# Rutting resistance of SMA determined with triaxial and wheel-tracking tests.

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ABSTRACT: In the Netherlands a CROW working group has developed a new mix design for SMA based on a volumetric approach. A software program can calculate the realised void content in SMA with the following input data: mix composition, densities of the components, air voids content of the compacted stone skeleton. The theoretical voids content in SMA, based on filling the air voids in the stone skeleton with a volume of mortar, can be translated into the realised air voids content in SMA with a socalled shift factor. This shift factor takes into account the enlarging effect of air voids content of the stone skeleton in SMA due to the presence of mortar between the stones in SMA. In this way the desired SMA mixture can be calculated based on air voids content requirements. This mix design procedure has to be validated by compacting three SMA mixtures: one mixture with the calculated required air voids content and two mixtures with a stone content +/- 2,5 % the calculated stone content. Based on the realised air voids content in SMA and the stone content in SMA the required mixture can be chosen by interpolation.

To validate the new mix design procedure two mixtures from test sites were studied. To study the effect of filling the air voids content of the SMA stone skeleton with mortar on the resistance to rutting different variations of filling of those SMA mixtures were investigated with the wheel-tracking and triaxial test. For the mixture of each test site 5 different compositions were tested varying from strongly underfilled to strongly overfilled with mortar. The 5 different mix compositions were volumetrically kept constant. For one test site the normal crusher sand in the mixture was substituted by Scottish granite crusher sand and in the other case by fine natural sand. This was done to investigate the effect of the sand on the enlarging effect of the stone skeleton and on the resistance to permanent deformation. In this paper the results of wheel-tracking and triaxial tests on these mixtures are discussed.

## 1 INTRODUCTION

The Dutch CROW working group Implementation Volumetric Mix Design SMA (IVO-SMA) has developed a new volumetric mix design method, see Van de Ven (2008). With new software using as input the data of grading, densities of components and air void contents of the compacted stone skeleton (HRS), SMA mixtures can be designed by calculation. The idea is based on filling the HRS of the stone skeleton in such a way with mortar volume that the SMA mixture will meet the target air void content (AV). The software takes into account the enlarging effect of the stone skeleton, the socalled shift factor. The cause of this enlarging effect of the stone skeleton (higher HRS in the stone skeleton in the mix) is that sand and/or filler grains are between the stones of the stone skeleton after compaction resulting in higher HRS of the stone skeleton. The shift factor translates the theoretical AV into the realised AV in a compacted SMA mixture.

The major parameter in the SMA mixture design is still the specified AV of the compacted SMA specimen. To investigate if the specified AV will lead to an optimal SMA mixture, rut tests were carried out on two SMA mixtures from test sites of the working group, by varying the mix composition from underfilled to overfilled with mortar. The idea was that with triaxial and/or wheel-tracking tests a turning point in the permanent deformation could be found between underfilled and overfilled SMA mixtures. This was based on the assumption that underfilled SMA mixtures would hardly deform due to the stable stone skeleton and that with increasing the filling of the stone skeleton with mortar a turning point could be found to more rutting sentive SMA mixture (no more stone-to-stone-skeleton).

The reason why in this project was choosen for two rutting tests is based on the experience of Van Dommelen (2004) and Surie (2006) that the triaxial test probably does not predict the rut resistance of SMA always well.

The theoretical degree of filling of SMA can be calculated with the filling ratio (FRS) conform Voskuilen (2000). The FRS is defined as the ratio between the mortar volume and the HRS of the compacted stone skeleton. The enlarging effect of the stone skeleton in the realised SMA is not taken into account, so the real AV in SMA is higher than based on FRS calculations. An FRS value of 0 will theoretically result in an AV of 0% (in reality higher due to the enlarging effect of the stone skelton), the more negative the FRS, the higher the AV in SMA. A possitive FRS value results in an overfilled SMA and a theoretical AV content of 0%.

SMA is well known as a durable stable mixture. Due to the grain-to-grain contact of the stone skeleton the mixture has a high restistance to rutting and due to the high binder content the mixture SMA is very durable. The stone skeleton is realised if the mortar volume (sand + filler + drainage inhibitors + bitumen) is smaller than the available HRS in the stone skeleton. This is shown in figure 1.

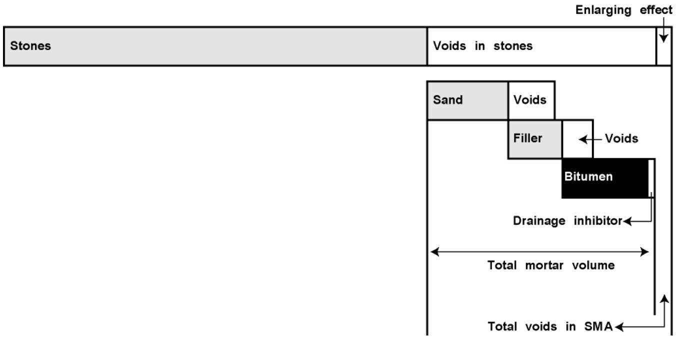

Figure 1. Schematic volumetric composition of SMA.

For volumetric calculations, the HRS of the stone skeleton > 2mm is determined with gyratory compaction conform CROW (2003). With data of mix composition, material densities and HRS the filling ratio (FRS) is calculated as follows:

$$FRS = (((Vm-HRS)/HRS)) \times 100\%$$

in which:

FRS = filling ratio (ratio between mortar volume and volume of available air void content in the optimal compacted stone skeleton)

$V_m$ = mortar volume (bitumen, drainage inhibitor, filler and sand)

HRS = air void in optimal compacted stone skeleton

The FRS is used as a tool to calculate the mix composition of the investigated series SMA mixtures to obtain mixtures with the same volumetric mix composition, but consisting of other materials.

## 2. OBJECTIVE

The aim of this research work was to get answers to the three following questions:

**Question 1**. – the current mix design is based on of the specified AV after lab compaction. Four SMA mixtures with constant bitumen content but with different coarse material contents are prepared with two times fifty Marshall blows. In those four mixtures the sand/filler ratio is kept constant and the sand/filler volume in the mortar changes dependent on the coarse material content; the more stone, the less sand/filler. The question is how the rutting resistance of those SMA mixtures with different mortar composition will be influenced.

The objective is to investigate what the effects of changes in mortar composition are on rutting resistance with underfilled SMA mixtures. (see figure 2).

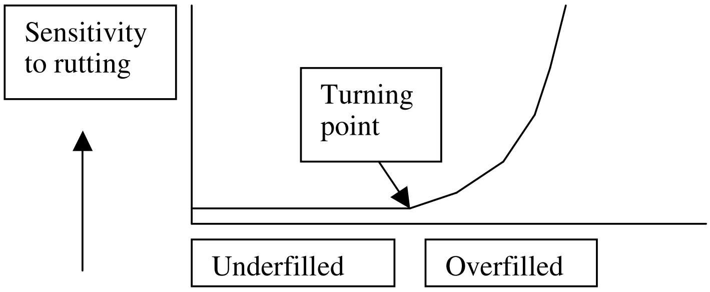

Figure 2. Hypothesis question 1

**Question 2.** In Van de Ven (2008) it was determined that the shift factor is dependent of the HRS value of the coarse material. With the help of the shift factor the theoretical AV in SMA, calculated with the HRS value, is converted into the realised AV in a compacted SMA specimen. Maybe the shift factor also can be influenced by de fineness and/or the quality of the sand. The objective of this research is to determine if the fineness and/or quality of the sand has influence on the enlarging effect of the stone skeleton with volumetricly equal mixtures.

**Question 3.** In Van Dommelen (2004) and Surie (2006) it is questioned if the triaxial test can predict resistance to rutting of SMA mixtures. The objective of this research is to determine if SMA mixtures varying from underfilled to overfilled act the same in the triaxial and the wheel-tracking test (small device). To answer these three questions a combined research was carried out.

## 3. EXPERIMENTAL

To investigate if a turning point in the rutting resistance can be determined in the range of under to overfilled SMA mixtures, four series of SMA mixture are investigated with FRS values of -12, -4, +4, +12 and +20. The expectation was that the turning point would be around –4, because in CROW (2003)] it was determined that an FRS value of -4 gives an AV of SMA of about 5% (= requirement of the SMA mixture for heavy trafficked roads). As basis of the research work two SMA mixtures were selected from the

IVO-SMA test sites: SMA 11 mixture from the Ureterp test site and SMA 11 mixture from the Zeddam test site. The coarse material of the Ureterp SMA mixture was Bestone with a HRS value of 38.4%, the coarse material of the Zeddam SMA mixture was Augit Porphyry with a HRS value of 40.9%.
The Ureterp SMA mixture was also used to investigate the influence of the sand. To investigate this separately from the standard Ureterp SMA also two 2 series SMA specimens were prepared with FRS values from –12 to +20, with the same materials as the standard Uretep SMA except the sand. Instead of moraine crusher sand as used in the standard Ureterp SMA in one case a fine natural sand was applied and in the other case Scottish granite crusher sand, with a lower resistance to crushing were used. Summarised mix compositions of the four groups are given in table 1.

Table 1. Mix composition in mass percentages of the tested SMA mixtures.

| Mix variation | FRS | -12 | -4 | 4 | 12 | 20 |
|---|---|---|---|---|---|---|
| Standard Ureterp Mixture | **Ureterp SMA test site mix (moraine)** | | | | | |
| | Passing sieve 2 mm | 25.1 | 27.4 | 29.6 | 31.6 | 33.4 |
| | Passing sieve 0.063 mm | 93.6 | 92.9 | 92.1 | 92.9 | 90.7 |
| | Bitumen in mix | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| Sand fraction in Ureterp mixture replaced | **Ureterp SMA Scottish crusher sand** | | | | | |
| | Passing sieve 2 mm | 25.1 | 27.4 | 29.6 | 31.5 | 33.4 |
| | Passing sieve 0.063 mm | 93.6 | 92.9 | 92.1 | 91.4 | 90.7 |
| | Bitumen in mix | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| | **Ureterp SMA natural sand** | | | | | |
| | Passing sieve 2 mm | 25.0 | 27.3 | 29.5 | 31.4 | 33.3 |
| | Passing sieve 0.063 mm | 93.7 | 92.9 | 92.1 | 91.5 | 90.7 |
| | Bitumen | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| Standard Zeddam mixture | **Zeddam SMA test site mix** | | | | | |
| | Passing sieve 2 mm | 27.2 | 30.1 | 32.4 | 34.3 | 36.4 |
| | Passing sieve 0.063 mm | 92.8 | 91.6 | 91.1 | 90.5 | 89.8 |
| | Bitumen in mix | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |

All mixtures in the series have the same FRS values, the bitumen content is constant, the coarse material content decreases if the FRS value increases. Note that also the volume of sand and filler decreases when the FRS value increases. As a consequence of this the free bitumen contant decreases in the mortar when the FRS value increases resulting in a mortar that will become stiffer. In figure 3 the volumetric compositions are presented of mixtures with FRS values varying from –12 to +20. These volumetric compositions are used for the FRS series of all four mixtures summarised in table 1.

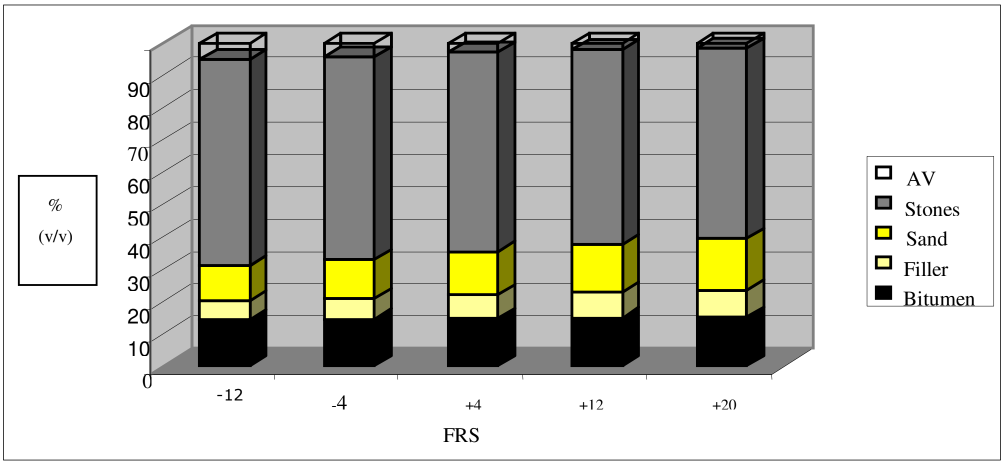

Figure 3. Volumetric composition of investigated SMA mixtures.

### *3.1 Specimen preparation*

To determine the reference density after compaction for all mixtures, first Marshall specimens were compacted with two times fifty blows. The asphalt was mixed conform EN 12697-35 with a laboratory mixer of 30 liter and compacted with a laboratory compactor conform FGSV (2003). The compacted slabs had a degree of compaction between 99 and 101% based on the target density determined with two times fifty Marshall blows.

### *3.2 Determination of rutting resistance*

The resistance to permanent deformation of the SMA mixtures is determined with the triaxial and wheel-tracking test (small device), both conform the European norms EN-12697-25B and EN 12697-22. In Gharabaghy (2006) and FGSV (2003) more background information is given about this research. The Technical University of Aachen has prepared the specimens for the rutting tests and carried out the research work.

## 4. RESULTS

### *4.1 Air voids contents (AV) in SMA mixtures*

In figure 4 the AV of SMA is given of the Marshall compacted specimens of the Ureterp SMA specimens. The standard Ureterp test site mixture contains moraine crusher sand, and in the two other series specimens the moraine crusher sand is substituted by fine natural sand and Scottish granite crusher sand (table 1).

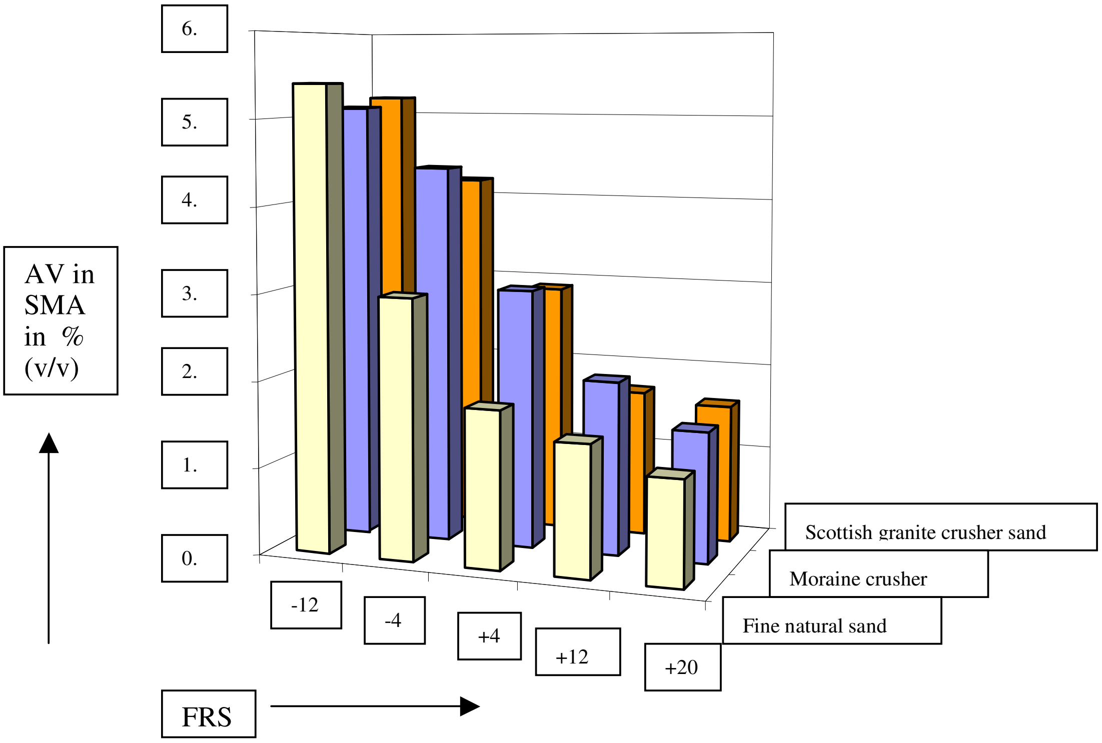

Figure 4. Air void contents versus FRS values of Ureterp SMA mixtures.

From figure 4 the following conclusions can be made:

- The Ureterp SMA has at FRS –4 a lower AV compared to earlier investigated SMA mixtures with the same FRS value.

- The fine natural sand has lower enlarging effect than both crusher sands. As a consequence of that the AV in SMA with fine natural sand is lower.
- Although overfilled SMA mixtures (positive FRS) theoretically should have an AV of 0%, AV's of these SMA's are between 1.2 to 3%. Possibly this is due to trapped air in the mortar. Based on experiences it is well known that SMA mixtures with such low air void content have a low rut resistance.
- SMA mixtures with different types of sand with FRS values of –12 have the same AV level. The sand type doesn't have influence on the realised AV content of SMA. The relatively low volume of mortar and the very bitumen rich mortar can explain this.

In table 2 the AV is given of the Marshall compacted SMA specimens of the Zeddam SMA mixture at FRS values of –12 to +20.

Table 2. Results of AV of SMA Zeddam mixtures of FRS values from –12 to +20.

| FRS | -12 | -4 | +4 | +12 | +20 |
|---|---|---|---|---|---|
| Air void content in SMA (v/v%) | 7.7 | 6.2 | 4.8 | 3.7 | 3.3 |

From table 2 it can be seen that positive FRS values can result in air void contents of 3.3 to 4.8% or higher, while the realised AV's in SMA theoretically on basis of filling the AV content of stones with mortar should be zero. This means that besides the enlarging effect of the stone skeleton also air must be trapped in the mortar.  Because there is no real stone-to-stone contact, these mixtures can be sensitive to rutting.

## *4.2 Reseach into the turning point between under and overfilled SMA mixtures.*

### *4.2.1. Results of the wheel-tracking test (small device)*

In figures 5 and 6 results are given of the small wheel-tracking device for the Ureterp and Zeddam SMA mixtures.

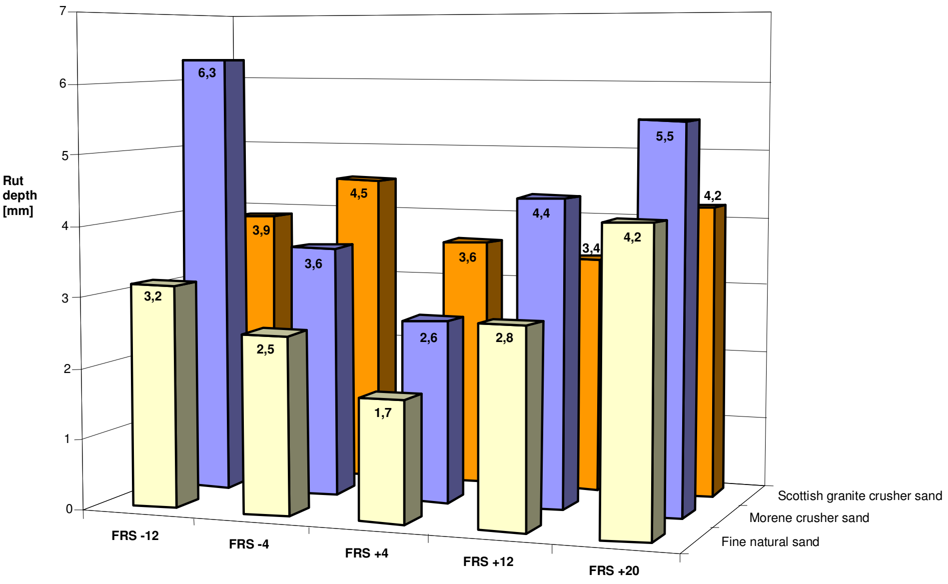

Figure 5. Results of the wheel-tracking tests of the Ureterp SMA mixtures (small device).

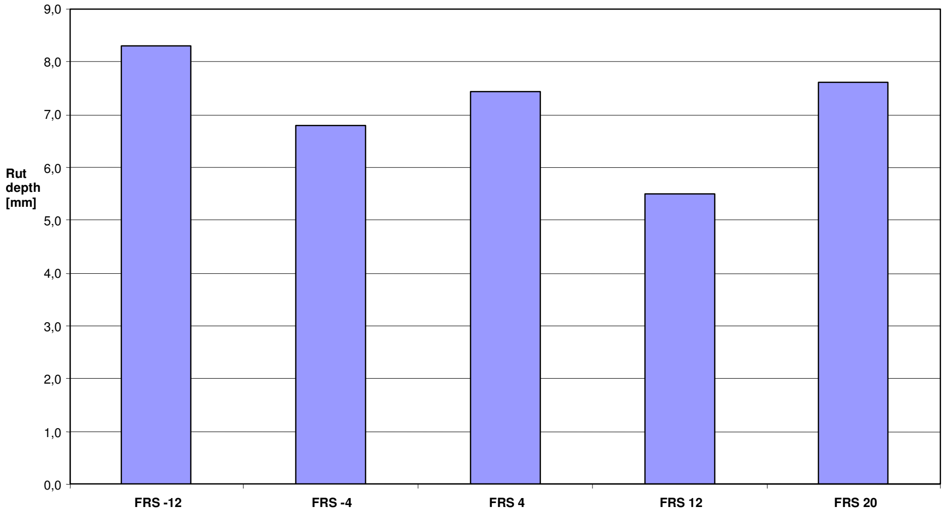

Figure 6. Results of the wheel-tracking test of the Zeddam SMA mixture (small device).

### *4.2.2. Results of triaxial tests.*

In figure 7 and 8 results are given of the traiaxial tests of the Ureterp SMA series and the Zeddam SMA mixture. Parameters used are strain after 1000 and 10000 cycles and the slope of the creep curve in the steady state , see Gharabaghy (2006).

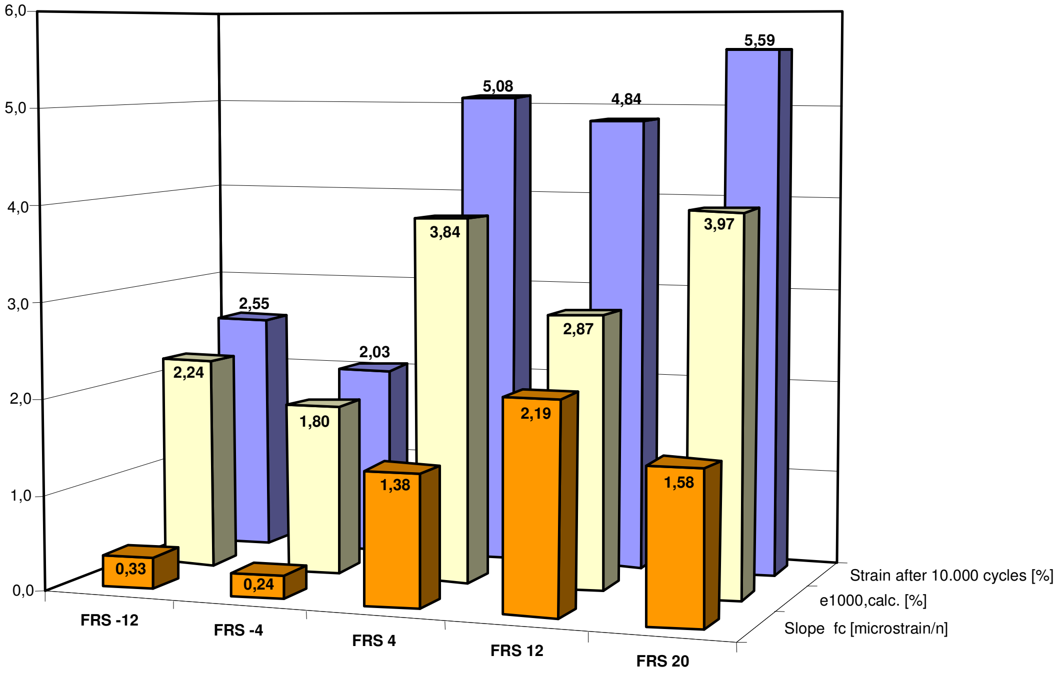

Figure 7. Results of the triaxial tests of the Ureterp SMA mixtures.

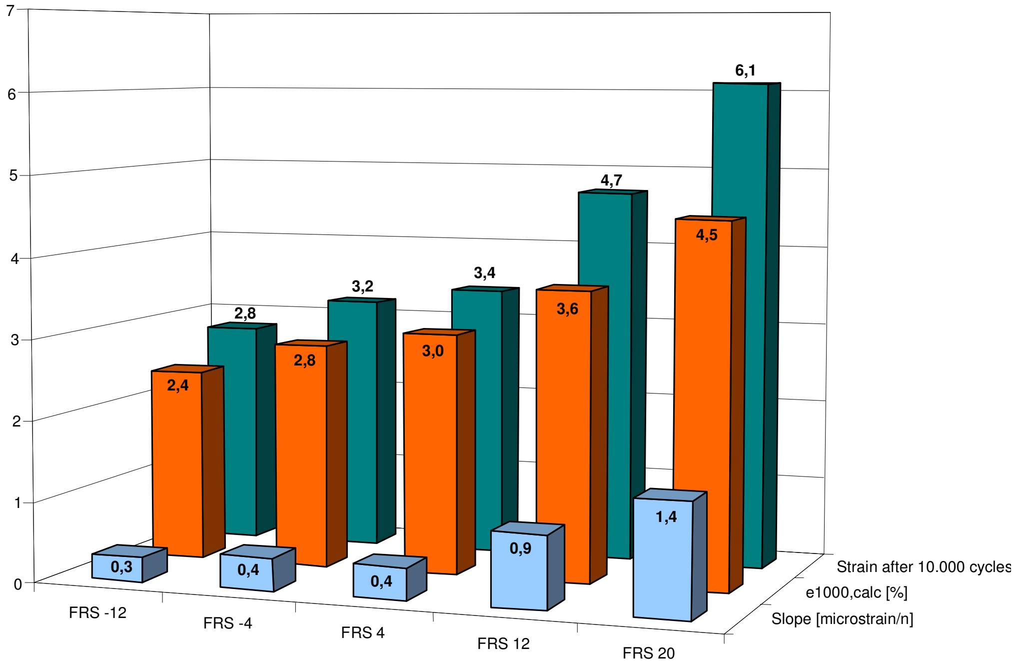

Figure 8. Results of the triaxial tests of the Zeddam SMA test site mixture.

## 5. DISCLUSION

### *5.1 Air void content (AV) in the mix design*

The question to be asked is whether it is sufficient to design the SMA mix only on AV to guarantee a good rut resistance. This is very relevant, because during the Dutch mix design no mechanical tests are carried out to determine the rut resistance. The idea with SMA is that if at the used compaction level a mixture is underfilled and has sufficient AV, the mixture cannot get overfilled with mortar during service life and will have a good rut resistance due to the grain-to-grain contact of the stone skeleton.

The results of the wheel-tracking tests show that the Ureterp SMA test site mixtures with FRS values of –12 to –4 with air void contents from 6.3 to 3.6% still can be sensitive for rutting!

The triaxial test results show that the same Ureterp SMA mixtures have a good rutting resistance!! This can probably be explained by the continuous confinement of the specimen in this test, making it difficult to develop permanent deformation.

If SMA mixtures are designed with a high stone content (very negative FRS) with sufficient AV, these mixtures still can be sensitive for rutting if the mix composition is outsite the field of experience, for example by using alternative stones with a high HRS value. It is recommended to design SMA mixtures in the field of experiences with FRS values varying between approximately –6 tot 0.

### *5.2 Fixed bitumen percentage*

To ensure the durability the high bitumen content is kept constant during mix design, while the stone percentages vary of the investigated mixtures. As a consequence of this the composition of the mortar varies, because the mortar is compensated volumetrically by adding or deminishing sand/filler at the fixed bitumen content, by which the sand/filler ratio is kept constant (65/35). To give insight in the permissable deviations in mortar composition in table 3 a comparison is given of the mortar compositions of SMA and Porous Asphalt conform the Dutch national standard RAW 2005. The minimum and maximum tolerances of SMA 11 mortar are shown. Based on assumed densities of sand and filler of 2700 kg/m$^3$ and bitumen of 1020 kg/m$^3$ the ratios between volumes of the sand/filler mix and bitumen are given to show some insight in the allowed deviations. The same is done for the PA 16 mortar.

Table 3. Overview of mortar compositions of PA 16 and SMA 11.

| | PA | SMA | | |
|---|---|---|---|---|
| | standard PA 16 | standard SMA 11 | minimum tolerance SMA 11 | maximum tolerance SMA 11 |
| | mortar composition (mass %) | mortar Composition (mass %) | mortar composition (mass %) | mortar composition (mass %) |
| Sand | 10 | 15 | 10 | 20 |
| Filler | 4.5 | 8 | 6 | 10 |
| bitumen | 4.5 | 7 | 7 | 7 |
| | | | | |
| Volume ratio (sand+filler)/bitumen | 1.22 | 1.24 | 0.86 | 1.62 |

Table 3 shows that the volume ratio for SMA is allowed to vary considerably. It is striking that the volume ratio between sand/filler and bitumen of PA and SMA are quit simular. Because of the gap between 2 and 6 mm, the air void content of 20% of PA is coarse divided. To keep the stone skeleton stable, a stable mortar is needed. Field experience have shown that the mortars of PA and SMA are stable and durable.

SMA mixtures with a high free bitumen content and with a low mortar volume ratio will cause a shorter service life. Wheel-tracking results show that those mixtures can't keep the stone skeleton stable, resulting in premature rutting.

Due to high stone percentages the mortar will consist of a relatively low amount of sand and filler. As a result of this the mortar will have a high free bitumen content. These mortars will be more unstable than the standard mortar composition.

Relatively low stone contents will result in mortars with a relative high amount of sand and filler. Due to that these mortars will have lower free bitumen content and will be stiffer than the standard mortar.

The differance in mortar composition in combination with high and low stone percentages will have influence on the bonding strengh of the stone skeleton and thus stability.

For the benefit of stability it should be considered to keep the mortar composition constant during mix design and to vary only the mortar volume. To ensure the durablity a requirement for minimum bitumen content in the mortar is recommended.

### *5.3 Enlarging effect*

If realised AV contents of SMA mixtures with the same volumetric mix composition (theoretical same AV content) but prepared with coarse and fine natural sand it can be seen that the fineness of the sand has influence on the realised AV content of SMA. From this it can be concluded that the grading of the sand fraction has influence on the enlarging effect of the stone skeleton and so also on the shift factor. It is recommended to take into account this enlarging effect of the sand fraction if the shift factor is determined.

### *5.4 Predictability of rut resistance tests*

The wheel-tracking tests give unexpected results. Especially SMA mixtures with very low negative FRS values and very high FRS values had the worst rutting resistance. Underfilled SMA mixtures (high stone %) with a strong overfilled mortar are more sensitive to rutting than SMA mixtures with a less overfilled mortar. Mixtures with FRS values of about +4 show the best rut resistance.

The triaxial results were as aspected; mixtures with a negative FRS have a good rut resistance and the more positive the FRS, the worse the rut resistance.

The results of the triaxial tests possibly differ from wheel-tracking tests because underfilled SMA mixtures with overfilled mortar can't develop permanent deformation due to the confinement. This is different in the wheel-tracking test, where the specimens have only temporary passive confinement.

On the A2 close to Maastricht premature rutting developed in SMA 11 four months after construction (rut depth up to 20 mm!). The contractor had to replace this layer in the guarantee period. From the emergency lane consisting of the same SMA mixture specimens were taken.
On these specimens the Technical University of Aachen did triaxial tests as well as wheel-tracking tests. From the triaxial tests, which were carried out with the same test conditions as the tests shown in figure 7 and 8, it can be seen that the strain after 10.000 load repetitions was 1.62% and the slope`was 0.33 (micro strain/cycle) and the strain after 1000 load repetitions was 1.39%. From these results it can be concluded that the failed A2 SMA act excellent in the triaxial test.
The small wheel-tracking test had to be finished prematurely, because the test specimens were exceeding the maximal allowable deformation. From this it can be concluded that the A2 SMA acts very poor, which agrees with the field performance on the A2. Because it is only one test with one asphalt mix type the conclusion cannot be generalised, but it seems that the predictability for field performance of the small wheel-tracking device is better than that of the triaxial test.

The triaxial test as well as the small wheel-tracking test predicts the same trend for field rutting, if the SMA mixtures are overfilled. If the SMA mixtures are underfilled, but the mortar is overfilled, the small wheel-tracking test predicts well and the triaxial test not. The trend of the observations is schematically summarised in figure 9.

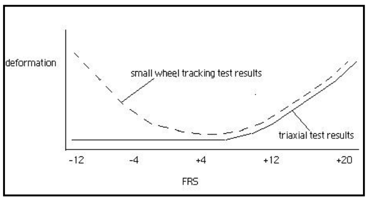

Figure 9. Trends from triaxial and small wheel-tracking tests.

If the designed SMA mixtures consist of standard materials, the mix composition is within the field of experiences and the air void content and the bitumen content is sufficient, a good rutting resistance will be realised. If one moves outside the field of experience (for example high HRS of the coarse material), extra attention must be given to the mortar composition and probably extra mechanical testing is necessary.

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