AAPA's 14th International
Flexible Pavements Conference

Sydney
25–28 September 2011

Design of Recycled Asphalt Mixtures

André A.A. Molenaar
Professor of Road Engineering
Delft University of Technology NL

AAPA
AUSTRALIAN ASPHALT PAVEMENT ASSOCIATION

Co-Authors

Mohamad Mohajeri
Martin F.C. ven de Ven

Delft University of Technology

Contents

- Recycling of hot mix asphalt in the Netherlands
- Mix design issues of mixtures with high RAP content; effects of moisture and mixing method
- Effect of RAP content, moisture and mixing method on mechanical characteristics

Some Statistics about the Netherlands

16 million people
3 million tons of RAP
15 million tons of CDW
No natural aggregates
No space for dumping waste
Recycling is a must

Government policy

- **Recycling is a must.**
- **Costs per ton for dumping RAP are very high, close to costs of producing new mixture.**
- **Active policy in development of techniques, specifications, test methods etc.**
- **Since 1990, recycled asphalt mixtures are in the Dutch standards.**
- **Since 1990, RAP is treated as “normal” material.**

Some early Developments

- 1976 Renofalt process; recycling with up to 100 % RAP
- 1990 MARS process; recycling with up to 100 % RAP

State of the Art Recycling in the Netherlands

- Asphalt production of $9*10^6$ ton/year mostly for binder and surface layers.
- Consumption of bitumen $0.37*10^6$ ton/year.
- At the moment $3.5 * 10^6$ ton/year of RAP.
- 80 % of the RAP is used in hot mix.
- 65 % of new HMA production contains RAP.

State of the Art Recycling in the Netherlands

- Recycling in STAC (base layer) maximum 50 %.
- Recycling in OAC (binder layer) maximum 50%.
- Recycling in DAC (wearing course) maximum 50%.
- Recycling in Porous Asphalt (wearing course) maximum 20 %.
- No recycling in SMA.
- Log pen rule is used for the combined penetration (old –new bitumen) in the mix design for all mixes.

$$a \log pen_{RAP} + b \log pen_{virgin} = (a + b) \log pen_{mix}$$

$$a + b = 1$$

Hot Mix Asphalt plants (partial recycling PR) in the Netherlands

Type of plant	Number
Batch plant with parallel drum	38
Batch plant with cold RAP feed	1
Drum mixer suitable for PR	5
Double barrel drum	1
Total	45

Some Issues

- From max 50% to 70% recycling in base layers
- Many PA layers are to be replaced in a first or second maintenance cycle. This is RAP with extremely hard bitumen (pen < 15).
- How to keep the temperature of virgin aggregate at reasonable level at higher RAP contents.
- For surface layers, requirements PSV stone are increased (>57). Is aggregate in current RAP good enough?

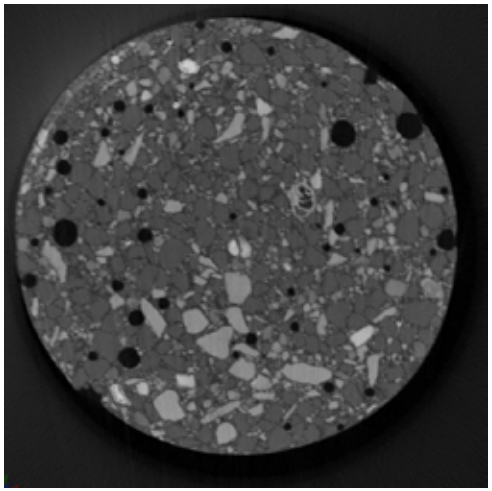
CE marking effective since January 2009

- **Functional requirements in CE marking also for RAP mixtures:**
  - **water sensitivity (retained ITS),**
  - **stiffness (4 point bending),**
  - **fatigue (4 point bending),**
  - **permanent deformation (triaxial test).**

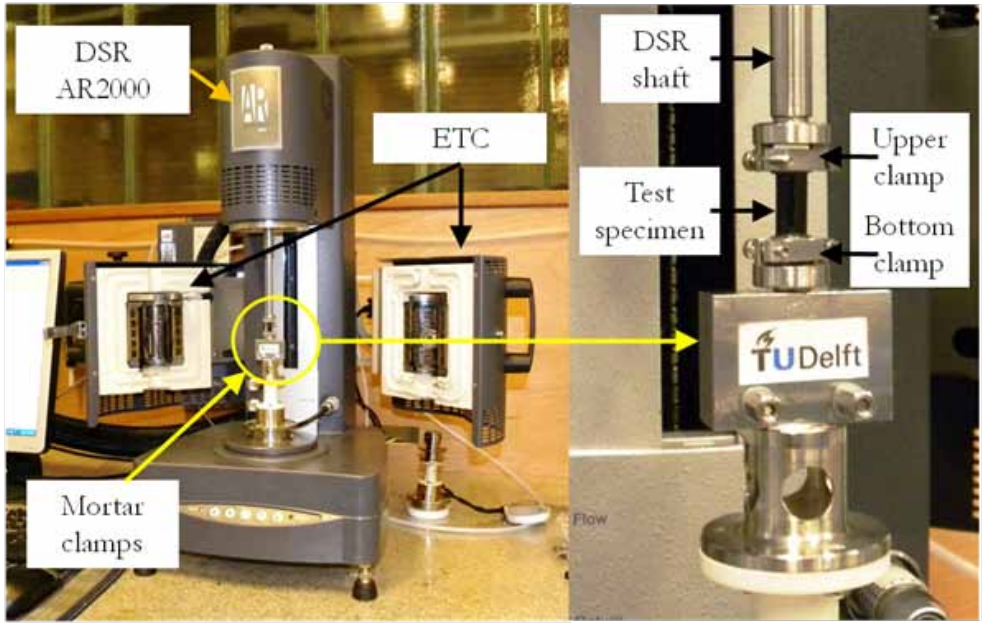
Important Research questions

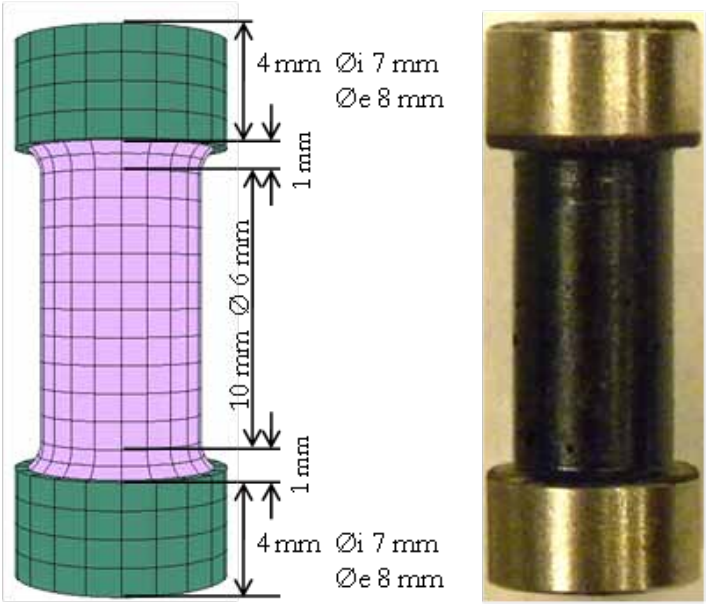
- Fatigue properties of mixtures with very high RAP contents.
- Healing of mixes with RAP.
- How to recycle mixtures with PMB (can log (pen) rule be used).
- Re-use of Porous Asphalt RAP .
- More general: increase amount of RAP in the top layers

Fatigue and Healing Tests

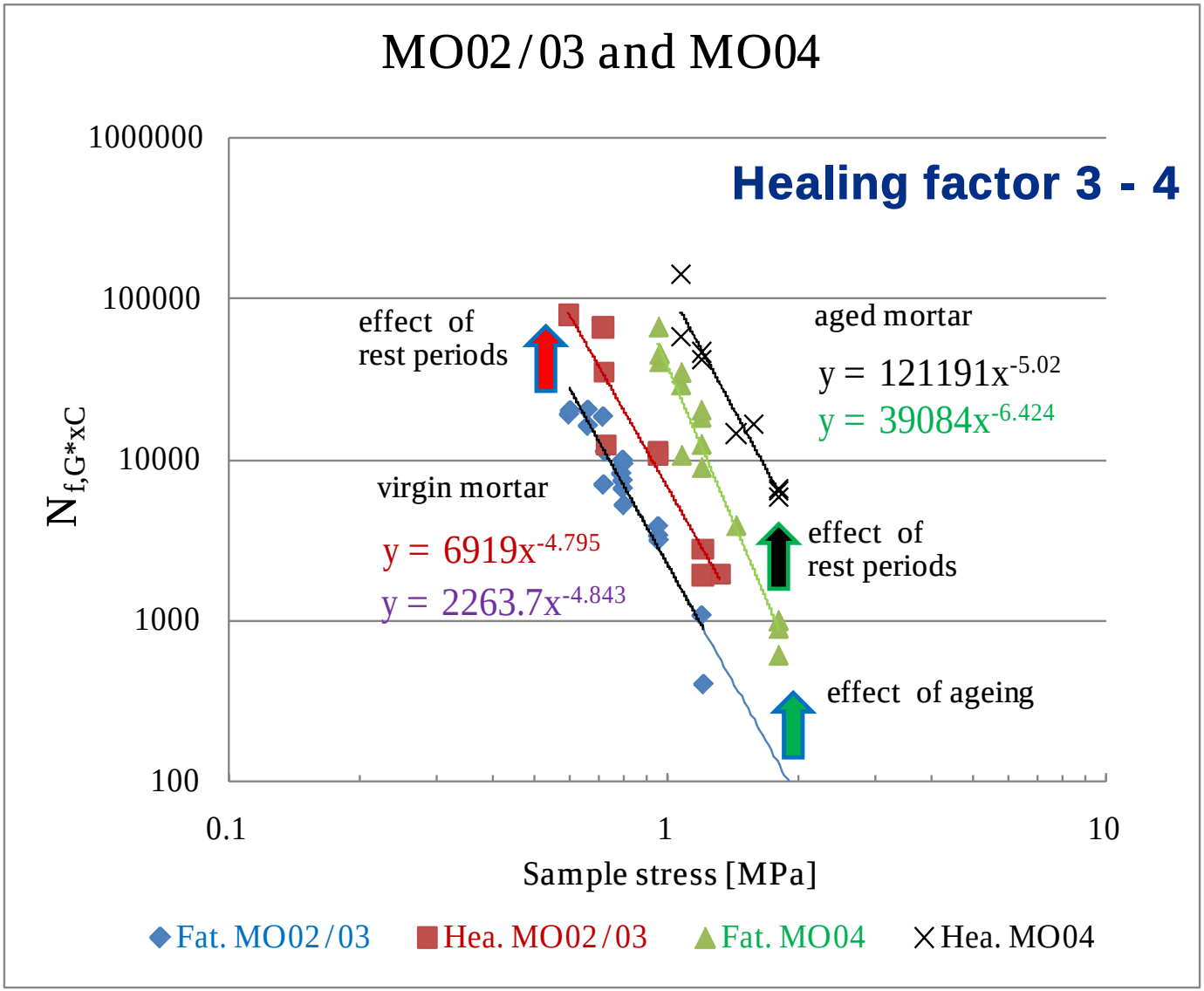


Mortar samples h = 10 mm f = 6 mm
Mortar means all aggregates
with f < 0.5 mm + bitumen





Fatigue and Healing Results of Virgin and Aged Mortars



Consequences for Recycling

- **Aged mortar has better fatigue resistance than virgin mortar**
- **Ageing does seem to have bad effect on healing**

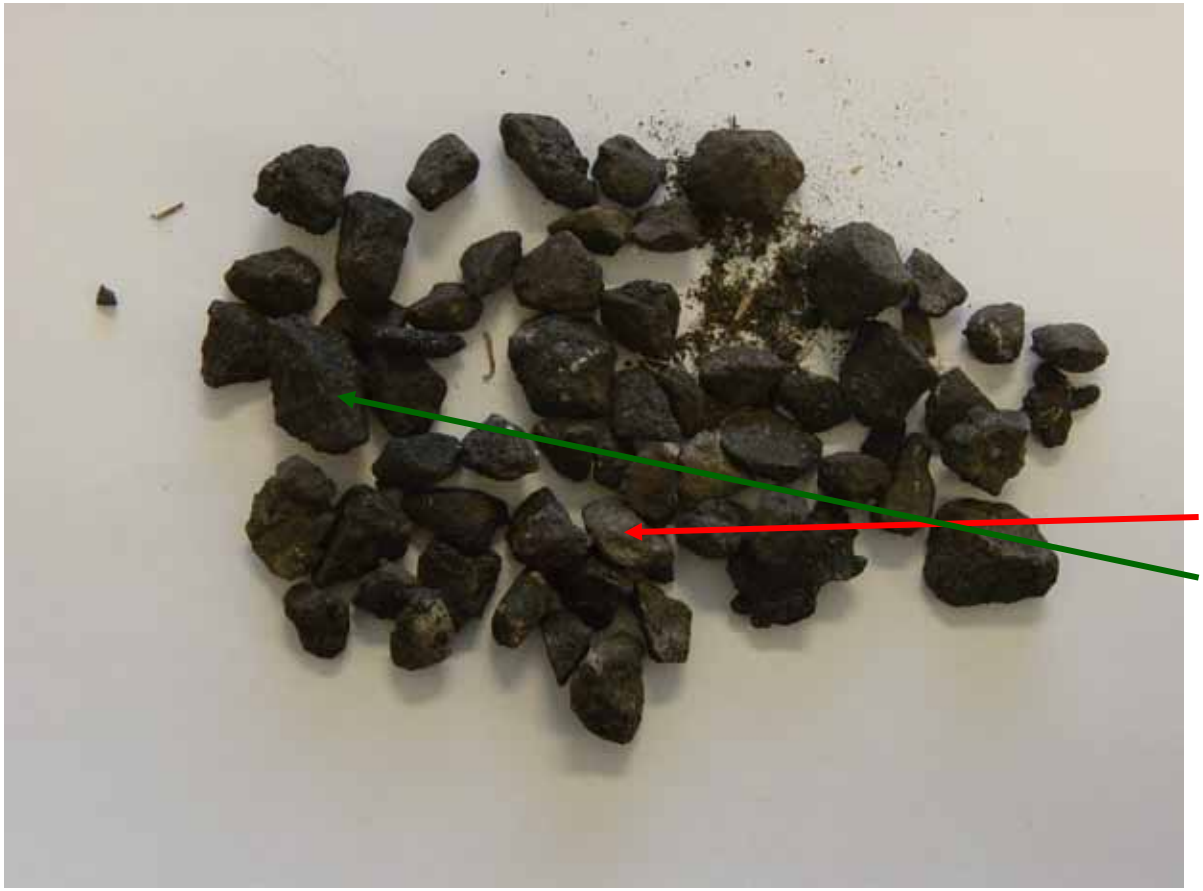
CAREFUL!!!!

- **Results are obtained on artificial aged mortars**
- **However, rheological and chemical characteristics of artificial aged binder were the same as those of binder extracted from RAP**

Comparison Lab vs “Field”

- Rheological properties of lab aged binder = rheological properties of binder recovered from RAP
- Chemical composition lab aged binder = chemical composition binder from RAP
- Fatigue characteristics were the same (no rest periods)
- Healing lab aged mortar 3 – 4
- Healing mortar with RAP (field aged) binder 1.8
- In all cases mortar aggregates were the same

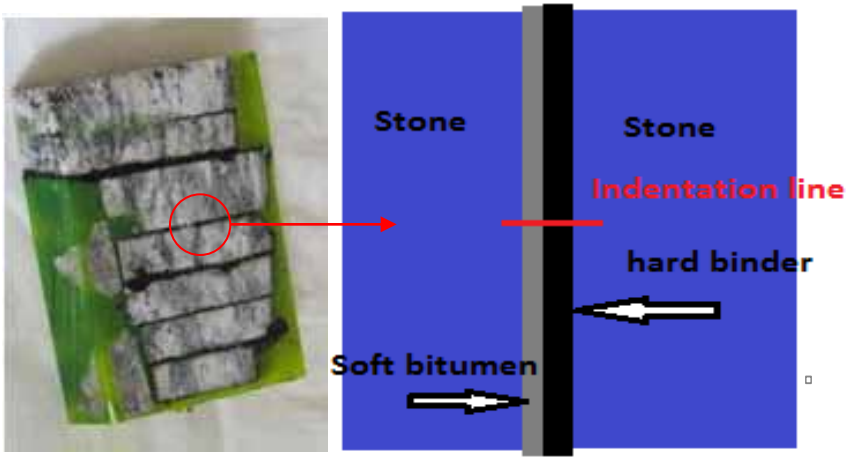
Blending



Will this binder blend with new binder?

“naked” stone
“black rock” ?

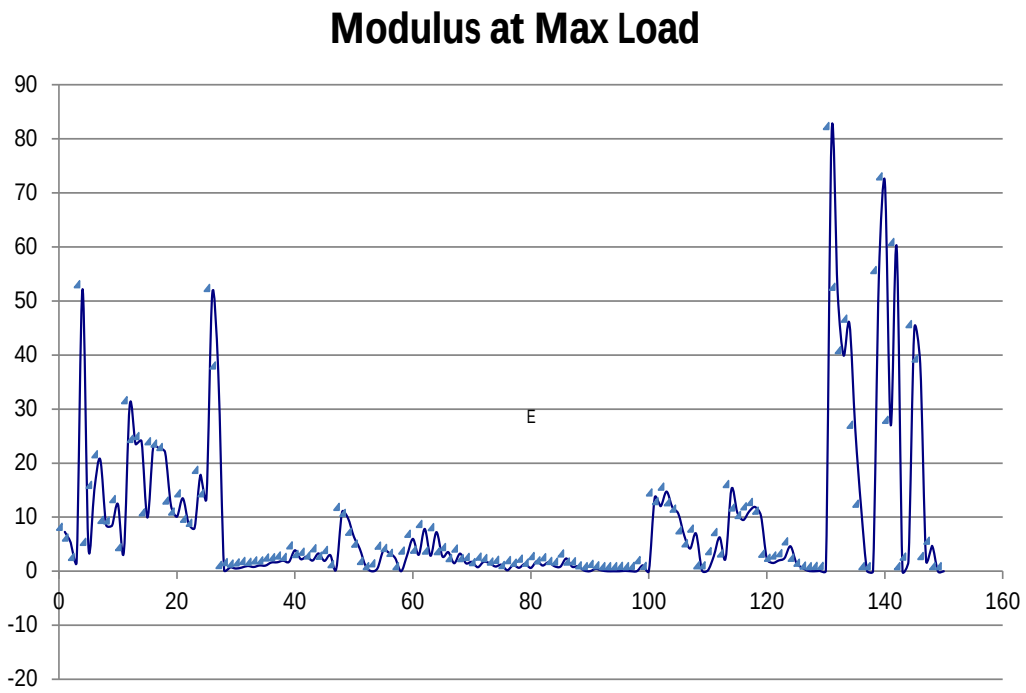
Nano-indentation Tests to measure Blending



Hard binder 20/30
Soft binder 160/200

Difficult to measure blending via nano-identation

CT scanning may be the way to go



Expectations

- **Full blending will not occur**
- **Some kind of layered structure will develop**
- **Fines will influence layer development**

Recycling in Europe

Country	Available Reclaimed asphalt mix [tons]	% re-used in hot mix	% re-used in cold mix	% of new hot mix production
Germany	$14 * 10^6$	82	18	60
Spain	$2.25 * 10^6$	8	4	3.5
Italy	$14 * 10^6$	18	2	
France	$6.5 * 10^6$	13	< 2	< 10
Norway	$0.59 * 10^6$	7	26	8
Netherlands	$3 * 10^6$	80		63

The Problem

- **Mixture design process in laboratory ≠ Field conditions**
- **Simulate in the lab as good as possible real mixing conditions**
- **BUT CURRENTLY in the lab, RAP is preheated to same temperature as virgin materials!**
- ***Field:* Hot Recycling:**

  Warm feed: Parallel drum preheats RAP to 130 ^{0}C

  Cold feed: Cool and moist RAP is added to the mixing unit
- **In both cases virgin aggregates have to be heated to high temperatures**
- **High temperature virgin aggregates might harm mixture quality**

Goals

- **Determine effects of:**
  - **amount of RAP**
  - **moisture content RAP**
  - **preheating of virgin aggregates**

    on
  - **mechanical characteristics of of recycled asphalt mixture.**
- **Derive a laboratory mixture design method that simulates as close as possible the mixing procedures that are used in practice.**

Virgin Materials

- **Base course mixture**
- **Norwegian granite f_{max} = 20 mm**

Properties bitumen	Unit	Q8 pen 40/60		Q8 pen 70/100	
		Nominal values	Measured values	Nominal values	Measured values
Penetration @ 25 ° C	0.1mm	40-60	50	70-100	90
Softening point $T_{r\&b}$	° C	48-56	51	43-51	46
Penetration Index		-1	-0.96	-1	-0.45
Density at 25 ° C	kg/m³	1035	1035	1029	1029

RAP

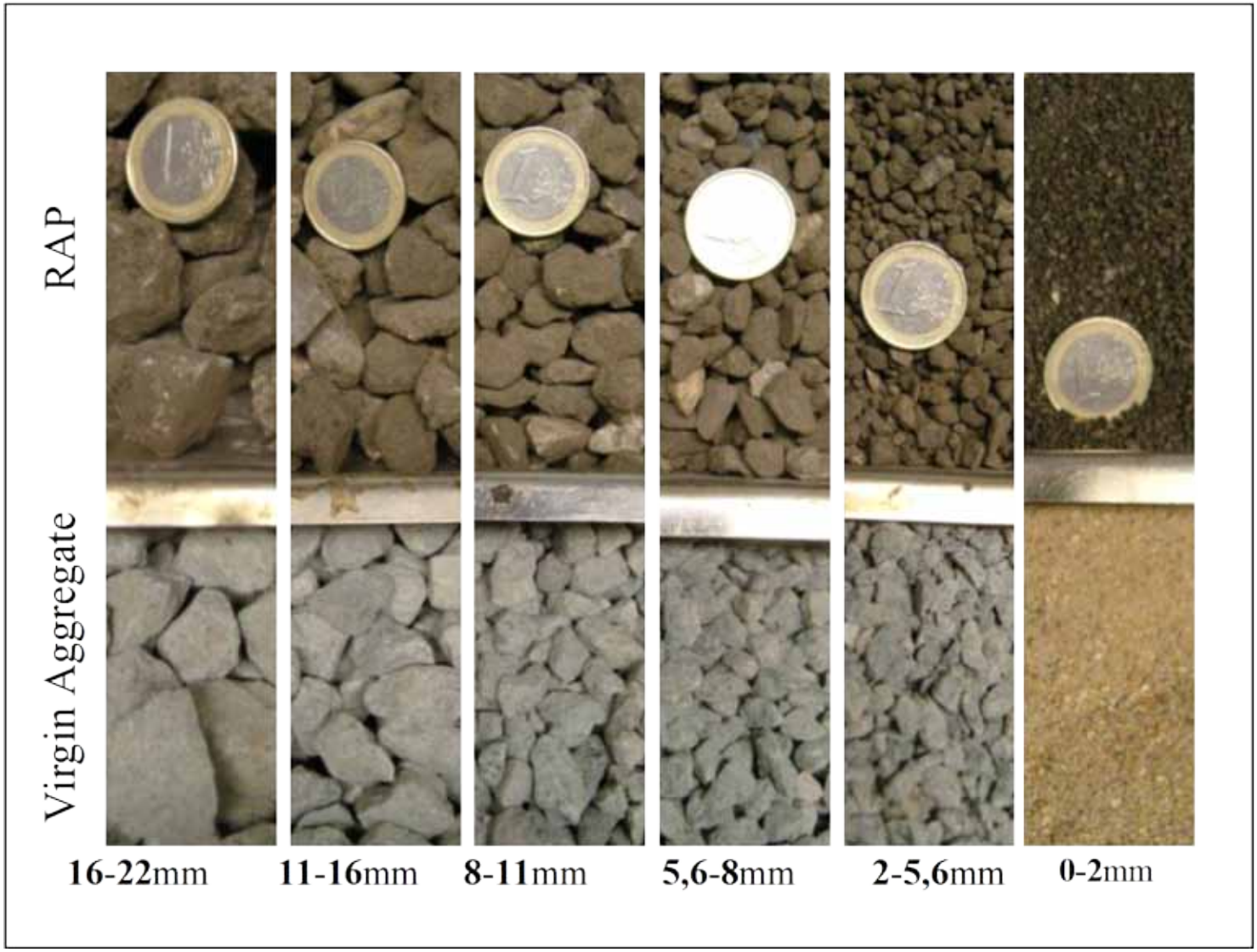
- **2.9 % moisture**
- **Crushed to maximum size of 20 mm and fractionized**

RAP was fractionized to get better control on composition

RAP fractions & binder content

Fraction size [mm]	0 - 2	2 - 5	5 - 8	8 - 11	11 - 16	16 - 22
Mass percentage of total aggregate fraction	22	21	15	18	16	8
Percentage of binder in that fraction	33	25	11	13	13	5

RAP and Virgin Aggregates



Mixture Compositions

Size (mm)	RAP	0% RAP	30% RAP		60% RAP		Target
		Virgin material	30 % RAP	Virgin material	60 % RAP	Virgin material	
> C22.4	0,0	1,2	0,0	1,2	0,0	1,2	1,2
C22.4 - C16	6,0	12,2	1,8	10,4	3,6	8,6	12,2
C16 - C11.2	11,0	6,6	3,3	3,3	6,6	0,0	6,6
C11.2 - C8	14,0	20,2	4,2	16,0	8,4	11,8	20,2
C8 - C5.6	9,2	7,0	2,8	4,2	5,5	1,5	7,0
C5.6 - C2	16,3	9,8	4,9	4,9	9,8	0,0	9,8
River Sand (0/2)	35,7	37,0	10,7	26,3	21,4	15,6	37,0
< 0.063	7,8	6,0	2,3	3,7	4,7	1,3	6,0
Total (%)	100,0	100,0	30,0	70,0	60,0	40,0	100,0
bitumen	4,3	4,5	1,3	3,2	2,6	1,9	4,5

Mixing Methods

Laboratory mixing method	code	Related actual plant	Preheating conditions and temperatures (°C)		RAP	
			Virgin Agg	RAP	Moisture	Content
Standard method	SM	-	170	170	0%, 4%	0, 30, 60
Partial Warming	PW	Conventio-nal partial warming	> 170	130	0%, 4%	30, 60
Upgraded method	UPG	Astec double barrel	>> 170	23	0%, 4%	30, 60

Mixing Temperatures

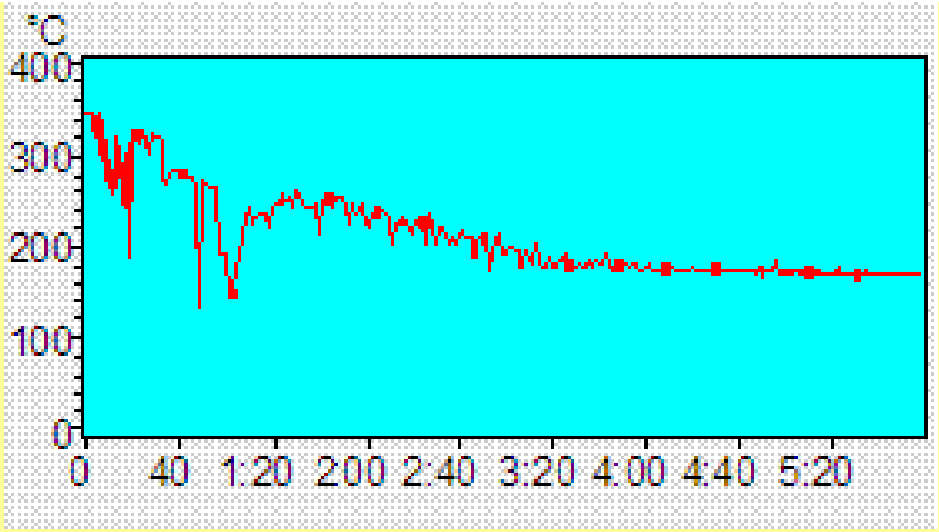
Final mixing temperature 170 °C

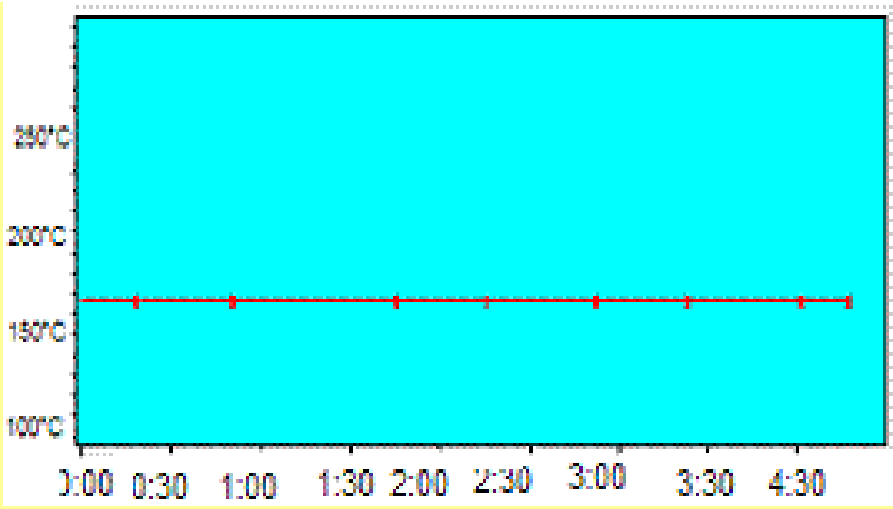
Mixing method	Virgin aggregate preheating temp (+ 30% RAP)	Virgin aggregate Preheating temp (+ 60% RAP)	RAP preheating temp
SM	170 °C	170 °C	170 °C
PW	240 °C	330 °C	130 °C
UPG 0% moisture	290 °C	430 °C	25 °C
UPG 4% moisture	345 °C	515 °C	25 °C

Observation

- Mixing 60% RAP which is at ambient temperature and containing 4% moisture with very hot aggregates is a violent process
- Steam develops
- Does foaming occur in outer drum of double barrel?

Temperature during mixing

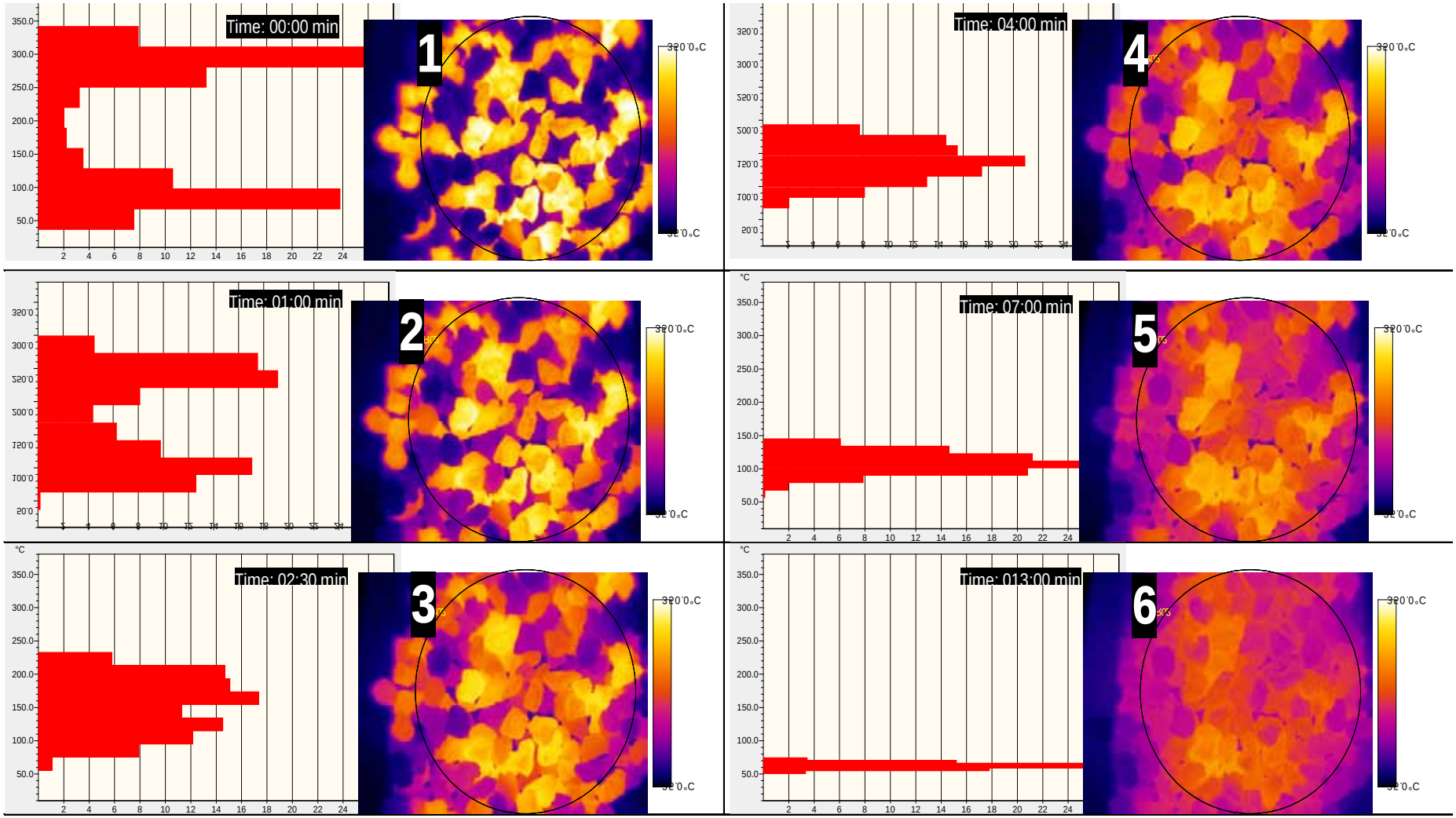




UPG

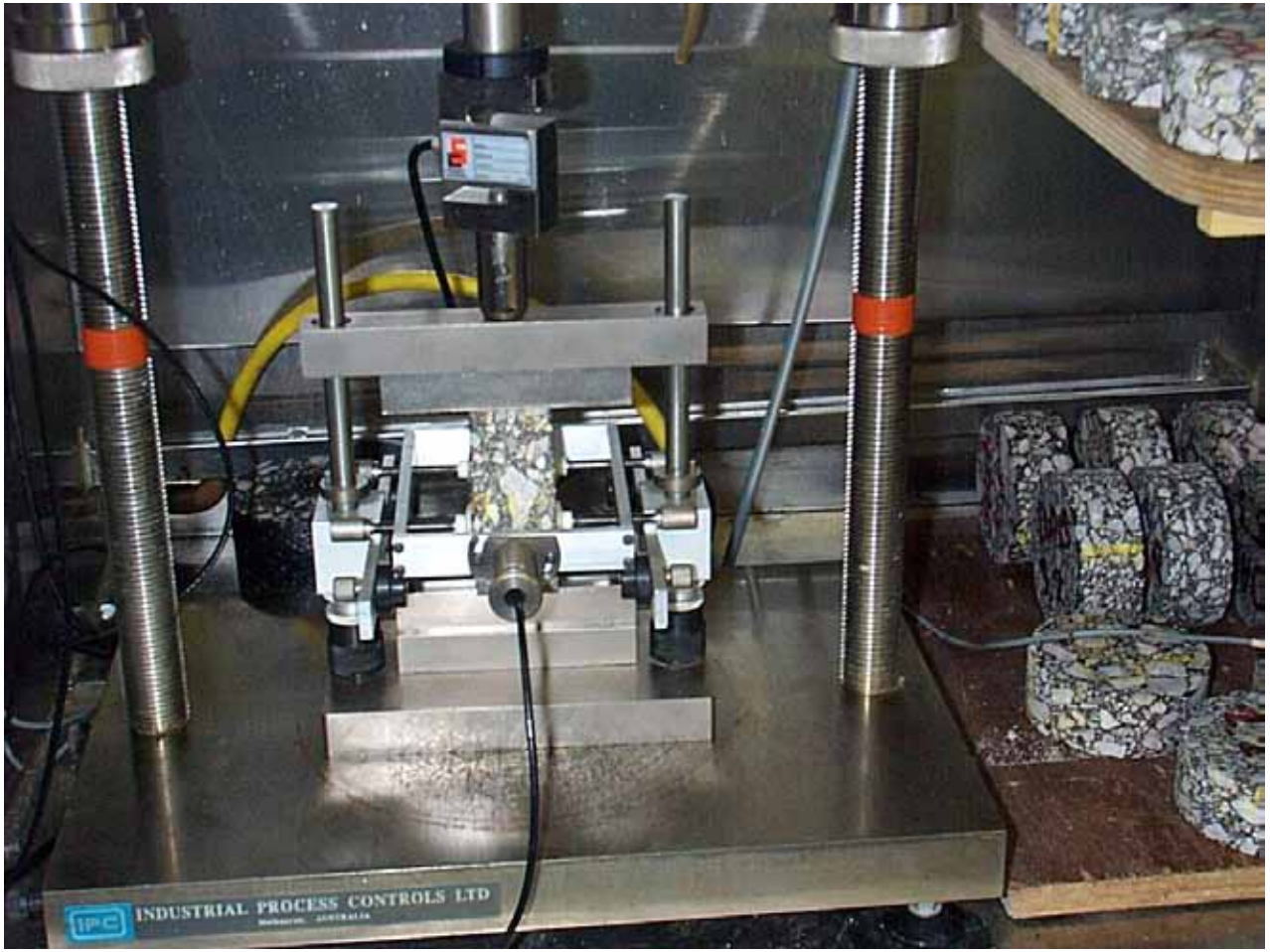
SM

Temperature Change in Time

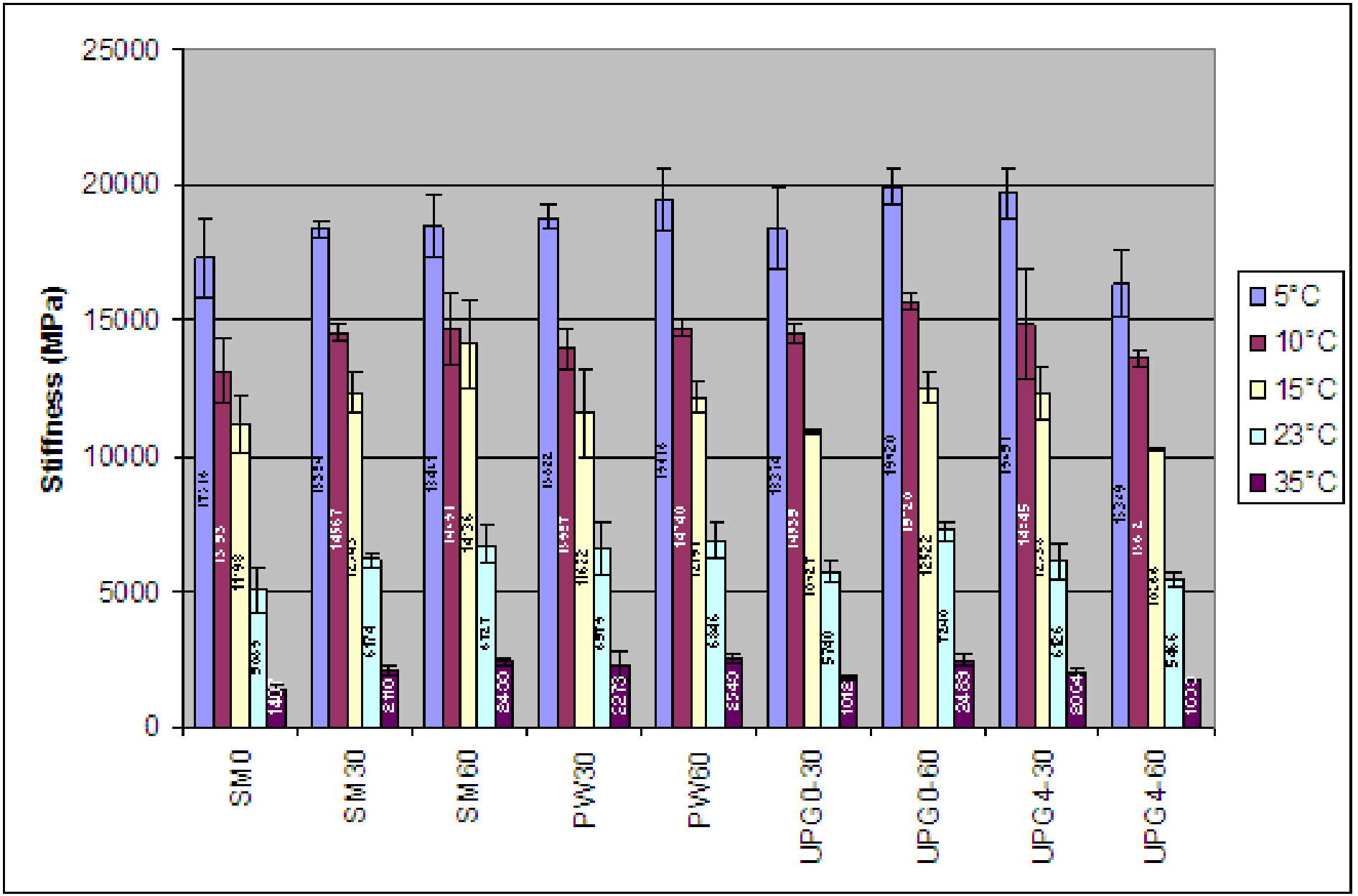


Stiffness testing

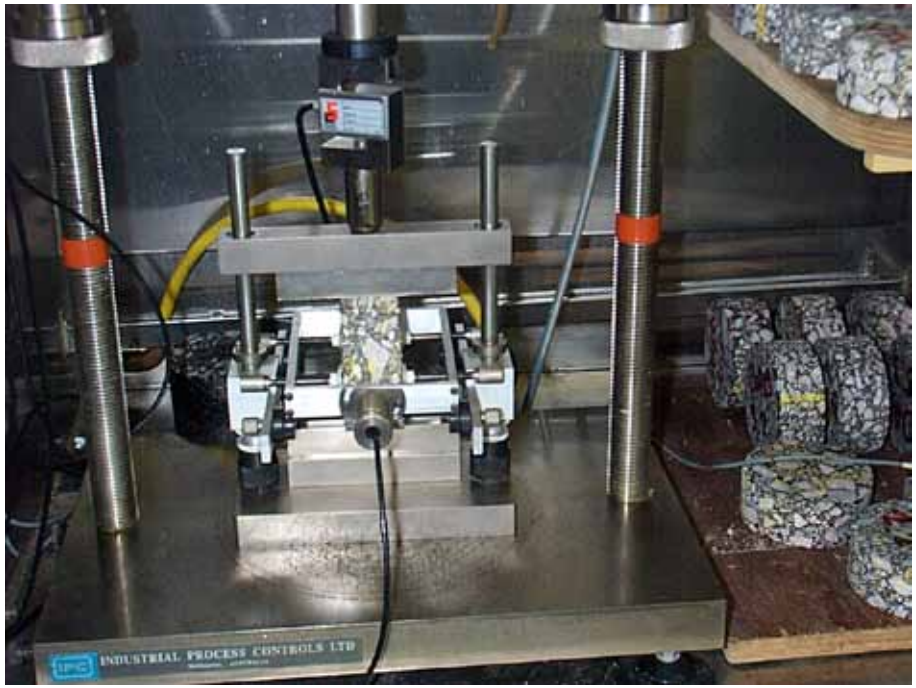
Frequency sweeps at 5, 10, 15, 23 and 35 ^{o}C



Mixture stiffness at 8 Hz



Fatigue Testing by means of ITT

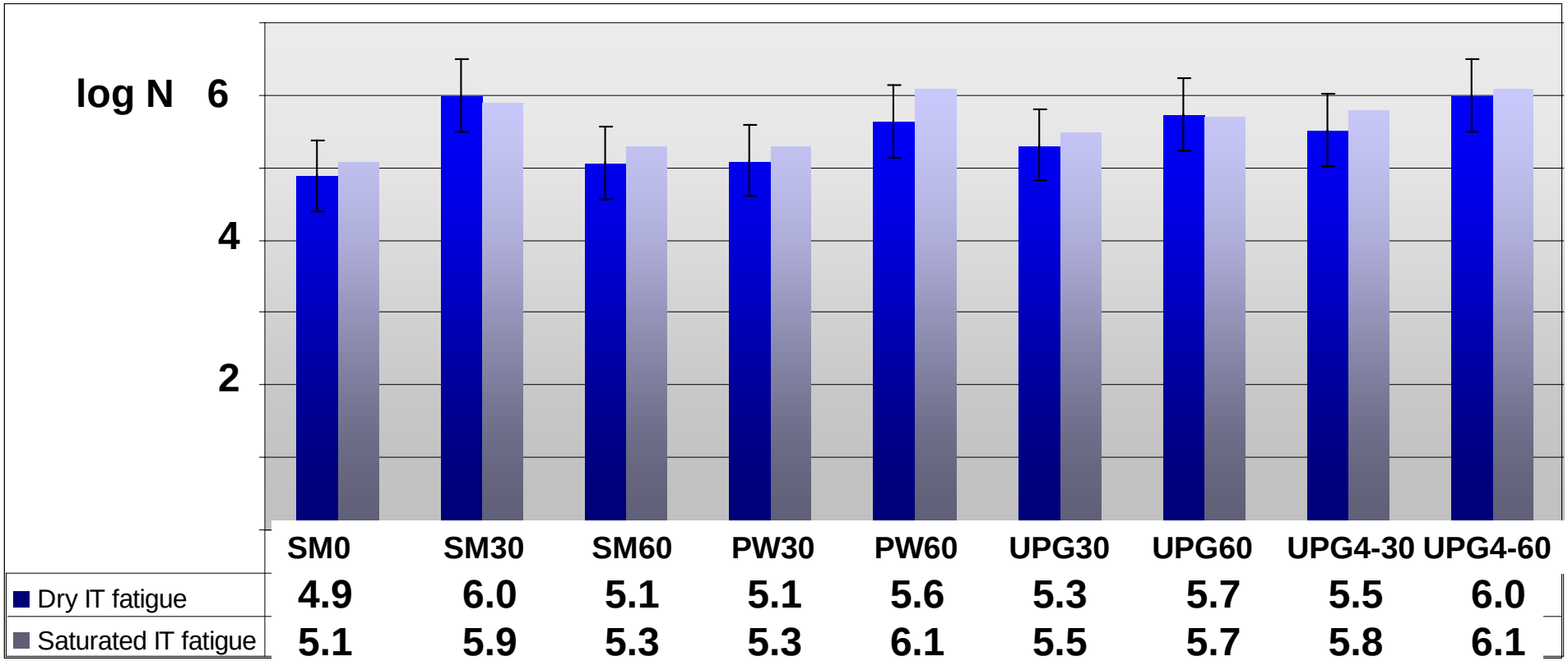


- 20 ºC / 10 Hz
- Only one stress level: 220 kPa
- Reason: limited availability of specimens

Fatigue “dry” and “wet”

Fatigue “wet”: fatigue test sample is kept under water during fatigue test

Possible reason: low void content of mixture (appr. 3 %)



Conclusions

- The amount of RAP as well as its moisture content does not have negative effects on the mechanical properties of the investigated recycled mixtures.
- Even when the virgin aggregate is preheated to (very) high temperatures there seems to be no negative effect.
- It takes quite a while for relatively cool RAP to take the same temperature as the entire mixture when mixed with super heated aggregates.
- Effect of shorter mixing times on the mechanical characteristics of the recycled mixtures should be studied.
- The ADBM mixing process is very difficult to simulate in the laboratory.
- The UPG method allows studying the effect of mixing super heated aggregates with cool, moist RAP on the mechanical properties of recycled mixtures.


Thank you for your attention