ASPHALT MIXTURES WITH WASTE MATERIALS: POSSIBILITIES AND CONSTRAINTS

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Abstract

Sustainable developments in flexible pavements strongly promote protection of the natural resources from earth. One possibility is to use recycled/waste materials as aggregates. A number of waste materials were studied on their application into asphalt mixtures. Materials tested were sintered granulate from burned household waste, plastic waste as (soft) granular material, ceramic waste from electrical insulators, and foundry sand. Large fractions of sintered household waste, plastic waste and crushed ceramics can be used as partial replacement for the coarse aggregate fraction. Foundry sand could partially replace natural sand in asphalt mixtures. In all cases it was necessary to check basic requirements and for some properties like leaching behavior need to be determined. Basically aggregates of reference mixtures were replaced. Mechanical tests were done on several mixtures with waste components to determine indirect tensile strength, stiffness, fatigue. In order to estimate the water sensitivity of some mixtures, retained indirect tension tests were done. The properties are reported and compared with each other and reference mixtures. From the research it becomes clear that replacement of virgin materials in asphalt mixtures with waste materials is not straight forward. Each waste material has its specific problems.

1. INTRODUCTION

The goal of sustainable practices is to sustain economic prosperity and a high quality of life for everybody, and at the same time protecting the natural systems of planet earth. Sustainability contains economical, environmental, and social components. The road building industry in the Netherlands is using high quantities of bulk materials like asphalt concrete. Each year approximately 10 million tons of asphalt mixture is produced. Sustainable developments in flexible pavements strongly promote protection of the natural resources from earth and to use recycled/waste materials as aggregate or component where possible. In this paper the focus is on burned household waste, but special aspects of some other recycled/waste materials are also discussed. Materials tested were sintered granulate from burned household waste, plastic waste as (soft) granular material, ceramic waste from electrical insulators and foundry sand. Sintered household waste, crushed plastic waste, crushed ceramics could be used as partial replacement for coarse aggregates. Foundry sand could partially replace natural sand in asphalt mixtures. The first step is always to find out if the waste materials could satisfy basic requirements and in some cases special properties like leaching charactereistics are needed. In the second step mixtures are designed and mechanical tests done on several mixtures with waste components to determine indirect tensile strength, stiffness, fatigue. In order to investigate the water sensitivity of some mixtures, retained indirect tension tests were done. The properties are reported and compared with each other and reference mixtures. Much attention is given to specific aspects of the different waste materials. The paper starts with the applicability of burned household waste. Then special aspects of plastic-, ceramic waste and foundry sand will be discussed. The paper ends with conclusions

2. SINTERED HOUSEHOLD WASTE

In this chapter the replacement by both sand and stone fraction with sintered household waste is discussed. For detailed information and results see (Van de Ven et al, 2006)

2.1. Characterization of the fraction and mix design

The expectation was that large fractions of sintered household waste could be used as partial replacement for coarse aggregates. Granulate was made available in four fractions by the producer of the household waste: Granulate 6-20 mm, Granulate 2-6 mm, Sand fraction 0.05-2 mm, Filler <0.05 mm. The fractions were characterized in the first place by grading and density of the fractions. The results are given in Table 1.

Table 1. Density of the materials and bulk densities of the fractions

Fraction	Theoretical density	Bulk density
11.2-16	2.55	2.24
8-11.2	2.63	2.32
5.6-8	2.70	2.33
2-5.6	2.76	2.27
Sand	2.77	
Filler	2.41	

The grading of the filler fraction was determined with the hydrometer test, but it was very difficult to determine a grading curve, because of the fibre type shapes found in the material. They stick together and for larger sizes than 63 micrometer it was not possible to predict the grading. From the grading below 63 micrometer 10% was finer than 2 µm. Due to the above mentioned problems and the fact that first trials indicated that a large amount of extra bitumen was needed when using this filler fraction, it was decided not to use the filler fraction in bituminous mixtures. From the available gradings a dense asphaltic concrete 0/16 with maximum aggregate size of 16 mm was designed (DAC 0/16) , see Table 2.

Table 2. DAC 0/16 mixture with all fractions except filler from sintered household waste. Mixture composition and recovered aggregate fractions after Marshall compaction

	Fraction	**Mass [gr]**	**Fractions (gr) after extraction**	
		In mixture	**I**	**II**
Sintered household waste	16-11.2	110.6	72.2	88.3
	11.2-8	102.6	83	80.9
	8-5.6	113.4	117.7	106.7
	5.6-2	200.4	234.5	232.1
	Sand	406.3	420.6	419.2
	Filler	66.7	72	72.8
		1000	1000	1000
	bitumen	70		

The specimens were compacted with two times 50 blows Marshall.

From Table 2 it can be seen that approximately 20% of the two large fractions is crushed down. The result is that the compacted mixtures are much finer graded than originally before compaction. It was also necessary to add extra bitumen (0.5%). The results of Marshall tests on the specimens are given in Table 3.

Table 3. Marshall properties of the DAC 0/16 mixture with household waste (2*50 blows)

	Spec. traffic class 4		**Test result**
	min	Max	
Marshall stability Pm [N]	7500	-	8100
Marshallflow Fm [mm]	2.0	4.0	2.4
Marshallquotient Qm [N/mm]	3000	-	3375

For all testspecimen the density was determined with two methods. The so-called dry method and the wet method were used. In both cases specimens were dried and the weight was determined. In the dry method dimensions were determined of the cylinder and density was determined. In the wet method the specimen was weighted above and under water. The mean density of the specimen was: dry method, mean 1996 kg/m3, standard deviation 29 kg/m3: wet method, mean 2006 kg/m3 and standard deviation 26.5 kg/m3. It can be concluded that these mixes with aggregates from household waste have a high voids content of probably around 20 % and durability could be an issue, especially for surface layers. For this reason water sensitivity should be a first test to perform on the mixture.

2.2. Mechanical properties of mixture

To get an indication of the mechanical properties that could be obtained, indirect tensile tests (strength, water sensitivity, stiffness, fatigue) and creep tests at high temperatures were done. For the indirect tensile strength both dry and in water immersed (retained) spec imen were tested according to EN 12697-12. The ratio between ITSdry and ITSwet is called ITSR. Some results at several temperatures are given in Table 4. The ITSR values are between 50 and 65 % and these values are very low for normal DAC mixtures. Normally the test is done at 15°C and a requirement for the ITSR will be at least 80% for a surface layer. The reference mixture has an ITSdry of 4.49 MPa at 5°C, more than twice the value of the tested material. Again an indication is given that one should be careful using this mixture as a surface layer.

Table 4. Results of ITSdry and ITSretained of mixture with household waste.

Temperature [C]	ITSdry [MPa]	ITSwet [MPa]	ITSR %
5	2.04	1.27	62.39
15	1.14	0.74	64.64
25	0.69	0.36	52.44
35	0.34	0.22	65.37

Uni-axial dynamic creep tests were done to evaluate the behavior at high temperatures in case this mix would be used high in the pavement structure. Test specimens for the unconfined uni-axial creep test were polished to prevent friction. Tests were done at 40 and 50°C at three stress levels (100, 200, 300 kPa). The load signal was composed of a pulse of 200 msec, followed by a rest period of 800 msec. Results are given in Table 5.

Table 5. Results of dynamic creep tests (unconfined, uni-axial)

Temp [°C]	**Stress level [kPa]**	**Slope (µm/m)/pulse**	**Accumulated strain after 7200 pulses (µm/m)**	**Slope (µm/m)/pulse**	**Accumulated strain after 7200 pulses (µm/m)**
		Household waste mix		**Reference mix**	
40	100	0.33	7561	0.34	9532
	200	1.93	18342		
	300	12.86	failure	0.92	16736
	500			5.1	failure
50	100	0.4	7935	0.62	12083
	200	18.8	Failure	1.93	34689
	300	41.8	failure	4.5	failure

From Table 5 some interesting conclusions can be drawn. At both 40 and 50° C the household waste mix shows good permanent deformation at a low stress level of 100 kPa. At higher stress levels (200k Pa or more), the reference mixture performs much better. This means that one should be very careful in placing the household waste material at places in the structure where high compressive stresses (without confinement) can occur.

3 PLASTIC WASTE

Each year a lot of plastic waste is collected from household waste. For these large quantities all kind of applications are studied. The possibility to use plastic waste based on technical properties of asphalt mixtures was studied and results reported in this chapter can be found in (Menges, 1991). In the Netherlands plastic waste granulates are at the moment considered for surface layers to improve the mechanical impedance in relation to noise reduction.

3.1 Materials and mixture variations

Primarily the possibility of using the plastic waste as a replacement of part of the mineral aggregate fractions (sand and gravel) for a base course mixture was studied. The plastic waste contains temperature susceptible material (thermoplastics) and for this reason an 80/100 pen bitumen was used, because in that case the mixing temperature could be kept to 150°C to prevent fully melting of the added thermoplastics.

For the research a large amount of plastic waste was reduced to small particles with special equipment. The plastic waste was seized into small flat particles with dimensions between 1 and 7 mm. The shape was in general rectangular. (more than 90%). The thickness of the particles varied between 0.1 mm (thin foils) and 1 mm (plastic plates) with a mean thickness of approximately 0.2 mm. An important aspect was also the density of plastic waste. An indication of the density of several types of plastic waste is given in Table 6.

Table 6. Types of plastic waste and their densities.

Plastic waste type	Density kg/m3
LDPE	0.92
HDPE	0.95
PE mix	0.93
PP	0.90
PE/PP	0.93
PVC	1.38
PS	1.05

The plastic waste was used in a gravel asphalt concrete (GAC) mixture with a maximum grain size of 32 mm (GAC 4/32). This is a standard base course mixture in the Netherlands.

Several variations of plastic waste were added to the reference mixture and optimum bitumen content was determined with the Marshall test (Menges, 1991). First of all the optimum mixing procedure needed to be developed in the laboratory. Some possibilities tested were:

- Sand substitution (SandSub): 5.8% V/V of sand was replaced by a similar mass of plastic waste The optimum bitumen content was 10.5% V/V
- addition (ADD): 12.97% V/V of plastic waste was added with reduction of the same volume of mineral aggregates. The optimum bitumen content was 9.7% V/V.

3.2 Discussion points on plastic waste

With the calculation of the dimensions of the plastic waste and the standard methods used to determine specific surfaces an indication is given from the influence of addition of the plastic waste to the specific surface of the aggregate fractions and the resulting bitumen film. Table 7 gives the results.

Table 7. Change in specific surface and bitumen film thickness by adding plastic waste

	Ref	**SandSub** (5.8% of sand fraction)	**ADD** (12.97% of aggregate)
Amineral*10^6 mm2	7.8	6.8	4.7
Aplasticwaste*10^6 mm2	-	0.9	0.8
Atotal*10^6 mm2	7.8	7.7	5.5
Vbit*10^3 mm3	48	44	42
Bitumen film thickness (µm)	6.2	5.7	7.6

From Table 7 it can be concluded that in the case of addition (ADD) the mineral aggregate specific surface reduces so much that even after addition of the plastic waste the total specific surface is considerably lower than that from the reference. As a consequence the bitumen film thickness is remarkably higher compared to the reference mixture.

Higher amounts of plastic waste (more than 10%) always resulted in conglomerates during mixing, indicating segregation. With lower amounts of plastic waste this risk reduced considerably. Segregation is also dependent of the shape of the waste. With higher amounts of plastic waste in the mixture, conglomerates were observed as fat spots on the specimen. Also the surface texture of the asphalt mixture became more coarse. Another possible problem of increasing the amount of plastic waste up to 18.83% V/V is the increased shrinkage during cooling, as observed in some trial mixtures.

With the SandSub mixtures another interesting observation was made: with a decreasing amount of sand and increasing amount of plastic waste the mixture became more bitumen rich. Replacement with 5.15 %V/V plastic waste resulted in an under filled mastic, but replacement with 12.77 %V/V plastic waste resulted in an overfilled mastic.

Uni-axial unconfined creep tests were done at 40°C. The peak stress was 0.1 MPa and a pulse loading was used with a loading time of 1 sec and unloading time of 7 seconds. After2200 load repetitions the tests were stopped. The test results are summarized in a log- log formula relation for the permanent strain and number of load repetitions:

$$\log \varepsilon_p = a \cdot \log N + b$$

In the formula a and b are regression constants, ε_p is the permanent strain and N is the number of load repetitions. The linear regression results are given in Table 8.

Table 8. Regression results of the creep tests at 40° C.

Mixture	**a**	**b**	**R^2**
Reference	0.45	-3.5	0.99
	0.44	-3.57	0.98
	0.47	-3.59	0.98
ADD	0.19	-3.61	0.97
	0.22	-3.42	0.98
	0.23	-3.70	0.99
SandSub	0.31	-2.71	1
	0.35	-2.82	0.95
	0.30	-2.47	1

From Table 8 it can be concluded that the SandSub mixture is most sensitive to permanent deformation and the ADD mixture is even better than the reference mixture.

4. CRUSHED CERAMICS AND FOUNDRY SANDS

Ceramic waste and industrial sand were chosen for incorporation in asphalt mixes , but concerns were stated with regards leaching behavior. Results presented in this chapter and details about the research can be found in (Nguyen, 2007).

4.1 Leaching characterisation and mixture design

The composition of ceramic waste indicates the presence of a few undesirable elements like : aluminum, chromium, copper, nickel, lead, titanium, zinc, potassium and sulfur. For the solid composition of industrial sand, the spectrometer detected the presence of aluminum, chromium, copper, nickel, titanium, potassium, chlorine and sulfur.

The leaching characteristics were obtained according to the column test method, NEN 7343, developed in the Netherlands and the German test, DIN 38414-S4. The first method simulates percolation of the material due to acidic rain. The leaching water slowly passes through a fixed volume of crushed sample and is collected for analysis. In the second method, the sample is mixed with water at a ratio of liquid to solid of 10: 1 for 24 hours. Then the solid is filtered out. Only the results of the Dutch leaching test are reported here. The concentrations of leached elements in the eluted water were measured by inductively coupled plasma with optical emission spectroscopy (ICP-OES) (Vista-MPX Varian), for cations, and high-pressure liquid chromatography (HPLC) (ILC-2 Waters Millipore) for anions. An average of three measurements was recorded for each material. Some concentrations for both waste materials are given in Table 9 for the Dutch leaching test.

Table 9. Results of some concentrations according to Dutch leaching test (mg/kg dry material).

	Leaching concentrations		
Elements	Ceramic waste	Industrial sand	Limits
Sb	< 0.16	< 0.16	0.3
As	< 0.12	< 0.12	0.8
Cr	0.12	0.15	0.5
Co	< 0.012	< 0.012	0.25
Cu	0.03 - 0.04	0.2	5
Pb	0.1	< 0.08	2.2
Ni	0.03– 0.04	0.28	1.8
Ti	< 0.01	0.38	2.4

The maximum percentage of waste material that could be added into the mixture was determined with the Marshall test. In one modified mixture, 15% of the coarse aggregates were replaced by ceramic waste. In another mixture, 20% of the sand fraction was replaced by industrial sand. The optimal binder content was similar to the reference mixture.

In Table 10 the Marshall properties of the three mixtures are given. The modified mixtures give similar results compared to the reference mixture. As can be seen all mixtures were quite easy to compact (Marshall 2 times 50 blows).

Table 10. Results of the Marshall test for the three mixtures.

Marshall properties	**Reference**	**With ceramic wast (15% coarse)**	**With industrial sand (20%sand fraction)**
Stability (N)	7200±1100	7500 ± 700	7900 ± 1000
Flow (mm)	3.0 ± 0.2	3.1 ± 0.4	3.3 ± 0.3
Quotient (N/mm)	2400±200	2400 ± 200	2400 ± 300
Voids (%)	3.2 ± 0.6	4.2 ± 0.8	2.4 ± 0.8
Voids filled (%)	77.3 ± 3.4	72.0 ± 4.1	72.0 ± 4.1
Stability ratio	0.96	0.87	0.86

4.2 Mechanical properties

A number of mechanical tests were performed. Tests used for the mechanical characterization were the indirect tensile strength test, the compression test (Erkens, 2002), the beam fatigue and the beam stiffness test (Medani et al, 2003).

The indirect tension test (ITS) results for ITS(dry) and ITSR (ratio of strength immersed in water versus dry) are reported in Table 11. The stress at failure for the three mixtures (including the reference mixture) is in good agreement.

Table 11. Results of the indirect tension test and compression test.

	Indirect tensile strength		**Compressive strength**
Mixtures	Dry(MPa)	ITSR	(MPa)
Reference	1.4 ± 0.1	0.93	5.3 ± 0.1
With ceramic waste	1.4 ± 0.1	1.21	6.5 ± 0.3
With industrial sand	1.3 ± 0.1	1.08	6.3 ± 0.1

No water sensitivity was detected as shown in table 11. The modified mixtures even show an increase in stress at failure after water immersion. It indicates that the incorporation of waste materials into asphalt concrete does not increase the sensitivity of the mixture to water. The mixture with ceramic waste has the highest compressive strength. However, as shown in Figure 1, many smooth pieces of ceramic waste came off from the crushed samples at the end of the test. It could be a lack of adhesion with bitumen, but surprisingly it did not show up in the ITSR values for the indirect tensile test in Table 11. However, It could be a point of concern.

Figure 1. Compressive failure of the reference mixture (right) and the modified mixture with ceramic waste coarse aggregate (left).

The stiffness has been measured with frequency sweeps at three temperatures. Master curves are given in Figure 2.

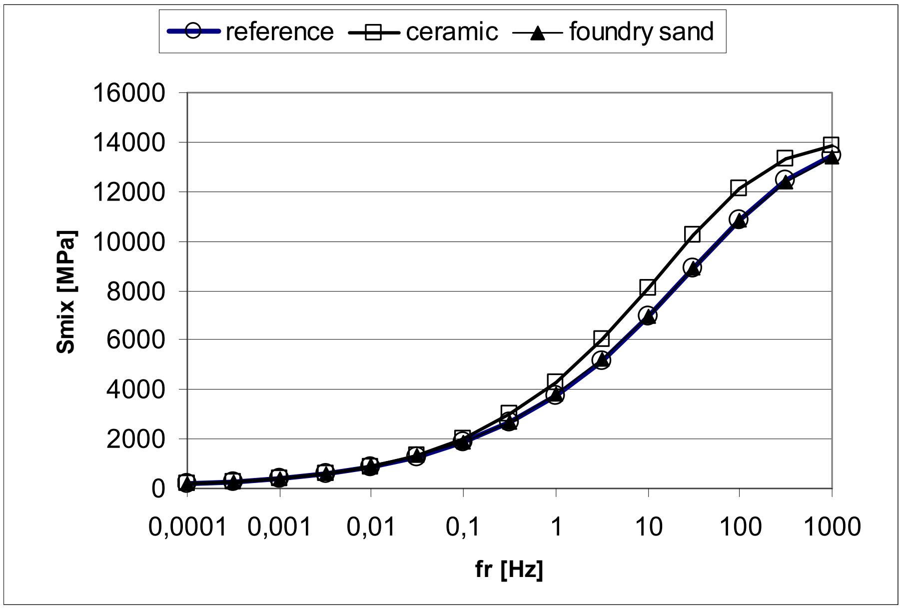

Figure 2 . Master curves for the stiffness at 20°C.

The reference temperature was chosen at 20°C. The sigmoidal model (Medani and Huurman, 2003) was used to construct the master curve. From Figure 2 it can be seen that the modified mixture with ceramic waste has a higher stiffness than the two other mixtures over the whole frequency range.

Figure 3 shows the regression fatigue lines from the four-point bending tests in strain controlled mode at 20°C and 10 Hz.

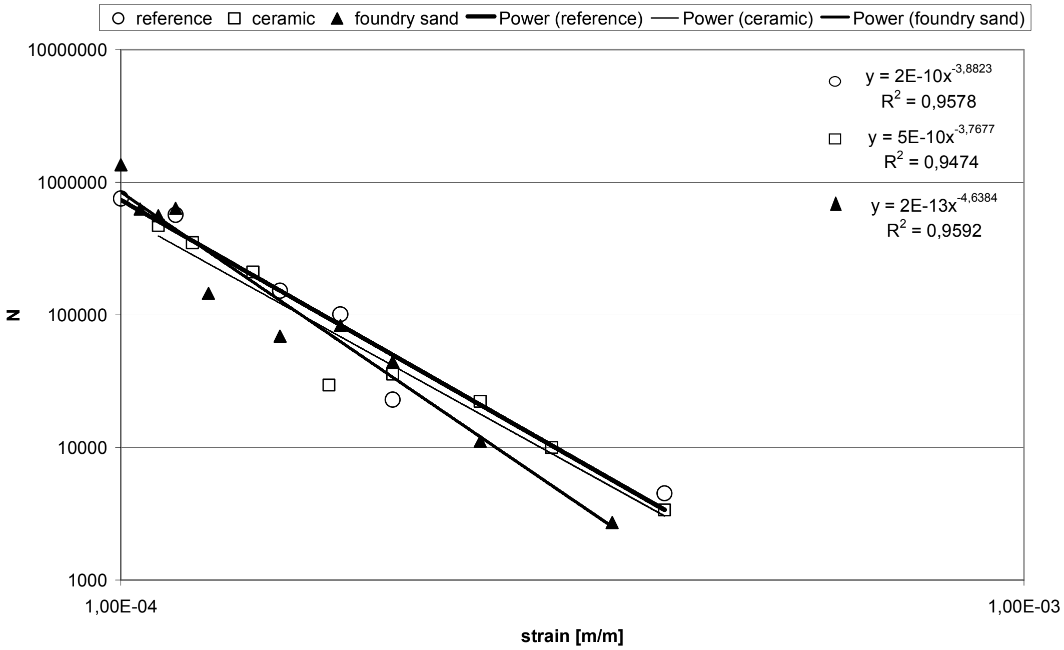

Figure 3. Fatigue lines of the mixtures at 20°, 10 Hz.

The slope of the fatigue lines varies in such a way that at higher strain levels, the modified mixture with industrial sand gives a lower fatigue live than the other two mixtures. At strain levels above 2.10^{-4}, the decrease in the fatigue life for this mixture is quite pronounced compare to the other two.

5. CONCLUSIONS

Three totally different types of waste materials were discussed and all three types needed a very different approach for the mix design. In most cases a base course mixture was considered the best way to start with the research.

Replacement of the sand and stone fraction with the sintered household waste sand and stone fraction (without filler) shows considerable crushing during compaction, a higher voids content due to the porosity of the sintered material, higher binder content, high water sensitivity and at high temperatures uncertain creep behavior.

Partial replacement of stone and sand fraction with ceramic waste and industrial sand seems to be relatively easy applicable in base course mixtures resulting in good properties.

Plastic waste requires a very special approach in the mix design due to the low density of this material, the flat shape, order of mixing and uncertainty if the plastic is melting during mixing. More study is needed.

Overall conclusion: use of household waste as a replacement of scarce natural resources is not a straight forward procedure. It is difficult to satisfy environmental requirements for these mixtures and at the same time satisfy the normally required properties for equal performance as the reference.

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