DESIGN OF RECYCLED ASPHALT MIXTURES USING A DOUBLE DRUM MIXER

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Abstract

Because of the very limited natural resources in the Netherlands and because of "saving the environment" inspired policies including reduction of the energy consumption and use of virgin materials, maximum asphalt recycling at the lowest possible temperature is very important. In hot mix asphalt (HMA) recycling, preheating and moisture handling conditions for recycled asphalt pavement (RAP) and virgin aggregate differ depending on the type of asphalt plant used. When designing mixtures in the laboratory, which include a certain percentage of Reclaimed Asphalt Pavement (RAP), it is essential that the way in which these mixtures are produced in practice is as closely as possible simulated in the laboratory. In this research project two mixture production techniques have been simulated being the Astec double barrel drum mixer process and the partial warming method with a parallel drum for batch plant mixtures. These processes are called UPG and PW method respectively. Both the UPG and PW method are compared to the standard method of designing mixtures in the laboratory. Three percentages of RAP and two RAP moisture conditions were considered.

Resilient modulus, indirect tensile strength and fatigue tests were done on compacted cylindrical specimens. Initial results indicate that when the RAP has a high moisture content, mixtures made by means of the UPG method have a lower stiffness, a lower indirect tensile strength and maybe a lower fatigue life compared to mixtures prepared with the other mixing methods. In case the RAP only contains a little bit of moisture, the UPG method results in better mechanical characteristics.

The research showed that preheating and moisture conditions have a significant effect on the blending degree of RAP binder with the virgin materials.

1. INTRODUCTION

In the Netherlands approximately 3.5 million tons of RAP becomes available each year. A total of approximately 80% of the available RAP is re-used again in new hot mix asphalt. In base course, binder course and dense wearing course mixtures a total amount of 50% RAP is allowed. No RAP is allowed in SMA mixtures while a maximum of 20% RAP is allowed in Porous Asphalt (void content > 20%) Concrete mixtures. The total asphalt mixture production is about 9 million tons per year.

The most common way to produce the recycled mixtures is to preheat the RAP in a parallel drum to 130 °C and then mix the preheated RAP with the virgin materials in a batch plant at the preferred mixing temperature (around 180 °C). At the moment there are 38 batch plants with a separate parallel drum for preheating the RAP.

Since 2007 also an other technique became available to the Dutch market which is the double barrel drum mixer as produced by Astec. In the double barrel drum mixer, mixing occurs in a chamber which is folded around the central drying drum while the inner drum is rotating and the outer chamber is stationary. Virgin aggregate is heated up and dried in the inner drum and discharged from underneath the burner into the non rotating outer drum. Shortly after the virgin aggregate enters the mixing chamber, RAP is added to it. In this chamber RAP is not exposed directly to the burner flames. Heat transfer occurs from the super heated virgin aggregate to the cold introduced RAP. Figure 1 illustrates the Astec double barrel mixing (ADBM) principle.

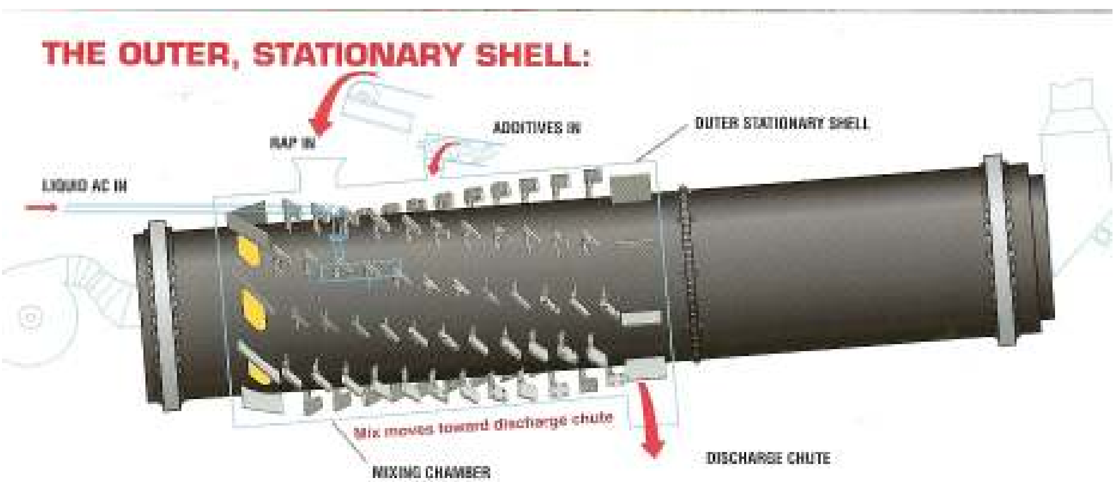

Figure 1. ADBM procedure.

Since the ADBM differs significantly from the traditional system which uses a parallel drum for preheating and a batch plant for mixing, it is important to know whether both methods produce the same mixture quality. Furthermore it is important that mixture design procedures in the laboratory simulate as good as possible what is happening in the field. In order to achieve these goals, a research program was started in which different mixing procedures were adopted and the mechanical properties of samples of the obtained mixtures were determined. The work presented here is partly an extension of the work presented earlier by Mengiste e.a. (2009). The goals of the research project can be summarized as follows:

a. Determine the effect of the amount of RAP, its moisture condition and the level of preheating of virgin aggregates on the quality of recycled asphalt mixtures.
b. Derive a laboratory mixture design method that simulates as close as possible the mixing procedures that are used in practice.

2. ASPHALT MIXTURE

The mixture that was tested in this research program was a base course mixture. First of all some information will be given about the virgin materials. This will be followed by a description of the RAP used.

2.1 Virgin materials

The virgin aggregates were Norwegian granite with a maximum grain size of 20 mm. Figure 2 shows the gradation of this 0-20 mm mixture. This figure also shows additional information which will be discussed later.

Table 1 shows the properties of the virgin bitumen used in this project.

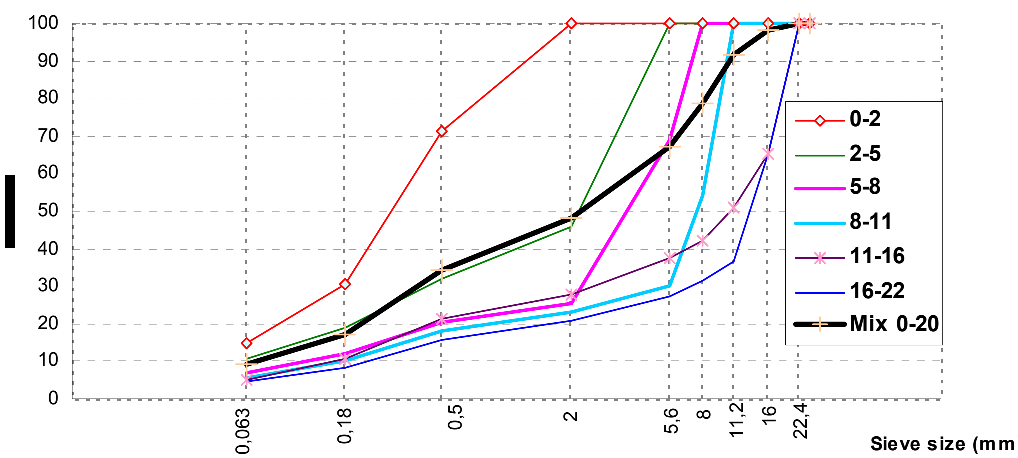

Figure 2. Composition of the 0-20 mm mixture.

Table 1. Properties of the virgin bitumen

Properties	Unit	Q8 pen40/60		Q8 pen 70/100	
		Nominal values	Measured values	Nominal values	Measured values
Penetration @ 25°C (# @ 15°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, 25°C, typical	kg/m3	1035	1035	1029	1029

2.2 RAP

Crushed RAP was sampled from the stockpile near the asphalt plant of the contractor who was involved in the project. The average moisture was 2.9% . RAP was crushed and sieved to a nominal size of 0-20mm. Then the RAP was air dried in the lab to have more control on the moisture content during mixing and it was sieved and fractionized to have more control on the grading when composing the final mixture. Then each fraction was analyzed with respect to its binder and filler content by mass. The results are shown in Table 2. The particle distribution of each fraction is shown in **Error! Reference source not found.**2 as well. **Error! Reference source not found.**3 shows the fractionized RAP together with the virgin aggregates that were used in the mixtures. Figure 3 shows that each fraction was still carrying a significant amount of fines. Table 2 shows that the fine fraction (0 – 5 mm) composes 43% of the total RAP and carries 58% of the binder.

Table 2. Fractions composing RAP and percentage of total binder per fraction.

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

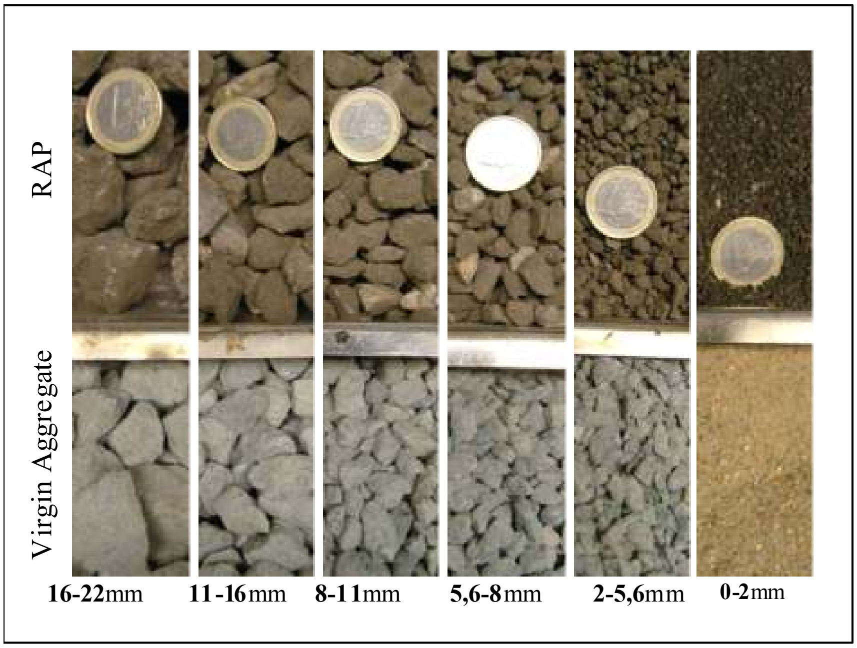

Figure 3. RAP and virgin aggregate fractions.

The average moisture content of the RAP samples taken from the stockpile was 2.9% and the total binder content (according to EN 12697-1) by weight after extraction was 4.3%. The specific gravity of RAP aggregates was 2495 kg/m^3.

The recovered RAP binder properties are presented in

Table 3. Properties of the extracted RAP binder

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Table 3. Properties of the extracted RAP binder

Properties	Unit	Measured values for RAP extracted binder
Penetration @ 25°C (# @ 15°C)	0.1 mm	30
Softening Point $T_{R\&B}$	°C	59
Penetration Index	(-)	-0.8
Density, 25°C	kg/m^3	1035

2.3 Recycled mixture

The composition of the final mixtures, with 0%, 30% and 60% RAP are shown in Table 4.

Table 4. Amount of virgin aggregate and RAP in each mixture

Size (mm)	RAP	0% RAP		30% RAP		60% RAP		Target
		0 % RAP (% m/m)	Virgin material (% m/m)	30 % RAP (% m/m)	Virgin material (% m/m)	60 % RAP (% m/m)	Virgin material (% m/m)	
> 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

The requirements specify a penetration of the completed mixture between 40 and 60. In order to realize this the log(pen) rule (Equation 1) was used to determine the amount and penetration of the virgin bitumen.

$$a \log Pen_{RAP} + b \log Pen_{virgin} = (a + b) \log Pen_{mix} \qquad \text{(Eq. 1)}$$

Where: a = percentage of RAP binder in the total amount of binder,
b = percentage of virgin binder in the total amount of binder,
a + b = 100%

Table 5 shows the percentage of new binder used in the mixtures.

Table 5. Blended binder properties (according to log-pen rule)

No.	RAP binder (%)	Virgin Bitumen (%)	Penetration @ 25°C (# @ 15°C) [0.1 mm]		
			RAP binder	Virgin binder (Q8 Pen70/100)	Blended binder
1	30	70	28	90	63
2	60	40	28	90	45

Table 6 shows the amount of new binder used in each mixture.

Table 6. Amount of virgin binder to be added

RAP Content (%)	RAP binder content (P_{bRAP}) (% m/m)	Total Binder (% m/m)	New binder to be added ($P_{b\ NEW}$) (% m/m)
30 %	0.30*4.3=1.3	4.3	4.3-1.3=3.0
60 %	0.60*4.3=2.6	4.3	4.3-2.5=1.8

3 MIXING PROCEDURES

Three mixing methods were used in this program. The first method is the so called "Standard Method" (SM) which is currently used and prescribed in the Netherlands for the design of mixtures containing RAP. The disadvantage of this method is that the RAP is preheated to a high temperature which is not used in practice. Therefore a second method is used in which the RAP is preheated to 130 ^{o}C as is done in practice. This is called the "Partial Warming" (PW) method. The third method is the so called "Upgraded Method" (UPG) and is meant to simulate to some extent the mixing procedure of the ADBM. The mixing conditions are shown in table 7.

Table 7. Mixing method simulations and conditioning

Laboratory mix method	code	Related actual plant	Preheating conditions and temperatures (ºC)		RAP	
			Virgin Agg	RAP	Moisture	Content
Standard Method	SM	-	170	170	0%, 4%	0, 30, 60

Partial Warming	PW	Conventional partial warming	240~330	130	0%, 4%	30, 60
Upgraded method	UPG	Astec double barrel	290~515	23	0%, 4%	30, 60

Table 7 shows that a reference mixture containing no RAP was prepared using the SM. Mixtures containing 30% and 60% RAP as well as 0% and 4% moisture were prepared using the PW and UPG methods.

Different preheating temperatures of the virgin aggregate had to be used in the PW and UPG method because of different RAP and moisture contents. The preheating temperatures were adjusted by trial and error to achieve a mix temperature of 160°C at the end of the process.

In order to simulate the short term aging during real production process, all samples were stored at 160°c in the oven for 30 minutes prior to compaction. That is also done in the standard sample preparation procedure.

The mixing time at the actual plants differ from each other and are different from what is commonly used in the laboratory. It was decided to keep the mixing time constant for all methods which. Therefore mixing time of the virgin aggregate was 1 minute. After mixing the aggregates, the virgin materials were mixed with the RAP, bitumen and filler during 1.5 minutes.

The materials were added all in following order: virgin aggregate (sand + crushed aggregate), RAP, bitumen, filler. Mixing was done using a Hobart mixer

4. MIXING MOIST RAP WITH HOT VIRGIN AGGREGATES

As mentioned above, the virgin aggregates needed to be preheated in order to bring the entire mixture of RAP and virgin materials to a temperature of 160 °C. When preheating the virgin aggregates also the moisture content of the RAP had to be taken into account. Table 8 shows the preheating temperatures required when preparing mixtures with different RAP and moisture contents. Table 8 clearly shows that the virgin aggregates have to be heated up significantly in case of high RAP and high moisture contents.

Table 8. Preheating temperature used for different mixing methods at varying RAP and moisture contents

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

It will be clear that mixing of cool and moist RAP with super heated aggregates results in a violent mixing process. Especially at high RAP contents with 4% moisture a lot of steam developed. It is believed this will also be the case in the ADBM. Although precautions were taken to keep the steam inside the mixing unit, a lot of steam escaped during mixing.

Thermo-graphic video imaging was performed during mixing the UPG (4% moisture, 30% RAP) mixture and the SM (30% RAP mixture). The maximum surface temperature of all aggregates during mixing of both mixtures is shown in figure 4. The figure shows a continuous heat loss of the aggregates during mixing according to the UPG method. Rises and falls in this chart are because of the hot and cold aggregate movement due to the mixing action and because the infrared camera can only detect surface temperature. Heat balance is achieved in the UPG mixture 3 minutes after starting the mixing.

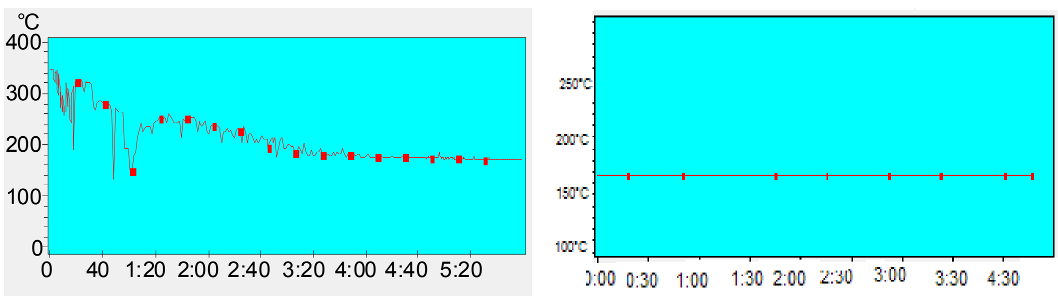


Figure 4. Aggregate temperature during mixing (left: UPG and right: SM); the horizontal scale shows the mixing time in minutes.

As expected the temperature did not vary during mixing following the SM method simply because of the fact that both the virgin aggregates and the RAP were at the same temperature.

Figure 5. shows another temperature analysis made during mixing according to the UPG method of a mixture with 4% moisture and 30% RAP. Histograms of the temperature distribution measured at different moments in time are plotted from the start of the mixing procedure till the end. It is recalled that mixing was continued only for 3 minutes. The thermo-graphic imaging was still running to observe the heat balance and heat loss during storage time after mixing. The temperature distribution shows a lot of scatter in the first minute of mixing. In the second and third minute, the mixture is reaching its temperature balace. At the end of the third minute of mixing, all aggregates are almost at the same temperature. Because of the presence of moisture there is huge amount of heat loss in the first 30 seconds of mixing period. In this period moisture tries to absorb enough thermal energy to escape from the mixture.

5. TEST PROGRAM

The main test program consisted of resilient modulus testing using the indirect tension set up and fatigue testing which was also carried out in indirect tension. The results of both tests will be reported hereafter.

5.1 Resilient modulus values from cyclic load Indirect Tensile Test

Cylindrical specimens prepared for each mix design were exposed to cyclic indirect tension according to EN 12697-26 to measure their stiffness. The tests were done at different temperatures (5, 10, 15, 23 and 35°C) and frequencies (1, 2, 4, and 8 Hz).

Specimens were prepared with the gyratory compactor and had a diameter of 100mm and a height of 77mm height. Then they were cut to obtain a thickness of 50 mm.
A brief summary of the results is given in **Error! Reference source not found.**. A comparison of the stiffness values at the lowest and highest test temperature (5°C and 35°C) is given in Figure 6.

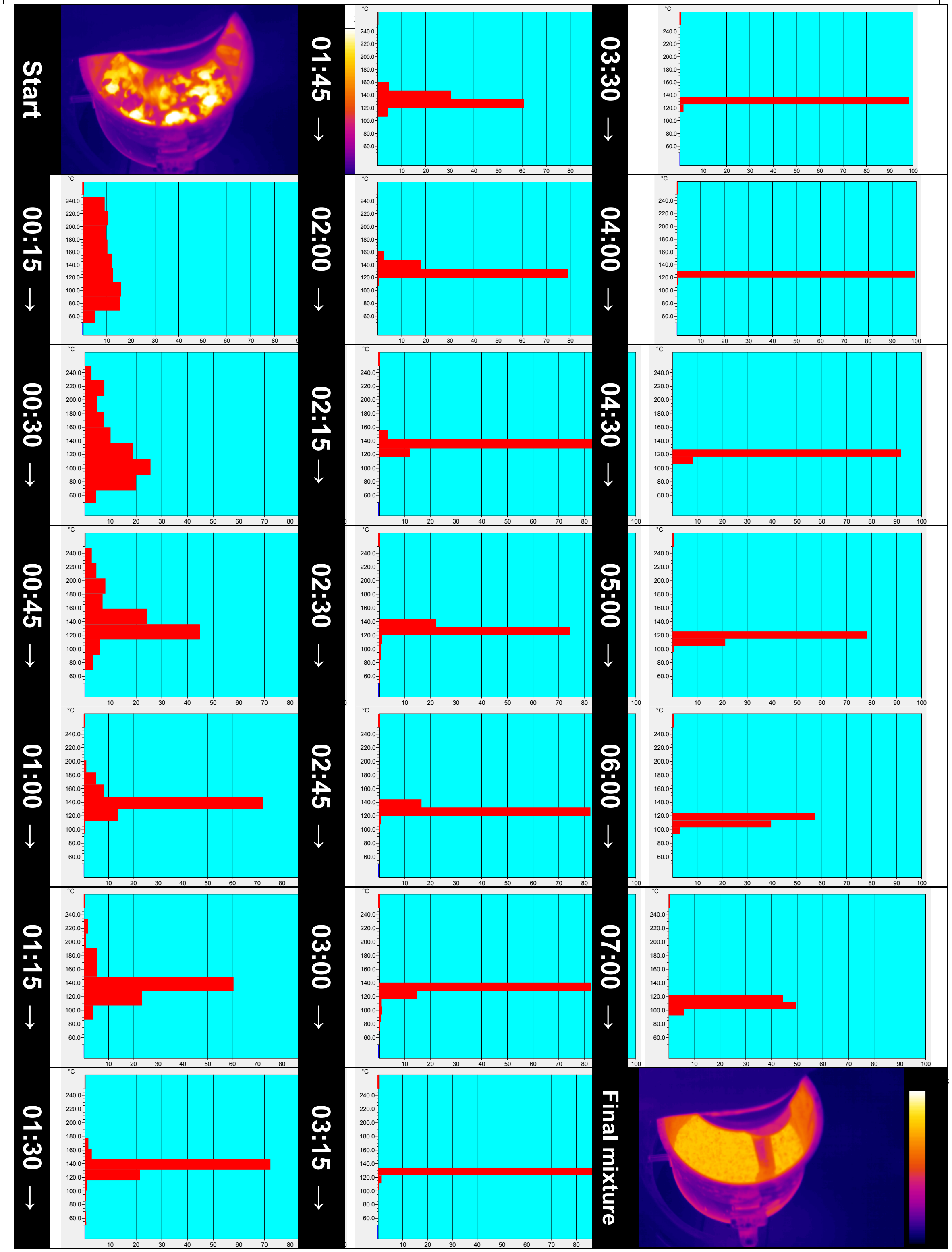


Figure 5. Temperature frequencies during UPG mixing of virgin aggregates with 30% RAP having 4% moisture.

Table 9. Stiffness values [MPa] at different temperatures and loading frequencies

f [Hz]	T [°C]	SM0	SM30	SM60	PW30	PW60	UPG0-30	UPG0-60	UPG4-30	UPG4-60
1	5	12793	13995	13963	14316	14966	13848	15045	15095	12183
2	5	13756	14956	15073	15464	15897	14936	16213	16355	13272
4	5	15842	16643	16778	17117	17615	16540	17896	18206	15062
8	5	17316	18354	18461	18822	19416	18374	19920	19651	16349
1	10	8390	9726	10230	9809	10312	9951	11394	10118	9026
2	10	9657	11109	11494	10937	11485	11274	13199	11284	10263
4	10	11265	12783	12929	12493	12993	12858	14309	13124	11873
8	10	13153	14567	14691	13957	14740	14535	15720	14845	13612
1	15	6097	7673	8121	7374	7963	6664	7802	6906	6372
2	15	7336	8934	9322	8522	9127	7824	9090	8097	7449
4	15	8992	10632	11020	10029	10489	9366	10745	9820	9010
8	15	11198	12343	14136	11622	12191	10927	12522	12338	10266
1	23	2385	3054	3573	3388	3730	2852	3749	3031	2614
2	23	2868	3742	4327	4107	4473	3493	4523	3702	3274
4	23	3807	4900	5375	5244	5603	4973	5785	4771	4252
8	23	5089	6174	6727	6579	6846	5740	7240	6126	5466
1	35	619	963	1128	1055	1159	809	1101	909	709
2	35	716	1179	1378	1310	1387	1019	1388	1157	919
4	35	1036	1529	1826	1683	2141	1322	1802	1468	1372
8	35	1407	2118	2439	2273	2549	1812	2489	2064	1693

Note: SM0 = mix with 0% RAP; SM30 PW30 = mix with 30% RAP; SM60 PW60 = mix with 60% RAP
UPG0-30 = mix with 0% moisture and 30% RAP; UPG4-30 = mix with 4% moisture and 30% RAP
UPG0-60 = mix with 0% moisture and 60% RAP; UPG4-60 = mix with 4% moisture and 60% RAP

The results show that all the mixtures have about the same stiffness although the reference mixture (SM0) has the lowest stiffness at all temperatures and loading frequencies. Furthermore one can conclude that the mixtures with the highest RAP content, except the UPG4-60 mixture, have the highest stiffness. Finally one can conclude that in spite of the high moisture and high RAP content, the UPG4-60 mixture is performing well.

5.2 Indirect tension fatigue tests

An IPC Universal Testing Machine (UTM-25) was selected to run the indirect tension fatigue tests on the cylindrical specimens. Since only a limited number of specimens were available per mixture, testing at different stress levels was not possible. Therefore it was decided to do the test only at one stress level. This decision was also based on the fact that, because the mixtures had approximately the same stiffness, they would be subjected to similar stress levels if they were used at an equal thickness on a base and subgrade of equal thickness and stiffness.

The selected test conditions were 20°C and 10 Hz and a stress level of 220 kPa was used in all tests. Loading was applied continuously without any rest period and the vertical cumulative deformation was measured during the tests. Repetitive loading was applied until failure occurred.

Figure 7 shows the cumulative vertical deformation of the specimens both using a normal scale and logarithmic scale for the number of load repetitions. The failure point was determined according to EN 12967-24.

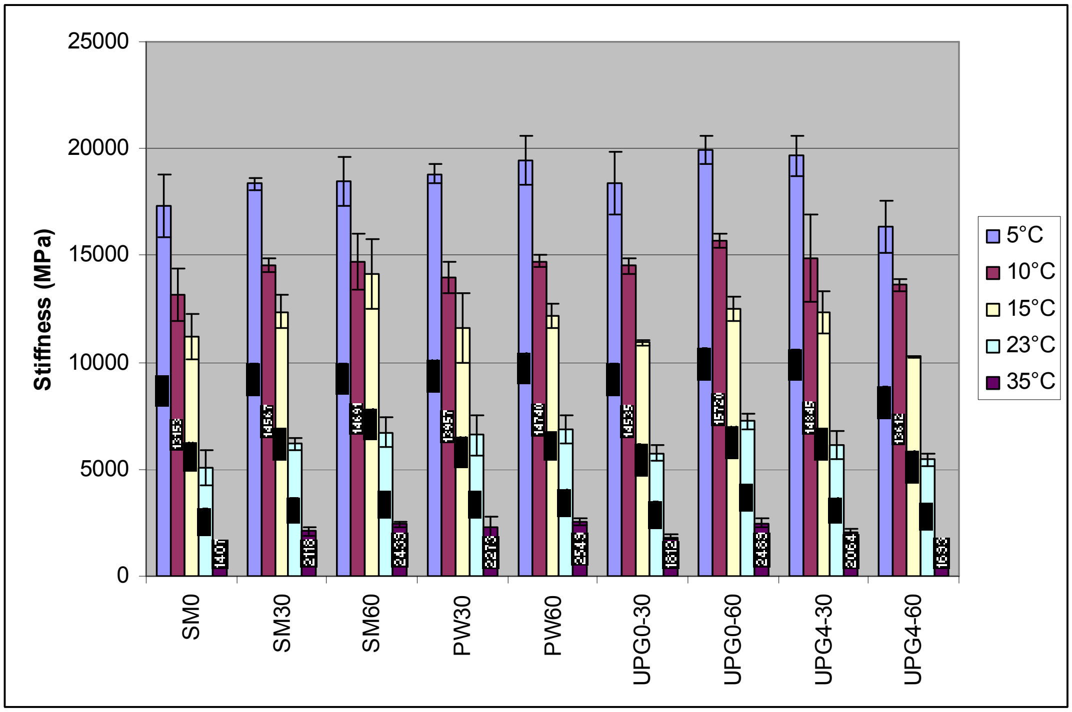


Figure 6. Stiffness values at various temperatures and 8Hz loading frequency.

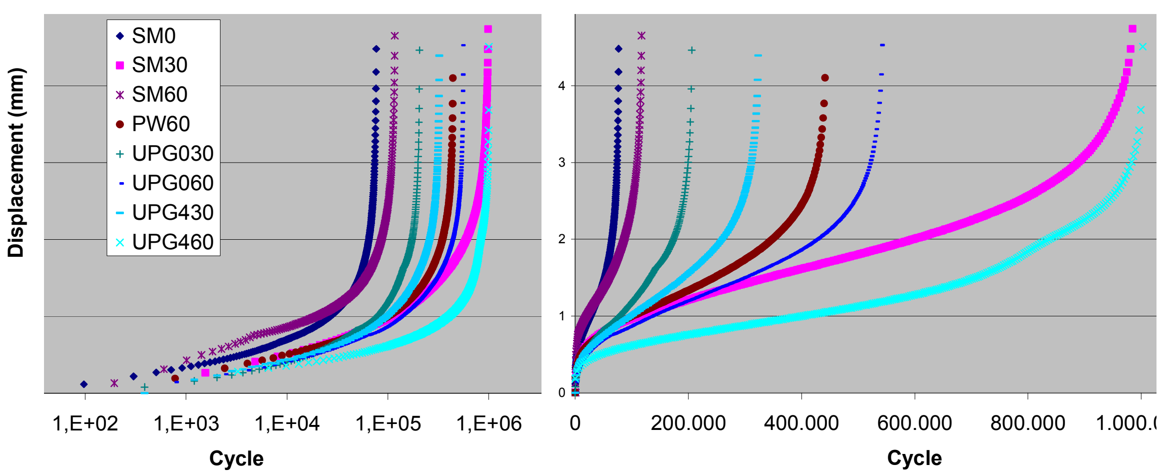


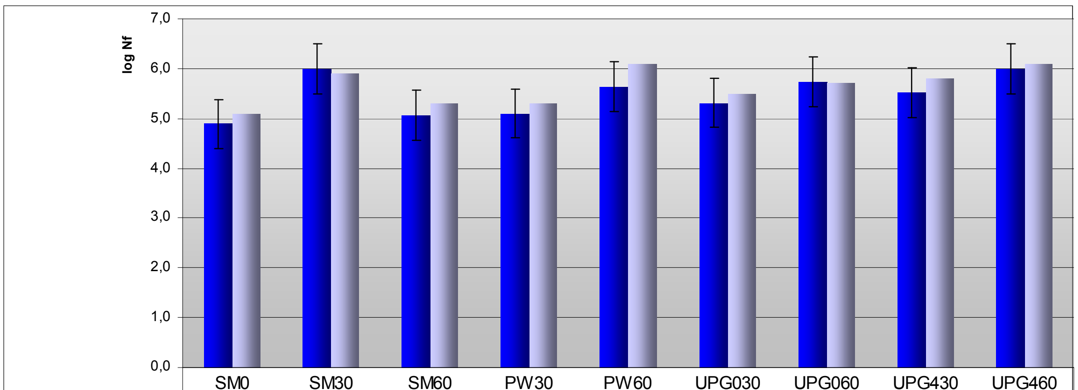
Figure 7. Vertical cumulative deformation vs. loading cycles as observed during the fatigue tests (left: number of load repetitions in log scale; right: number of load repetitions in linear scale)

Next to the fatigue tests in dry conditions a non standard IT fatigue test was performed. With this non standard fatigue test, the effect of saturation on the fatigue life was investigated. This non standard test was performed because it was hypothesized that the mixing of the super heated aggregates with the moist and cool RAP could have an effect of the adhesion of the binder to the aggregates because of excessive hardening.

During this alternative fatigue test, which was also conducted at 20°C, 8Hz and a stress level of

220 kPa, water was continuously pumped and circulated around the specimen in order to maintain the temperature as well as saturation. The water level was 20mm higher than the upper edge of the specimen.

The results of the fatigue tests under dry and saturated conditions are shown in figure 8. The figure shows that the reference mixture had the lowest fatigue resistance. Furthermore the picture is a bit inconsistent since e.g. the SM60 mixture has a lower fatigue life than the SM30 mixture while it is the other way around for the PW and UPG mixtures. Furthermore it can be observed that the fatigue results obtained for the UPG prepared samples are certainly not less than those obtained on the samples prepared in a different way. This in spite of the (very) high temperature levels to which the virgin aggregates were heated and to which the RAP was exposed. It is also remarkable to see that saturation had no effect on the fatigue life. This is probably caused by the fact that the void content of the mixtures was around 3% implying that water cannot enter the specimen because of absence of interconnected voids.



	SM0	SM30	SM60	PW30	PW60	UPG030	UPG060	UPG430	UPG460
Dry IT fatigue	4,9	6,0	5,1	5,1	5,6	5,3	5,7	5,5	6,0
Saturated IT fatigue	5,1	5,9	5,3	5,3	6,1	5,5	5,7	5,8	6,1

Figure 8. Fatigue results obtained under dry and saturated conditions at 20 ^{o}C, 8Hz and a stress level of 220 kPa

It is often debated whether specimens fail in creep in a load controlled fatigue test or whether the failure is really due to fatigue. This is a valid discussion especially when specimens are loaded in only one direction as is the case in the indirect tension fatigue test. From figure 7 one might conclude that creep is indeed the governing failure mechanism. From the log N vs ε_p relationship (figure 7, left part) one might conclude that failure occurs when the cumulative vertical deformation is approximately 1.3 mm. From the right hand part of figure 7 however a somewhat higher cumulative vertical strain at failure is estimated but also in this figure it seems that the strain at failure is approximately the same for all mixtures. The authors believe that failure in the indirect tension fatigue test can be considered as a mix of creep and fatigue failure. In any case the results show (clearly visible in figure 7) the good fatigue resistance and resistance to permanent deformation of the mixtures containing RAP and the good performance of the UPG mixtures.

6. CONCLUSIONS

The objectives of this research project were twofold being:

- Determine the effect of the amount of RAP, its moisture condition and the level of preheating of virgin aggregates on the quality of recycled asphalt mixtures.

- Derive a laboratory mixture design method that simulate as close as possible the mixing procedures that are used in practice.

Based on the results obtained, the following conclusions can be made.

a. The amount of RAP as well as the moisture content of the RAP does not have negative effects on the mechanical properties of the investigated recycled mixtures when compared to those of a reference mixture made of virgin materials.
b. Even when the virgin aggregate is preheated to (very) high temperatures there seems to be no negative effect.
c. It takes quite a while for relatively cool RAP to take the same temperature as the entire mixture when mixed with super heated aggregates. This arises the question what the mechanical characteristics of the recycled mixtures would be when the mixing time would be reduced.
d. It is obvious that the ADBM mixing process is very difficult to simulate in the laboratory. It is concluded that the used UPG method is not really a simulation of the mixing that takes place in the ADBM. Nevertheless it is concluded that the UPG method allows studying the effect of mixing super heated aggregates with cool, moist RAP on the mechanical properties of recycled mixtures.
e. Finally it is concluded that a comparison of the mechanical properties of a recycled mixture produced with the parallel drum and batch mixer on one hand and the ADBM on the other is highly recommendable.

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KEY WORDS

Asphalt recycling, mixing, temperature distribution, fatigue, resilient modulus