Development of a Lab Production Method with Recycled Asphalt Pavement in a Double Barrel Drum Mixer

M.F.C. van de Ven & A.A.A. Molenaar
Faculty of Civil Engineering and Geosciences ,Delft University of Technology, Delft, the Netherlands

G. Mengiste
Gebr. Van der Lee, Lelystad, The Netherlands

ABSTRACT: The use of high amounts of recycled asphalt pavement in hot produced mixes and the introduction of functional requirements for mixes in the CE marking system in Europe have urged to look into the accuracy of the production process in the laboratory. In the Netherlands traditionally all aggregates are added together in dry condition at the same temperature in the laboratory mixer. Plant processing with high amounts of recycled asphalt pavement in a mix is different from processing virgin materials. In this paper lab procedures related to temperatures and moisture content are introduced which relate better to the type f production plant. Introduction of a double barrel drum mixer in the Netherlands accelerated the revision of current procedures.
In this paper three different laboratory procedures are proposed to simulate the asphalt plant production more closely and the influence on the mechanical properties is reported. For a base course mix mechanical properties like stiffness, permanent deformation and water sensitivity were determined. It is concluded that the laboratory procedures considerably influence the mechanical properties. Fundamental research is needed to explain the differences.

KEY WORDS: Hot mix asphalt plant, recycling, mixing procedures, mechanical testing.

1 INTRODUCTION

In the Netherlands the mixing of the components in the laboratory mix design methods is normally done at a fixed temperature (CROW, 2005). All aggregates are dried and pre-heated to the same temperature. Two important reasons are given to reconsider this approach in the laboratory.

First of all since some 20 years in the Netherlands use of recycled asphalt pavement (RAP) at percentages of 50% in hot mixes is standard. All batch plants work with a special added parallel drum. The RAP is dried and pre-heated in the parallel drum to 130°C and added in the pugmill to the extra heated virgin aggregates in the other drum. Another important reason to better control the laboratory process is, that since March 2009 in the Netherlands the CE marking for asphalt mixes has to be applied. For dense asphalt concrete the functional route has been chosen, including determination of properties like water sensitivity with indirect tensile strength, stiffness, fatigue and permanent deformation on a laboratory prepared mix (NEN EN 13108-20, 2006). These parameters are used for the design of the pavement structure, so they better be as realistic as possible.

2 DOUBLE BARREL DRUM MIXER

Most asphalt manufacturing plants in the Netherlands are batch plants and they use the system with a parallel drum to produce mixes with high RAP contents. With this system standard 50% of RAP is allowed in the specifications. In the parallel drum the RAP is dried and preheated to a maximum temperature of 130^o C and added to very hot (easily 250º C, dependent on the amount of RAP) virgin aggregate in the pug mill.

In a drum mix plant the functions of a dryer and a continuous–process mixer are combined in one compact system. There is doubt that a standard drum mix plant can be used with high amounts of RAP. To allow high percentages of RAP the double barrel drum was developed. In the double barrel asphalt plant of ASTEC, the virgin material is superheated to a very high temperature in the inner drum (up till 400º C, dependent on the RAP content and the moisture content in the RAP) and the mixing with the cold moist RAP takes place in the outer drum.

During the mixing process, the cold, moist RAP comes in direct contact with the superheated aggregate and the total will be heated to the required mixing temperature. The double barrel drum mix plant is claimed to produce high quality mixes with 50% RAP just like the normally used batch plants with parallel drum for RAP in the Netherlands. For a schematic view, see figure 1.

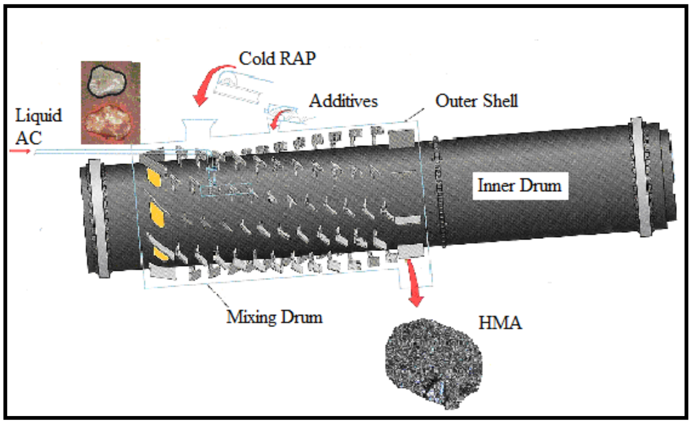

Figure 1: Schematic view of the double barrel drum mixer with cold RAP added in the outer drum (courtesy to ASTEC).

The current laboratory mix design method, in which all materials are dried and added in the mixer at the same temperature not only differs compared to the mixing process in parallel batch mix plants, but definitively does not simulate the mixing process in the double drum mixer. In the literature information was found on the influence of different methods on the properties of the final product (McDaniel et al. 2000, 2007).

From mixing tests it was found that the handling of the RAP material prior to mixing has impact on the performance properties of asphalt mixes. In the UPG method with 4 % moisture content, the heating temperature of the virgin aggregate should be sufficient to remove the moisture from RAP and soften the RAP binder to promote blending with virgin binder. The sequence of mixing of materials and mixing time is important to maximize the temperature transfer from virgin aggregate to RAP material. Minimizing the heat loss during the mixing process of the UPG method is also important. Heat insulation was used for the mixing equipment and the surrounding environment. The UPG mixing method is thought to minimize the extra hardening of the RAP binder by avoiding the preheating of the RAP before mixing and minimizing the availability of free oxygen during the mixing process due to steaming of the moisture in the RAP. The effect of contact with the superheated virgin material is not known. The mineralogical composition of the virgin aggregate did not change by heating the virgin aggregate to the high temperatures (300 to 400°C) in the UPG method.

Based on the literature and our own experience three lab mixing methods were considered as shown in table 1. After the whole mixing process all three methods will result in a loose mix temperature of 170°C.

Table 1: Material processing related to the production process in the plant (loose mix out at 170°C).

Material processing	Production plant	Code
Both the virgin and RAP material are dried and heated together at the same temperature, in this case 170^{o}C.	standard method for virgin material in the batch mix plant	SM
The RAP is dried, heated to 130^{o}C and the virgin material to extra high temperature (dependent on amount of RAP)	simulating recycling with a parallel drum in the batch mix plant	PW
Virgin aggregate is superheated (level dependent on amount of RAP and moisture content) and mixed with cold, wet RAP.	simulating recycling with the double barrel drum, in this case cold RAP with 4% moisture	UPG

3 MECHANICAL TESTING PROGRAM

The performance of asphalt mixes with high RAP content by using different laboratory mix preparation methods was analyzed. A base course mix (STAC 0/22) was used with 40 and 50 % RAP content. For the mix design simulating the double barrel drum mixer (UPG) 4% moisture was added to the RAP. Mechanical properties according to Dutch and European standards were determined. The results are given in chapter 4. Important is to relate these results to the CE marking for mixtures. This is partly done in this research. The three processing methods were used to prepare samples and their coding as given in table 2 is used in the results in this paper.

Table 2: Processing methods and amount of RAP added (UPG: 4% moisture added).

Processing Method	RAP (%)	Abbreviation
Mixing of RAP and virgin aggregate at same temperature (Standard Mixing - SM)	40	SM 40
	50	SM 50
Mixing of dry RAP at 130^{o} C with hot virgin aggregate (Partial Warming Mixing - PW)	40	PW 40
	50	PW 50
Mixing cold RAP with 4% moisture with superheated virgin aggregate (Upgraded Mixing Method - UPG)	40	UPG 40
	50	UPG 50

The mechanical tests on compacted samples for the three processing methods with 40 and 50 % RAP contents were:

- Resilient modulus from Indirect Tensile Test
- Indirect tensile strength test
- Permanent deformation test

Information on the test procedures for the European CE marking is given in (NEN-EN 13108-20, 2006).

4 TEST RESULTS AND ANALYSYS

4.1 Effect of Processing Method on Resilient Modulus

The addition of RAP to the mixture has a pronounced effect on the stiffness of the mixture. In this study the effect of increasing the percentage of RAP from 40 to 50 % on the stiffness of the mixture was studied for the three mixing procedures.

The heating and mixing operations in production of asphalt mixes with RAP have a significant effect on the mixture stiffness. Some master curves (Medani et al, 2004) for the three mixing methods on a log-linear scale are shown in figure 2.

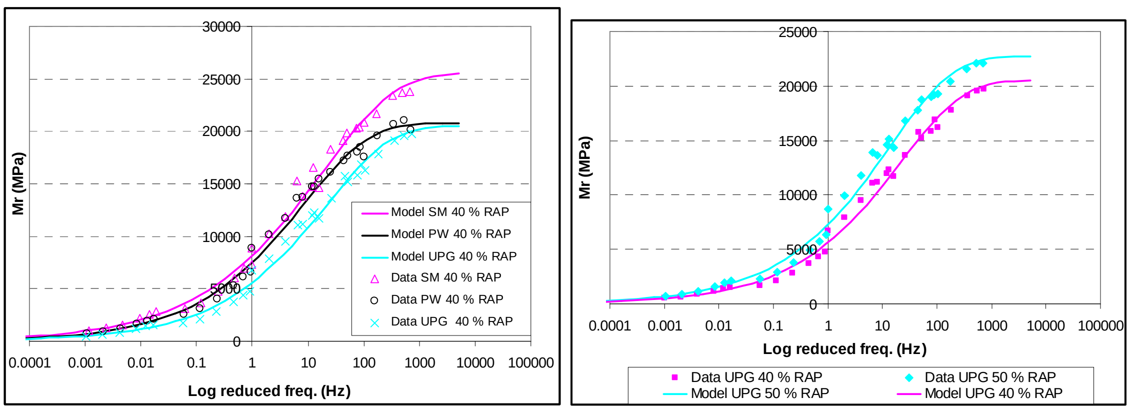

Figure 2: Master curves for the stiffness with 40 % RAP for all methods(left) and for the UPG method with 40 and 50% RAP (right) at a Tref of 15°C.

An impression of the difference between the results of the UPG method compared to the other two methods in given in figure 3. As can be seen the differences can be very large at high temperatures (even 40%) and at all temperatures the two other methods have equal or higher stiffness values.

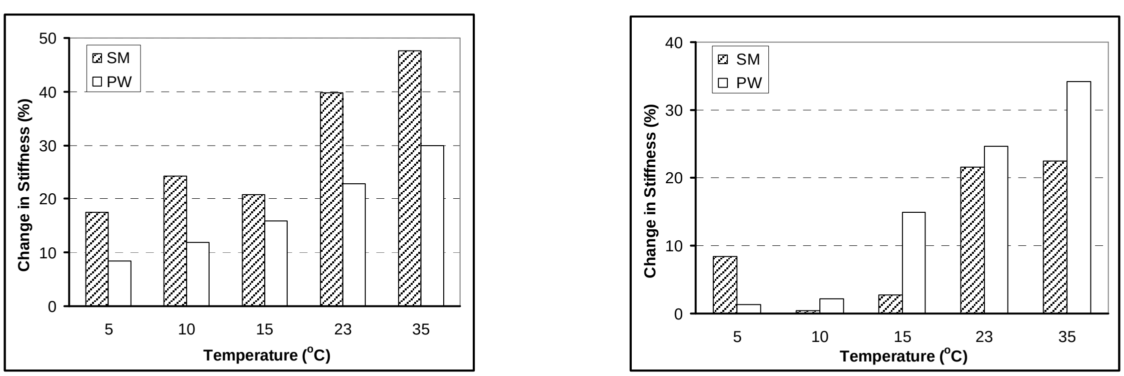

Figure 3: Percentage increase in stiffness for SM and PW method at different temperatures at frequency of 10 Hz compared to the UPG method. 40 % RAP left and 50 % RAP right.

4.2 Comparison of the Slopes of the Master curves

The slope of the master curve is an important parameter since it contains information on the slope of the fatigue line and permanent deformation characteristics of the mixture (Molenaar, 2007). The slope of the fatigue line “n” is a material property and depends on the slope of the master curve. In addition, the slope of the master curve indicates the sensitivity of the change in the modulus with time of loading. The higher the slope, the larger the change in modulus for corresponding changes in frequency or vehicle speed. Figure 4 shows the plot of the slope of the master curve (stiffness vs. reduced loading time) in log-log scale with 40 and 50 % RAP contents respectively. It can be seen from figure 4 that the highest absolute value of the slopes are observed for the UPG method and the lowest absolute value of the slopes are observed for the SM method with 40 and 50 % RAP contents.

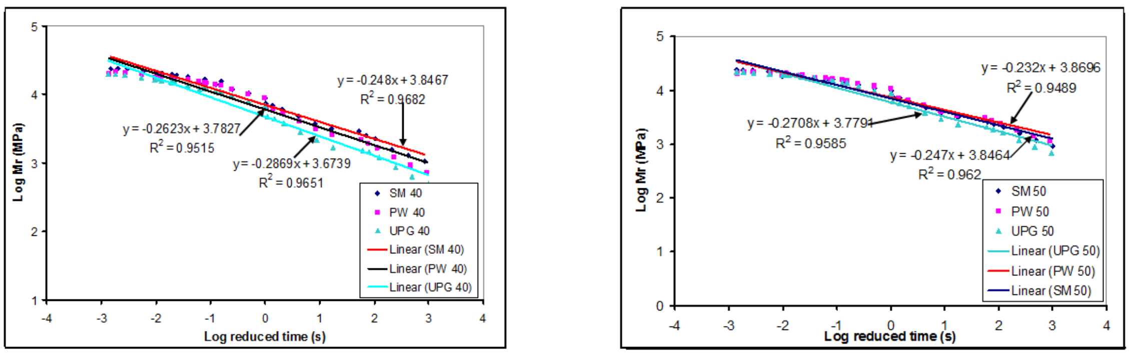

Figure 4: Slope of Master curves for different mixing methods at 40 % RAP and 50 % RAP.

4.3 Indirect Tensile Strength test results

Indirect Tensile strength (ITS) under dry and wet conditions are measured for the three mixing methods. Figure 5 presents the results of indirect tensile strength test of the unconditioned (dry) and conditioned (wet) specimens with 40 and 50 % RAP contents. Each value in figure 5 represents the average of three test replicates. From figure 5 it can be seen that the highest tensile strength value is observed for mixtures prepared using SM methods 40 and 50 % RAP.

The lowest indirect tensile strength value is found with the UPG method. It can be observed that the increase in tensile strength is related to the increase in RAP heating temperature (0, 130 and 170^{o} C for UPG, PW and UPG methods respectively). This trend could be related to the blending power, because in the SM method mixing was done with the highest temperature RAP (maybe also most aged RAP) showing also the highest stiffness values.

The moisture sensitivity is reported as the percentage of the retained tensile strength of the conditioned (wet) specimens compared to unconditioned (dry) specimens. It can easily be calculated that the ratio between conditioned and unconditioned (ITSR) for all mixes higher is than 80 % (related to CE marking).

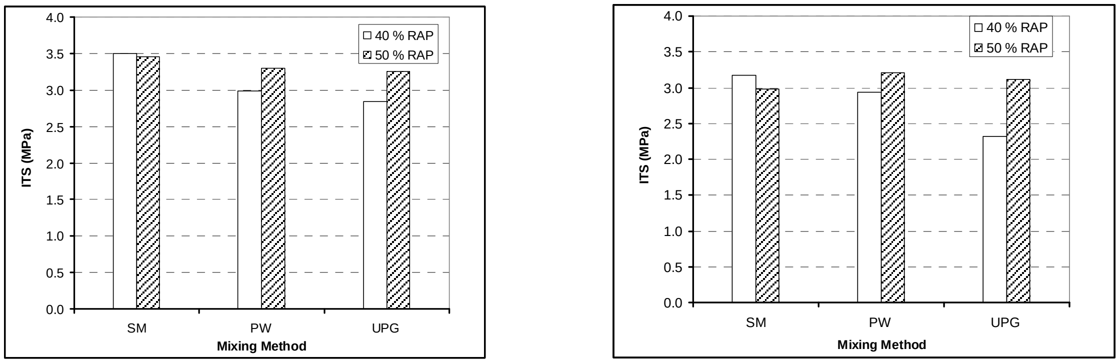

Figure 5. Indirect Tensile Strength results at 40 and 50 % RAP: unconditioned-left figure and conditioned –right figure.

4.4 Resistance to Permanent Deformation

The resistance to permanent deformation of the mixes can be expressed by parameters obtained from axial permanent strain versus loading cycles curves. Only primary and secondary stages were observed in the axial permanent strain versus loading cycles curves. The permanent strain at 1000 pulses and the slope of strain in the linear part (secondary stage) of the curve are used for comparisons of the results of different mixing methods.

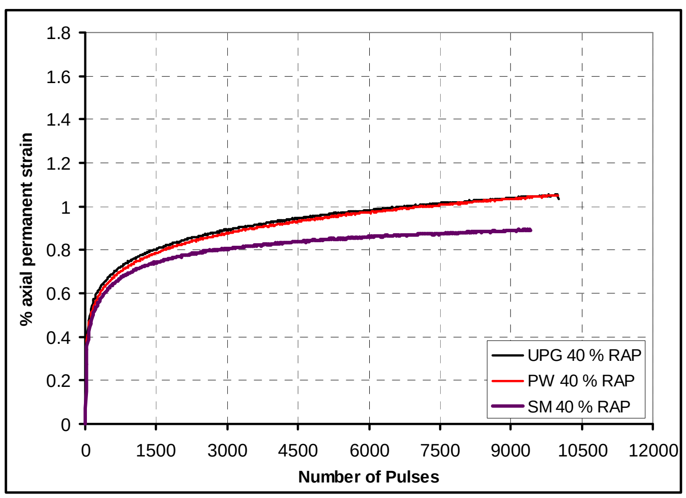

Figure 6: Results of the % axial permanent strain versus number of pulses at 40% RAP.

An example of the results of the percentage of axial permanent strain corresponding to the number of load repetitions for different methods is given in figure 6 for 40% RAP (each plot represents an average of three test replicates). The effect on the permanent deformation behaviour of the mixtures, the slope of axial permanent strain and the % axial permanent strain after 1000 and 10000 load pulses were compared for the three mixing methods. At 50% RAP the UPG methods shows a considerable higher creep rate compared to the other two mixing methods as can be seen in figure 7. In figure 7 the rate of axial permanent strain is compared and in figure 8 the cumulative axial permanent strain at 1000 and 10000 load cycles are given.

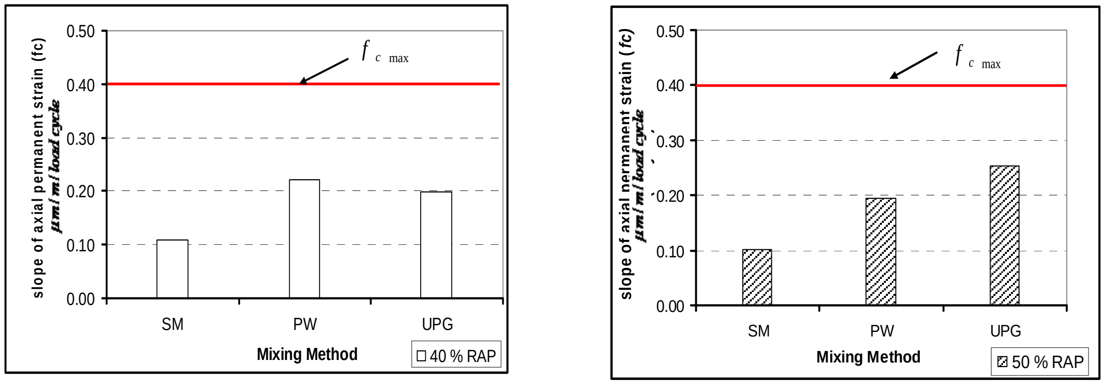

Figure 7: Rate of axial permanent strain ‘fc’ at 40 % RAP (left) and 50 % RAP (right).

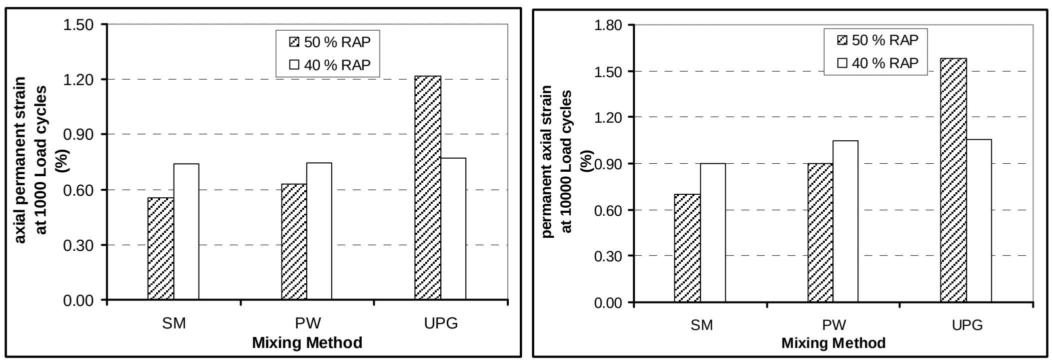

Figure 8: Cumulative axial permanent strain (%) at 1000 (left) and 10000 load repetitions.

5 DISCUSSION

5.1 Effect of Processing Method on the Stiffness

The research has shown that the stiffness of the mix increases with increasing preheating temperature of the RAP (RAP heating temperature 0, 130 and 170^{o} C for UPG, PW and SM methods respectively).

Figure 9 gives an impression of the development of the stiffness for the three mixing methods at a fixed frequency of 10 Hz for a change in the RAP content. Clearly the different trend between the SM and the other two methods can be observed.

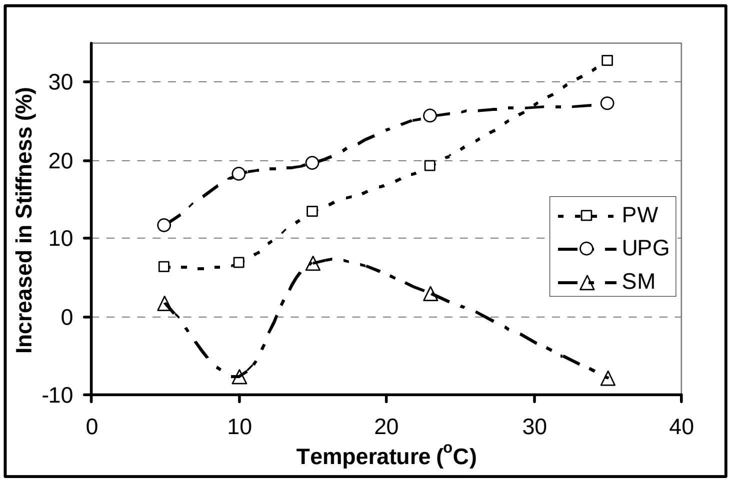

Figure 9: Increase in % of stiffness at different temperature by increasing RAP from 40 to 50 % at a frequency of 10 Hz.

Although the stiffness of the mix is influenced by aggregate gradation and air voids, the most significant factor is the stiffness of the binder. The degree to which the RAP binder blends with the virgin binder is also related to the degree to which the RAP is heated during mixing. If the RAP material is not heated sufficiently, the RAP binder does not blend with the virgin binder to the extent possible and the RAP then tends to act more like a black rock material. In such case only the softer virgin binder becomes the binding agent which subsequently will cause a lower mix stiffness. The highest change in mix stiffness was observed at high temperature for both 40 and 50 % RAP content.

5.2 Effect of Mixing Method on Water Sensitivity and Indirect Tensile Strength

All mixes exhibited a relatively high value of indirect tensile strength ratio (ITSR) for a base course mix. No clear indication was found for the effect of mixing method on water sensitivity. The study has shown an increase in tensile strength with increasing RAP heating temperature. The highest tensile strength at 40 and 50 % RAP was observed for the SM method and the lowest for the UPG method. A similar trend is also observed for the mix stiffness. At 40 % RAP the mixing method results in a higher difference in tensile strength than at 50 % RAP.

5.3 Effect of mixing method on permanent deformation

The results show that the rut resistance increased with increasing preheating temperature of the RAP (RAP heating temperature 0, 130 and 170 °C for UPG, PW and SM methods respectively). For all mixing methods the percentage axial permanent strain per load cycles '*fc*' was found to be below the maximum requirement (f_{cmax} = 0.4 μm/m/load cycle) as specified by the Dutch standard (CROW, 2005) . For all mixing methods it was found that 80 % of the cumulative axial permanent strain occurred in the first 1000 number of pulses. The effect of the processing on axial permanent deformation and on axial strain slope is higher for 50 % RAP than for 40 % RAP.

6 CONCLUSIONS

Laboratory handling of RAP material has impact on the mechanical properties of the mix. Therefore, mix production in the laboratory with high RAP content highly depends on the heating time and temperature of the RAP material prior to mixing with virgin aggregate. The existing standard mix design procedure (RAP and virgin materials heated dry to the same temperature) does not simulate the mixing processes in parallel drum batch plant and double drum mixer plant. Therefore, the mechanical properties of laboratory produced mixes with the standard mixing method can not be used to predict the performance properties of mixes made in parallel batch plant and double drum mixers.

The higher value of the stiffness observed for mixes produced with SM method may improve the rutting resistance of the mixture, as is also indicated by the creep test results. It seems that in the UPG method with 50% RAP the highest creep rate is observed. On the other hand it is not clear how the fatigue behaviour is influenced by the different production methods.

Preliminary conclusion is that the results can impact on the requirements for CE marking in the Netherlands.

More research is needed to fully understand the effect of mixing method on performance properties, because both temperature and moisture (in the double barrel drum micer)) play an important role. The blending of the RAP bitumen with the softer bitumen seems to be a key factor at the different temperatures, and specifically for the drum mixer the role of moisture when cold RAP is added need clarification. Further fundamental research on these issues is started in a PhD study.

REFERENCES

CROW, 2005, *RAW 2005, Standaard RAW bepalingen.* CROW, The Netherlands (in Dutch).

Medani, T, Huurman, M, Molenaar, A, 2004. *On the computation of master curves for bituminous mixes.* Proceedings of the 3th Eurobitume Congress, Vienna, Austia.

McDaniel ,R, Soleymani, H, Anderson, R, Turner, P, Peterson, R, 2000. *Recommended use of Reclaimed Asphalt Pavement in the Superpave Mixture Design Method*; NCHRP Final Report (9-12). TRB, National Research council, Washington, D.C.

McDaniel, R, Slah, A, Huber, G, Gallivan, V, 2007; *Investigation of Properties of Plant-Produced RAP Mixtures;* Transport Research Board 86th annual Meeting, TRB, National Research Council, Washington, D.C.

Molenaar, A, 2007. *Lecture notes CT4850. Road Materials Part III: Asphaltic Materials*. Delft University of Technology, Delft, The Netherlands.

NEN-EN 13108-20, 2006. *Bituminous materials – Material Specification. Part 20; Type Testing.*