Application of AMORAS Filter Cakes in Infrastructures

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***Abstract**: By* the maintenance of the many canals and docks, there is a large amount of sludge for which there are only limited applications. AMORAS (Antwerp Mechanical Dewatering, Recycling and Application of Sludge) too annually faces an amount of 500.000 tons dry matter in form of filter cakes. This study aims to apply the material in infrastructures, more specifically the road sector by replacing filler in asphalt.

In the first stage, research is done to classify the product as filler on the basis of the voids, bitumen number, delta ring and ball, water susceptibility and methylene blue. The obtained results show a high rate of fine particles, with a certain percentage of clay, and very high bitumen absorption.

A second stage is devoted to the influence of filter cakes on the characteristics of a SMA-C2 asphalt mixture in terms of voids, indirect tensile strength and water sensitivity. Four compositions are created with the same mass ratio of the raw materials, only the filler is replaced. The reference mixture consists of Duras Filler 2 (type IIa), two mixtures with two different batches of filter cakes and a mixture of 50 % Duras Filler 2 and 50 % filter cakes batch 2. The results show a strong increase in terms of water sensitivity as more filter cake is added. The limited adhesion between mastic and rocks needs to be notified.

Finally, an economic analysis of the application as filler is examined. It is determined whether or not it is economically viable, from a social point of view, to process filter cakes into filler. Quantities which could be processed are defined and at what price. The balance between processing as filler and deposit should be evaluated, just as the determination of the competitive position. The ultimate cost for the refining, drying and grinding into filler should not exceed the price of alternative products plus the deposit costs. Grants can ensure the economic position of filter cakes to minimise deposit and maximise sales as filler.

Keywords: AMORAS, maintenance sludge, filter cakes, filler, filler classification, road building, asphalt, water susceptibility, economical analysis

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1 Introduction

AMORAS is a sustainable and innovative plant, located in the port of Antwerp and exploited by 'SeReAnt' for another 15 years. Flemish authorities and the Antwerp Port authority are investing in a sustainable solution for the storage and processing of maintenance sludge from the docks. [1]

The dredged material passes several treatment stages before it is actually stored. First the sand gets separated from the fine particles, in order to prevent the machinery and piping from being damaged. Next, the material is pumped to the settling pond where it can consolidate and where the polluted suspension gets separated. The thickened sludge is then pumped to the dewatering hall. A series of filter presses ensure that the filter cakes obtained have a dry matter content of at least 60 %. Finally the received product can be stored. [2]

Up to now, the filter cakes with a capacity of 500.000 tons dry matter per year are being deemed as waste material. The ambition of this project is to reuse and revalue the filter cakes as a renewable raw material.

Figure 1: The AMORAS plant in the port of Antwerp (source: [1])

2 Research objectives

Because of the large annual amount of filter cakes processed and the limited storage space (about 13 million tons dry matter, equivalent to 26 years), there is a need for an application with a significant market. This way the product filter cakes are reused and upgraded to secondary materials, allowing the amount of storage to be reduced.

Several studies have been performed (bricks, concrete, expanded clay), however no suitable solution has been found yet. In this paper, results of the research in terms of bituminous bound applications are elaborated.

More specific, the following topics will be covered:

- Analysis of filter cakes with regard to the filler classification;
- Comparative study between the influence of a regularly used filler and the fine particles of filter cakes on hot mix asphalt characteristics;
- Research on the possibility to add the filter cakes with high water content;
- Examining a method to reduce filter cakes in size, with regards to an efficient drying process;
- Analysis of the economic opportunity of the product against existing reference alterantives.

3 Research methodology

To provide a certain degree of structure, this research is divided in four stages, each supported by laboratory research or data processing.

3.1 Research orientation

To start off, a method is required to reduce the filter cakes in the desired fraction. Subsequently the fine fractions will, for the first time, be mixed with bitumen in different forms, respectively hot or cold and wet or dry. As it is the first time the product will be in contact with bitumen, and no former experience is available, safety measures must be followed strictly.

3.2 Filter cakes as an alternative filler

Stage 1 is the classification of filter cakes as filler, described in 'SB250 v3.1' and the related standards. The following tests will be executed:

- Methylene blue (NBN EN_1097-7);
- Maximum density (NBN EN_1097-7);
- Voids (NBN EN_1097-4);
- Bitumen number (NBN EN_13179-2);
- Water susceptibility (NBN EN_1744-4);
- Deltaring and ball (NBN EN_13179-1).

3.3 Influence of filter cakes on hot mix asphalt

In this second stage, the effect of filter cakes on hot mix asphalt in comparison with reference filler is defined. Gyratory samples will be made and tested in order to determine the voids, indirect tensile strength and water susceptibility.

During this study, a reference SMA-C2 asphalt mixture will be used with a fixed quantity of 70/100 bitumen and aggregates. The filler on the other hand will be different for each composition.

Five different mixtures will be made as shown in green in Figure 2:

D:	100 % filler 2 (Reference)
F1:	100 % dry filter cakes batch 1
F2:	100 % dry filter cakes batch 2
DF2:	50 % filler 2 + 50 % dry filter cakes batch 2
F1(W):	100 % wet filter cakes batch 1

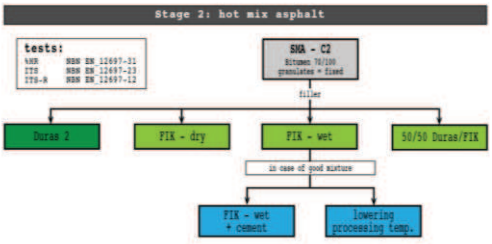


Figure 2: Diagram of the second stage, hot mix asphalt

Only when the wet filter cakes are easily mixable, the second phase will be initiated (blue in Figure 2). A first step would be to add cement to the mixture, a second step will be focused towards the possibility of lowering the process temperature. However if the wet product isn't suitable for mixture, this phase will be skipped.

3.4 *Economical analysis*

To ensure the commercial viability of a new product on the market, several minimal requirements need to be fulfilled.

A trade-off between processing into filler and deposit must be made by checking whether filter cakes can be an alternative for the current primary fillers. Therefore representative data about the primary fillers will be collected and analysed.

4 Literature

In this paragraph, results of already finished research is summarized.

4.1 *Physical and chemical characteristics of filter cakes*

Because of the strict policy imposed by the renewed VLAREMA standards, analysis has been completed whether or not filter cakes can be classified as building material by L. Horckmans and P. Nielsen from 'VITO'. [3,4]

4.1.1 *Concentration of metal*

One of the conditions of the VLAREMA imposes the allowed metal concentration of a certain product to be eligible as building material. However this standard isn't mandatory, these results are very important to ensure proper processing.

Metal	Current VLAREMA-standard building material	Batch 1	Batch 2	Batch 3	Batch 4
As	250	36,6	32	-	29,7
Cd	10	7,58	5,64	-	4,84
Cr	1250	155	118	-	131
Cu	375	88	62	-	67
Pb	1250	184	143	-	133
Ni	250	36,5	27,9	-	38,6
Zn	1250	916	758	-	677
Hg	5	1,42	1,09	1,19	-

Table 1: Concentrations of metal in mg/kg dry matter (source: [3])

The results (Table 1) indicate that none of the included metal exceeds the current or future maximum concentration for usage as building material.

4.1.2 *Leachability of metal*

In contrast to the concentration of metal, the limits for the leachability are mandatory. The results were determined by 'VITO' using the shake test CMA 2/II/A.12, however VLAREMA states that the column test CMA 2/II/A.9.1 should be applied. The results (Table 2) should therefore only be used as an indication. They typically understate the column test.

Table 2: Leachability of metal in mg/kg dry matter (source: [3])

Metal	Current VLAREMA-standard building material	Batch 1	Batch 2	Batch 3
Bromide	0,25	**10**	**10**	**16**
Chloride	430	**2900**	**2400**	**2700**
Fluoride	4,6	3,5	<2,0	2,6
Antimony	0,1	**0,26**	**0,17**	**0,17**
Arsenic	0,8	**1,1**	0,46	0,4
Barium	1,6	0,13	0,11	0,12
Cadmium	0,03	0,0028	0,0032	0,0025
Chromium	0,5	0,098	0,091	0,089
Cobalt	0,2	0,12	0,11	0,091
Copper	0,5	**1,2**	**2,3**	**2**
Mercury	0,02	< 0,0020	< 0,0020	< 0,0020
Lead	1,3	< 0,020	< 0,020	< 0,020
Molybdenum	0,2	**0,36**	**0,3**	**0,31**
Nickel	0,75	0,4	0,51	**0,77**
Selenium	0,04	**0,16**	**0,092**	**0,09**
Vanadium	0,8	**0,92**	0,65	0,63
Zinc	2,8	< 0,040	< 0,040	< 0,040
Sulphate	540	**2300**	**2800**	**3200**

Some of the results clearly fail to meet the limits imposed by the VLAREMA, mainly the leachability of bromide, chloride and sulphate. It is, however, to note that leachability should be determined in bound conditions of the particular application.

4.1.3 *Mineral oil*

In terms of concentrations of mineral oil, one of both test batches exceeds the allowed concentration (Table 3).

Table 3: Concentrations of mineral oil in mg/kg dry matter (source: [3])

	Current VLAREMA-standard building material	Batch 1	Batch 2
Mineral oil C10 - C12	-	<15	<15
Mineral oil C12 - C20	-	221	155
Mineral oil C20 - C30	-	582	458
Mineral oil C30 - C40	-	394	323
Mineral oil C10 - C40	1000	1200	940

This, however, is not a necessary limitation for application. Certificates may be requested for the following reasons [3]:

- It involves a limited excess (20 %) which is not measured in all of the samples;
- Most of the mineral oil occurs as longer chains (C20-C40) which are toxicologically less dangerous;
- Thermal processes (partially) degrades mineral oil, concentrations are therefore lower in bounded products.

4.2 *Previous valorisation projects*

Prior to this research, application of AMORAS filter cakes has been examined in certain different products, such as bricks (Weinerberger), concrete (De Ryck) and expanded clay (Argex). [3]
The general conclusion of these tests is that the filter cakes are not applicable in the current state, because of the amount of water present. The dry matter content after dewatering is 60-70 %, however the application of expanded clay, bricks and concrete require respectively 70-75 %, more than 80 and even higher percentages of dry matter. An efficient way to dewater the filter cakes even more is therefore required.

Additionally, there are two more important parameters in terms of emissions. According to §4.1.2, both the leachability from chlorine and sulphur are rather high. Because of the high temperatures to which the filter cakes are being exposed in these applications, special attention should be given to the emissions. In case the material is implemented in these products, adjustment is necessary in terms of composition or quantity.

5 Materials

During the study, the same composition is used however with each time a different filler. The reference mixture is defined with 'PradoWin' on the basis of data imposed by SB250 v3.1. [5]

5.1 *Reference mixture SMA-C2*

The composition used in this study is a SMA-C2 (stone mastic asphalt), a commonly used top layer for roads classed B1-B5. Typical for this type of mixture is a high content of stones (> 70 %) with a missing fraction between 2 and 4 mm.

In addition to granulate, mastic is added in order to obtain a closed mixture. Large proportions of bitumen (at least 6,2%) and filler are needed to ensure this filling, which makes the SMA composition very suitable for this research. High grade of mastic gives a clear picture of the effects of the filler. [6]

5.2 *Raw materials*

5.2.1 *Granulates*

Stone and sand fractions are implemented in the composition in form of porphyry, which can be classified as igneous rock. This type of stone is well suited for applications that require high standards in terms of shock, pressure and abrasion resistance.

Two stone fractions are added, 4/6,3 and 6,3/10, together with the single sand 0/2.

Figure 3: Granulates, from left to right: fractions Porphyry 6,3/10 - 4/6,3 - 0/2

5.2.2 *Bitumen*

As for the binder, bitumen 70/100 is applied in the mixture despite SB 250 v3.1 prohibits this for current SMA-C2 mixtures. Nevertheless, this will be applied in this study in order to bypass the influence of the elastomer bitumen. [6]

5.2.3 *Filler*

This research has been specially dedicated to the study of the effects of filler, therefore the filter cakes will be compared to a reference filler 2.

As reference, 'Duras filler 2' will be applied. This filler consists of limestone, several fly ashes like coal, AVI and SVI and $Ca(OH)_2$. This calcium hydroxide serves as adhesion improver, which increases the interaction between mastic and aggregates.

The filter cakes, on the other hand, will be added in pure form without any additives.

5.3 Designing the reference mixture

In order to start with the design of the mixture, certain values should be known to enter in the 'PradoWin' software. Initially the imposed sieve passing data from SB 250 v3.1 (Table 4), together with the sieve passing of the different aggregates and filler (Table 5).

Table 4: Sieve passing data for SMA-C mixtures according to SB 250 v3.1

Sieve in mm	Sieve passing in %
14,0 mm	100
10,0 mm	90 -100
6,3 mm	35 - 55
4,0 mm	25 - 40
2,0 mm	24 - 29
1,0 mm	16 - 26
0,063 mm	7,5 - 10,0

Table 5: Sieve passing data of the different aggregates and filler in %

Sieve in mm	14	10	6,3	4	2	1	0,063
Porphyry 6,3/10	100	81,4	8,2	0,6	0,5	0,5	0,2
Porphyry 4/6,3	100	100	85,1	12,4	0,1	0	0
Porphyry sand 0/2	100	100	100	100	95,8	61,2	1,2
Duras Filler IIa	100	100	100	100	100	100	83

The implemented software then defines the mixture in volume percentages of the added aggregates. This, however, is only the reference composition. The other four are determined by calculation, taking into account that the wet filter cakes contain a certain amount of sand (14 m/m%). An overview of the different compositions is given in Table 6.

Table 6: composition of the asphalt mixtures in m/m%

Raw material	D	F1	F2	DF2	F1 (W)
Porphyry 6,3/10	53,77	53,77	53,77	53,77	53,77
Porphyry 4/6,3	18,06	18,06	18,06	18,06	18,06
Porphyry sand 0/2	17,29	17,29	17,29	17,29	15,52
Duras Filler 2	10,88	-	-	5,44	-
Filter cakes B1 dry	-	10,88	-	-	-
Filter cakes B2 dry	-	-	10,88	5,44	-
Filter cakes B1 wet	-	-	-	-	12,65
Total	**100**	**100**	**100**	**100**	**100**
Bitumen 70/100	6,84	6,84	6,84	6,84	6,84

6 Filler classification

Before new filler can be used in infrastructures, the product needs to be submitted to the European and Belgian standards. For road works in Belgium, SB 250 contains the guidelines that are based on the current standards.

For fillers, Table 7 summarizes the most important characteristics. [6]

Table 7: Classification of filler according to SB 250 v3.1 and NBN EN 13043

Characteristics	Type Ia	Type Ib	Type IIa	Type IIb
Voids	$V_{28/38}$	$V_{28/38}$	$V_{38/45}$ of $V_{44/55}$	$V_{38/45}$ of $V_{44/55}$
Delta ring and ball	$\Delta_{R\&B}NR$			
Water susceptibility	value defined by manufacturer			
Grade $Ca(OH)_2$	KaNR	KaNR	KaNR	Ka20
Grade Ca	CC_{NR}	CC_{70}	CC_{NR}	CC_{NR}
Bitumen number	$BN_{28/39}$, $BN_{40/52}$ of $BN_{53/62}$			
Methylene blue	MB_F10			

On the basis of these values, conclusions can be made regarding the influence of filler. The characteristics affect the following items [7]:

- workability of the mixture;
- interaction with bitumen;
- chemical compositions;
- production control.

6.1 Experimental design

6.1.1 Maximum density NBN EN 1097-7

The maximum density is determined by using the pyknometer method. The procedure is to fill the calibrated pyknometer with 10±1 grams of filler, after which demineralized water is added. The suspension is then evacuated for at least 30 minutes. Subsequently, the pyknometer is placed in a water bath at 25±0,1°C during a period of 60 minutes. Finally the stopper is set in place, causing an amount of liquid to come out of the capillary. The pyknometer gets cooled and weighed a last time. The actual density can ultimately be determined by the following formula:

$$\rho_f = \frac{m_1 - m_0}{V - \frac{m_2 - m_1}{\rho_l}} \qquad (1)$$

ρ_f: maximum density of the filler at 25°C (Mg/m^3)

m_0: mass of the pyknometer with stopper (g)

m_1: mass of the pyknometer filled with test portion (g)

m_2: mass of the pyknometer filled with

test portion and stopper (g)
V: volume pyknometer (ml)
ρ_l: density of water at 25°C (Mg/m³)

6.1.2 Voids NBN EN 1097-4

By using the 'Rigden apparatus', the percentage of voids is determined. 10 grams of filler will be compacted, after which the height of the filler within the dropping block is measured. According to the following formula, the voids can be defined:

$$\nu = \left(1 - \frac{4\times10^3\times m_2}{\pi\times\alpha^2\times\rho_f\times h}\right) \times 100 \qquad (2)$$

v: voids (%)
m_2: mass of the compacted filler (g)
α: inner diameter of the dropping block cylinder (mm)
ρ_f: particle density of the filler (Mg/m^3)
h: height of the compacted filler within the dropping block (mm)

The ratio of voids defines certain characteristics of the filler, more specifically particle size, shape, and texture. It is a way to state the stiffening. [7]

6.1.3 Delta ring and ball NBN EN 13179-4

For each mastic mixture (37,5 V% filler with 62,5 V% bitumen) and for the 70/100 bitumen itself, two rings are filled. The beakers should be set on starting temperature (5°C for water and 30°C for glycerine), after which the test can start. The rings are placed in the equipment, which heats the water or glycerine at a constant temperature. The moment when the steel ball touches the plate underneath, because of the softening of the mastic, the softening point is reached and the temperature is defined. The delta value can then be calculated by subtracting the mean softening temperature from the bitumen from the mastic.

On the basis of 'Delta ring and ball', the softening point is determined which is, just as the percentage of voids, a characteristic for the stiffening effect of filler.

6.1.4 Bitumen number NBN EN 13179-2

The bitumen number equals double the amount of water that needs to be added to 50g of filler, in order to obtain a homogeneous mixture. This pasta is than loaded with a stamp during 5 seconds. The defined penetration must be between 5 and 7 mm in order to be qualified. If not, the test should be repeated.
The bitumen number is a measure of the absorbability of bitumen by filler.

6.1.5 Methylene blue NBN EN 933-9

For this test, annex A is used (procedure for filler with fraction 0/0,125 mm) which defines a test portion of 30 grams. 5 ml of methylene blue is systematically added to the suspension, well stirred to ensure a homogenous mixture. Each time, after waiting one minute, a drop of the water-methylene blue mixture is put on a filter paper until an aureole can be seen. Finally, the methylene blue value can be calculated using the following formula:

$$MB_F = \frac{V_1}{M_1} \times 10 \qquad (3)$$

MB_F: methylene blue value (g methylene blue/kg dry matter)
V_1: total volume of dye solution injected (ml)
M_1: mass of the test portion (g)

This test defines the amount of clay particles present in the filler. Clay will swell in contact with water, leading to an unstable mixture of asphalt when the methylene blue value is too high.

6.1.6 Laser diffraction

To analyse the particle size of fillers, laser diffraction is applied. This equipment uses laser light at 750 nm to measure particles within the filler from a range of 0,02 to 2000µm diameter by light diffraction. The light passes a lens system through a cell filled with diluted sample of the suspension. The suspension scatters the light depending on its particle size distribution. Via theoretical models and the scattered light, the actual particle size distribution is defined.

Given the distribution, the sediment properties can be defined (Table 8).

Table 8: sediment properties, division by fraction size

Gravel		> 2000 µm
Sand	Very rough	1000 – 2000 µm
	Rough	500 – 1000 µm
	Medium	250 – 500 µm
	Fine	125 – 250 µm
	Very fine	63 – 125 µm
Silt		2 – 63 µm
Clay		< 2 µm

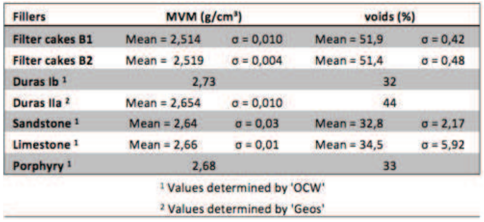
6.2 *Results*

Two batches of filter cakes were collected at AMORAS on which tests have been done. By testing two different samples, it is possible to estimate the homogeneity of the material.

6.2.1 *Maximum density and voids*

Tests were performed on both batches of filter cakes, providing the following results (Table 9). In comparison, values determined by 'OCW' and 'Geos' from some commonly used fillers and the reference are added.

Table 9: Results in terms of MVM and voids



Fillers	**MVM (g/cm³)**		**voids (%)**	
Filter cakes B1	Mean = 2,514	σ = 0,010	Mean = 51,9	σ = 0,42
Filter cakes B2	Mean = 2,519	σ = 0,004	Mean = 51,4	σ = 0,48
Duras Ib [1]	2,73		32	
Duras IIa [2]	Mean = 2,654	σ = 0,010	44	
Sandstone [1]	Mean = 2,64	σ = 0,03	Mean = 32,8	σ = 2,17
Limestone [1]	Mean = 2,66	σ = 0,01	Mean = 34,5	σ = 5,92
Porphyry [1]	2,68		33	

[1] Values determined by 'OCW'
[2] Values determined by 'Geos'

It is worth mentioning that both batches of filter cakes produce comparable results, V44/55. However, in comparison with the other fillers, filter cakes show a remarkable increase in voids. This will result in increased bitumen absorption and much stiffer mastic.

6.2.2 *Delta ring and ball*

First, ring and ball were determined for pure bitumen and Duras II in water. As the maximum temperature for this test in water is 80 °C, results of Duras (69,9 and 70,9 °C) and the already determined voids made clear that tests for filter cakes should be completed in glycerine. For pure bitumen, FIK batch 1 and FIK 2, softening points of respectively 46,0 - 45,9 °C / 123,9 – 125 °C and 115,0 - 113,4 °C were defined. Delta values are given in Figure 4.

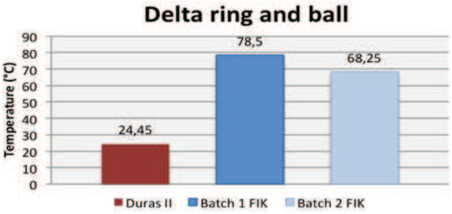


Figure 4: Results delta ring and ball

These results show a slight difference between the two batches filter cakes, the difference with Duras is much bigger. The very high softening point of filter cakes predicts a very stiff mastic, which indicates that high temperatures are required to actually produce asphalt mixtures. This may be an advantage in terms of rutting, however this characteristic makes it impossible to apply cold recycling.

6.2.3 *Bitumen number*

For each mixture, the amount of water required in order to obtain a penetration of 5-7mm was defined. The test was performed three times per mixture.

Figure 5: Penetration during 5 seconds

Figure 6 shows clearly the difference in water absorption. This will result in a higher amount of bitumen required in asphalt compositions, which result in a higher cost. NBN EN 13043 classifies fillers with a maximum bitumen number of 62, filter cakes exceeds this value.

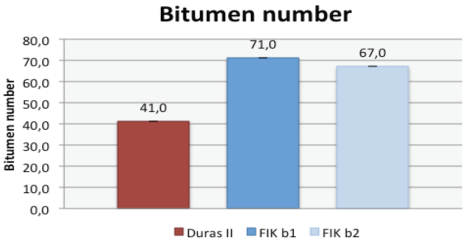


Figure 6: Results bitumen number

6.2.4 Methylene blue

In additional to the determination of methylene blue on batch 1 and 2 of the filter cakes, test results obtained by 'OCW' are added (green in Figure 7). The batches of OCW were not identical to our samples.

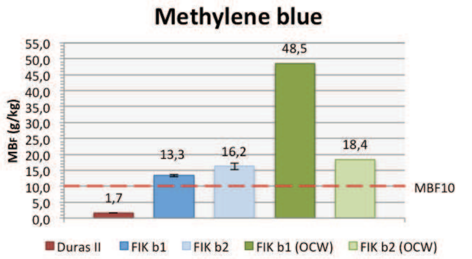


Figure 7: Results methylene blue, own results and values obtained by 'OCW'

The results obtained for the different batches filter cakes are in general fairly similar, however the result of batch 1 determined by 'OCW' stands out. In comparison with Duras, filter cakes contain a high amount of clay though. This may result in an asphalt composition with very high water sensitivity.

NBN EN 13043 imposes a maximum methylene blue value of 10, however in the Netherlands a maximum of 25 is adopted according to NEN 6240.

6.2.5 Laser diffraction

The laser diffraction is only executed for Duras 2 and filter cakes batch 2. These test are performed with aid of 'Nynas'.

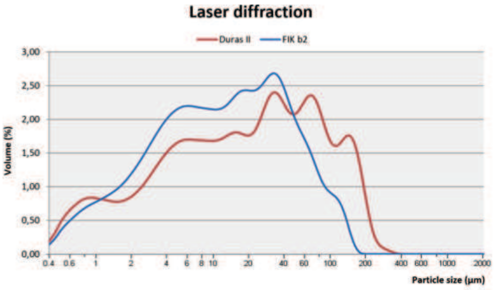


Figure 8: Results laser diffraction

Test results (Figure 8) clearly illustrate a higher amount of fine particles for filter cakes. Further subdivision in terms of sediment properties is given in Table 10. As filter cakes will be used in asphalt as particles smaller than 0,063mm, recalculation is added in the right-hand column.

Table 10: Sediment properties for filter cakes batch 2

		Particle size	FIK (< 2 mm)	FIK (< 63 µm)
Sand	Fine	125 – 250 µm	0,85 %	-
	Very fine	63 – 125 µm	7,47 %	-
Silt		2 – 63 µm	78,94 %	86,10 %
Clay		< 2 µm	12,74 %	13,90 %

7 Hot mix asphalt

As quoted in §3.3, five different asphalt mixtures have been designed. Compositions can be found in §5.3.

In order to draw conclusions in terms of durability of the different mixtures, tests were executed which are discussed in the next paragraphs.

7.1 Experimental design

7.1.1 Voids *NBN EN 12697-8*

Percentage of voids is determined by two different procedures in this research. On the one hand with the gyratory compactor and on the other hand calculated from the maximum and bulk density.

Determination with the gyratory compactor is executed on asphalt mixtures, compacted with 120 gyrations for SMA-C mixtures. The machinery automatically calculates the percentage.

The other procedure needs some preparation. Before the actual calculation, both maximum (ρ_{mv}) and bulk (ρ_{bssd}) densities are determined following the volume procedure (respectively according to standards NBN EN 12697-05 and NBN EN 12697-06). Maximum density is determined using the pyknometer method, bulk density using the saturated surface dry-procedure.

Theercentage of voids can then be calculated with the following formula:

$$V_m = \frac{\rho_{mv} - \rho_{bssd}}{\rho_{mv}} \times 100\ \% \qquad (4)$$

V_m: Voids (%)
ρ_{mv}: Maximum density (kg/m^3)
ρ_{bssd}: Bulk density (kg/m^3)

7.1.2 ITS NBN EN 12697-23

ITS or indirect tensile strength is tested on two different sets of test cylinders, one set in dry form (before conditioning) and one set in conditioned form. Test cylinders are compacted with 25 gyrations for SMA-C mixtures.

Test cylinders are placed in between two loading strips. Pressure is applied, ensuring indirect tensile in the tangential direction of the pressure. On the basis of the maximum pressure applied, the ITS can then be calculated according to the following formula:

$$\mathrm{ITS} = \frac{2 \times \mathrm{P}}{\pi \times \mathrm{D} \times \mathrm{H}} \qquad (5)$$

ITS: Indirect tensile strength (MPa)
P: Maximum pressure (kN)
D: Mean diameter of the cylinder (mm)
H: Mean height of the cylinder (mm)

The rupture surface is examined and is a way to visually determine the weakest link in the mixture.

7.1.3 Water sensitivity NBN EN 12697-12

The water sensitivity or ITS-R of all mixtures is defined by comparing the mean ITS results of the dry set with the set after conditioning. The percentage difference is a good indicator for the water sensitivity.

$$\mathrm{ITS} - \mathrm{R} = \frac{\mathrm{ITS}_{\mathrm{dry}}}{\mathrm{ITS}_{wet}} \times 100\% \qquad (6)$$

7.1.4 Swelling

This test is not included in the standards. However, because of the high methylene blue value, impact of water on the asphalt cylinders will also be tested in terms of dimensions as well.

The same conditioning as for the test cylinders for ITS is applied, this time measurements taken from both before and after conditioning. The percentage of volume increase will be calculated as a measurement for swelling.

7.2 Results

7.2.1 Asphalt production

The results from the investigation of filter cakes as filler are clearly conclusive, as during the production of the different asphalt mixtures certain characteristics were instantly noticed. Firstly the compositions with filter cakes were stiffer, resulting in a much more difficult mixing procedure. Secondly, it was immediately clear that filter cakes absorbed a lot more bitumen than the reference filler, which increases the production cost.

From a mixing point of view, application of the wet filter cakes was no option. After adding the cold, wet filter cakes in the hot mixture, temperatures dropped almost immediately below the point that homogenous mixing was possible. This resulted in asphalt with chunks of wet filter cakes, surrounded with bitumen and stones. Four asphalt cylinders were made for testing in terms of ITS (§ 7.2.3) (see Figure 9), but based on the current findings further ITS tests are not conducted.

Figure 9: Asphalt cylinder applying wet filter cakes

7.2.2 Voids

Results (Figure 10) show a clear increase in voids as more filter cakes are added. However, when only 50 % of the filler is replaced, the percentage of voids decreases slightly when calculated according to the standards. Voids still increase as for the results obtained by the gyratory.

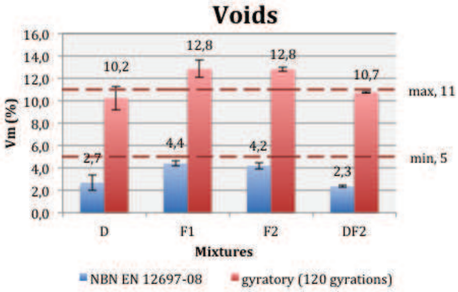


Figure 10: Results voids, different mixtures

It should be noted that values determined by the gyratory (red in Figure 10) are slightly deviating because of an error in the settings. The global trend of the different mixtures can be used as comparison though.

The design of the composition was mainly meant to check the characteristics of the filler, it was not the intention to create a perfect mixture.

7.2.3 ITS

As for indirect tensile strength, results before conditioning (BC) show (Figure 11) a slight decrease when all of the filler is replaced by filter cakes and even a slight increase when only 50 %. All of these values can be interpreted as acceptable for an SMA-C asphalt mixture.

Results after conditioning (AC), however, show a significant bigger decrease, especially for the compositions with all of the filler replaced. The comparison between values before and after conditioning will be discussed in §7.2.3.

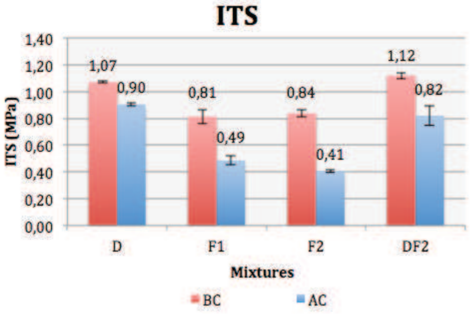


Figure 11: Results ITS, before conditioning (BC) and after conditioning (AC)

ITS before conditioning is also examined for mixtures were filter cakes are added in pure, wet conditions. Results are very poor though. As for mixtures F1 and F2 respectively an ITS-value is defined of 0,81 and 0,84 MPa, the test cylinders with wet filter cakes only reach 0,25-0,28 MPa. Because of these bad results, test after conditioning have been cancelled.

7.2.4 Water sensitivity

Further analysing results shown in Figure 11, water sensitivity is defined for the different mixtures (see Figure 12).

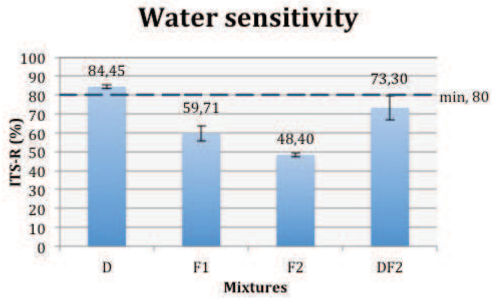


Figure 12: Results ITS-R

It is obvious that when adding more filter cakes, water sensitivity reduces vastly. SB250 v3.1 defines a minimum of 80 % ITS-R for SMA-C mixtures. None of the compositions which contain filter cakes comply with this rule, the mixture with only 50 % filter cakes is close too the minimum level reaching 73,30 % though.

Explanation can be found when looking closer to the fracture surface, comparing before and after conditioning. For mixtures D and DF2, both fractures went through the stones. However, for mixtures F1 and F2, only the fracture before conditioning went through the stones. The fracture after conditioning exhibits a fracture along the surface of the stones, indicating a detachment of the mastic (see Figure 13).

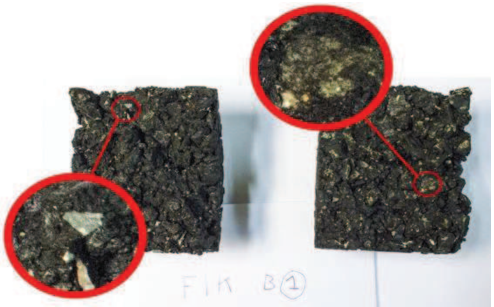


Figure 13: Fracture surface before (left) and after (right) conditioning

7.2.4 Swelling

In order to explain the results in terms of water sensitivity and detachment of the mastic, swelling of test cylinders after conditioning is measured. The following results, shown in Figure 14, are obtained.

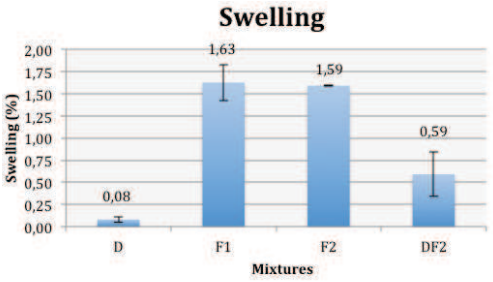


Figure 14: Results swelling, after conditioning

It is clear to say that filter cakes significantly increase the amount of swelling. This can be explained by the amount of fine particles in filter cakes, defined by the rather high methylene blue value (§6.2.4).

8 Economic analysis

To guarantee the success of a new product, an economic analysis should be made. Applying filter cakes as filler must be viable for both the user (in terms of quality and price) and society (in terms of environment and sustainability).

"Is there a market?" and "At what price?" are two of the many questions that should be answered. In order to specify these factors, the theory of the 4 P's is implemented (Table 11).

Table 11: Declaration of the 4 P's

4 P's	Description
Product	What is the core function of the product and why does the consumer wants it? What makes this product a better alternative? Functionality, quality, packaging and warranty are key.
Price	Price is an important factor to dissociate a product from the competitors, it defines the profit that can be mad. It is very important to take all costs into account, if available grants too.
Place	Does the quantity of product available meet the needs of the market at the right time? Or the other way around, does the current market support such quantities? Transportation cost is a major connection between price and place.
Promotion	How will potential customers be convinced of the product? The benefits of the product should be emphasized.

Due to the large amount of dredging and infrastructure sludge in Flanders, P. Nielsen, S. Broekcx, L. De Nocker, R. De Sutter and J. Smits (VITO) conducted a study about the policy instruments for efficient deployment. [8]

This economic analysis is based on the assumption that processing of filter cakes is independent of the further application. Up until now, the filter cakes are deposited as waste material. However, the goal is to reuse the material in processed form as secondary product.

Table 12 shows the requirements of the 4 P's for recycled products.

Table 12: Market requirements for recycled products

4 P's	Market requirements
Product	Quality requirements are achieved for the particular application; Quality assurance; Knowledge for correct usage by both provider and consumer.
Price	Price high enough to generate profit; Price low enough to face competition.
Place	Clear marketplace; Supply of a product that meets the local needs; Sufficient suppliers and users.
Promotion	Technical features comply inspections; Recognition as a safe and environmentally friendly product.

Examination regarding viability is required on two perspectives:

- Comparison between disposal and processing;
- Accordance the market segment of the particular application, in this case filler.

Note that this study only applies for non-contaminated sludge.

8.1 Product

Filter cakes are deemed as recycling or waste product, derived from maintenance dredging executed in the port of Antwerp. One of the possible applications in order to revalue the product is road construction filler.

On the market, filler is divided into certain types, more specific Ia-Ib and IIa-IIb. This classification is mainly determined by the percentage of voids (§ 6.1.2). Filter cake is considered to be a type II filler.

8.1.1 Product requirements

Technical requirements:

- Moisture content of filler less than 1 %;
- Chlorine and sulphur content should not exceed limits;
- Particle size distribution complies NBN EN_13043;
- Uniformity and consistent quality.

Legal requirements:

Filter cake filler will be valorised as secondary raw material. This requires a statute, else filter cakes will still be deemed as waste material. In case the statute is not obtained, problems may be encountered with environmental permits and additional requirements with regard to emissions.

Environmental hygiene requirements:

The filler must meet the criteria for secondary building materials, imposed by the VLAREMA.

8.1.2 Filler manufacturers

In order to determine the position on the market, the competitors must be identified and judged. The filler market is dominated by a select number of manufacturers. The major firms are the following:

- Sibelco Europe MineralsPlus;
- Rheinkalk;
- HeidelbergCement.

8.2 Place

It is important to make a correct estimate of the share that a new product will dominate within the existing market. This is mainly determined by the place of distribution. AMORAS annually produces an average of 500.000 tons dry matter. It will, however, only be possible to apply a fragment within a certain region.

Figure 15 shows the quantity of filler, delivered with the BENOR certificate. In 2013, 93.822 tons filler were delivered throughout Belgium.

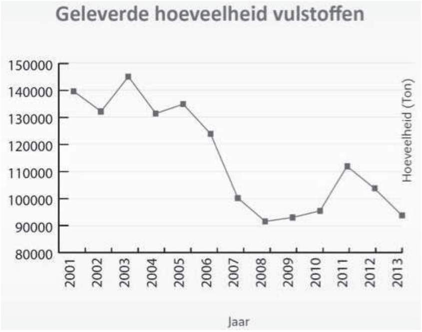
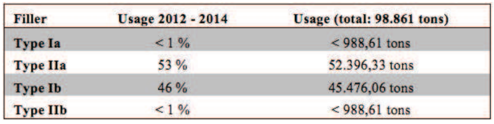


Figure 15: BENOR certificated filler delivered to asphalt plants in Belgium (source:[9])

Not every asphalt plant applies the same type of fillers, therefor the used quantities are very different for each plant. Table 13 shows the total amount of the different types of filler, applied in asphalt mixtures in Belgium. For this analysis, the total amount of distributed type II filler should be recalculated to AMORAS's situation by taking only the asphalt plants into account within a certain perimeter (see Figure 16).

Table 13: Filler usage 2012-2014 (source:[9])



Filler	Usage 2012 - 2014	Usage (total: 98.861 tons)
Type Ia	< 1 %	< 988,61 tons
Type IIa	53 %	52.396,33 tons
Type Ib	46 %	45.476,06 tons
Type IIb	< 1 %	< 988,61 tons

Table 13 shows that, in total, more or less 52.890,64 tons type II filler is distributed in Belgium. In this study, the assumption is made that 40 % of this total will be replaced with filter cake filler, which corresponds to 21.156,26 tons.

Recalculation to AMORAS's situation is divided into two situations, a perimeter of 50 and 100 km is set. Within these regions, respectively 7 and 17 asphalt plants are located out of a total of 38. For both situations, filter cakes can replace respectively 3.897,20 and 9.464,64 tons of filler.

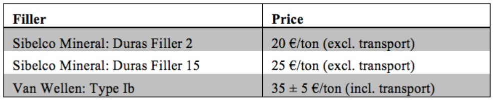
8.3 Price

Just as the quantity that can be processed, the price is a determining factor for further development. In this paragraph, an estimate is defined for the cost that may be charged for refining, drying and grinding the filter cakes in order for the process to be profitable. Since this situation is delicate (new product) and little information is available, some assumptions are made.

8.3.1 Filler pricing

Prices of existing fillers were retrieved from various firms. Results are shown in Table 14.

Table 14: Filler pricing



Filler	Price
Sibelco Mineral: Duras Filler 2	20 €/ton (excl. transport)
Sibelco Mineral: Duras Filler 15	25 €/ton (excl. transport)
Van Wellen: Type Ib	35 ± 5 €/ton (incl. transport)

Further calculations will be made with Duras Filler 2 pricing, as this is the only type II filler.

8.3.2 Transportation cost

Since filler has a relatively low economical value per ton, transportation costs will have a high impact on the pricing. Therefore, filter cake filler will only be available within a certain region. The perimeter of this region will have to be compared to the existing suppliers (Figure 16). In this study a perimeter of 50 and 100 km's is set.

Figure 16: Asphalt plants within a perimeter of 50 or 100 km (respectively green and orange)

Transportation cost were retrieved from various firms for bulk transportation of 30 tons, resulting in a price range of 1-2 €/km.

In addition to the basic cost, fuel surcharge should be taken into account. This factor was introduced in order to charge the fluctuating fuel prices in a simple manner. In the future (April 2016), an extra road tax for trucks will be introduced.

8.3.3 Deposit costs

By depositing material, two costs need to be taken into account. These being the actual physical cost and the capital levy, charged by the government.

Because of confidentiality, actual figures cannot be given.

8.4 Promotion

As test results indicate that filter cake filler is an inferior product (for now, further investigation is needed) in comparison with the existing type II fillers, financial support for reuse is necessary. Currently, the deposit of filter cakes is more likely to be cheaper than processing. Therefore resources are necessary to stimulate sustainable reuse.

8.5 Final calculation

In order to upgrade the processing installation of AMORAS, a maximum cost needs to be defined for the refining, drying and grinding of filter cakes. This value will be the break-even point in terms of comparison with both the existing filler and the deposit. Pre-processing of the sludge into filter cakes is not taken into account, as this is required for deposit too.

The cost (described above) will be determined by two factors, current filler pricing and deposit costs. Adding these two together indicates the maximum cost.

9 Conclusion

This study shows that filter cakes can't be applied in pure, wet form in asphalt mixtures. The bound water cools the mixture in such a way that homogeneous mixing is impossible. Tests on poorly mixed cylinders show a very low tensile strength.

According to test results, application of filter cakes as processed dry filler is neither possible in pure form. The product contains a high amount of fine particles, which decreases water sensitivity vastly. However, the mixture with only 50 % filter cakes is more promising. Water sensitivity only drops slightly below the 80 % limit imposed by SB250 v3.1. Further research is required to design the optimal mixture.

Results in order to classify pure filter cakes as filler are neither very promising. Certain tests exceed the set limits such as methylene blue and bitumen number. The stiffening effect is so distinct that results in terms of delta ring and ball avoid usage in cold recycling. Further research may be done into the use of filter cakes in liquid asphalt.

The economic analysis indicates a certain possibility to apply filter cake filler within the current market. Only a small partition of the annual 500.000 tons dry matter will be available though. Therefore, new research is required with regard to different applications which require identical processing.

Additional processing involves refining, drying and grinding of filter cakes into filler. The break-even point of this treatment is estimated on the basis of the existing fillers and the deposit costs. It should be checked whether or not this guideline is also valid for the additional applications that need this processing.

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