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Comparing lab to field properties in CEN Type Testing for Asphalt Concrete – the NL-LAB program

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Abstract

In 2008 Europe introduced the CEN standards for Asphalt Concrete (EN13108 series). The Netherlands adopted the approach of fundamental requirements and input target composition. The aim was to achieve a better understanding of those mechanical properties and eventually enable less prescriptive requirements for the composition while retaining well-functioning pavement materials. This was seen as a pre-requisite for innovations in pavement engineering and pavement materials.

Some surprises in laboratory performance led to the initiation of a program using the Dutch road network as a living laboratory (NL-LAB). Using laboratory produced and field specimens, this program aims first of all to assess the effects of mixing and compaction on the fundamental properties used in the Netherlands. This paper describes the NL-LAB program and the results for the first projects that are analysed, focussing on the stiffness and resistance to permanent deformation. The results show that, although the fundamental approach indeed stimulates research into a more fundamental understanding of Asphalt Concrete, the current understanding is still far from complete. It also highlights the importance of well standardized tests and the importance of inter-laboratory studies.

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1. Introduction: reasons for the research program

In 2008 Europe introduced the CEN standards for Asphalt Concrete (EN13108 series). The standard for Asphalt Concrete (EN13108-1) allows the use of either empirical (related to composition, such as VMA) or fundamental (related to mechanical properties, such as stiffness) requirements in addition to general requirements such as composition and moisture sensitivity. The mix formulation can be based on either input (based on grading curve and bitumen content added) or output target composition (based on mid-point grading and soluble bitumen content). The Netherlands adopted the approach of fundamental requirements and input target composition. The aim was to achieve a better understanding of those mechanical properties and eventually enable less prescriptive requirements for the composition while retaining well-functioning pavement materials. This was seen as a pre-requisite for innovations in pavement engineering and pavement materials.
Prior to the introduction of the EN standards, there was elaborate experience in the Netherlands with the resistance to fatigue and stiffness (determined using the four point bending test, EN 12697-24 and EN 12697-26), while the triaxial test (EN 12697-25) and the Indirect Tensile test Ratio (ITSR, EN 12697-12 and EN 12697-23) as standardized by CEN were relatively new.
From experience it was known that stiffness and fatigue resistance are inter-related: if the if the stiffness increases, due to less or harder bitumen in the mix, the fatigue resistance decreases (Dommelen, van et al, 2008). Based on some research projects (CROW, 2011) it was expected that this would also hold true for the other properties, with resistance to permanent deformation increasing and the resistance moisture damage decreasing (where decreasing resistance to moisture damage = increasing water sensitivity) with increasing stiffness. As such it was expected that although the CEN standard allowed more freedom in mixture composition, the general trends would hold and that this combination of properties would provide a reliable framework for mixture design.

In the period between 2008 and 2012 there were several developments that lead to a wish to evaluate the current functional tests and to try and establish the relation between these properties and the performance in the pavement. These developments included (Erkens et al., 2014):

- The stiffnesses that were reported appeared to be higher than those known from the past, this could be due to improvements in the test set-ups, the materials used, or testing protocols. It is important since the mix stiffness directly affects the structural design (pavement thickness) and thus structural safety
- There were some issues regarding repeatability and reproducibility of the tests, this may be a matter of experience but it can also be due to the relatively long time between Type Tests (1 per five years if the mixture composition stays the same) the variety in constituent materials, particular PR may play a role.
- The relations based on past experience were valid for large groups of mixes, will they also hold when predicting the performance of a single mixture based on its lab characterisation?
- Mixes with increasing (50%) RAP appear not to follow the past trend, all four functional characteristics improve with increasing RAP%, if this is true also in the pavement that is good news, but past experience showed that for more 50% RAP the mixtures field performance become very variable, probable due to increased sensitivity to production and construction conditions, it is unclear if the quality of the production process with RA has improved, or the current set of tests has limits for asphalt concrete with RA
- For some, especially low temperature, mixtures laboratory production proved difficult. This raises the question how well lab conditions represented actual field conditions, which has a direct impact on the reliability of the performance predictions

The overall assessment in the Netherlands on using the functional requirements is positive, in combination with innovative contracts which place more responsibility with contractors, it has led to a lot of research and innovation. Despite that, the questions mentioned above need to be addressed and even a good system can be improved. This led to a long term research program that uses the Dutch road system as a living laboratory, trough long term field monitoring. Previous projects like the program that introduced double layer Porous Asphalt wearing courses showed the advantages of such a systematic approach (Bennis at al., 2008 and Erkens and van Vliet et al, 2014). The aim of the current project is to get an up to date reference frame based on commonly used mixtures, as well as a frame work for the evaluation and possibly improvement of the functional tests and the requirements based on them. This will help to improve the functional requirements and tests where necessary.
In this paper results from the first four construction projects are presented and analysed. This analysis builds on previous publications (Mookhoek et al., 2014 Sluer et al., 2014, Florio et al., 2014 and Erkens et al., 2015). The total overview up till the end of 2016 and an in-depth analyses can be found in Erkens et al., 2017.

2. Research program

2.1. Overall approach

The research program aims to use the Dutch road network as a living laboratory (NL-LAB = National Living LAB) to get the answers to the research questions. Although the Netherlands is a small country, the density of its road network provide ample opportunity for field testing (Fig. 1, the Dutch road network was in 2010 the 6th densest of the world with 331 km of road per 100 km^2 land area).

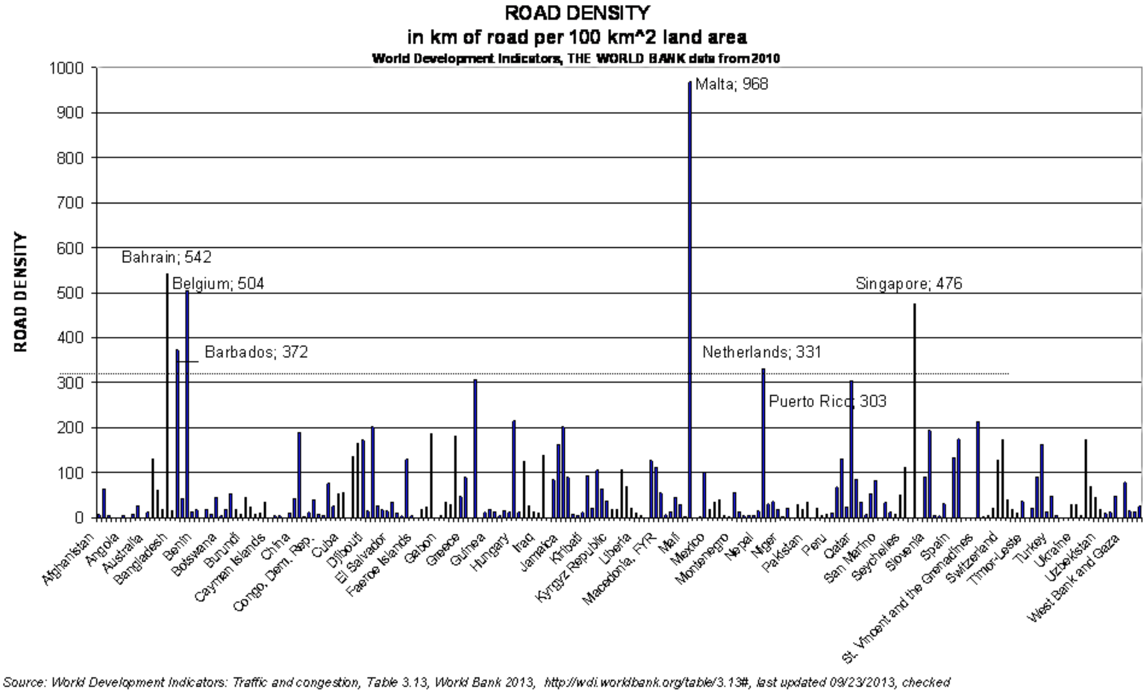

Fig. 1: The Dutch road network is one of the most dense in the world

However, field tests alone won't provide answers to the research questions. The program combines lab testing with field monitoring as follows:

I. Asses the effect of mixing and compaction on the lab determined properties
II. Follow the changes of lab determined properties over time
III. Monitor the pavement performance in time

The first step (I) is addressed by making specimens in three different ways:

F1: Lab mixed and lab compacted
F2: Plant mixed and lab compacted
F3: Plant mixed and field compacted, specimens taken from the pavement (F3c: specimens tested 2 years after construction)

This stage gives insight in the effects of mixing and compacting as well as providing a first indication of the relation between the predictive quality of lab mixed and compacted specimens for field properties.

Stage II consists of repeated tests on specimens taken from the pavement, showing the variation that occurs over time. Since damaging the pavement to take plates and repeatedly disrupting traffic discourages road agencies from participating, another method was chosen after the first project. Now, directly after construction plates are taken for the specimens for immediate testing as well as for testing after 2 and 6 years, respectively. Those plates are stored under controlled conditions. This way the effect of traffic is excluded and the changes in properties are solely related to changing material characteristics. Eventually, these changes can be related to aging indicators.

Stage III consists of monitoring pavement performance over time. This is straight forward for wearing courses, for binder and base courses it is more complicated. For those locations the monitoring is more indirect, based on the performance of the pavement structure as a whole.

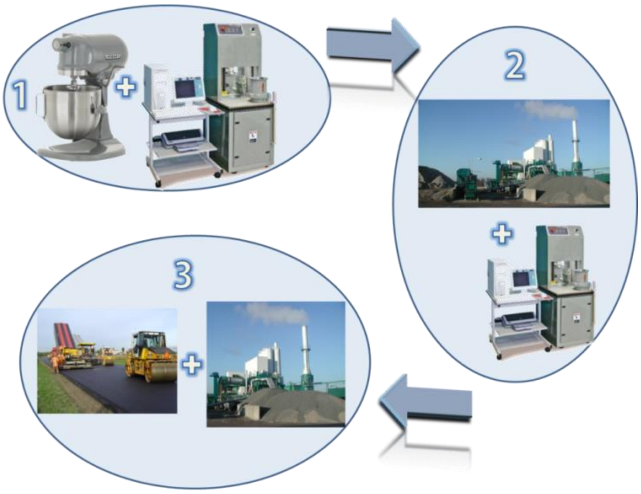

Fig. 2: In step I of the program, specimens produced in three different ways are tested

2.2. Tests and materials in the research program

2.2.1. Tests on asphalt concrete:

The tests performed on asphalt concrete are: bulk density (EN 12697-6), maximum density (12697-5), void content (12697-8), moisture sensitivity (EN 12697-12, method A and EN 12697-23), stiffness (EN 12697-26, Annex B four point bending on prismatic specimens (4PB-PR), resistance to fatigue (EN 12697-24, annex D, four point bending on prismatic specimens) and resistance to permanent deformation according to EN 12697-25 (Test method B — Triaxial cyclic compression test). These asphalt concrete tests are performed by the contractor.

***2.2.2.** Tests on bitumen:*

All bitumen samples are tested for penetration (NEN-EN 1426:2007), ring and ball temperature (NEN-EN 1427:2007), DSR stiffness (NEN-EN 14770:2012) en DSR fatigue (protocol RILEM TC 182 ATB, TG1 "Binders", 20) and en gel permeation chromatography (GPC, Methode TNO, version 3, 27-02-2012). The bitumen tests (except for project 3 (P3)) are performed by TNO, a research institute in the Netherlands.

2.3. Materials & requirements

For now, the program focusses on the testing of AC binder and base layer mixtures (EN 13108-1), since those can be specified functionally since 2008. At the moment five works have been constructed and tested, four of them are presented in this paper. The mixes used in these first four projects contain 60, 50, 65 and 65% reclaimed asphalt, respectively. These are normal amounts of RA in Dutch binder and base course mixtures. Up to the implementation of the European standards, the amount of RA in binder and base course mixes was limited to 50%. Because in the Netherlands the functional approach was taken, the more functional requirements meant less requirements on composition. As a result, since 2008 the amount of PA is no longer restricted.

The requirements for asphalt concrete mixes are based on the number of trucks that pass per 24 hours per driving direction. The more trucks, the higher for example the required stiffness. Categories go from A to C and there is a special category IB (Dutch for heavily loaded) for areas where slow driving trucks occur. The corresponding requirements are given in Table 1. The materials tested all fulfil the requirements for base/binder layers category C and all but Work (W) 3 meet also the requirements for base/bind IB.

Table 1: Dutch requirements for AC mixes for specific applications (EN 13108-1)

class	#trucks/24hrs/driving direction		speed
A		0<=VA<=50	NR
B		50<VA<=2500	NR
C		VA>2500	NR
IB		VA>250	<15 km/u

BINDER LAYER UNDER POROUS ASPHALT WEARING COURSE (Bind-PA)					
Class	**A**	**B**	**C**	**IB**	
Vmin	-	3,0	3,0	3,0	%
Vmax	-	7,0	7,0	7,0	%
ITSR	-	80	80	80	%
Smin	**-**	**5500**	**5500**	**5500**	**MPa**
Smax	**-**	**14000**	**14000**	**14000**	**MPa**
fcmax	**-**	**0,4**	**0,4**	**0,2**	**μm/m/cycle**
ε_6	-	80	80	80	με
BINDER LAYER UNDER OTHER WEARING COURSES (Bind)					
	A	**B**	**C**	**IB**	
Vmin	2,0	3,0	3,0	3,0	%
Vmax	7,0	10,0	10,0	10,0	%
ITSR	70	60	70	70	%
Smin	**5500**	**5500**	**5500**	**5500**	**MPa**
Smax	**11000**	**11000**	**14000**	**14000**	**MPa**
fcmax	**0,4**	**0,4**	**0,4**	**0,2**	**μm/m/cycle**
ε_6	100	70	80	80	με
BASE LAYER (Base)					
	A	**B**	**C**	**IB**	
Vmin	2,0	2,0	2,0	2,0	%
Vmax	7,0	7,0	7,0	7,0	%
ITSR	70	70	70	70	%
Smin	**4500**	**5500**	**7000**	**7000**	**MPa**
Smax	**11000**	**14000**	**14000**	**14000**	**MPa**
fcmax	**1,4**	**0,8**	**0,4**	**0,2**	**μm/m/cycle**
ε_6	100	80	90	90	με

2.3.1. Test results

The test results found in the four projects are shown and discussed in next few paragraphs. Because of space limitations, in this paper only results for two of the functional properties are discussed, the stiffness and the resistance to permanent deformation. These two properties were selected because the experience with the two test methods is quite different, allowing for the analysis of the usefulness of standardisation.

In the Netherlands there is a lot of experience with the four point bending test, which is used for stiffness and fatigue characterisation. For this test and both properties, Dutch contractors also regularly carry out Round Robin testing to ensure comparability of test results. As such, the test is mature and expected to be relatively free from variations in test procedures.

The triaxial cyclic compression test used for the determination of the resistance to permanent deformation is a relatively new test for which the test conditions were determined rather late in the development of the CEN standards. Since for this test there is also no regular Round Robin between Dutch contractors, it is the opposite of the four point bending test in the sense that it can be expected to show more influence from variation in test procedures.

2.3.2. Stiffness

The average stiffness and standard deviations found in the four projects are shown in Fig.3 and Table 2. In this graph, the horizontal axis shows the phase in the project:

- F1 = lab mixed & compacted,
- F2=plant mixed, lab compacted,
- F3=plant mixed, field compacted tested directly after construction and
- F3d=plant mixed, field compacted tested 2 years after construction

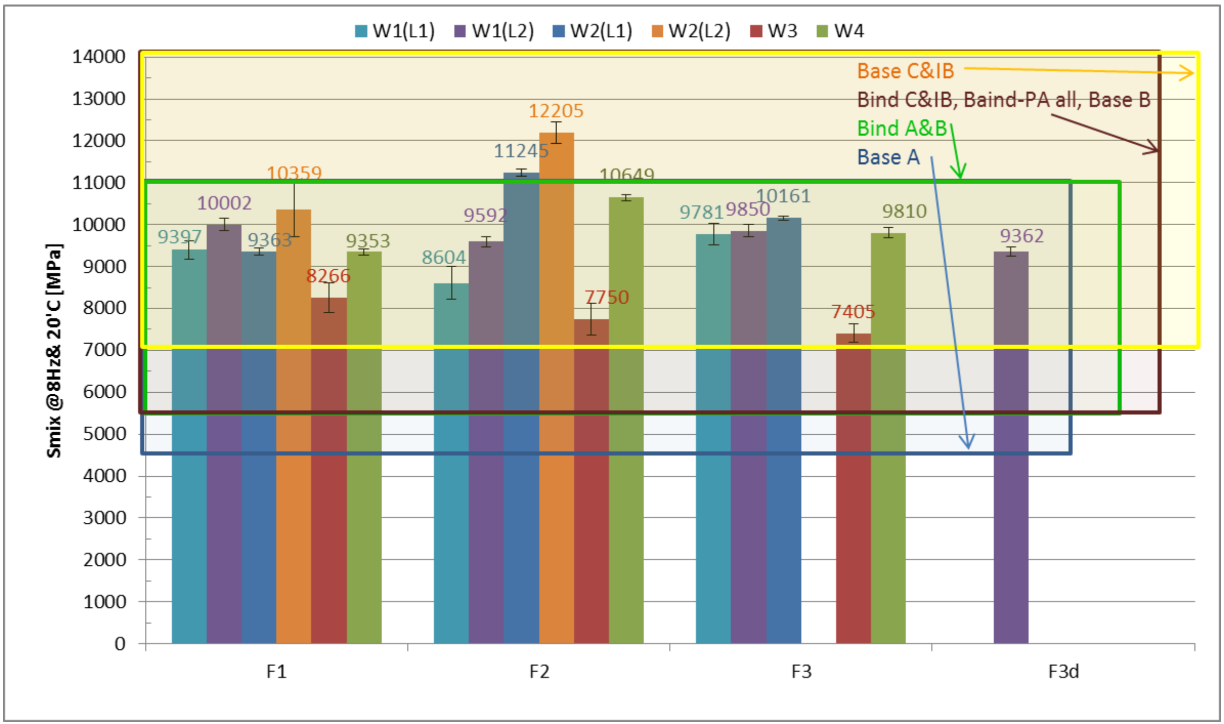

Fig. 3: Average stiffnesses for 4 projects, 3 types of production

The use of the extention L1 or L2 between brackets in the legend for the first two projects (W1 and W2) indicates that within these projects the contractors used two different methods of laboratory specimen production. In the first project (W1) the tests were carried out in two different laboratories, resulting in different mixing (Freundl (W1-L1) versus Bear (W1-L2) mixer) in Phase 1 (F1) and differences in lab compaction (plate compactor (W1-L1) versus mini roller compactor (W1-L2)) in Phase 1 and 2 (F1&F2).
For Phase 3 (F3) the mixing and compaction was the same, but the specimens were still tested in two laboratories, giving two results.
For the second project (W2), the mixing was the same and the tests were carried out in a single laboratory, but they compacted the specimens using both automated (W2-L1) and manual (W2-L2) plate compaction. As a result, there are two columns in the graph for F1 and F2 of the specimen production. Since only a single lab was involved, there is a single result shown for W2-F3.

The vertical axis shows the stiffness and the columns refer to a set of results with W1 being Work 1, W2 work 2 etcetera. If in a single work multiple labs participated, this is shown between brackets (L1 or L2). The boxes show the requirement boundaries for different layers and traffic classes as shown in Table 1. The blue box are the requirements for base layers in traffic class A, the green for binder layers in traffic classes A and B and so on.

From the graph it can be seen that although there is quite some variation between and within the mixtures, all mixes in all phases fit (almost) all these requirements. The extremes in this case are the mixes from W3 and W2, the former gets uncomfortably close to the lower limit requirements for high stability applications while the latter gets close to and even exceeds the maximum stiffness level for lower stability applications. For W2 the difference between F2 and the other phases is such that it may lead to a different category of response, but in all other cases the mixes fall in the same category for all phases.

Table 2: Numerical test results for the stiffness per Work (W) and phase (F)

Work↓	Property↓ Phase→	F1	F2	F3	F3c
W1(L1)	average Smix [MPa]	9397	8604	9781	
	Stdev Smix [MPa]	221	389	253	
	# measurements	8	9	9	
W1(L2)	average Smix [MPa]	10002	9592	9850	9362
	Stdev Smix [MPa]	447	374	438	458
	# measurements	9	9	9	18
W2(L1)	average Smix [MPa]	9363	11245	10161	
	Stdev Smix [MPa]	359	383	223	
	# measurements	18	18	18	
W2(L2)	average Smix [MPa]	10359	12205		
	Stdev Smix [MPa]	635	257		
	# measurements	12	6		
W3	average Smix [MPa]	8266	7750	7405	
	Stdev Smix [MPa]	881	678	832	
	# measurements	9	10	10	
W4	average Smix [MPa]	9353	10649	9810	
	Stdev Smix [MPa]	310	311	541	
	# measurements	18	18	18	

Historically, asphalt mixtures are designed on volumetric ratio's and produced using mass ratio's. As such, it makes sense to look into the mix volumetrics to see if differences in mix volumetrics explain the oberved differences in properties. If the volumetrics fully explain the differences, it means that production en construction do not really affect the properties and that lab determined properties can be linked directly to pavement properties.

Unfortunately, the data do not provide composition information for all specimens. The mix design values (in mass percentages) are given and for every specimen the void content is known. Per phase also the bitumen content is determined, but this information is not available on a per specimen basis. As a result, the volumetric properties must be determined on the basis of the void content per specimen in combination with the bitumen and aggregate content per phase. Because the information on the density of the filler, aggregate and bitumen was not available for all works, despite the fact that the CEN standards state this information needs to be included, either generic (assumed) values had to be used, or an approximation using mass percentages had to be used. It was decided to use the latter while trying to obtain additional information. As such, in this analysis a mix of volumetric (void content) en mass (bitumen and aggregate content) are used. If this shows strong correlations, this can be expected to improve with real volumetric data. If it doesn't show a strong correlation, it doesnot neccesarily mean that there is no relation, so either way the analysis will have to be repeated once all background information on the constituent materials is received. Because of this limitation, the analysis is first of all done only for Work 1. In this analysis, the following explanatory variables were used:

- A constant
- Specimen density (know for each specimen)
- Penetration of the bitumen (known per phase)
- Void content (known for each specimen)
- % bitumen (known per phase)
- % aggregate (known per phase)
- Bitumen stiffness (at circa 8 Hz)

These parameters were used in over twenty different combinations, which resulted in a relation similar to the classic Ugé nomograph [Bonnaure et al., 1977]:

$$\boldsymbol{S_{mix} = -7906 \cdot M_b + 435 \cdot V'_g + 325\, S_{bit}} \qquad ; \boldsymbol{R^2 = 0,87}$$

With:
S_{mix}: mix stiffness @20°C and 8 Hz in the four point bending test
M_b: bitumen content in mass, determined per phase
V'_g: approximation of the aggregate volume content
S_{bit}: bitumen stiffness @ 20°C and 8Hz from the DSR test

Although these are not truly the Ugé parameters (these are the true volumetric composition values), the relation indicates a strong relation between volumetric properties and stiffness, which if it proofs consistent over all projects would indicate that, for the stiffness, the effect of variables in mixing, compacting and testing is limited relative to the mix volumetrics. To truly verify this, it is necessary to pursue the necessary information for a truly volumetric analysis over all projects. This is currently being carried out.

2.3.3. Resistance to permanent deformation

The results for the cyclic triaxial test are shown in Fig. **4** and Table 3. In this test, the values found are very small, but the variation per mixture is considerable. The legend and horizontal axis again denote the works (and labs) and the phases in the project, respectively. The horizontal lines show the requirements, less than or equal to 0,2 µm/mm/cycle for highly stable (IB) mixtures, 0,4 for most others. The requirements of 0,8 and 1,4 µm/mm/cycle for low traffic levels (class A and B) base layers are not shown in this picture.

In Phase 1 and 2 Works 2 and 3 are again the extremes, but in Phase 3 the resistance to permanent deformation for the W2 mixture is suddenly a lot lower (higher slope). From the bitumen test it was found that the bitumen for this work is different between Phase 1 and 2 on the one hand and Phase 3 on the other. In Phase 1 and 2 there appear to be polymer modifications present that are not found in Phase 3. In general, the variation between the phases for each mixture is large, the mixtures from W1(L2), W2 and W3 fall in different classes for different phases and even W1(L1) gets very close to the class boundary for Phase 2, leaving only W4 with a consistent assessment. These differences in results cannot be explained by the, limited, variation in composition.

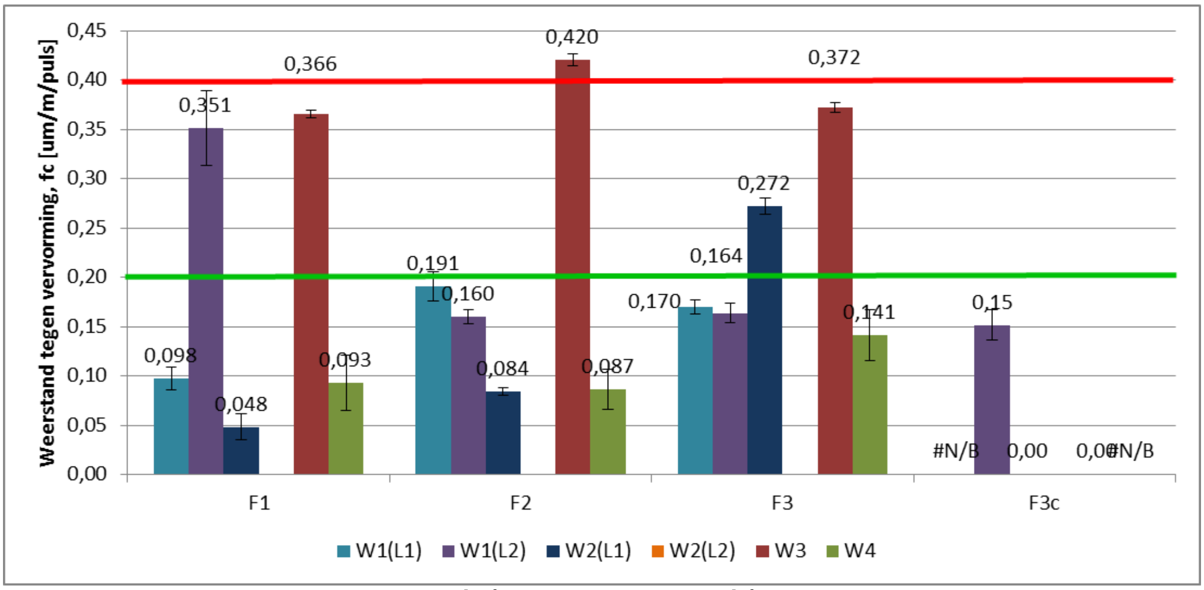

Fig. 4: Results for resistance to permanent deformation

When looking closely at W1(L1) and W1(L2), which deal with the same mixture but produced and tested in two different labs, it is striking to see that the tests on field cores (Phase 3) produce comparable results (0,17 versus 0,16 [(µm/m)/cycle]), while the Phase 2 and especially the Phase 1 test results are quite different. This indicates that the differences between these labs are not caused by differences in testing protocols or equipment, but by differences in mixing and compacting of the specimens.

Table 3: Numerical results for the resistance to permanent deformation

Work ↓	Property ↓	Phase→	F1	F2	F3	F3c

W1(L1)	**average fc (µm/m/cycle)**	0,10	0,19	0,17	
	Stdev fc (absolute)	0,024	0,029	0,014	
	# measurements	4	4	4	
W1(L2)	**average fc (µm/m/cycle)**	0,35	0,16	0,16	0,15
	Stdev fc (absolute)	0,076	0,014	0,020	0,003
	# measurements	4	4	4	5
W2(L1)	**average fc (µ/m/cycle)**	0,05	0,08	0,27	
	Stdev fc (absolute)	0,029	0,009	0,019	
	# measurements	5	5	5	
W3	**average fc (µm/m/cycle)**	0,4	0,4	0,4	
	Stdev fc (absolute)	0,07	0,12	0,09	
	# measurements	3	4	4	
W4	**average fc (µm/m/cycle)**	0,09	0,09	0,14	
	Stdev fc (absolute)	0,028	0,020	0,026	
	# measurements	4	4	4	

On the other hand, because of the limited experience and lack of Round Robin testing, there may also be variation due to differences in testing in the data. For example, there is considerable variation in the friction reduction systems used by Dutch contractors, and it is known that the friction reduction system can have considerable influence in this test. In the EN 12697-25:2005 it was stated that a membrane-lubricant-membrane system had to be used, with a note saying this membrane might consist of geotechnical latex (art 5.2.2.5). In the current, 2016, standard it is stated that a Teflon system must be used (art 8.4.3). It is known that both variants and others are used by Dutch contractors and the effect on the results is shown in **Fig. 5**. Just a different friction reduction system can lead to a different category of response.

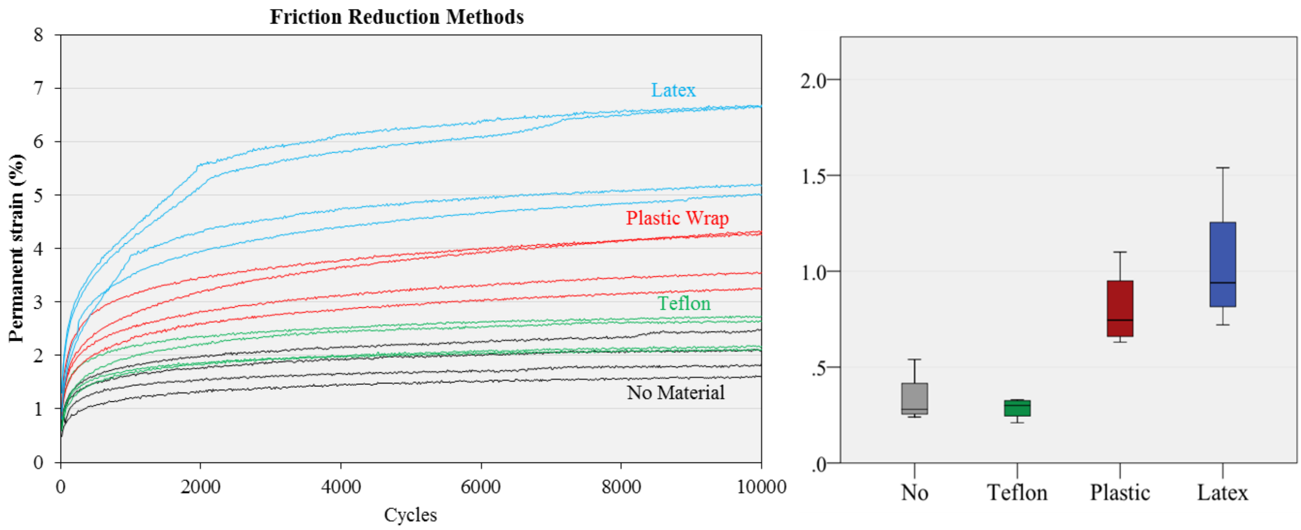

Fig. 5: Permanent deformation curves and boxplots for triaxial tests with different friction reduction materials (Seleridis, 2017)

3. Conclusions and recommendations

3.1. Conclusions

This testing program addresses the relation between functional characteristics and field performance, whether laboratory mixing and compaction are representative for field mixing and compaction and whether the current European functional tests effectively distinguish “good” from “bad” mixtures. The current data set is limited to four materials and construction projects. Considering the variation in the results, it is clear that more results are needed to arrive at any definite conclusions. However, the available data do lead to some preliminary conclusions:

- For the stiffness the results seem to be strongly affected by volumetric composition of the specimens, although some unexplained variation remains
- For the triaxial test, the variation in composition does not sufficiently explain the variation in test results

These conclusions may partially be explained by the larger experience with and standardisation in the four point bending test that is used for stiffness testing. As such, it appears that the standardisation in CEN tests is a good development, not only to achieve an open market, but also for the exchange and comparison of test results across Europe. However, to ensure the comparability, it is crucial to adhere to the standards and implement changes only if it has been objectively shown that the change is necessary, beneficial or does not affect the results of the test.

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experience in the Netherlands with the resistance to fatigue and stiffness (determined using the four point bending test, EN 12697-24 and EN 12697-26), while the triaxial test (EN 12697-25) and the Indirect Tensile test Ratio (ITSR, EN 12697-12 and EN 12697-23) as standardized by CEN were relatively new.