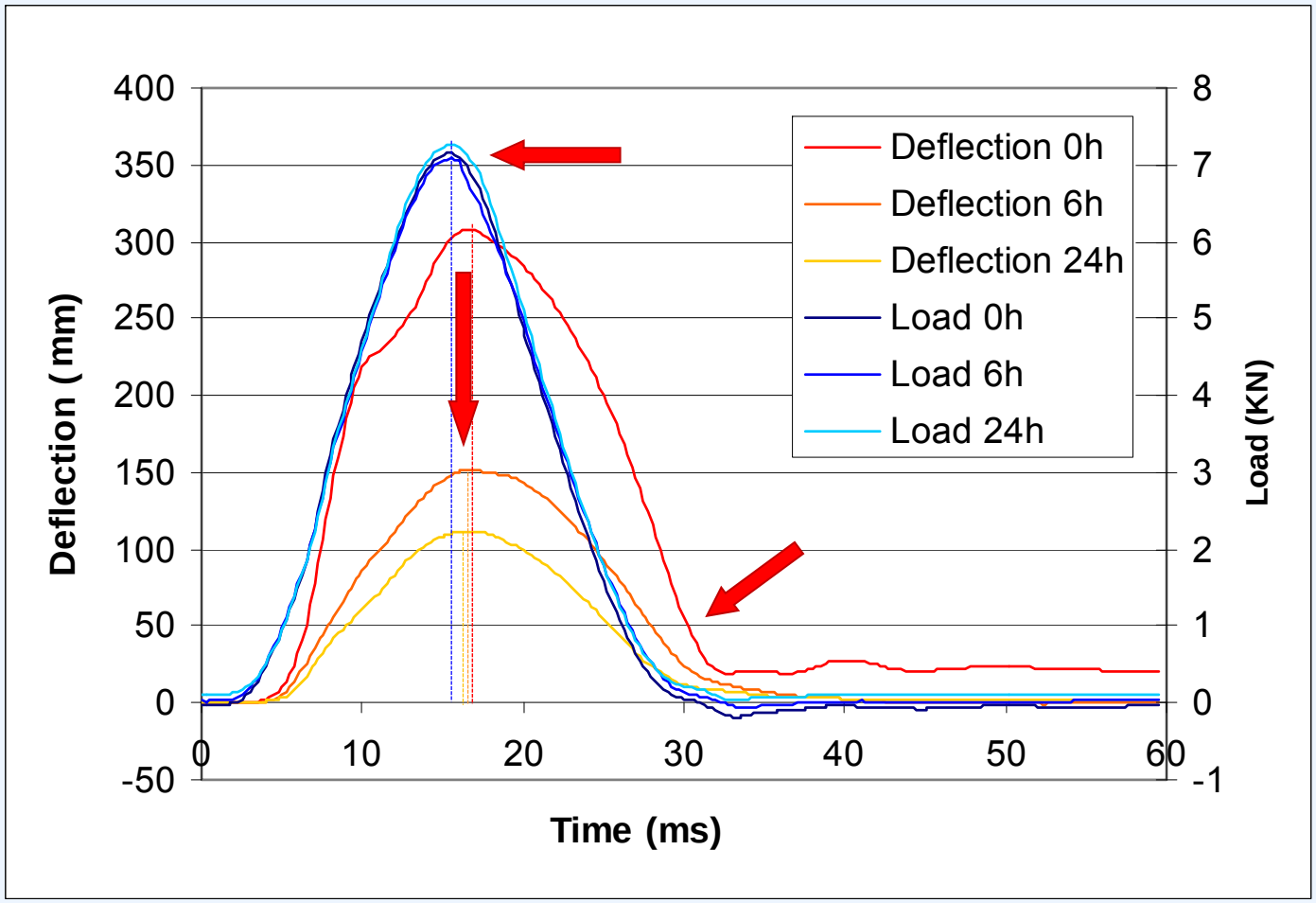
6 hours cu

24 hours curing time

LAYERS STIFFNESS ASSESSMENT
***QC* ACTIVITIES**

USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME

Stiffness evolution

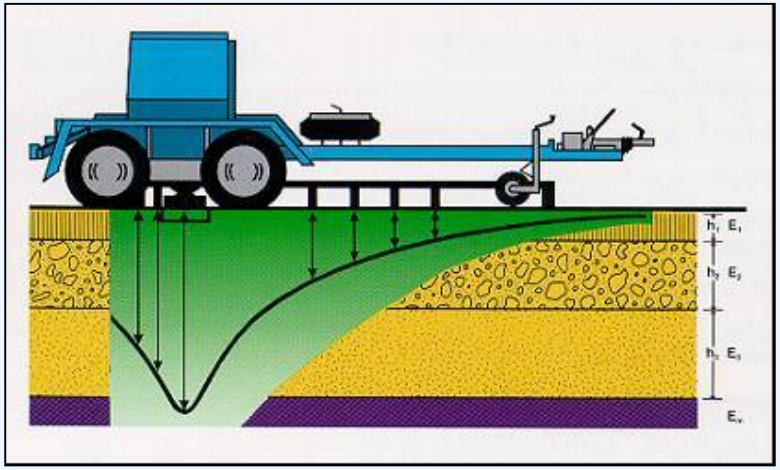


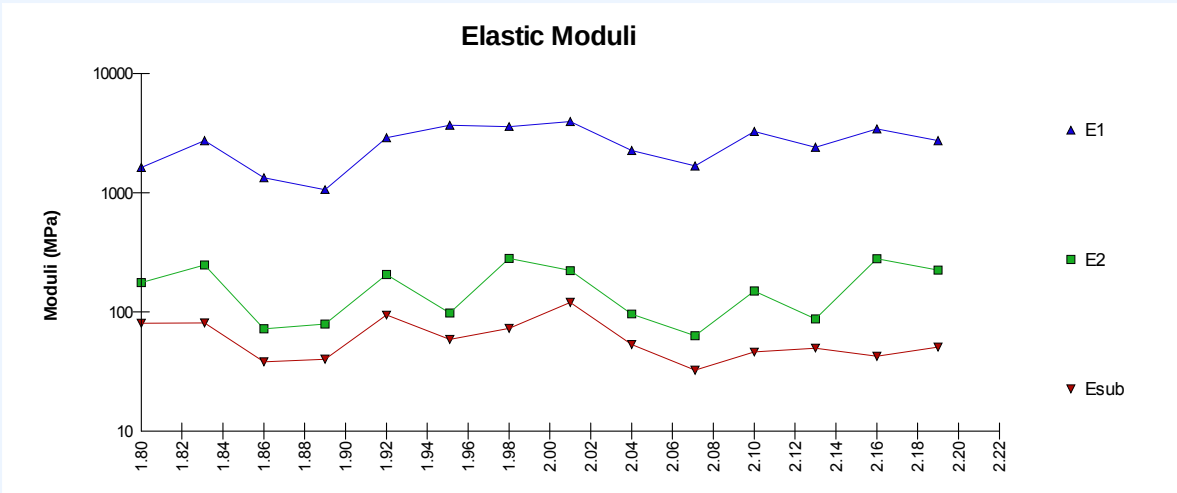
LAYERS STIFFNESS ASSESSMENT
QC ACTIVITIES

FOR ROAD AND AIRFIELD

(END OF CONSTRUCTION AND DURING SERVICE LIFE)

FWD *FALLING WEIGHT DEFLECTOMETER→BACK-CALCULATION OF ELASTIC MODULI*





Example back-calculation of elastic moduli.
Value are referred to pavement structure:

E1 = Asphalt layers moduli

E2 = Subbase layer moduli

Esub = Subgrade moduli

Effect of active fillers on field performances of cold mixture

PARTNERS

Gabriele Tebaldi
University of Parma

Kim Jenkins
University of Stellenbosch

Gordon Airey
University of Nottingham

Alessandro Marradi
University of Pisa

Research supported by private companies:

QUESTIONS:

- **Can the lime be used instead of cement?**
- **Can the lime partially replace the cement in the total amount of active fillers?**

GOALS

- **Evaluate the influence on bearing capacity of introducing lime in bitumen emulsion and foam bitumen recycled mixtures.**
- **Evaluate the influence on bearing capacity of use of lime instead of cement in bitumen emulsion and foam recycled mixtures.**
- **Evaluate the effect of using a blend of fillers.**
- **Evaluate the effect on the long term performances of the mixtures as the effect of cement substitution with lime.**

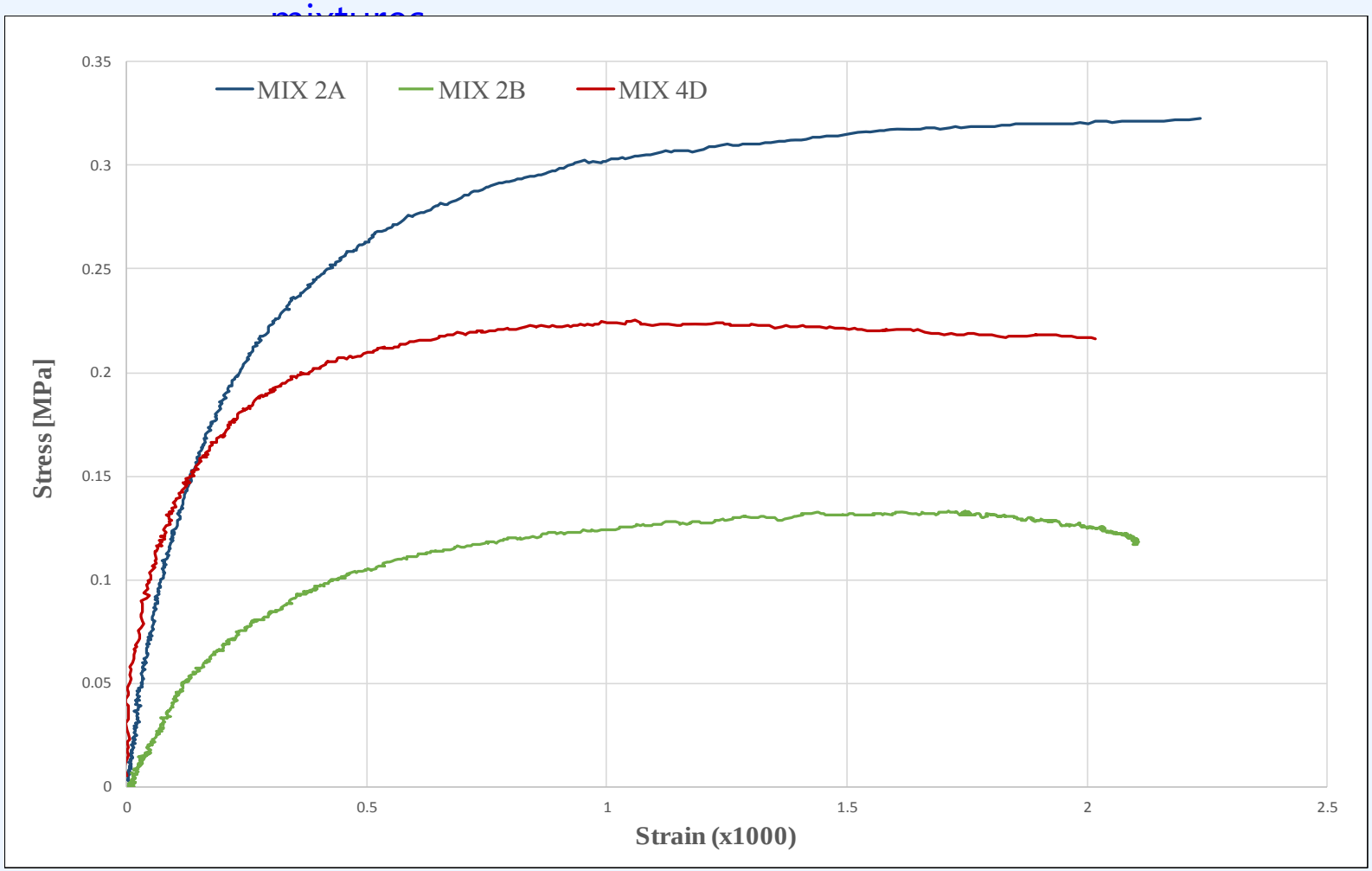
MIXTURES

Total amount of filler: 4.5%

	Mix	%binder	%cement	%lime	%mineral filler
Emulsion	2A	3	1.0	2.0	1.5
	2B	3	1.0	0	3.5
	4D	3	2.5	0	2.0
Foam bitumen	3A	2	1.0	2.0	1.5
	3B	2	1.0	0	3.5
	5C	3	2.5	2.0	0
	5D	3	2.5	0	2.0
	5E	3	0	2.0	2.5
	5F	3	0	3.0	1.5

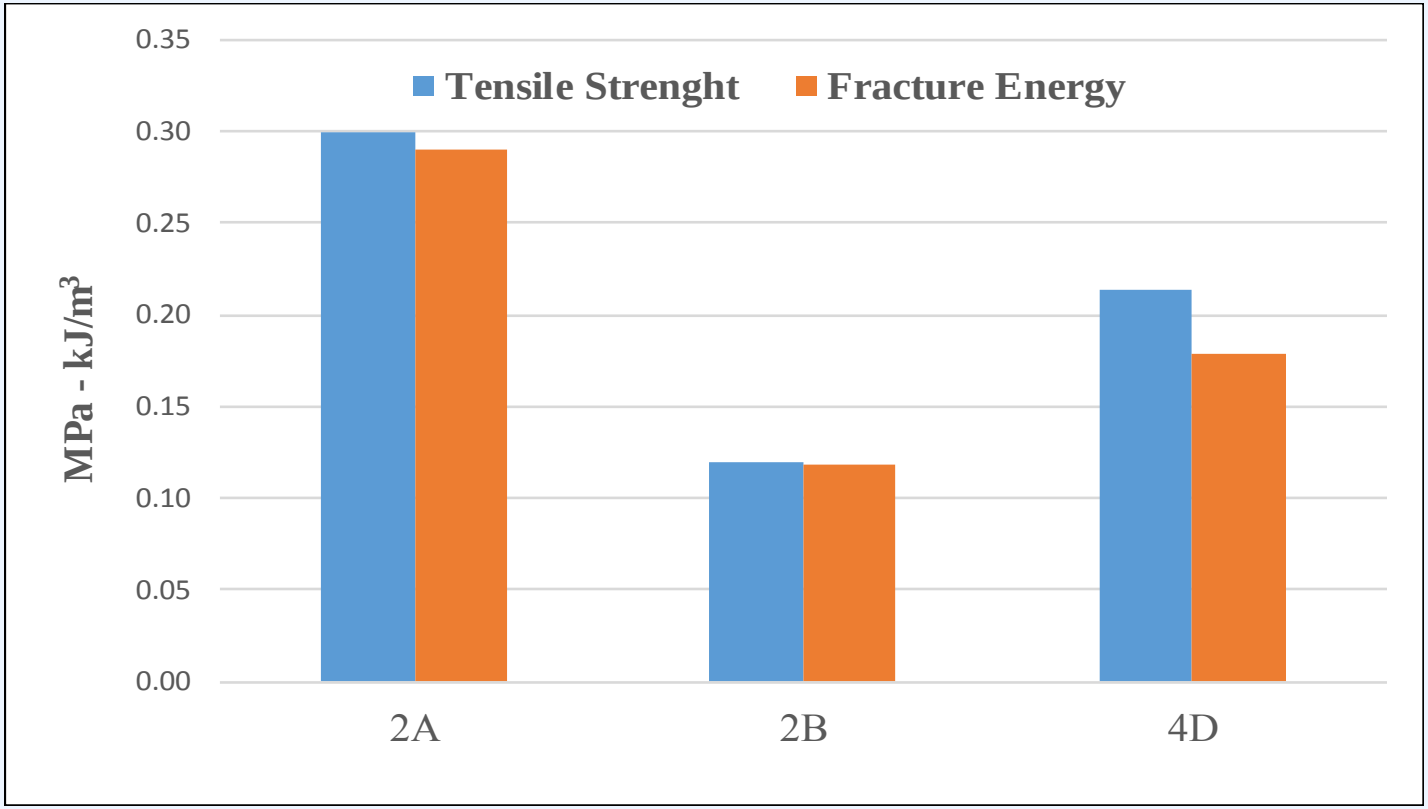
MIXTURES

Stress-strain curves of emulsion-stabilized mixtures



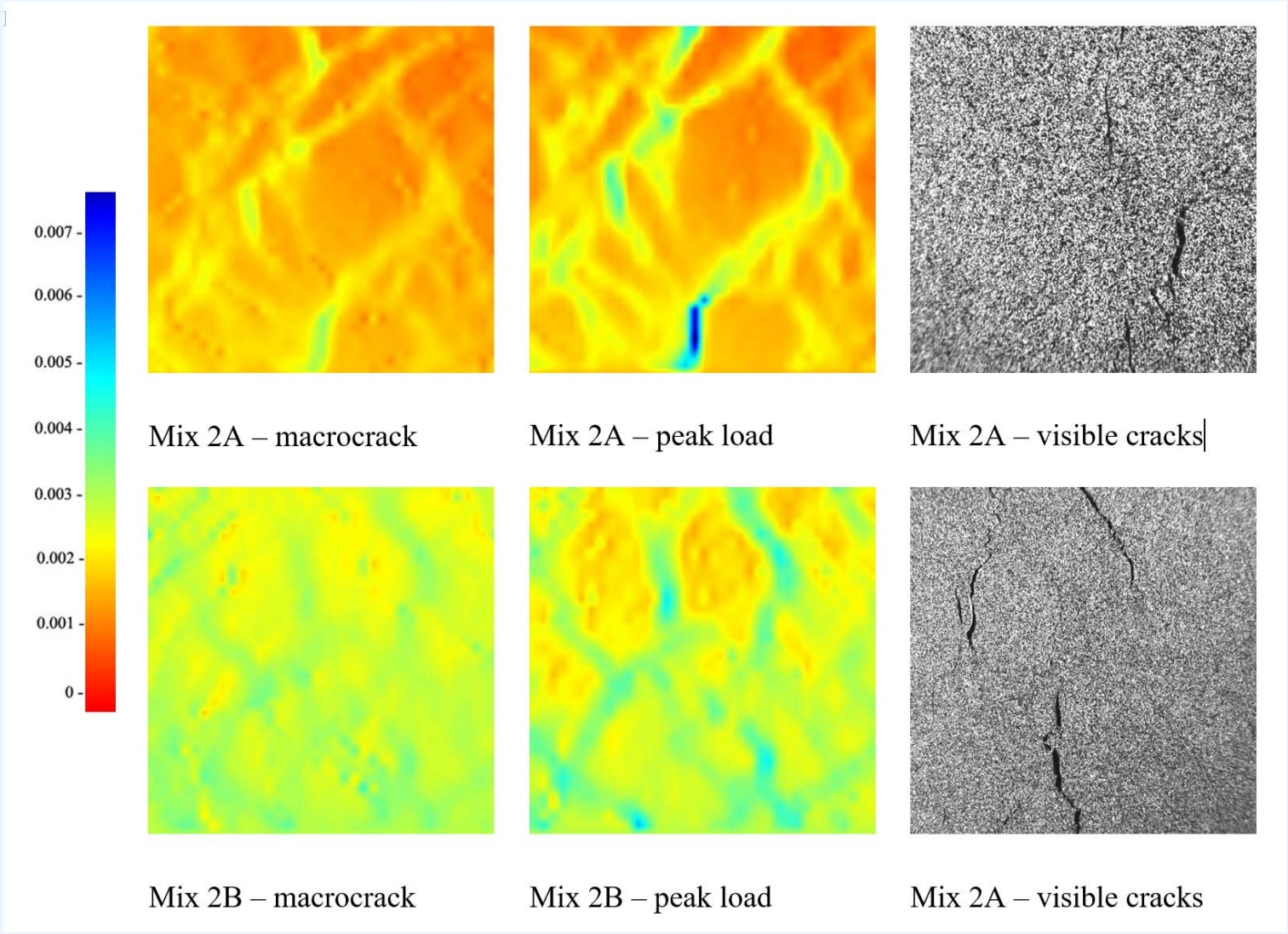
MIXTURES

Summary of the Superpave IDT results



MIX	St [MPa]	Failure Strain [με]	FE [Kj/m³]	Dissipated Energy [Kj/m³]	Strain Energy [Kj/m³]
2A	**0.30**	**910**	**0.29**	**0.136**	**0.153**
2B	0.12	814	0.12	0.049	0.070
4D	0.21	571	0.18	0.061	0.117

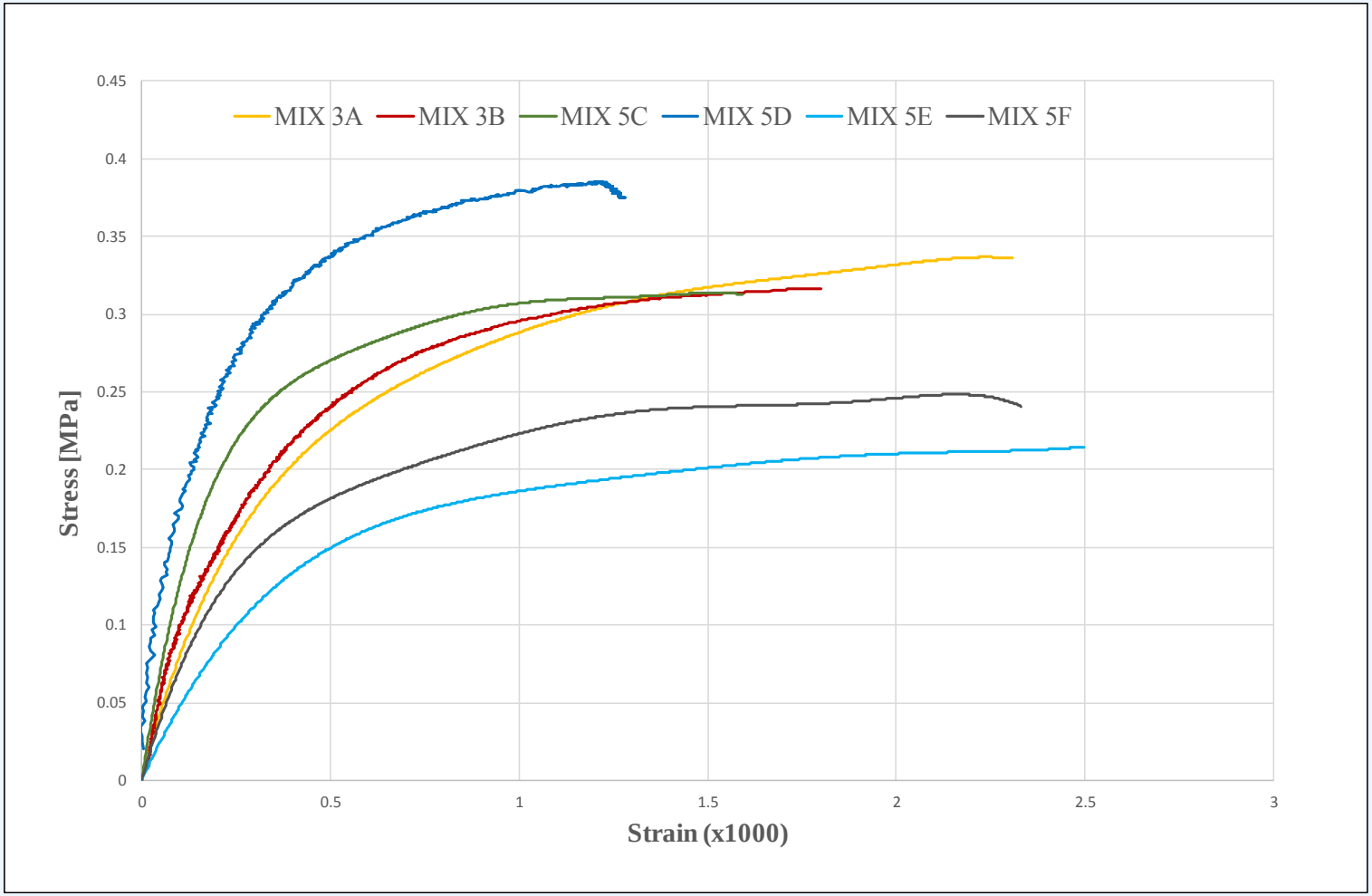
MIXTURES



Measured horizontal full filed strain map for mixtures 2A and 2B during IDT at macrocrack initiation and peak load.

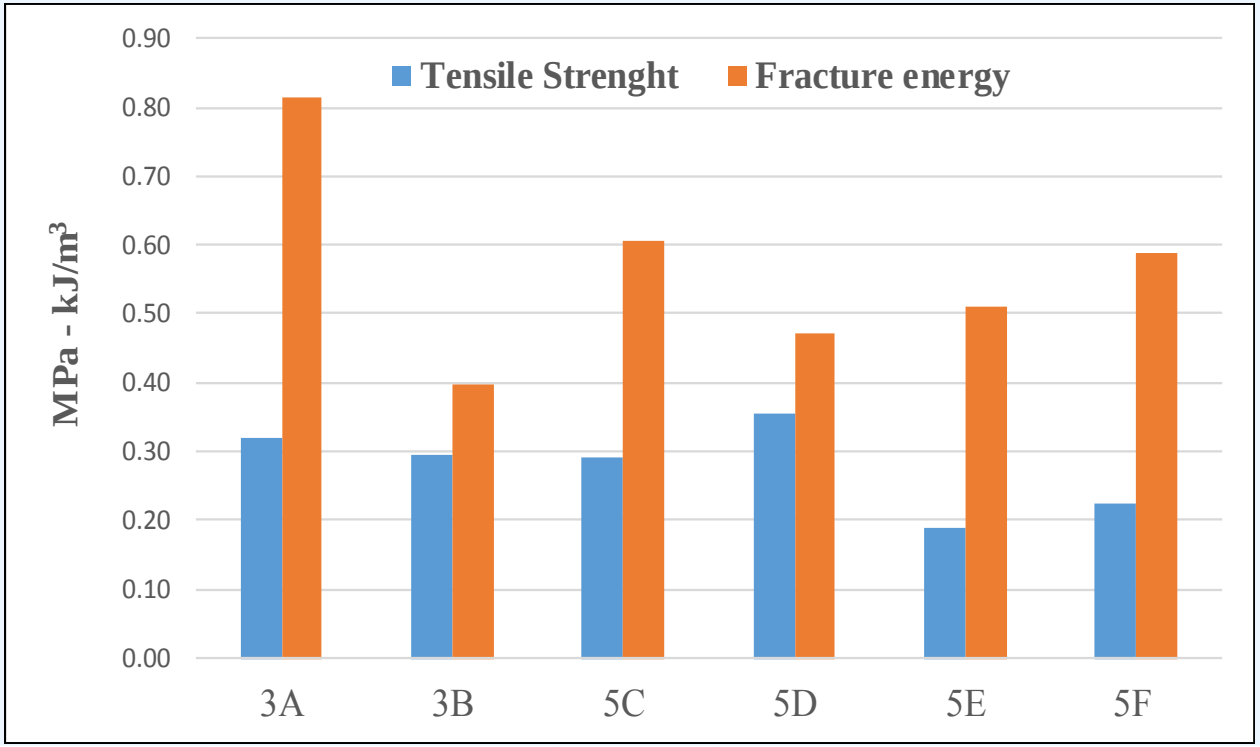
MIXTURES

Stress-strain curves of foam bitumen-stabilized mixtures



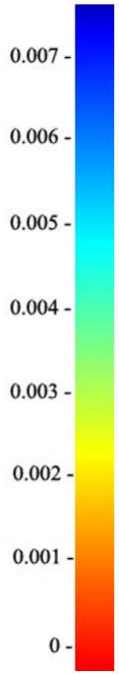
MIXTURES

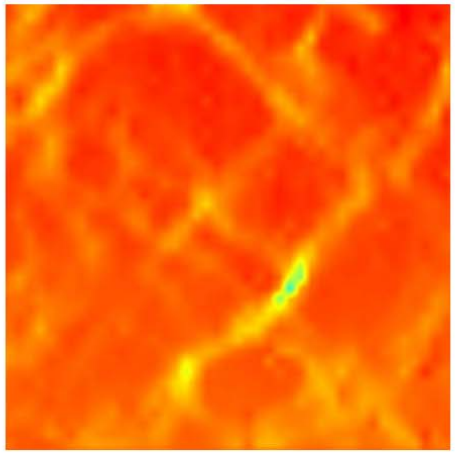
Summary of the Superpave IDT results



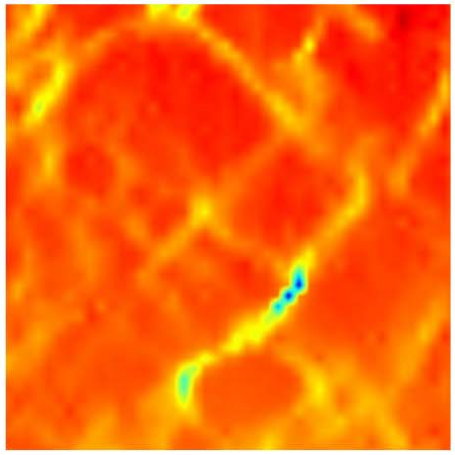
MIX	St [MPa]	Failure Strain [με]	FE [Kj/m³]	Dissipated Energy [Kj/m³]	Strain Energy [Kj/m³]
3A	**0.32**	**1624**	**0.81**	**0.261**	**0.552**
3B	0.29	938	0.40	0.138	0.258
5C	0.29	702	0.61	0.103	0.504
5D	0.36	636	0.47	0.114	0.359
5E	0.19	1092	0.51	0.103	0.408
5F	0.23	1091	0.59	0.123	0.464

MIXTURES

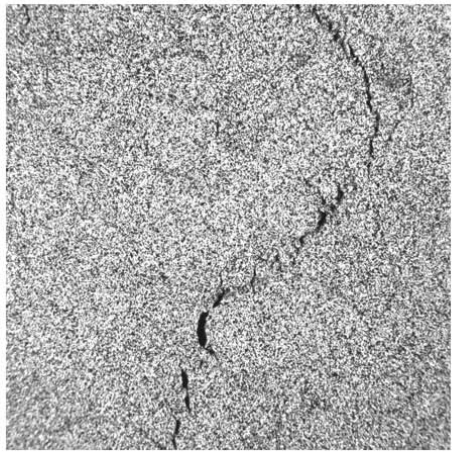




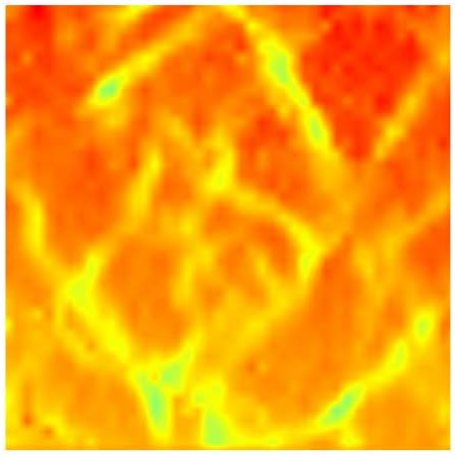
Mix 3A – macrocrack



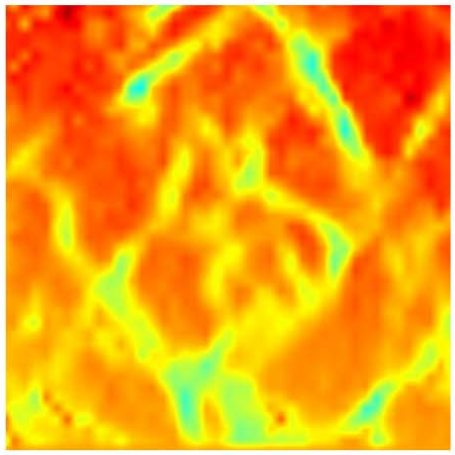
Mix 3A – peak load



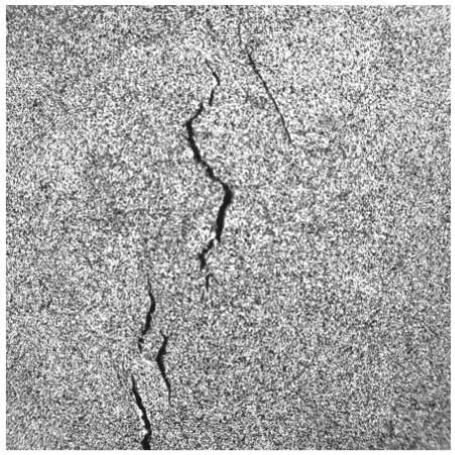
Mix 3A – visible cracks



Mix 5D – macrocrack



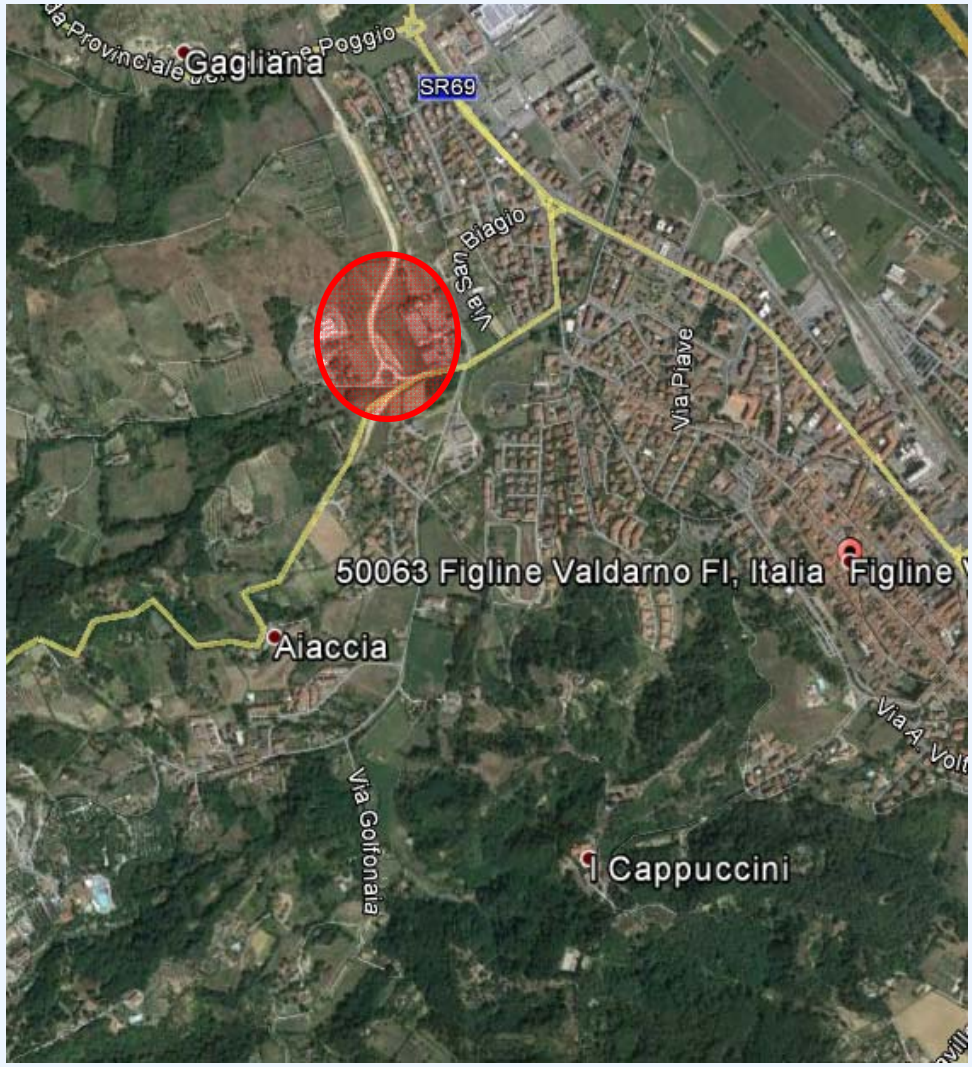
Mix 5D – peak load



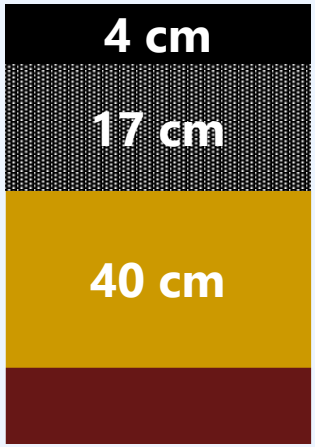
Mix 5D – visible cracks

Measured horizontal full filed strain map for mixtures 3A and 5D during IDT at macrocrack initiation and peak load.

TRIAL SECTION - FLORENCE (ITALY)



TRIAL SECTION - FLORENCE (ITALY)



Wearing course (not present at the beginning of FWD tests)

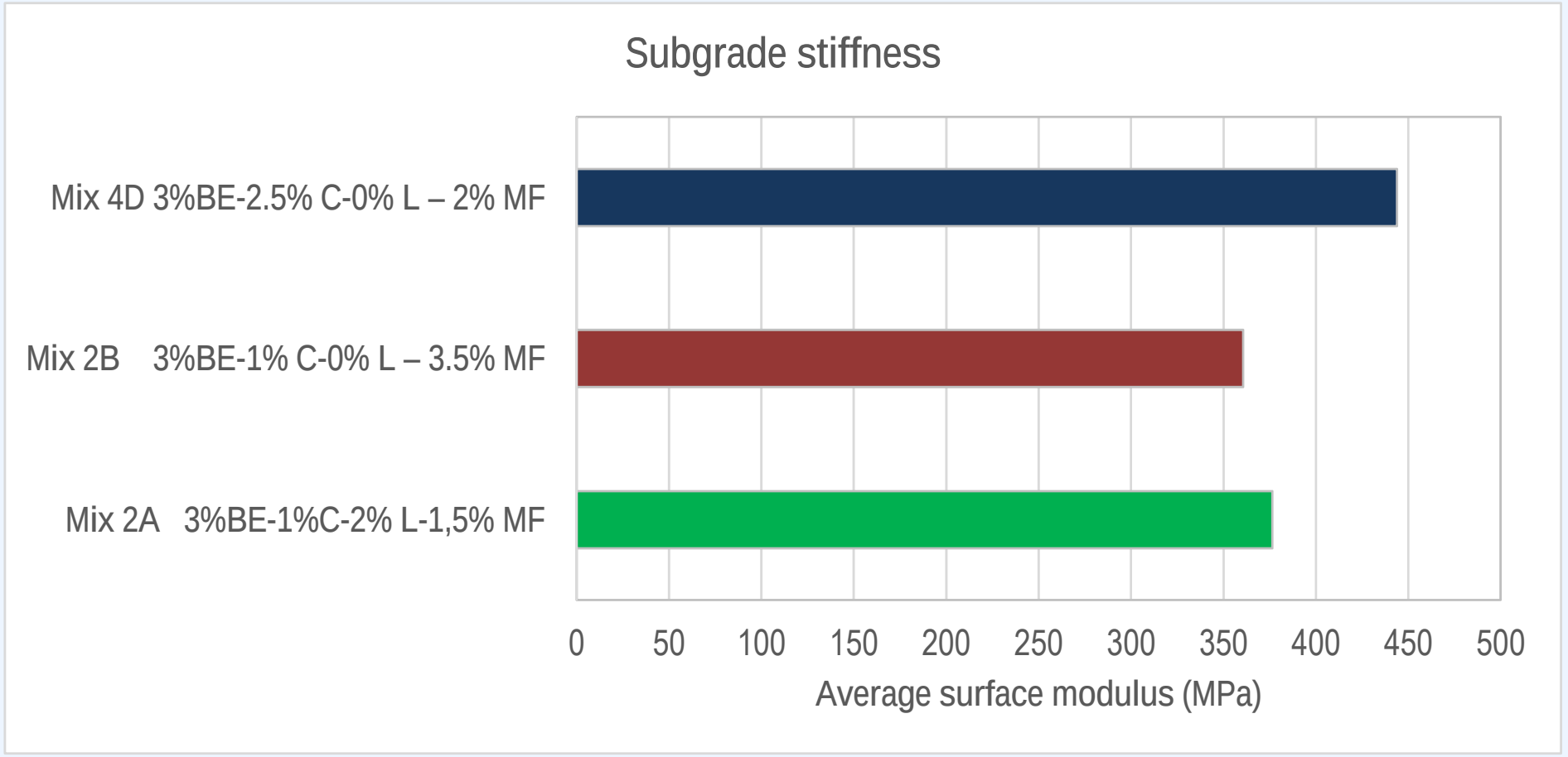
Base - Cold Recycled Mixture (bituminous emulsion/foam bitumen)

Subbase – lime stabilized soil

Subgrade

FWD Tests on the subgrade

Under bitumen emulsion recycled mixtures



TEMPERATURE SENSITIVITY

Reasons for temperature sensitivity evaluation

- Tests will be made in different seasons thus materials will experience different temperature due to environmental condition;
- Presence of bitumen: aged bitumen in RAP. New bitumen added to the mixes (foam bitumen and bitumen emulsion);
- Compare temperature sensitivity of recycled mixtures with those of asphalt concrete.

TEMPERATURE SENSITIVITY

Procedure:

Perform FWD tests on the same test location under significant differences in the material temperature.

Backcalculate the layer moduli obtained from deflection measured under different temperature conditions.

$$E_{Ts} = 10^{\alpha \cdot (T^2 - T_S^2)} \times E$$

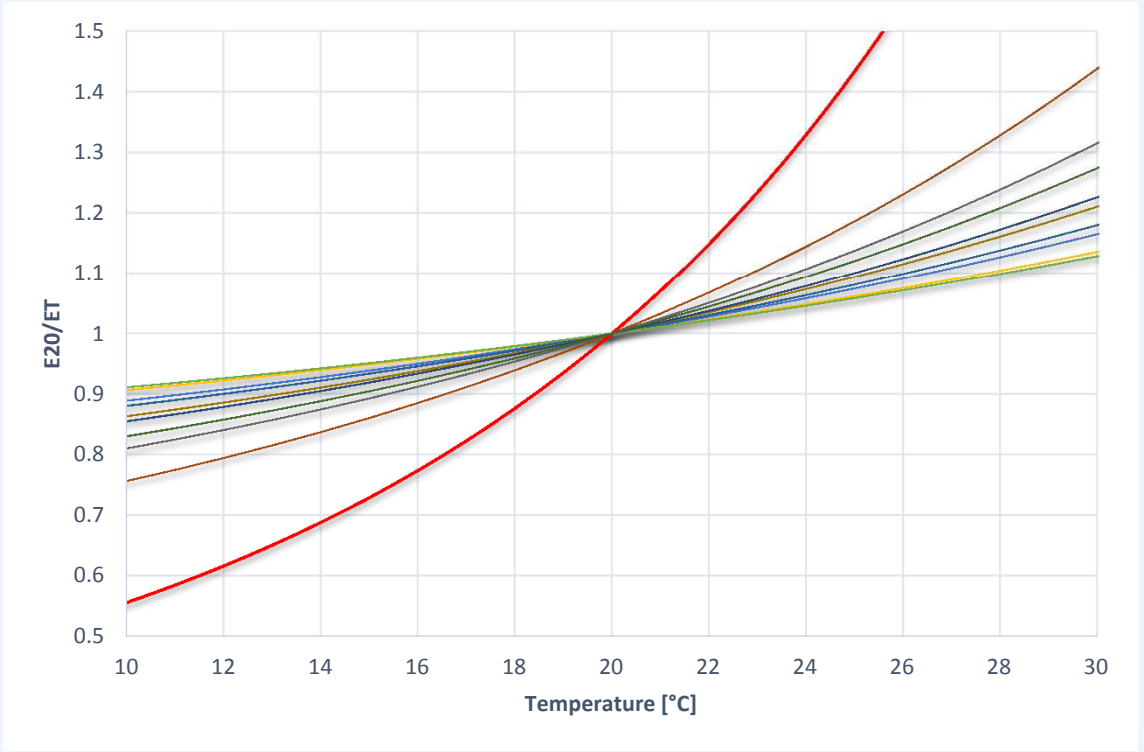
evaluate the α parameters for the different mixtures under evaluation.

MATERIALS TEMPERATURE SENSITIVITY

BITUMEN EMULSION RECYCLED MIXTURES

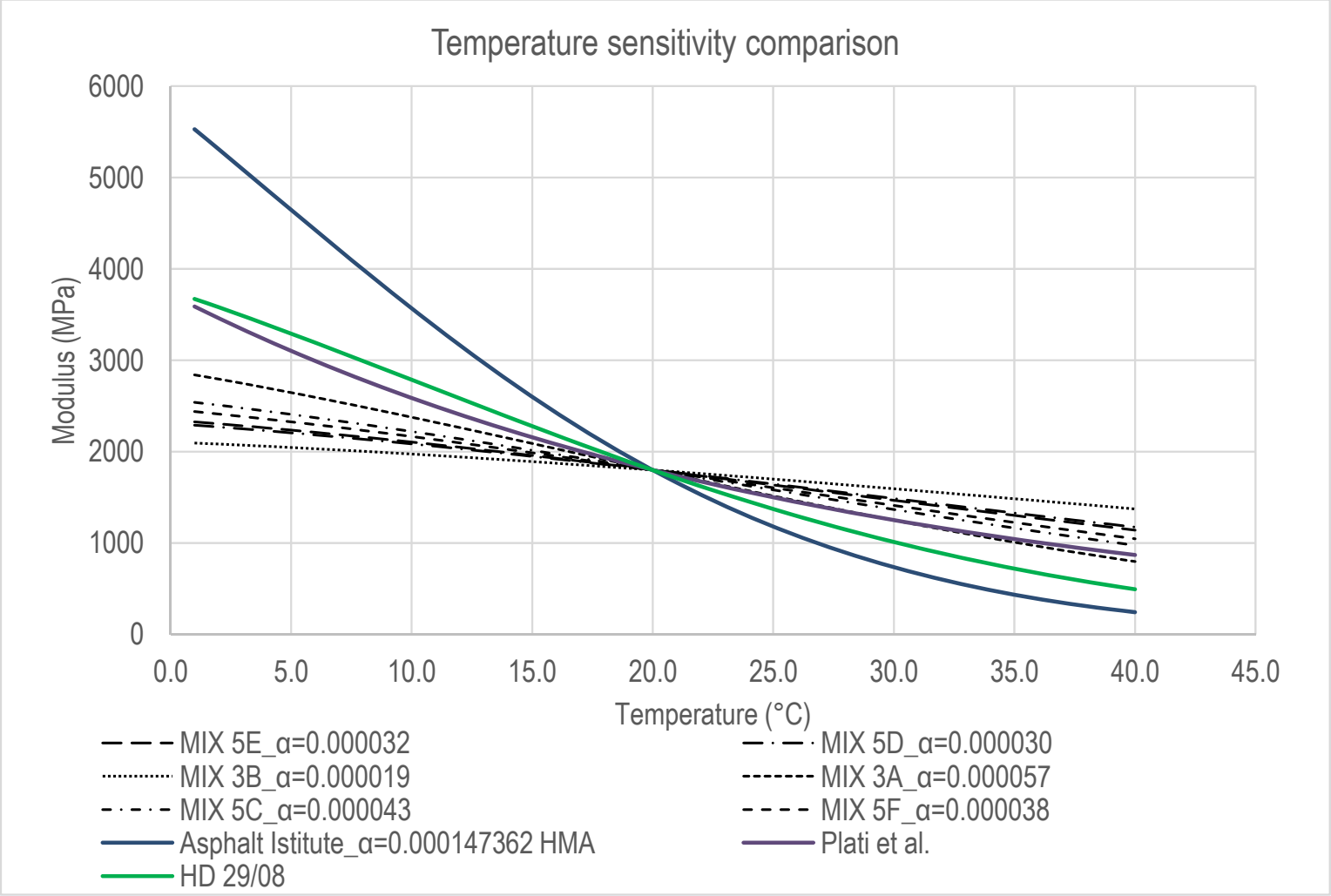
$$E_{Ts} = 10^{\alpha \cdot (T^2 - T_S^2)} \times E$$

Mix ID	α
2A	0.000020
2B	0.000024
4D	0.000026
3B	0.000019
3A	0.000057
5C	0.000043
5D	0.000030
5E	0.000032
5F	0.000038
HMA	0.00012



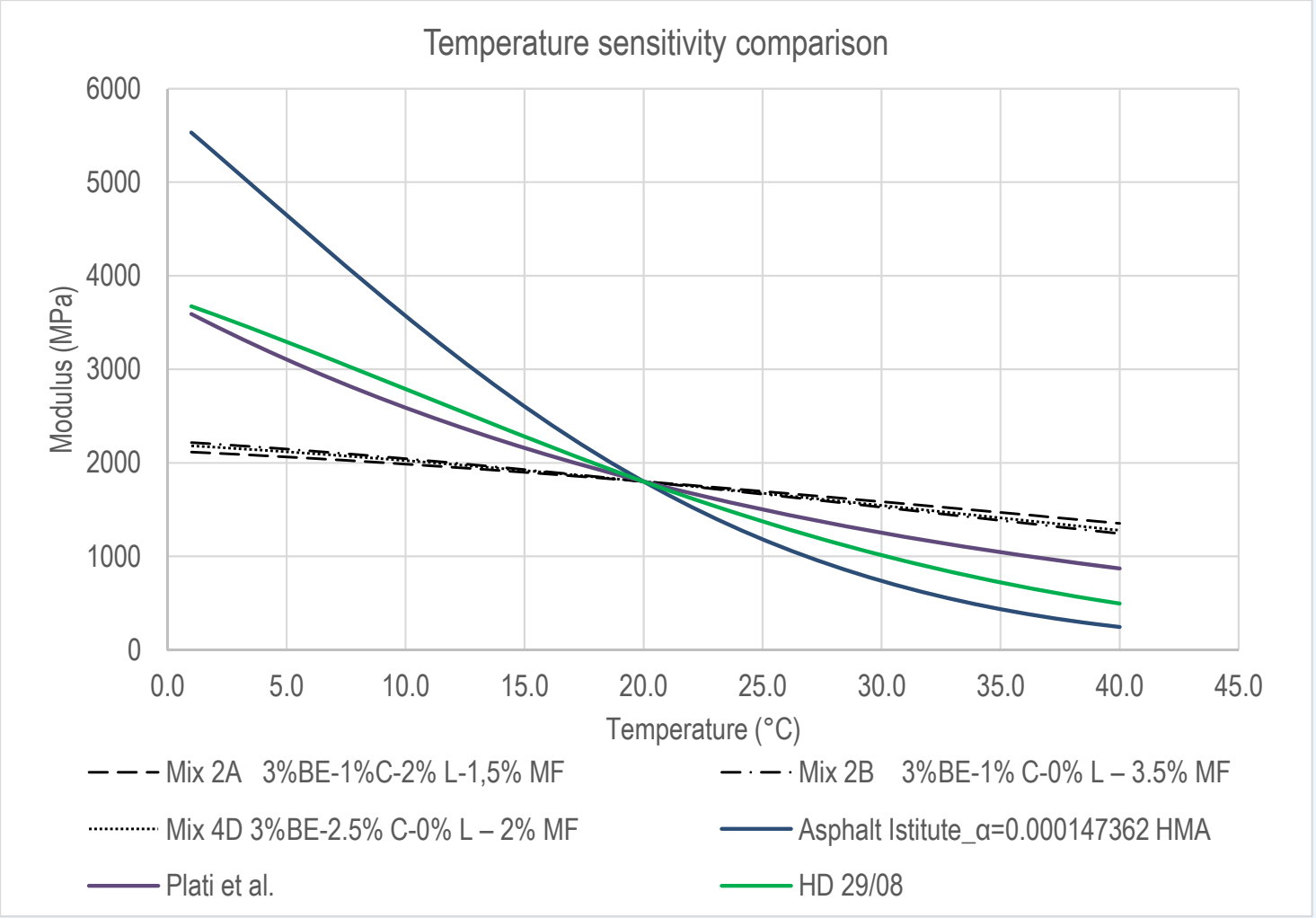
MATERIALS TEMPERATURE SENSITIVITY

FOAM BITUMEN RECYCLED MIXTURES



MATERIALS TEMPERATURE SENSITIVITY

BITUMEN EMULSION RECYCLED MIXTURES



FIELD TESTS

Before placing the wearing course

- LWD after 4 hour from compaction
- FWD after 24 hours
- FWD after 14 days
- FWD after 28 days
- FWD after 9 months

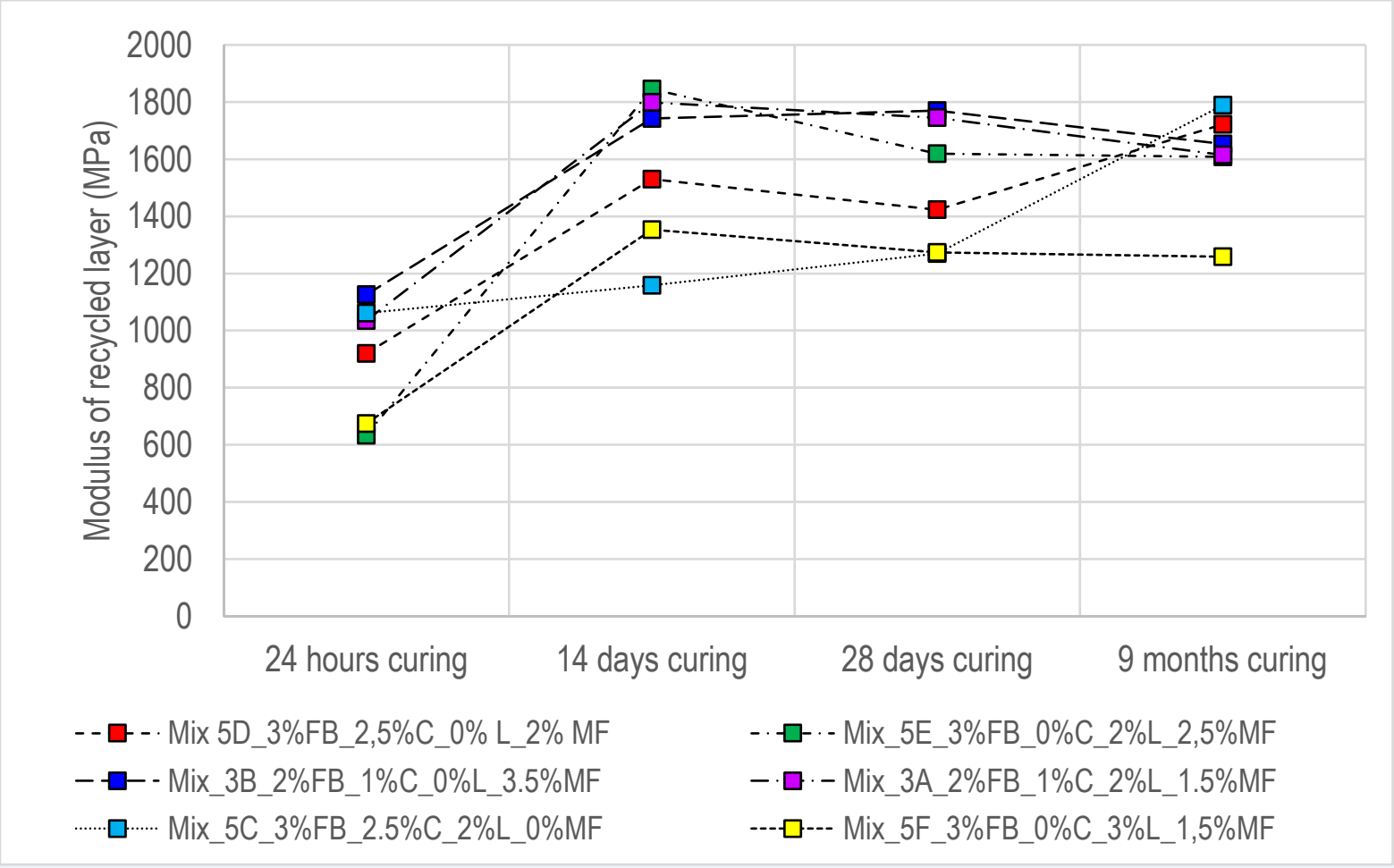
Pavement completed
(cold recycled layer covered with 4 cm AC wearing course)

- FWD after 26 months
- APT with a Fast FWD after 26 months from construction
- APT with a Fast FWD after 50 months from construction

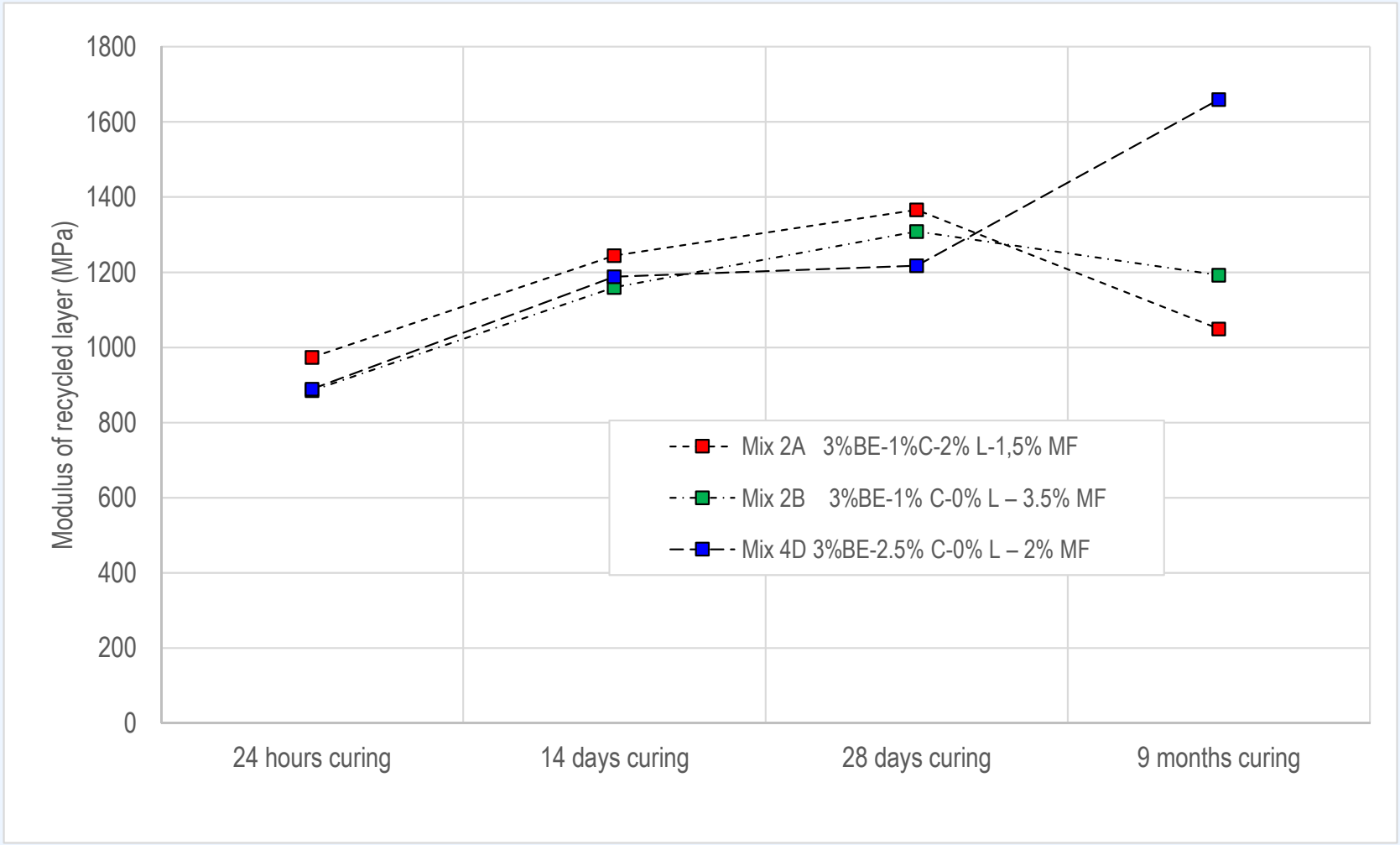
FIELD TESTS (NO AC WEARING COURSE)

AVERAGE MODULI EVOLUTION OVER TIME

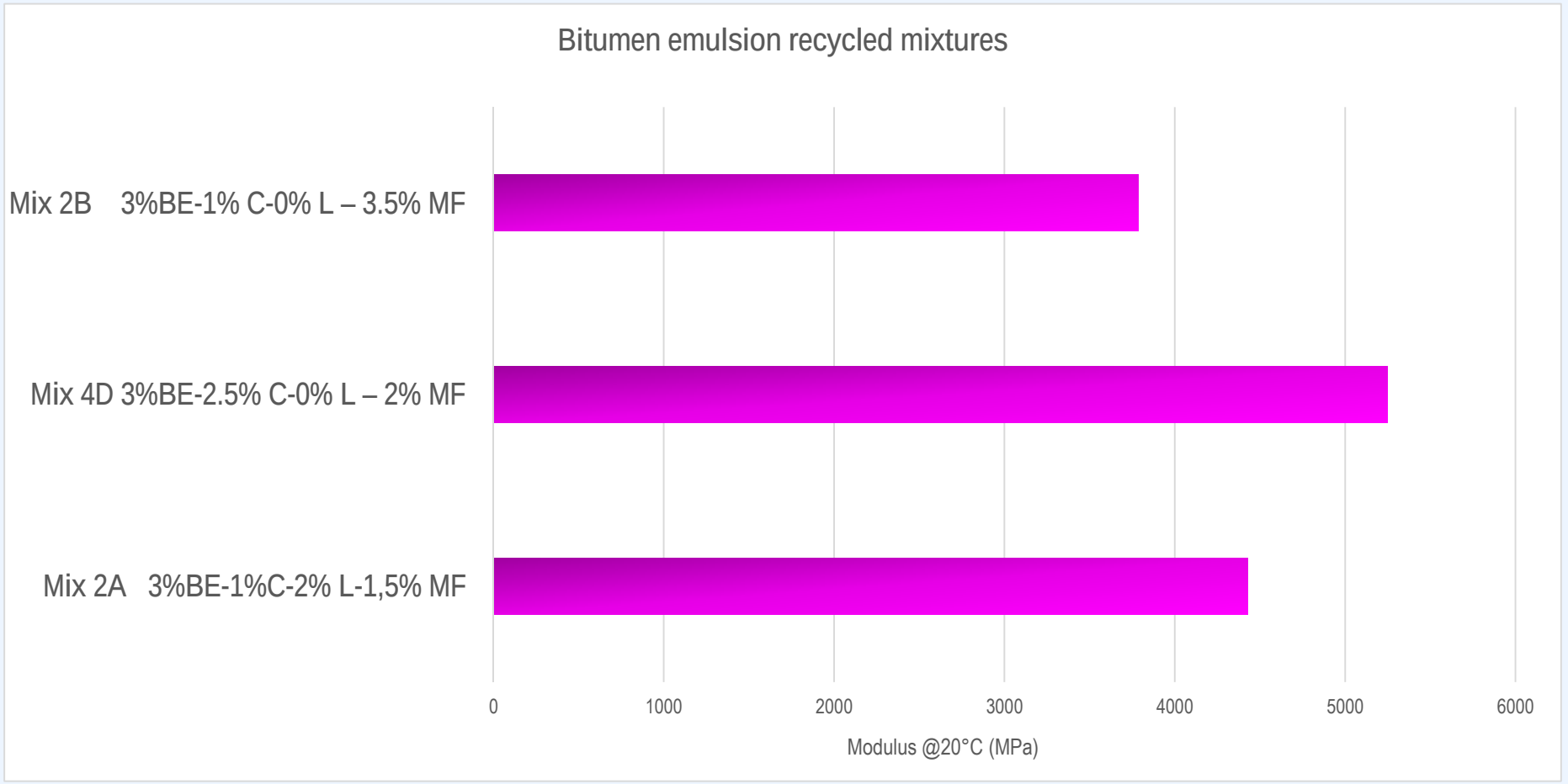
FOAM BITUMEN RECYCLED MIXTURES



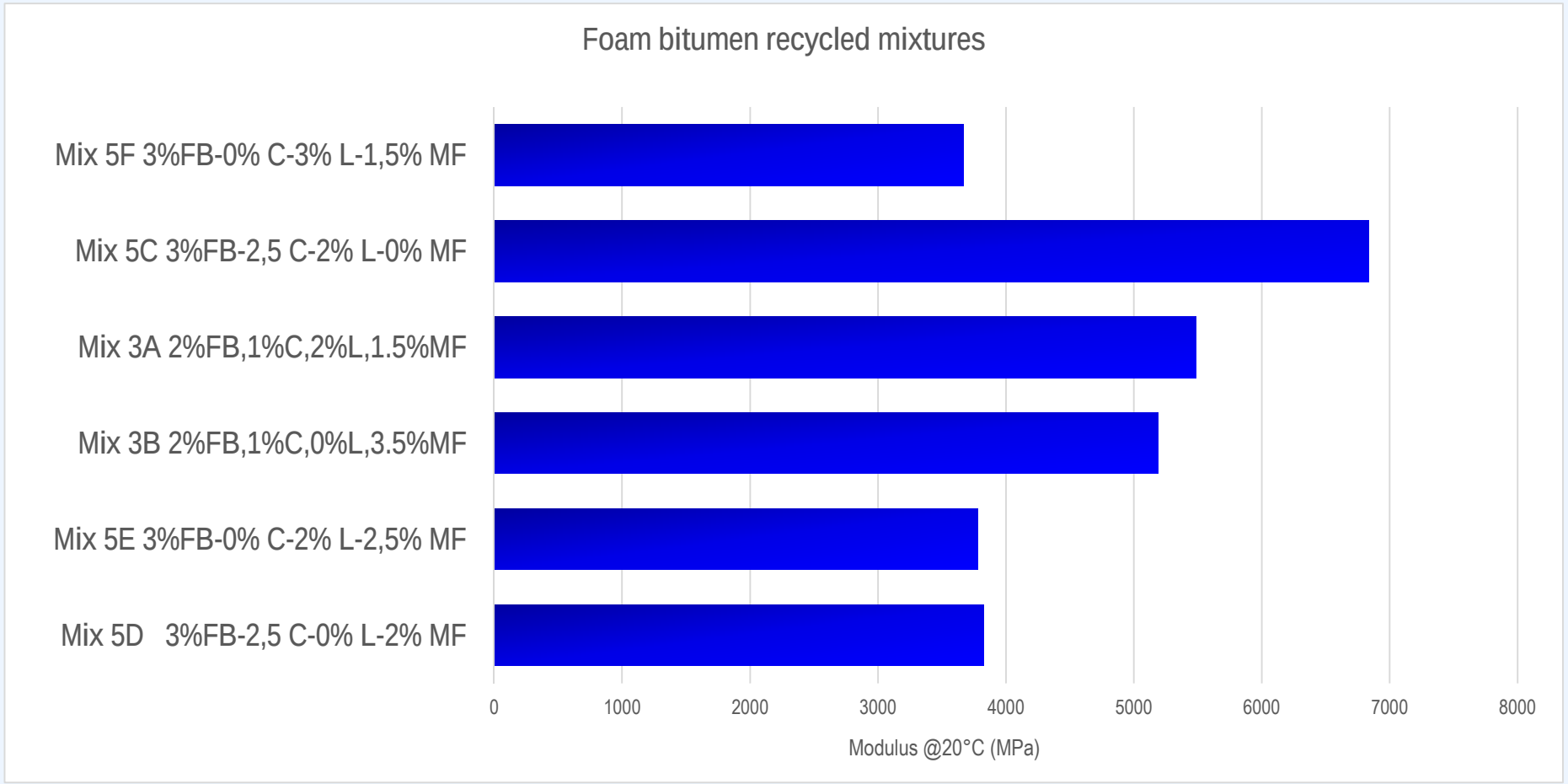
FIELD TESTS (NO AC WEARING COURSE)
AVERAGE MODULI EVOLUTION OVER TIME
BITUMEN EMULSION RECYCLED MIXTURES



FIELD TESTS (COMPLETED PAVEMENT)
AVERAGE MODULI
BITUMEN EMULSION RECYCLED MIXTURES



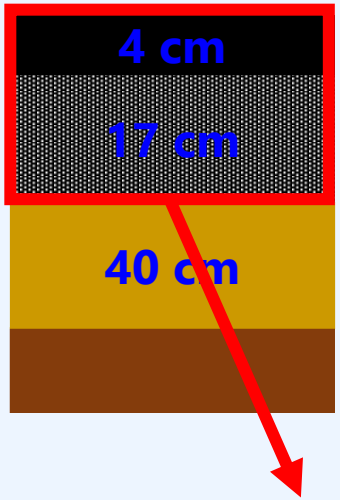
FIELD TESTS (COMPLETED PAVEMENT)
AVERAGE MODULI
FOAM BITUMEN RECYCLED MIXTURES



FAST FWD APT TEST

26 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST

Assumptions



Wearing course

Base - Cold Recycled Mixture (bituminous emulsion/foam bitumen)

Subbase – lime stabilized soil

Subgrade

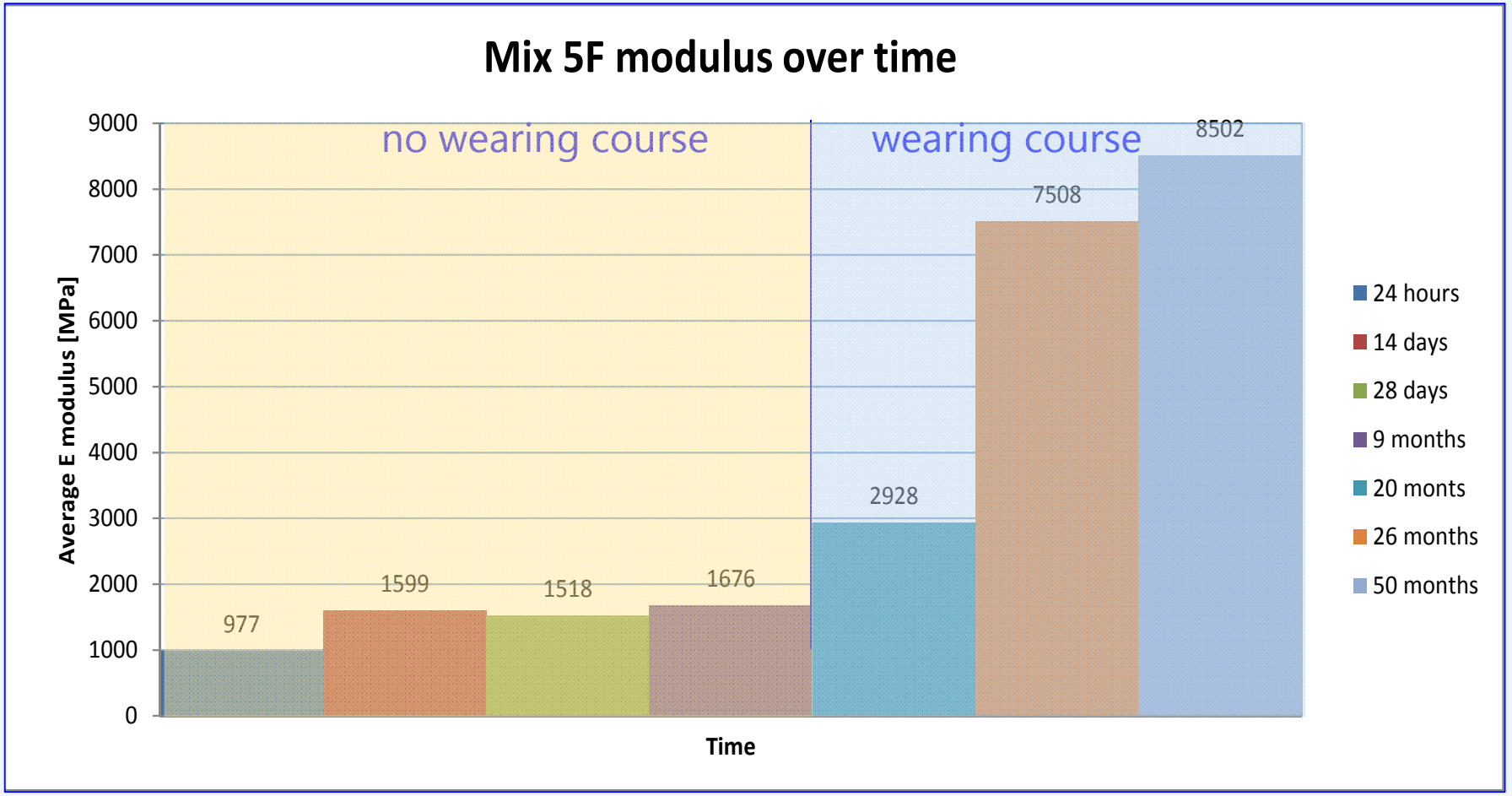
E_1 is the combined modulus of:

- **Layer 1 (4 cm wearing course)**
- **Layer 2 (17 cm cold recycled mixture)**

In the backcalculation process these two layers must be combined

FWD TEST

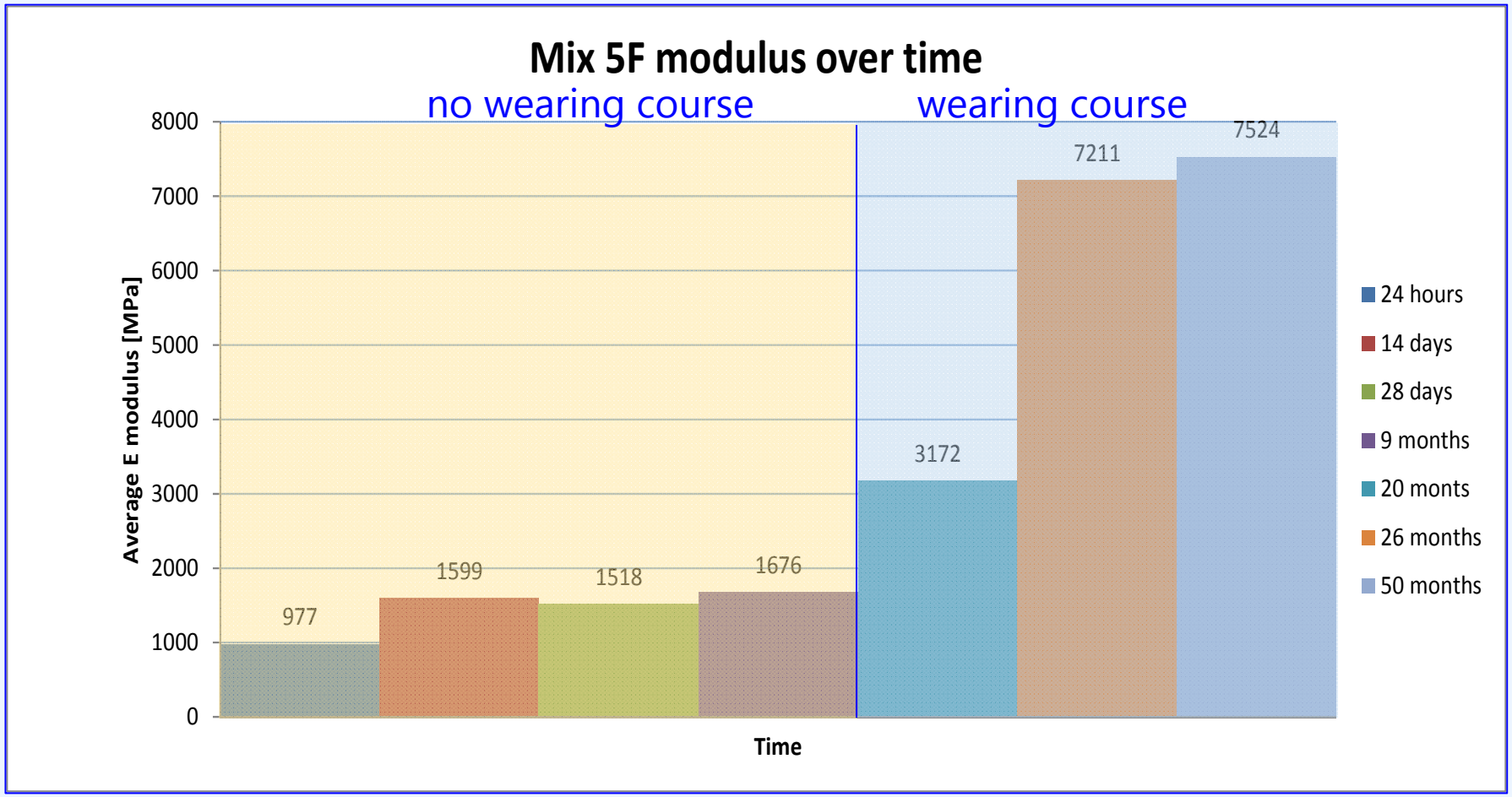
STIFFNESS EVOLUTION OVER TIME



$\alpha = 0.000038$

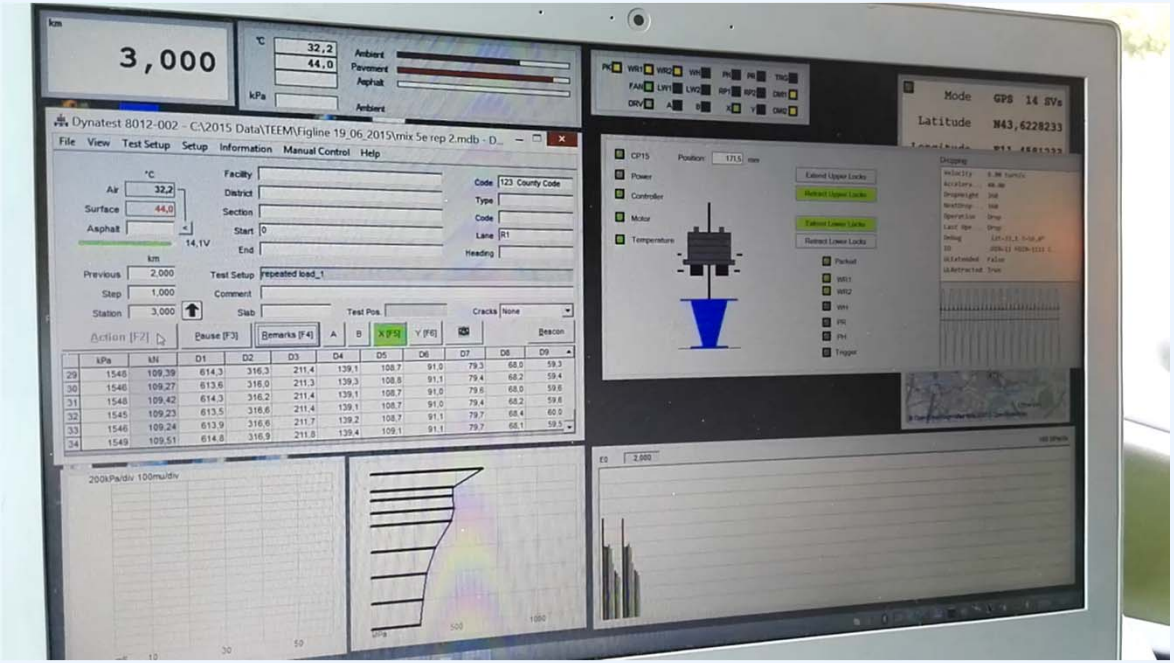
FWD TEST

STIFFNESS EVOLUTION OVER TIME



$\alpha_{avg} = 0.000054$

APT test with Fast FWD



APT TEST WITH FAST FWD

APT TEST WITH FAST FWD

APT TEST WITH FAST FWD (26 MONTHS)

Load applied: 1700 kPa

Productivity: ~1500 drops per hour

N° drops: 5600

$$N = \left[\frac{6918(0.856 \cdot V_B + 1.08)}{{S_{mix}}^{0.36} \cdot \mu\varepsilon}\right]^5$$

Review of Structural Design Procedures for Foamed Bitumen Pavements. Austroads (2011)

$$F_j = \frac{N_{fs}}{N_{fj}} = \frac{f(\epsilon_s)}{f(\epsilon_j)}$$

Determination of equivalent axle load factors on the basis of fatigue criteria. Judicky (2010)

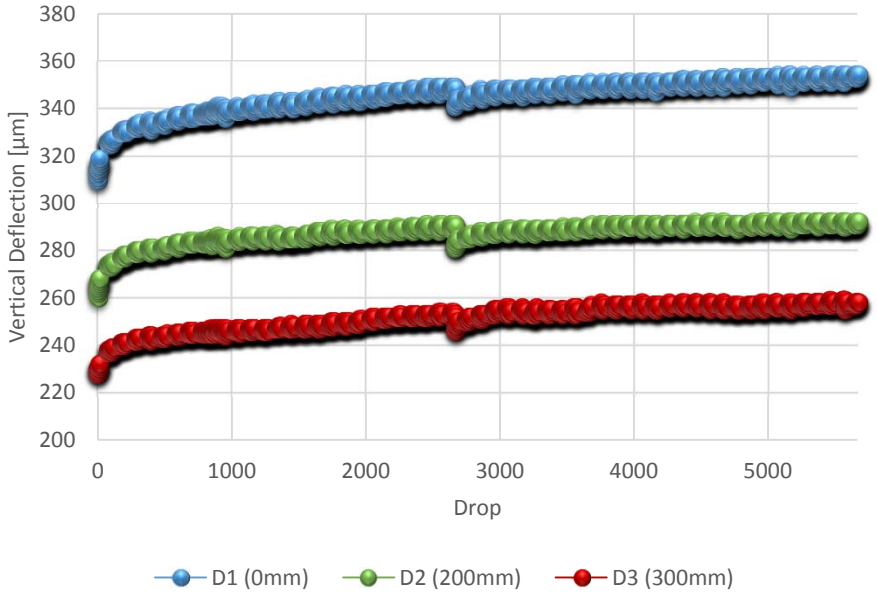
$$F_{8.2t} = \left(\frac{\mu\epsilon_{FWD}}{\mu\epsilon_{8.2t}}\right)^5 \cong 10$$

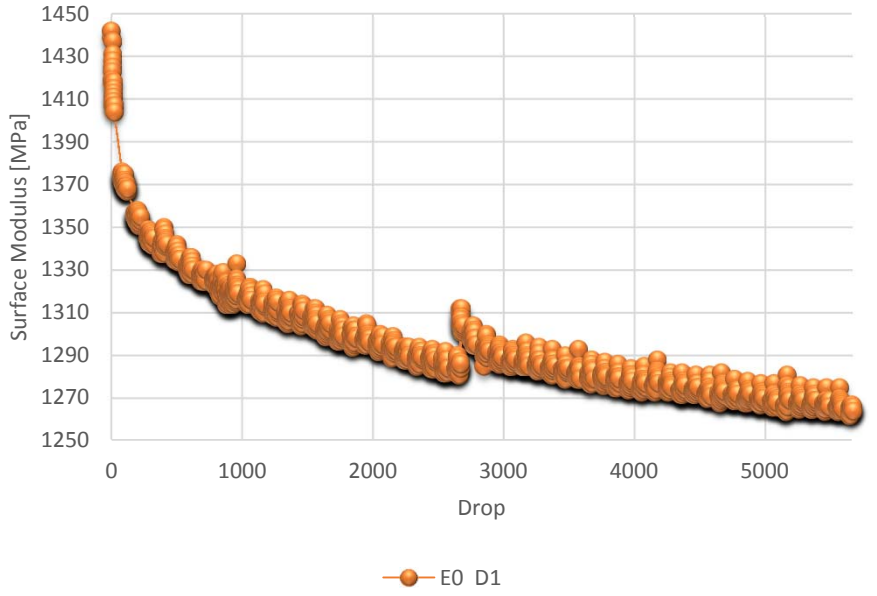
5600 drops at 1700 kPa correspond to≅ 6% *of layer fatigue life*

FAST FWD APT TEST

26 MONTHS RESULTS – STIFFNESS EVOUTION UNDER FFWD - APT TEST

Mix	% Foamed Bit	% Lime	% Mineral Filler
5F	3	3	1.5

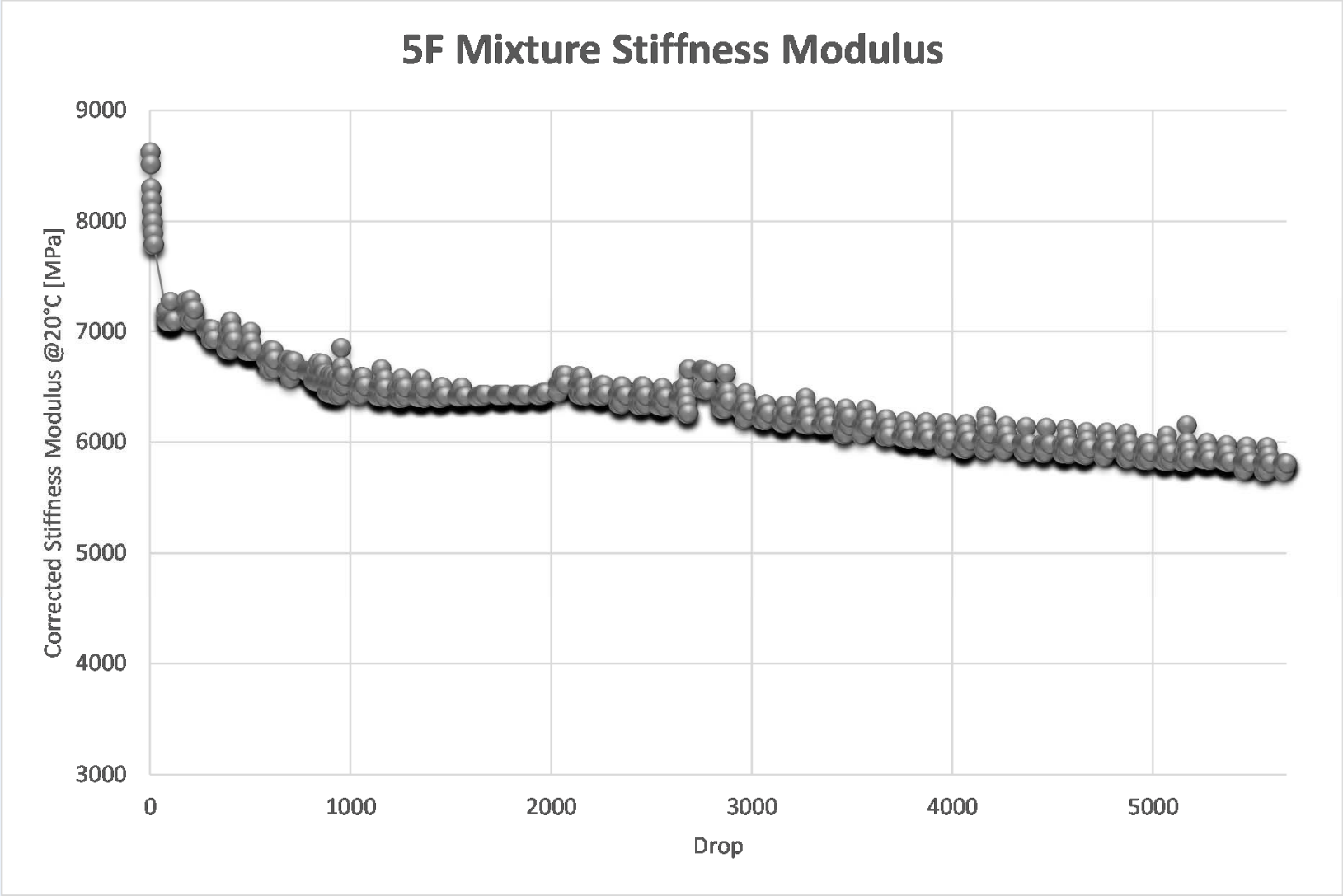




Tpav = 9.3°C

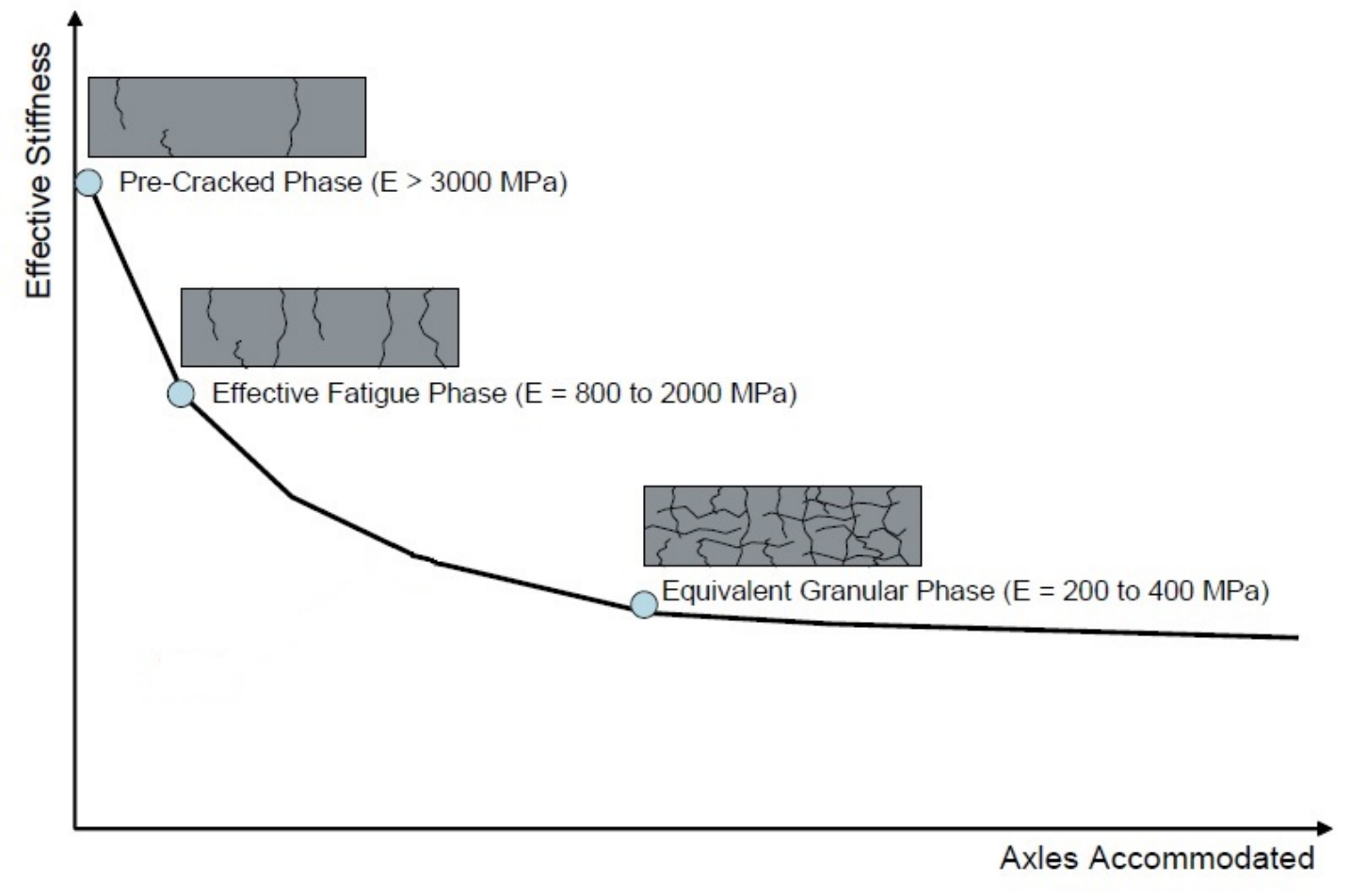
FAST FWD APT TEST

26 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



FAST FWD APT TEST

26 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



APT TEST WITH FAST FWD (50 MONTHS)

Load applied: 1700 kPa

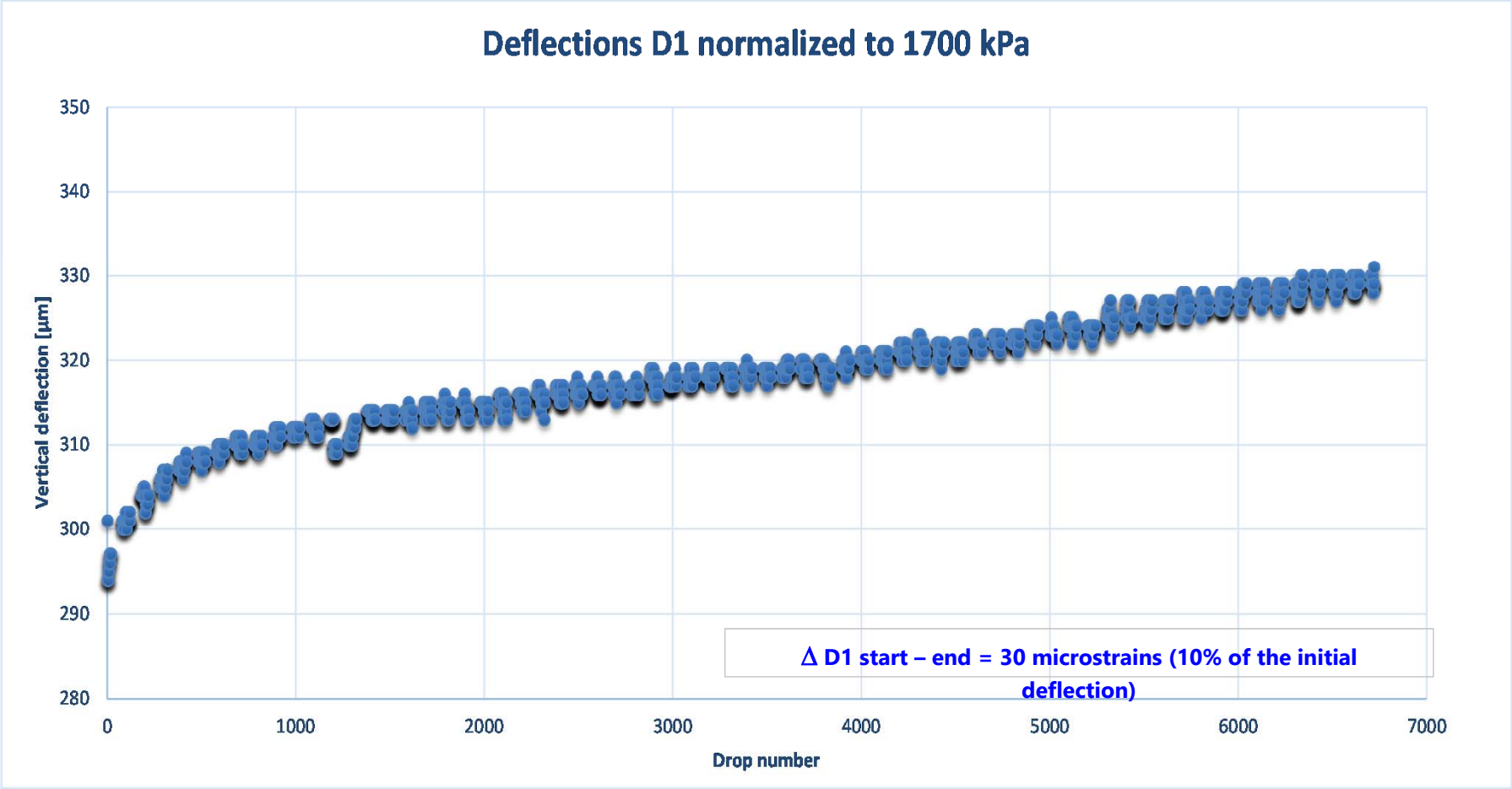
Productivity: ~1500 drops per hour

N° drops: 6700

H:mm	T pav (°C)
10:34	2,4
11:13	2,3
11:20	2,4
11:37	2,3
11:50	2,3
12:00	2,3
12:12	2,3
12:27	2,3
12:44	2,3
13:06	2,3
13:14	2,3
13:33	2,4
13:47	2,4
14:02	2,5
14:14	2,5
14:32	2,4
14:44	2,4
15:01	2,4
15:18	2,4
15:30	2,4

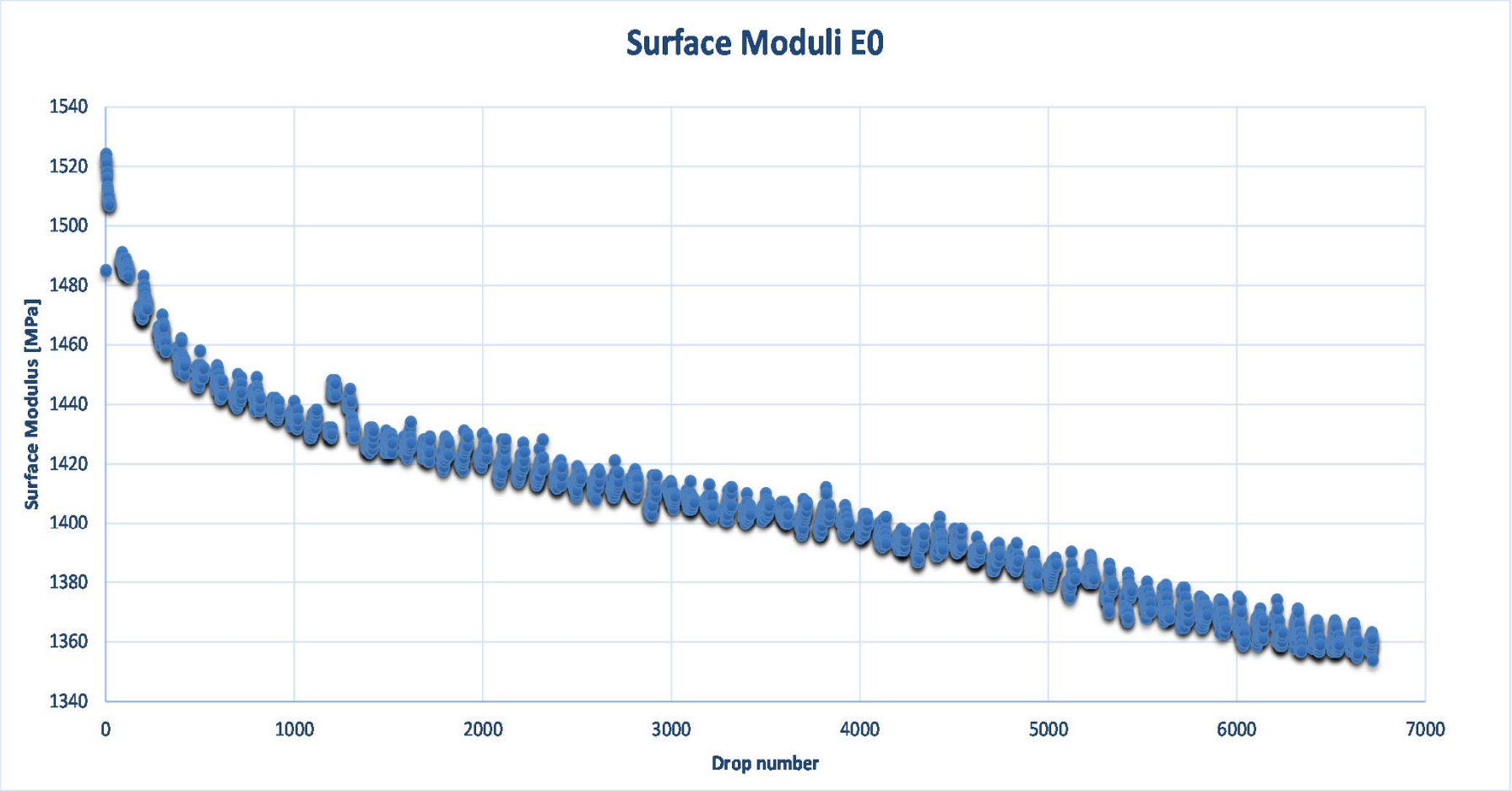
APT TEST WITH FAST FWD

50 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



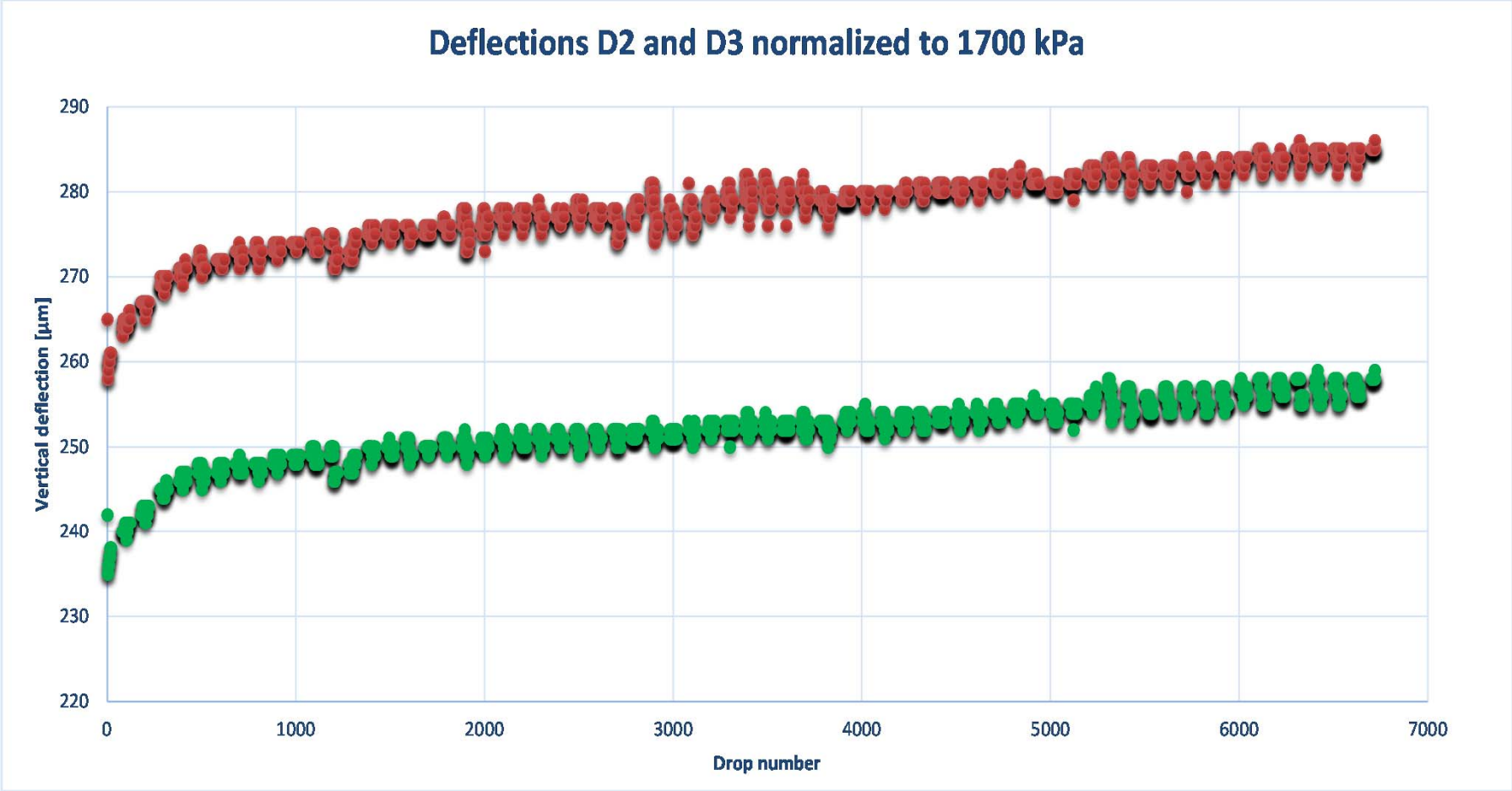
APT TEST WITH FAST FWD

50 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



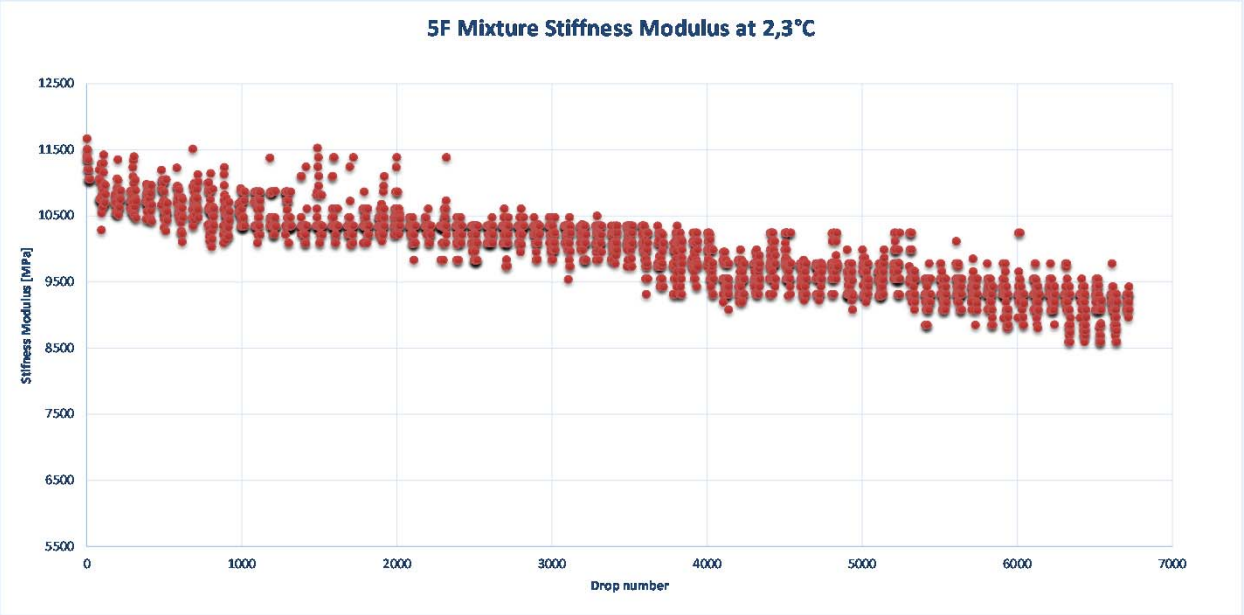
APT TEST WITH FAST FWD

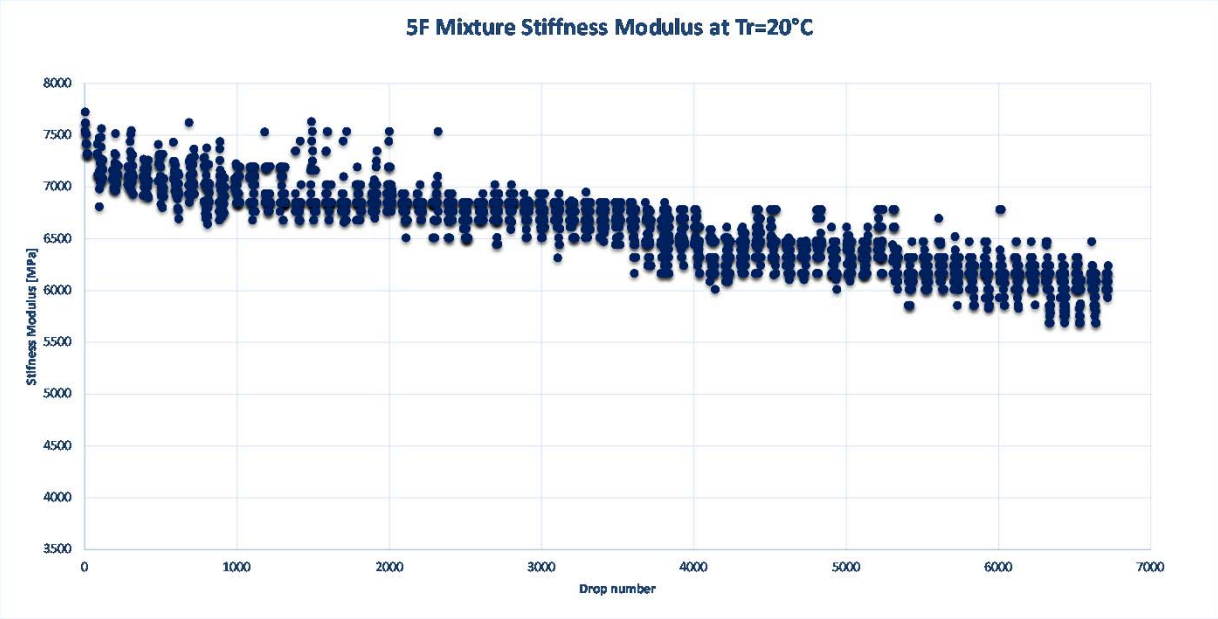
50 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



APT TEST WITH FAST FWD

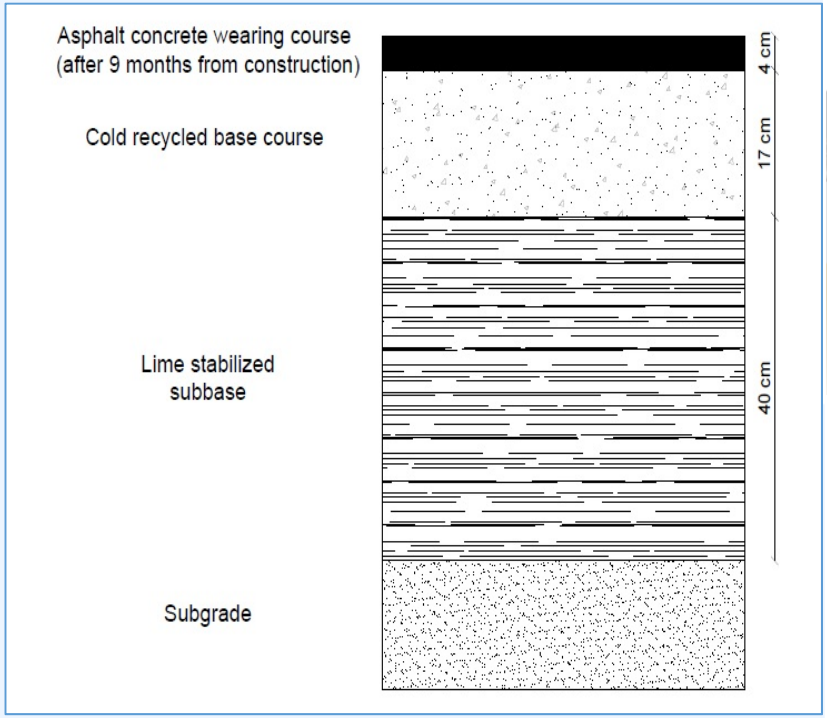
50 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST

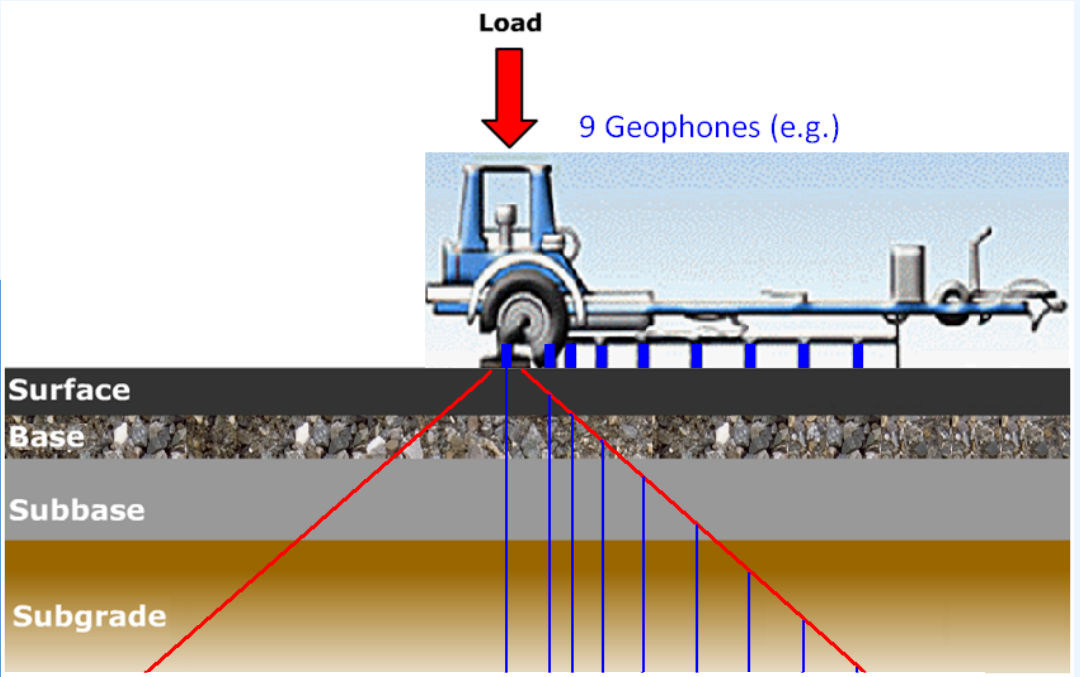


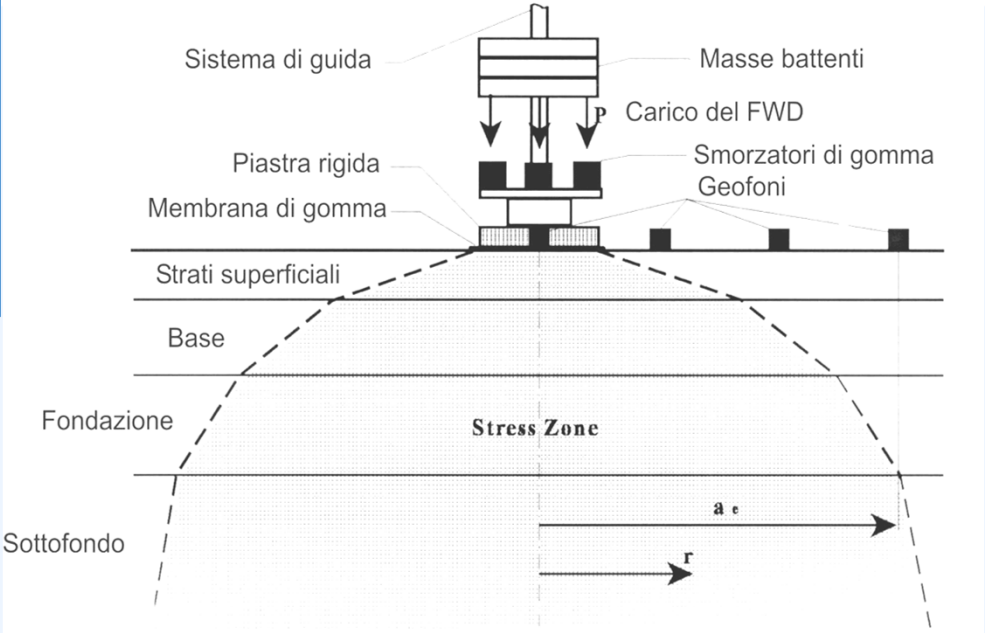


$\alpha_{avg} = 0.000054$

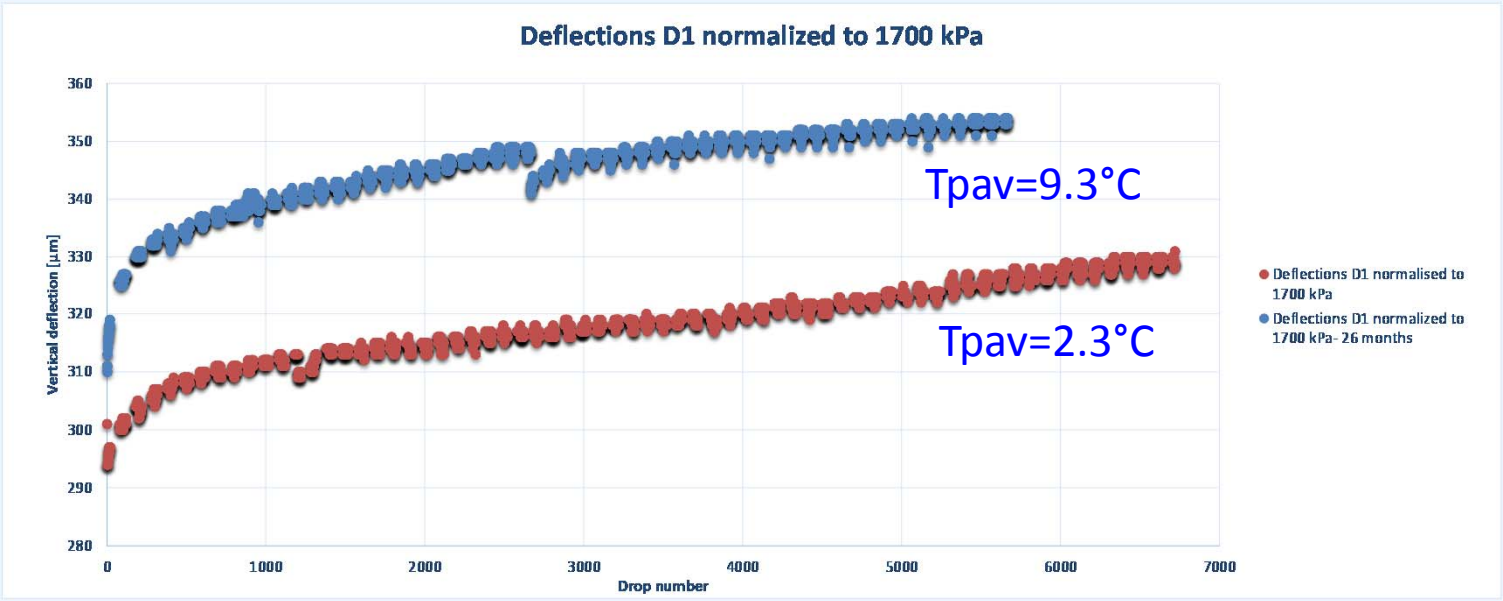
APT TEST WITH FAST FWD

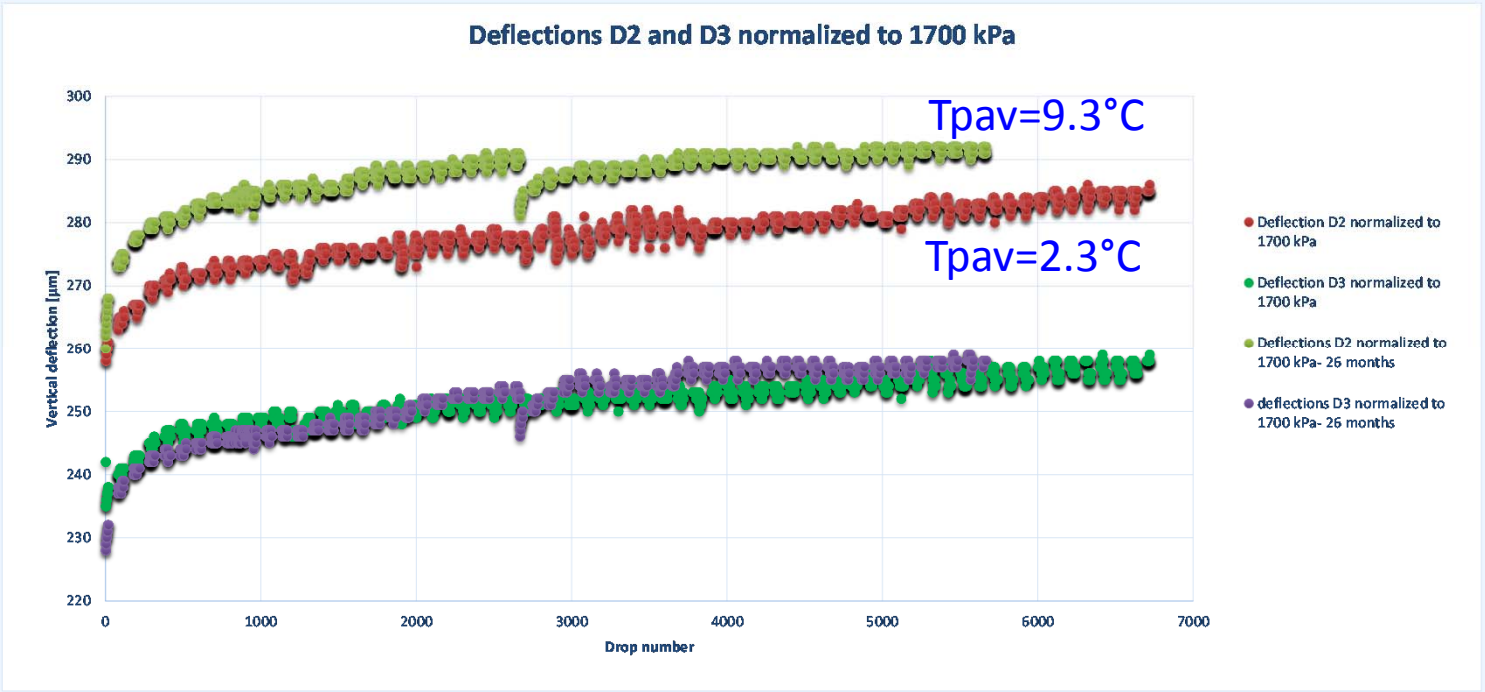






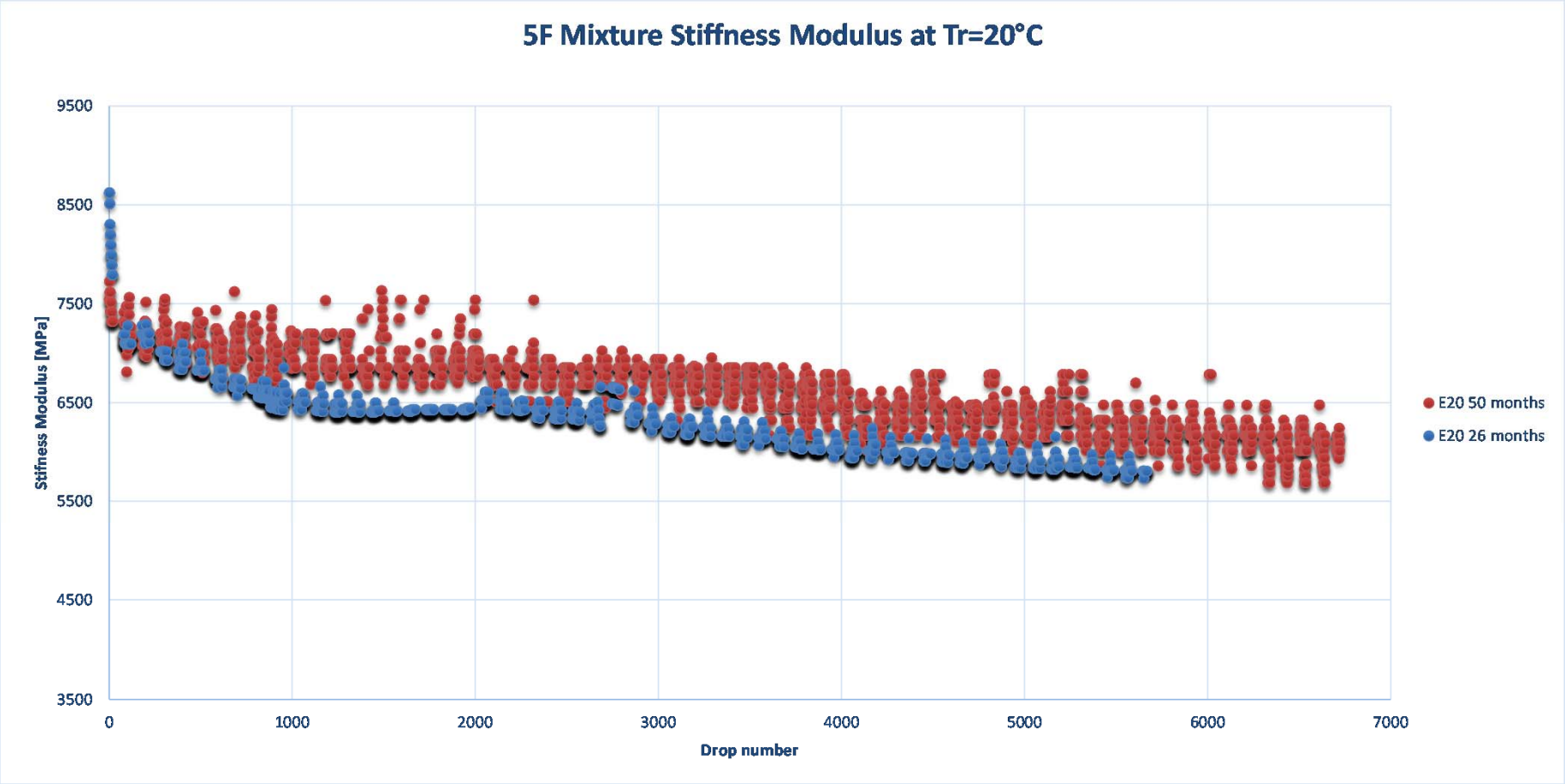
APT TEST WITH FAST FWD





APT TEST WITH FAST FWD

50 MONTHS RESULTS – STIFFNESS EVOLUTION UNDER FFWD - APT TEST



$\alpha_{avg} = 0.000054$

CONCLUSIONS

- Temperature effects on mixture performances are important to evaluate stiffness evolution and to make comparisons;
- Evolution of performance (stiffness and permanent deformation) under FFWD APT test conditions seems to be consistent and repeatable;
- One step closer to reality.




Thank You

ALESSANDRO MARRADI

UNIVERSITY OF PISA
CIVIL & INDUSTRIAL ENGINEERING DEPARTMENT
LARGO LAZZARINO - 56126 PISA ITALY
MOBILE: +39 339 3009148
PHONE: +39 050 2217747
EMAIL: a.marradi@ing.unipi.it

DYNATEST DENMARK A/S
EMAIL: amarradi@dynatest.com
WEB SITE: www.dynatest.com
MOB: (ITALY) +39 339 3009148
TEL: (ITALY) +39 0571 500509