Final Report
2015

Development of the Prall-test method in a Nordic perspective

EN 12697-16, Method A

Foreword

This project was initiated by Kenneth Lind, Swedish Transport Administration, as a NordFoU project (www.nordfou.org).

The aim was to get a common approach in the Nordic countries of the standard on abrasion by studded tires.

Thanks to all who contributed to the project through the production of asphalt mixes and the manufacturing of specimens and to the participants in the comparative testing.

Kenneth Lind, project leader
Swedish Transport Administration

Quality review

Internal peer review was performed by the project working group (See chapter 2).

Leif Viman, VTI, has made alterations to the final manuscript of the report.

The project leader Kenneth Lind, Swedish Transport Administration, examined and approved the report for publication.

Content

Summary

The main objective of this project was to improve the precision of the Prall method, EN 12697-16, Method A. All work was performed in a Nordic perspective, because this standard mainly is of interest to countries where studded tires are being used. A revised standard has been developed based on past experience and results obtained through this project.

Several minor changes and clarifications have been made as well as corrections of already known errors in text and figures. Two comparative tests have been conducted with laboratories in the Nordic countries Sweden, Finland, Iceland and Norway.

The results from the first comparative testing gives a variation within laboratories (repeatability) around r = 20 % and variation between laboratories (reproducibility) around R = 26 %. The second comparative test gives better precision within laboratories (r = 15 %) but almost the same between laboratories compared to the first test. For a Prall value of 25 the respective variation would be about 4 and 7 units.

When the revised standard is available, a new comparative testing, open to all laboratories, should be performed.

Sammanfattning (Swedish)

Huvudsyftet med detta projekt har varit att förbättra precisionen hos Prallmetoden, EN 12697-16, Metod A. Projektet har genomförts i ett Nordiskt perspektiv eftersom denna metod främst berör länder som har dubbdäckstrafik. En reviderad standard har tagits fram baserad på tidigare erfarenheter samt de resultat som framkommit inom detta projekt.

Många små förändringar och förtydliganden har utförts utöver de rena rättningar av text och figurer som redan var kända. Två jämförande provningar har genomförts med laboratorier i de nordiska länderna Sverige, Finland, Island och Norge.

Resultaten från den första jämförande provningen gav en variation inom laboratorier (repeterbarhet) på r = 20 % och variation mellan laboratorier (reproducerbarhet) på R = 26 %. Den andra jämförande provningen gav något bättre repeterbarhet (r = 15 %) men ungefär samma reproducerbarhet. För ett Prallvärde på 25 ger detta en variation på 4 respektive 7 enheter.

När den reviderade standarden är tillgänglig bör en ny jämförande provning, öppen för alla laboratorier, genomföras.

Tiivistelmä (Finnish)

Projektin tavoitteena oli kehittää Prall- menetelmän (EN 12697-16, osa A) tarkkuutta. Hanke toteutettiin pohjoismaisena projektina, sillä menetelmä on käytössä vain maissa, joissa käytetään nastarenkaita. Standardiin tehdyt muutokset perustuvat aiempiin kokemuksiin ja tämän hankkeen tuloksiin.

Standardin teksteissä ja kuvissa esiintyneet virheet on korjattu ja niihin on tehty pieniä muutoksia ja täsmennyksiä. Kaksi vertailukoetta järjestettiin ja niihin osallistui Ruotsissa, Suomessa, Islannissa ja Norjassa menetelmää käyttäviä laboratorioita.

Ensimmäisessä vertailukokeessa laboratorion sisäinen toistettavuus r oli noin 20 % ja laboratorioiden välinen uusittavuus R oli noin 26 %. Toinen vertailukoe tuotti paremman tarkkuuden laboratorion sisäiselle toistettavuudelle (r =15 %), mutta laboratorioiden välinen uusittavuus R ei parantunut. Prall –arvolla 25 tämä tarkoittaa 4 -7 yksikön vaihtelua.

Kaikille laboratorioille avoin vertailukoe järjestetään, kun uusittu standardi on käytettävissä.

Oppsummering (Norwegian)

Hovedmålet med dette prosjektet var å forbedre presisjonen til Prallmetoden, EN 12697-16, Method A. Prosjektet ble gjennomført i et nordisk perspektiv, siden denne metoden hovedsakelig er av interesse for land som har piggdekktrafikk. Standarden er revidert basert på tidligere erfaringer og resultater oppnådd i dette prosjektet.

Flere mindre endringer og korrigeringer er foretatt i tillegg til rettelser av kjente feil i tekst og figurer. To ringanalyser ble utført med laboratorier fra de nordiske landene Sverige, Finland, Island og Norge.

Resultatene fra ringanalysene viste en variasjon, repeterbarhet, på r ≈ 20 % innenfor hvert laboratorium og en variasjon, reproduserbarhet, på R ≈ 26 % mellom laboratoriene. Den andre ringanalysene ga litt bedre repeterbarhet (r = 15%), men omtrent samme reproduserbarhet. For en typisk Prall-verdi på 25 gir dette respektivt en variasjon på 4 og 7 enheter

Når den reviderte standarden foreligger, bør det foretas en ny ringanalyse, åpen for alle laboratorier som ønsker å delta.

Samantekt (Icelandic)

Meginmarkmið þessa verkefnis var að bæta nákvæmni Prall slitþolsprófsins, EN 12697-16, Method A. Verkefnið var unnið í Norrænu samstarfi, þar sem þessi aðferð er aðallega notuð í löndum sem hafa nagladekkja umferð. Endurskoðaður staðall hefur verið þróaður á grundvelli fyrri reynslu og niðurstöðum sem fengust í þessu verkefni.

Margar smávægilegar breytingar og skýringar hafa verið gerðar auk leiðréttinga á texta og myndum sem áður höfðu verið þekktar. Tvær samanburðarprófanir voru gerðar með rannsóknarstofum á Norðurlöndunum í Svíþjóð, Finnlandi, Íslandi og Noregi.

Niðurstöður úr fyrstu samanburðarprófununum gáfu enurtekningastuðla innan rannsóknarstofa r = 20 % og á milli rannsóknarstofa R = 26 %. Seinni samanburðarprófanirnar gáfu betri endurtekningarstuðla innan rannsóknastofa (r = 15) en nánast sömu stuðla milli rannsóknastofa. Þetta bendir til að Prall gildið 25 hafi breytileika upp á 4 og 7 einingar.

Þegar endurskoðaður prófunarstaðall verður gefinn út, er æskilegt að gera ný samanburðarpróf, sem verða opin öllum rannsóknarstofum.

1 Background and purpose of the project

The Prall test, EN 12697-16 Method A, is one of several laboratory methods for determining the wear of asphalt pavements. It was initially developed in the U.S. as a method for testing the adhesion properties of bituminous mixtures. Rubber bullets were used instead of the steel balls, described in the current standard. The method came to Germany in the early 1970s, but was never applied because the use of studded tires was banned in Germany.

In the 1980s the method was introduced in Sweden, where it became known as FAS Method 471. Comparative tests between road wear and the Prall test showed a correlation of $R^2 = 0.89 – 0.96$ (Jacobsen, 1995, Raitanen, 2005).

Method B of the EN 12697-16 standard is the “Pavement wearing ratio” (PWR). This method of Finnish origin (SRK) was not a subject for this study.

The dependence of the Prall value upon different test conditions and parameters have been investigated in order to improve the precision of the method.

Purpose

With the background from the results in the report VTI-notat 22-2010 and VTI Utlåtande 759, 2010-12-14 and Skanska 2010, Report on the Prall method the purpose of this Nord FoU-project was to:

- Improve the test method
- Develop the test method in a Nordic perspective
- Evaluate the correlation between laboratory made specimens and drilled cores from road

Use of the project

The results of this project will be used to:

- Revise and correct the existing European standard, EN 12697-16.
- Update the precision data in the standard
- Update the tables for abrasion values for Type Testing in relevant product standards in the EN 13108- series (Bituminous mixtures).
- Establish a common Nordic view on how to apply requirements and on how to evaluate the results from Prall testing.

2 Project group

Participants and interested parties of the Project

Role	Name	Organisation
NordFoU contact person	Brian Gross Larsen	Danish Road Directorate
Project steering group	Kenneth Lind	Swedish Transport Administration
	Nils Uthus	Norwegian Public Roads Administration
	Katri Eskola	Finnish Transport Agency
	Thorir Ingason	Icelandic Road and Coastal Administration
Project leader	Kenneth Lind	Swedish Transport Administration
Project working group	Kenneth Lind	Swedish Transport Administration
	Einar Aasprong	Norwegian Public Roads Administration
	Katri Eskola	Finnish Transport Agency
	Pétur Péturson	Consultant at the request of Icelandic Road and Coastal Administration
	Leif Viman	Swedish National Road and Transport Research Institute

3 Results

The aim of this project is to improve the precision and the procedure description of the European standard EN 12697-16, Method A. It has been recognized that there are deficiencies in the description of the standard.

The work was carried out jointly within the Nordic countries, assuring a consensus among the countries using the method. The planning of the Round Robin test was conducted by the project team while VTI has been responsible for the statistical analysis and reporting.

3.1 Phase 1: Round Robin test

Participating laboratories

NCC, Göteborg (Sweden)	Statens Vegvesen, Trondheim (Norway)
Peab, Göteborg (Sweden)	Destia Oy, Espoo (Finland)
Skanska, Farsta (Sweden)	Innovation Center Iceland (Iceland)
Svevia, Umeå (Sweden)	
VTI, Linköping (Sweden)	

Prior to the Round Robin test each laboratory answered a questionnaire regarding the applied test equipment.

Test samples

In each of the Nordic countries, a typical asphalt mix was selected for production in bulk. The following asphalt mixes were prepared for the Round Robin Test, phase 1:

- SMA 16 50/70, AN <7 (Finnish mix)
- SMA 16 100/150, AN <7 (Swedish mix)
- AC 11 160/220, AN <7 (Norwegian mix)
- AC 11 160/220, AN <10 (Icelandic mix)

Sample Preparation

From the mixes, Marshall Specimens were manufactured by impact compaction according to EN 12697-30 with 2x50 blows. Each specimen was cut in two, yielding two Prall Specimens.

Test conditions

Testing was carried out according to EN 12697-16, Method A, on the cut surface and with an alternative set of test conditions; lower frequency (800 rpm vs. 950 rpm according to standard) and extended duration (30 min vs. 15 min according to standard).

Results

The following tables provide a summary of the repeatability and reproducibility of this comparative testing.

The results from Laboratory 4 are excluded. During testing, this laboratory used a "flat rubber ring" not complying with the standard.

Table 1 Marshall compacted samples tested at 950 rpm/15 min (according to EN 12697-16)

Bituminous mixtures	**Average**	**r**	**R**	**r-%**	**R-%**
SMA 16 50/70, AN < 7 (Finnish mix)	20.8	5.1	5.1	24.7	24.7
SMA 16 100/150, AN < 7 (Swedish mix)	22.2	4.6	7.0	20.5	31.3
SMA 16:	average:	4.9	6.0	22.6	28.0
AC 11 160/220, AN < 7 (Norwegian mix)	30.5	5.7	7.6	18.8	25.0
AC 11 160/220, AN < 10 (Icelandic mix)	27.4	3.6	6.3	13.1	23.1
AC 11:	average:	4.7	7.0	16.0	24.0
	total average:	4.8	6.5	19.3	26.0

Table 2 Marshall compacted samples tested at 800 rpm/30 min

Bituminous mixtures	**Average**	**r**	**R**	**r-%**	**R-%**
SMA 16 50/70, AN < 7 (Finnish mix)	22.0	5.2	6.7	23.8	30.6
SMA 16 100/150, AN < 7 (Swedish mix)	23.1	3.9	8.3	17.0	35.9
SMA 16:	average:	4.6	7.5	20.4	33.2
AC 11 160/220, AN < 7 (Norwegian mix)	31.5	5.2	8.7	16.5	27.5
AC 11 160/220, AN < 10 (Icelandic mix)	30.0	3.2	6.0	10.7	20.0
AC 11:	average:	4.2	7.3	13.6	23.8
	total average:	4.4	7.4	17.0	28.5

The results in Table 1 shows a repeatability (variation within laboratories) ≈ 19 % while the reproducibility (variation between laboratories) ≈ 26 %. For a typical Prall value of 25 the respective variation would be 5.0 and 6.5 units.

The results from testing with reduced frequency and extended time according to Table 2 has not proved to give a better precision. This combination of rpm and test time gives a bit higher Prall values.

Individual Prall values and means, together with basic data and statistical data are presented in the following tables, figures and annexes:

- *Table 3-6*: Individual and mean Prall values, standard deviation and coefficient of variation at 950 rpm/15 min (according to EN 12697-16) and at 800 rpm/30 min
- *Figure 1-4*: Mean Prall values at 950 rpm/15 min (according to EN 12697-16) and 800 rpm/30 min
- *Figure 5-8*: Individual Prall values at 950 rpm/15 min (according to EN 12697-16)
- *Figure 9-12*: Individual Prall values at 800 rpm/30 min

Table 3 SMA 16 50/70 with aggregate AN < 7 (Finnish mix)

Lab	**950 rpm and 15 min (according to EN 12697–16)**				**800 rpm and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	23.2	19.8	18.4	18.9	26.5	20.9	22.8	23.2	20.1	23.4
2	19.6	19.3	19	21.1	20.5	19.9	26.5	21.1	19.8	22.0
3	21.4	22.6	18.5	21.1	21.7	19.2	19.9	17.6	20.9	19.6
4										
5	21.1	22.8	17.3	22.9	22.0	22.0	23.8	21.8	21.0	22.4
6	21.2	20.8	23.5	19.7	23.0	25.6	25.9	22.2	21.3	24.2
7	21.9	18.0	21.8	20.3	18.2	21.4	19.6	19.8	20.5	19.8
8	22.1	20.8	24.3	22.0	22.6	22.6	22.3	24.5	22.3	23.0
								avg	20.8	22.0
								s	0.8	1.8
								V-%	4.0	8.0

Table 4 SMA 16 100/150 with aggregate AN <7. (Swedish mix)

Lab	**950 rev/min and 15 min (according to EN 12697-16)**				**800 rev/min and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	22.9	23.7	23.6	23.4	26.1	24.2	22	25.7	23.4	24.5
2	25.7	27.8	27.2	21.3	20.5	23.3	22.2	24	25.5	22.5
3	18.3	19.7	19.4	21.3	20	20.4	19.6	19.4	19.7	19.9
4										
5	19.8	22.6	22	22.9	23.1	24.3	22.4	22.6	21.8	23.1
6	21.6	23.8	22.0	25.1	26.0	26.8	29.6	27.5	23.1	27.5
7	20.1	19.9	20.0	20.0	17.8	19.2	21.4	22.1	20.0	20.1
8	20.3	24.0	21.1	23.2	25.3	23.0	24.5	23.5	22.1	24.1
								avg	22.2	23.1
								s	2.0	2.6
								V-%	9.1	11.4

Table 5 AC 11 160/220 with aggregate AN <7. (Norwegian mix)

Lab	**950 rev/min and 15 min (according to EN 12697-16)**				**800 rev/min and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	33.9	30.1	33.4	31.4	32.9	32.7	34	32.7	32.2	33.1
2	31.5	29.9	33.8	31.4	30.5	31	29.6	30.3	31.7	30.4
3	28.3	29.5	30.7	27.4	27.5	28.2	28.1	28.8	29.0	28.2
4										
5	27.6	35.9	27.7	33.6	32.1	33.7	33.0	30.9	31.2	32.4
6	31.9	33.3	33.6	32.0	37.6	35.4	34.2	35.1	32.7	35.6
7	25.7	27.3	26.0	29.4	26.9	26.9	31.8	29.1	27.1	28.7
8	30.4	29.8	29.2	29.5	34.6	35.8	30.5	28.3	29.7	32.3
								avg	30.5	31.5
								s	2.0	2.6
								V-%	6.6	8.3

Table 6 AC 11 160/220 with aggregate AN <10. (Icelandic mix)

Lab	**950 rev/min and 15 min (according to EN 12697-16)**				**800 rev/min and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	29.5	29.9	30.2	28.2	31.5	31.3	31.5	32.9	29.5	31.8
2	26.1	27.3	28.6	26.7	30.5	29	28.8	28.8	27.2	29.3
3	25.1	25.6	27.4	24.6	26.4	27.6	28.1	25.1	25.7	26.8
4										
5	26.5	26	27.3	26.5	30.1	29.8	29.7	30.2	26.6	30.0
6	30.4	30.6	30.5	30.7	33.4	32.4	33.3	31.6	30.5	32.7
7	25.5	27.0	27.3	29.0	31.7	29.8	30.3	27.3	27.2	29.8
8	22.0	26.0	26.4	27.4	30.1	31.4	28.7	29.3	25.5	29.9
								avg	27.4	30.0
								s	1.9	1.9
								V-%	6.9	6.3

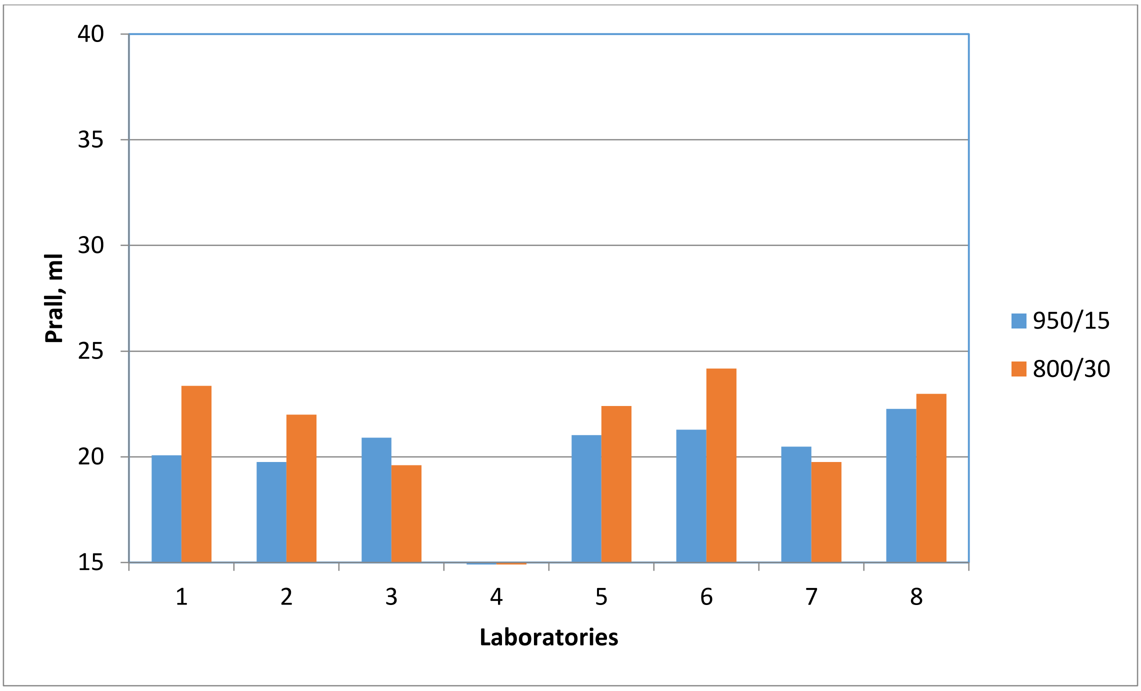


Figure 1 SMA 16 50/70 with aggregate AN <7 (Finnish mix)

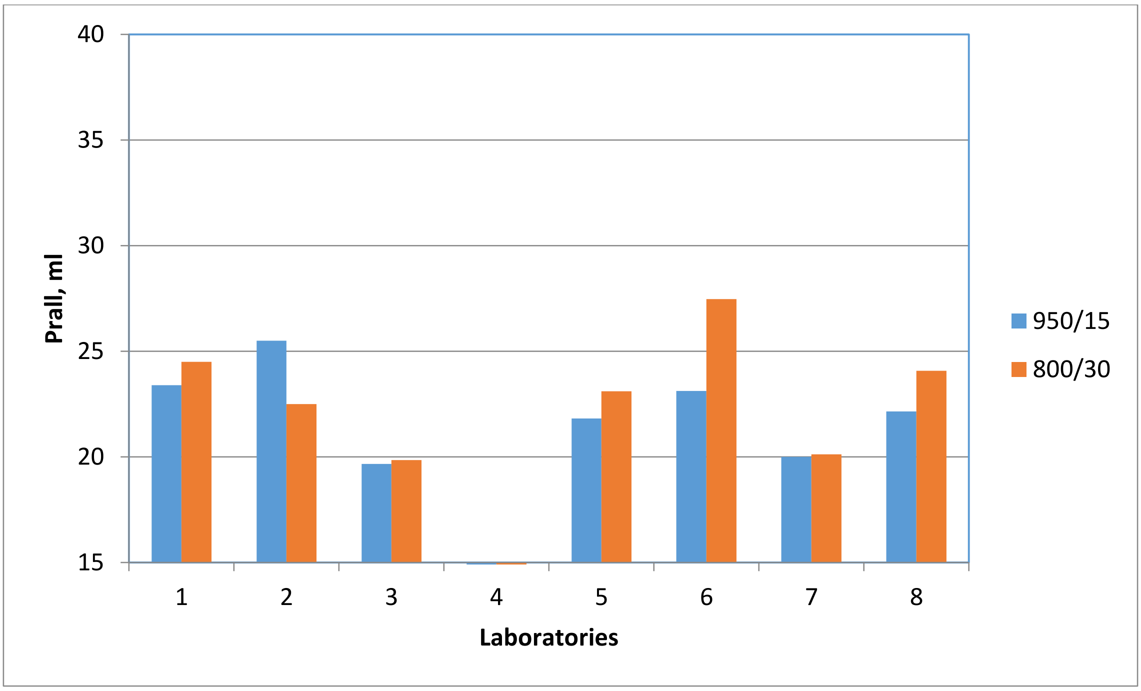


Figure 2 SMA 16 100/150 with aggregate AN <7(Swedish mix)

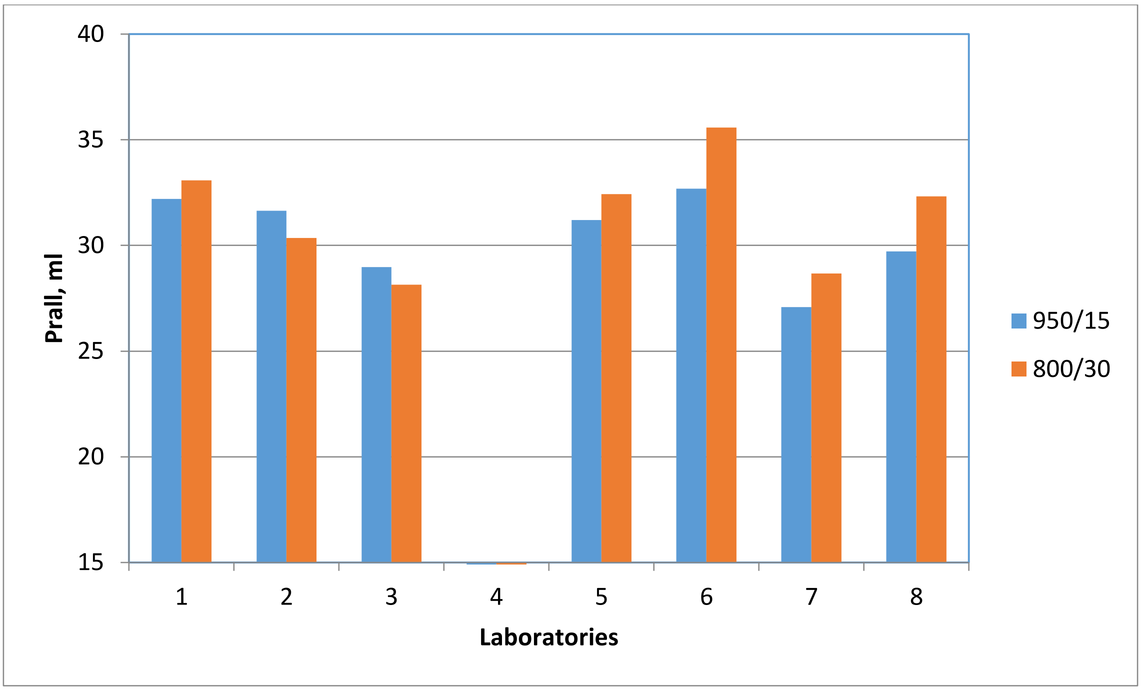


Figure 3 AC 11 160/220 with aggregate AN <7. (Norwegian mix)

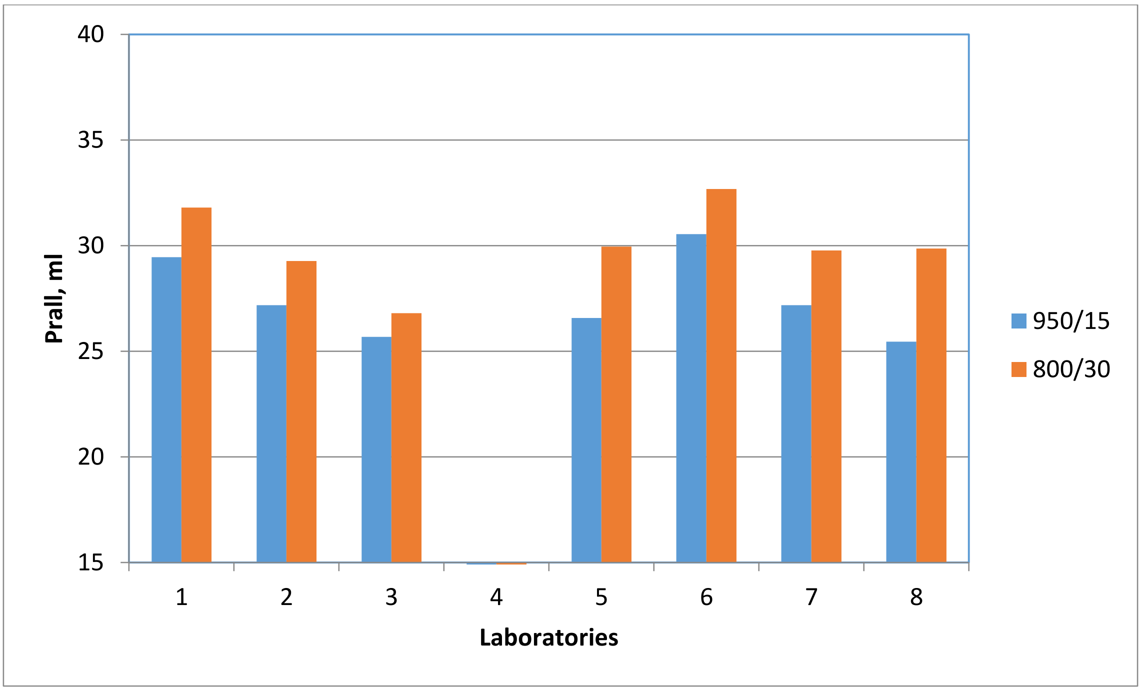


Figure 4 AC 11 160/220 with aggregate AN <10. (Icelandic mix)

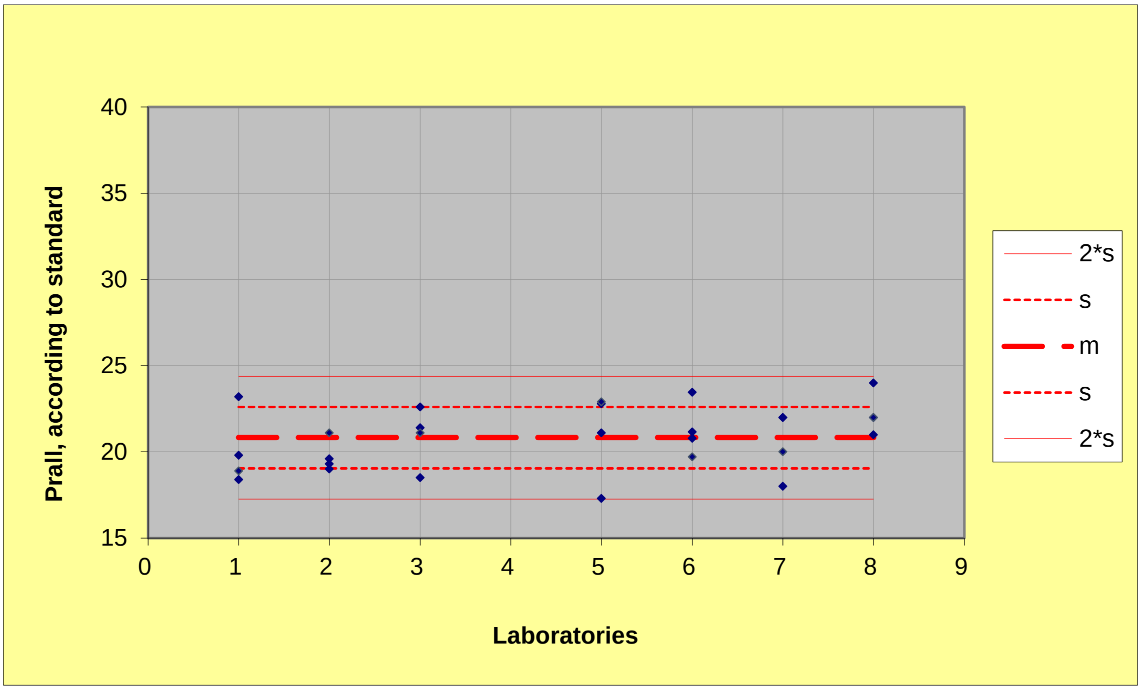


Figure 5 SMA 16 50/70 with aggregate AN <7 at 950 rpm/15 min (Finnish mix)

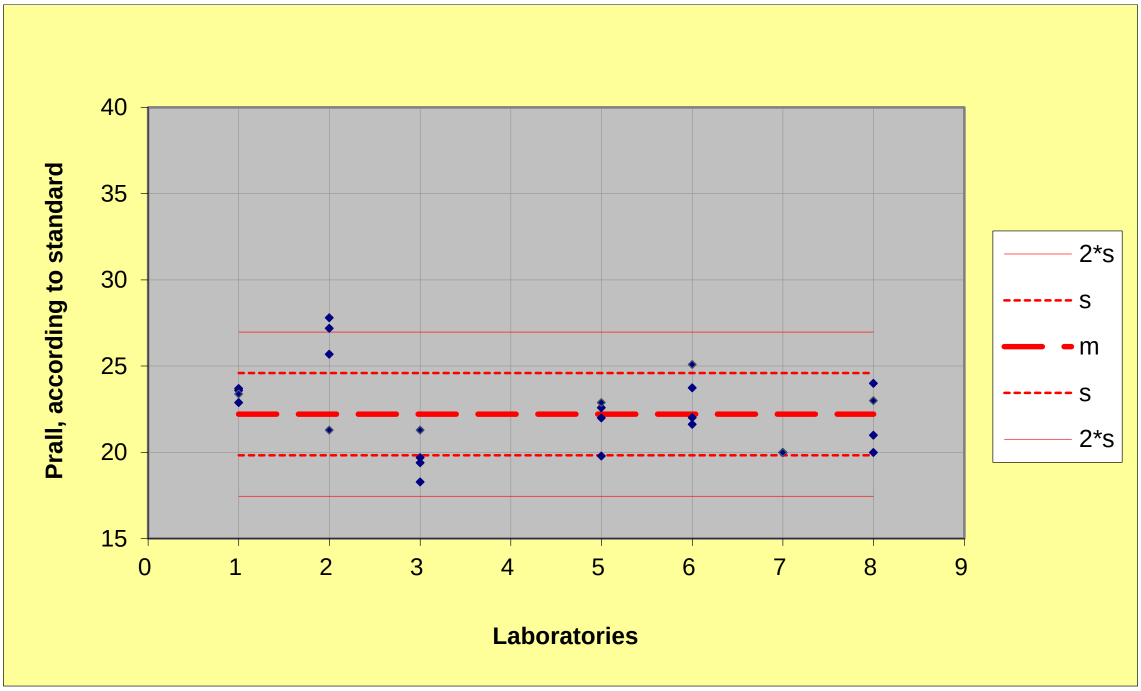


Figure 6 SMA 16 100/150 with aggregate AN <7 at 950 rpm/15 min (Swedish mix)

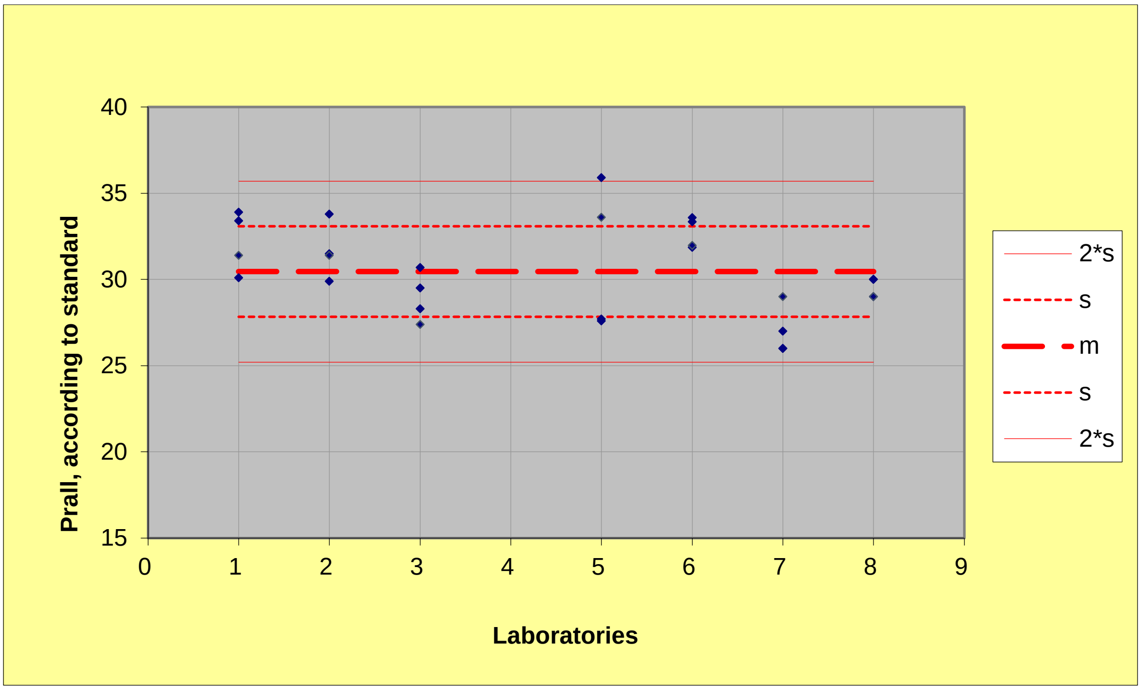


Figure 7 AC 11 160/220 with aggregate AN <7 at 950 rpm/15 min (Norwegian mix)

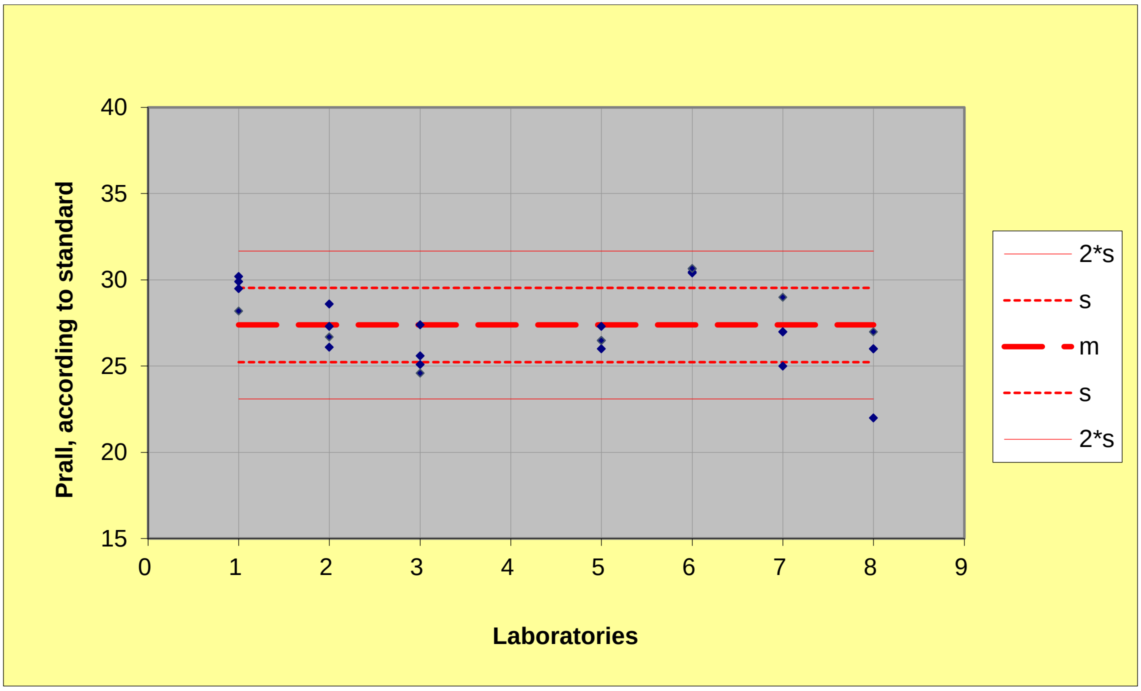


Figure 8 AC 11 160/220 with aggregate AN <10 at 950 rpm/15 min (Icelandic mix)

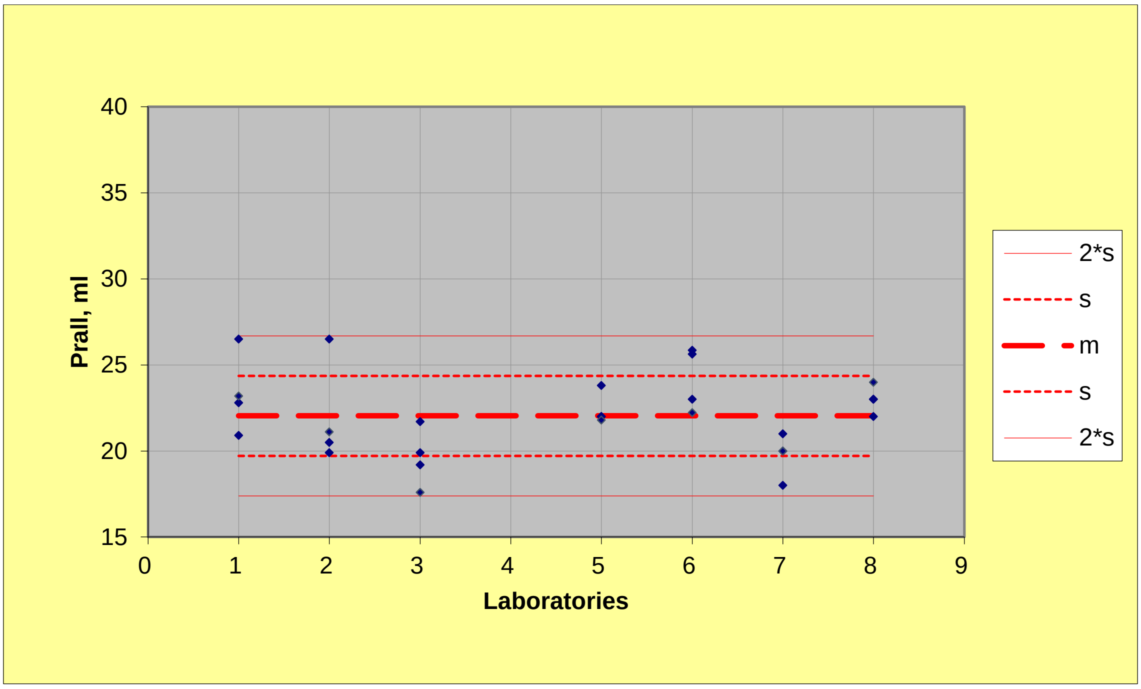


Figure 9 SMA 16 50/70 with aggregate AN <7 at 800 rpm/30 min (Finnish mix)

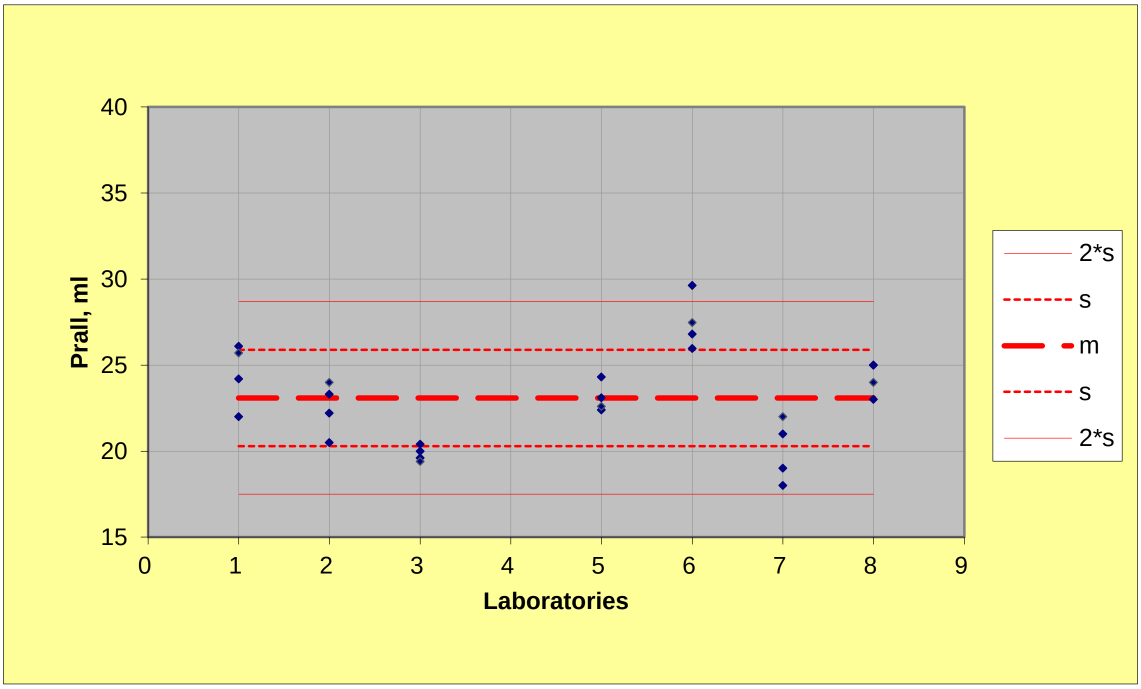


Figure 10 SMA 16 100/150 with aggregate AN <7 at 800 rpm/30 min (Swedish mix)

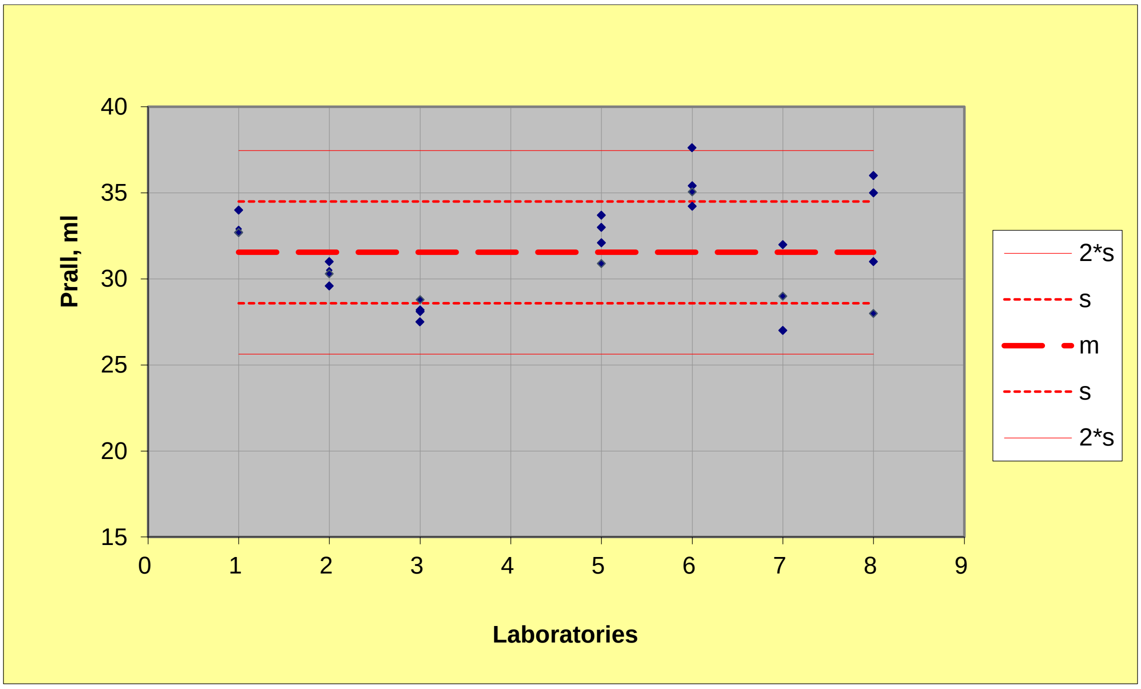


Figure 11 AC 11 160/220 with aggregate AN <7 at 800 rpm/30 min (Norwegian mix)

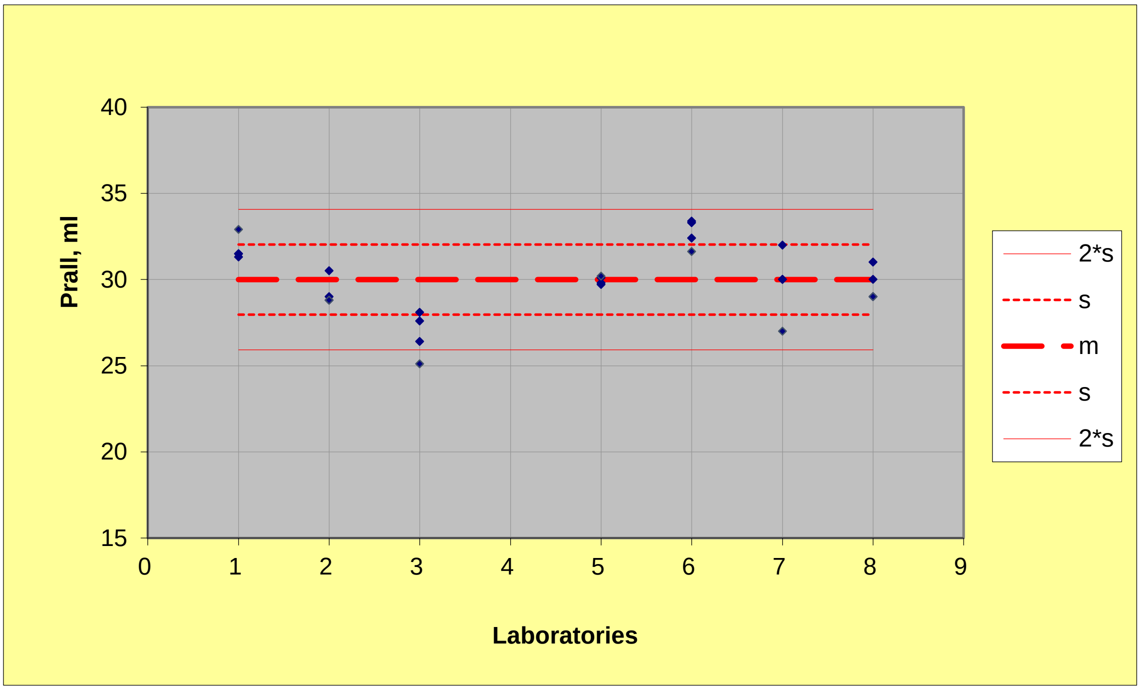


Figure 12 AC 11 160/220 with aggregate AN <10 at 800 rpm/30 min (Icelandic mix)

Summary of experiences from Phase 1

During the execution of Phase 1 the project found a number of important parameters that have a direct impact on the precision of the method. These parameters were taken into account in the preparation of proposals for improvements to the current method.

Stroke height
It is important to have control of the stroke height and how to measure it. After discussions during Phase 1 a guidance for measuring the stroke height was therefore created.

Steel balls quality and weight of ball charge
It was found during the performance of Phase 1 that the quality of steel balls prescribed in the existing standard has been difficult to provide from suppliers which has led to the fact that balls of either correct steel quality (stainless steel according to ISO 3290) with hardness out of the specification or wrong steel quality (chrome) with hardness close to the specification has been used.

A very limited test with SMA 16 70/100, presented in *Table 7*, was carried out to compare two different sets of steel spheres; both commonly used in Sweden:

- Stainless steel spheres of hardness HRC 52-55 (AISI 420)
- Steel spheres of chrome of hardness HRC 62-67 (GD 100)

Table 7 Prall test on SMA 16 70/100 with different type of spheres

Spheres	Type	HRC hardness	Prall value (ml)				
			1	2	3	4	Average
Stainless steel spheres	AISI 420	52-55	28.7	30.3	27.9	27.9	28.7
Chrome steel spheres	GD 100	62-67	38.3*	29.6	29.5	30.6	29.9
*/outlier cancelled						Diff:	1.2

The results according to *Table 7* indicates that the chrome spheres might give about 1 unit higher Prall values than the steel spheres.

The *weight of the ball charge* have not been defined in the method.
In order to minimize differences in weight between the steel ball charge, the project decided to insert a tolerance range for the weight of the ball charge with 40 steel balls to facilitate control of both the new batch of steel balls and after use.

Flat rubber ring
In the Round Robin test in Phase 1 it was noted that one laboratory has used an incorrect type of flat rubber ring, which may affect the size of the wear surface and the movement of the steel balls.

Conclusions
In order to minimize differences between laboratories it is necessary to prescribe and defined important parameters in the standard.

With background from the experiences and conclusions above the project decided to repeat the Round Robin with fixed criteria, see 3.2.

3.2 Phase 1b: Repeated Round Robin test

In this test all laboratories got a set of new stainless steel balls (HRC 52-55) and a new flat rubber ring to minimize differences in the equipment used for the test.

It was pointed out that important parts of the equipment should be controlled and documented in a provided checklist before testing. Eg, the stroke height, revolutions per minute and water temperature.

Participating laboratories

NCC, Göteborg (Sweden)	VTI. Linköping (Sweden)
Peab. Göteborg (Sweden)	Innovation Center Iceland (Iceland)
Skanska. Farsta (Sweden)	Statens Vegvesen. Trondheim (Norway)
Svevia. Umeå (Sweden)	Destia Oy. Espoo (Finland)

Test samples
The following bituminous mixtures where chosen for this part of the Round Robin test, phase 1b:

- SMA 11 100/150 GREEN. AN <7
- AC 11 160/220. AN <10

The mixtures were produced by NCC.

Sample Preparation
Marshall Specimens were compacted, prepared and assorted in equally groups based on bulk density at VTI and sent to the participating laboratories.

Test conditions
The test was carried out according to the European Standard EN 12697-16, Method A.

Results
The table below provide a summary of the repeatability and reproducibility of the comparative testing between the 8 laboratories.

Table 8 Marshall compacted samples tested according EN 12697-16, Method A

Bituminous mixtures	**Average**	**r**	**R**	**r-%**	**R-%**
SMA 11 100/150 GREEN (8 lab)	21.3	3.6	5.4	17.1	25.5
AC 11 160/220 (8 lab)	36.5	4.6	10.8	12.7	29.5
	average:	4.1	8.1	14.9	27.5

The results show a variation within laboratories of 15 % while the variation between laboratories is 27 %. For a Prall value of 25 the respective variation would be about 4 and 7 units.

It means that this second Round Robin test, has yielded improvement in the repeatability (r) precision, but similar for reproducibility (R).

Perhaps this is an expression of random rather than statistical facts?

We also asked the laboratory to measure the dry weight after Prall test to see if it gives more stable Prall values. The result show no advantages for this way to measure the Prall value, based on dry specimen before/after test instead of wet specimen before/after test as the standard says.

Individual Prall values, averages and other basic data and statistical data are shown in the following tables, figures.

- Table 9-10: Individual and mean Prall values, standard deviation and coefficient of variation.
- Figure 13: Average Prall values for both mixes
- Figure 14-15: Individual Prall values for both mixes

The results of all these measurements are presented in Annex 2.

Table 9 Prall values (ml) for AC 11 160/220

Lab	**Individual values**				**Average**
	1	2	3	4	
1	32.1	34.8	34.1	35.9	34.2
2	41.6	39.6	39.9	37.8	39.7
3	37.7	36.6	32.0	34.6	35.2
4	36.0	33.0	35.0	-	34.7
5	38.7	38.0	36.4	35.6	37.2
6					
7*	42.5	41.0	44.7	44.4	43.2
8	36.0	35.8	36.7	34.3	35.7
9	32.0	32.8	33.0	30.3	32.0
10					
				avg	36.5
				s	3.4
				V-%	9.3

**/ Lab 7 is a straggler, but was decided to be retained, because we have not found any reason to reject it.*

Table 10 Prall values (ml) for SMA 11 100/150 GREEN

Lab	Individual values				Average
	1	**2**	**3**	**4**	
1	19.0	19.2	18.8	20.9	19.4
2	23.2	21.5	26.1	20.8	22.9
3	19.0	19.1	21.3	20.6	20.0
4	22.0	-	22.0	22.0	22.0
5	23.0	21.6	20.6	21.5	21.7
6					
7	23.4	21.5	25.7	23.7	23.6
8	19.6	18.2	20.1	20.3	19.5
9	20.9	21.7	21.1	21.2	21.2
10					
				avg	21.3
				s	1.5
				V-%	7.2

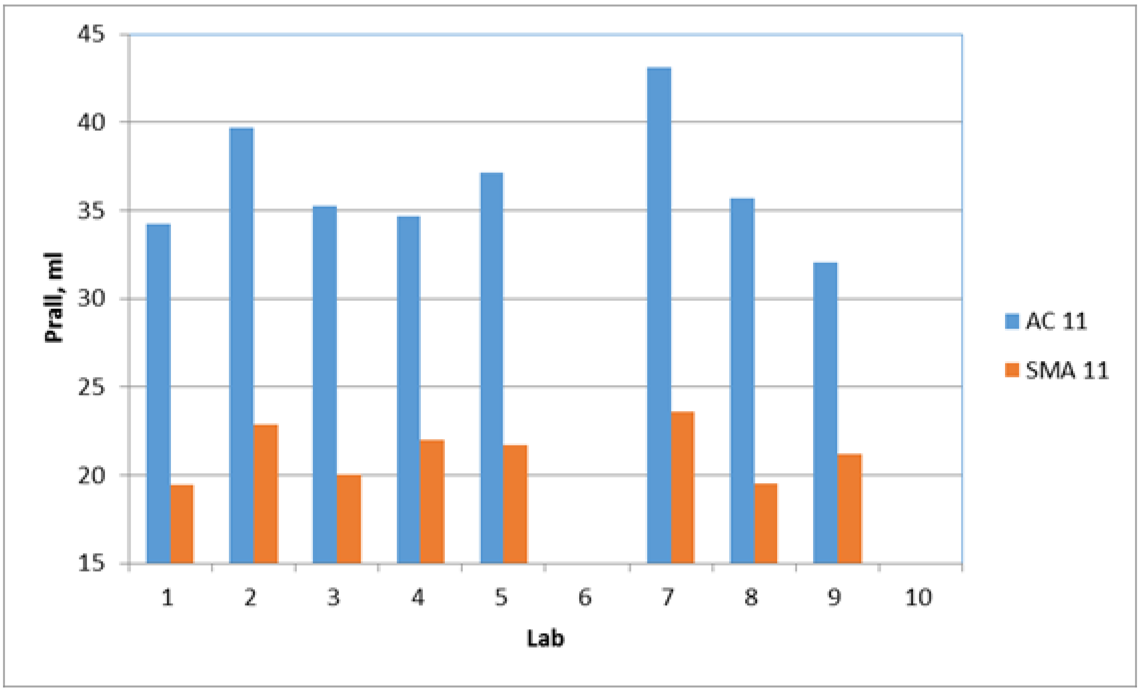


Figure 13 Prall average value

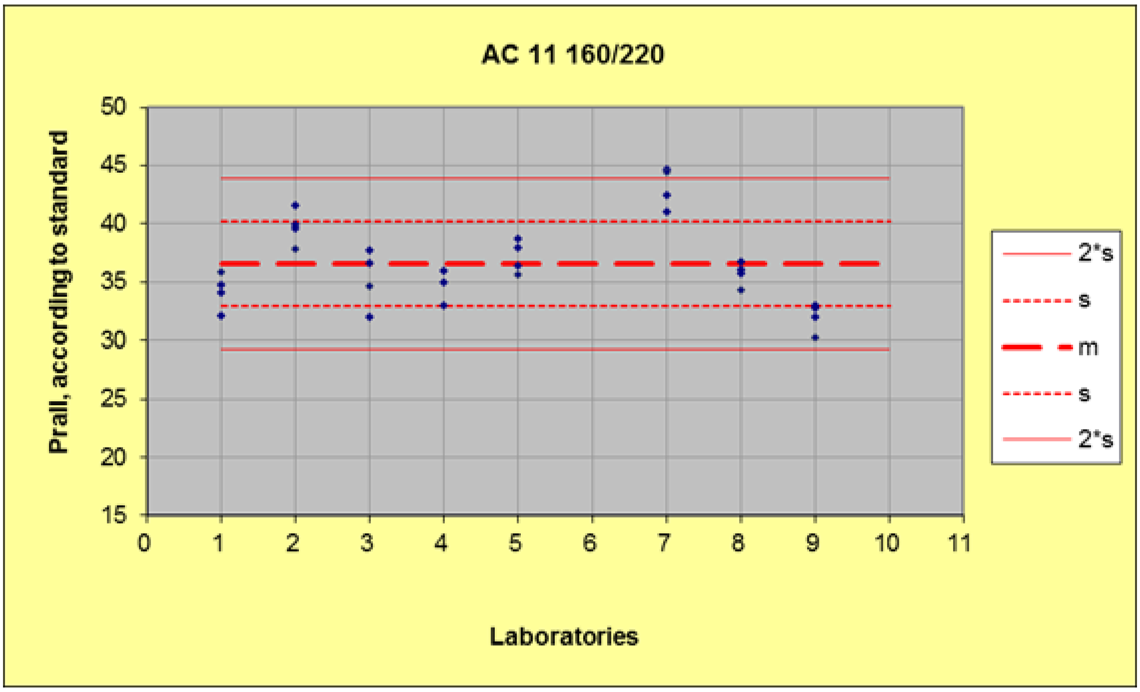


Figure 14 Individual Prall values for mix AC 11 160/220

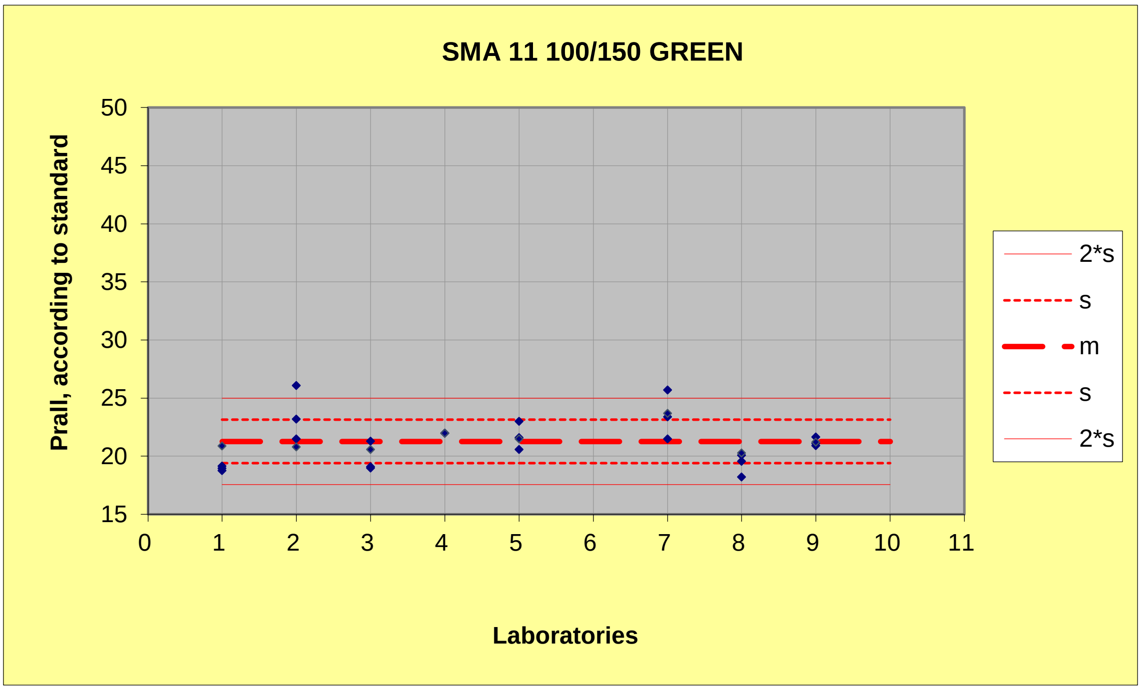
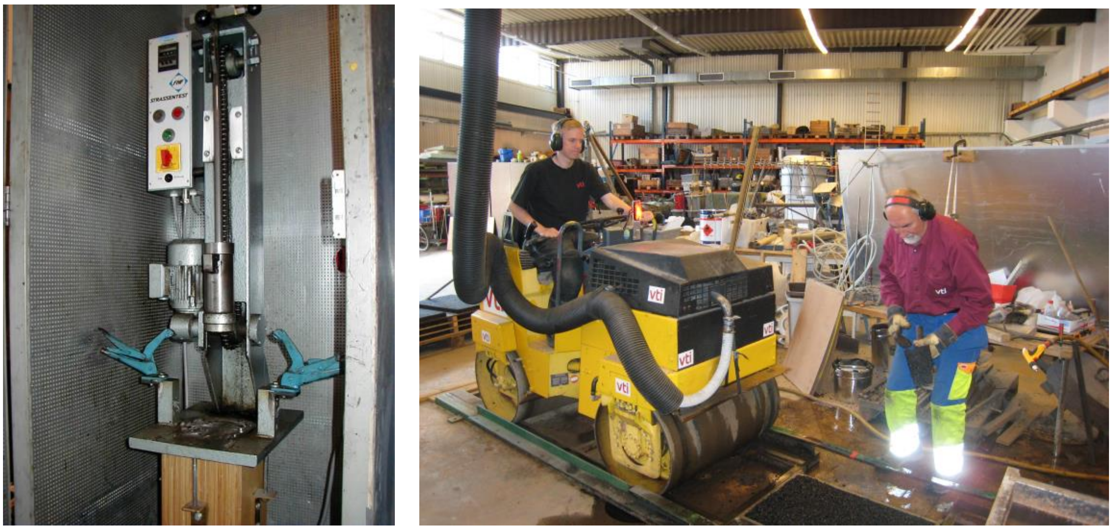


Figure 15 Individual values for mix SMA 11 70/100 GREEN

3.3 Phase 2: Evaluation of the correlation between lab and road

A comparative Prall test between Marshall compacted specimen and cored samples from laboratory compacted plates has been performed to study the difference between road and lab. In this case the cored samples from the plates simulate road samples and where tested on uncut surface, while Marshall specimen represent laboratory samples where tested on cut surface. Mixes used in this test where the same used in the second Round Robin test (AC 11 160/220 and SMA 11 70/100 GREEN).



a) *b)*

Figure 16 Marshall equipment (a) and Plate compaction (b)

The result show a difference on Prall value for AC11 between road and lab samples, but no difference for SMA 11 samples (*Table 11-12 and Figure 17*). An explanation could probably be that AC has more mastic in the surface than SMA, which affects the testing on uncut surfaces. According to *Figure 18* it seems as the samples are nearly the same regarding to bulk density.

Table 11 AC11 160/220

Sample	Individual values				Average	s	V-%
Marshall samples (Lab)	38.0	39.7	38.6	36.5	38.2	1.3	3.4
Cores from Plates ("Road")	32.0	32.8	33.0	30.3	32.0	1.2	3.8
				diff:	6.2		

Table 12 SMA11 100/150 GREEN

Sample	Individual values				Average	s	V-%
Marshall samples (Lab)	20.6	21.7	22.0	21.0	21.3	0.6	2.8
Cores from Plates ("Road")	20.9	21.7	21.1	21.2	21.2	0.3	1.5
				diff:	0.1		

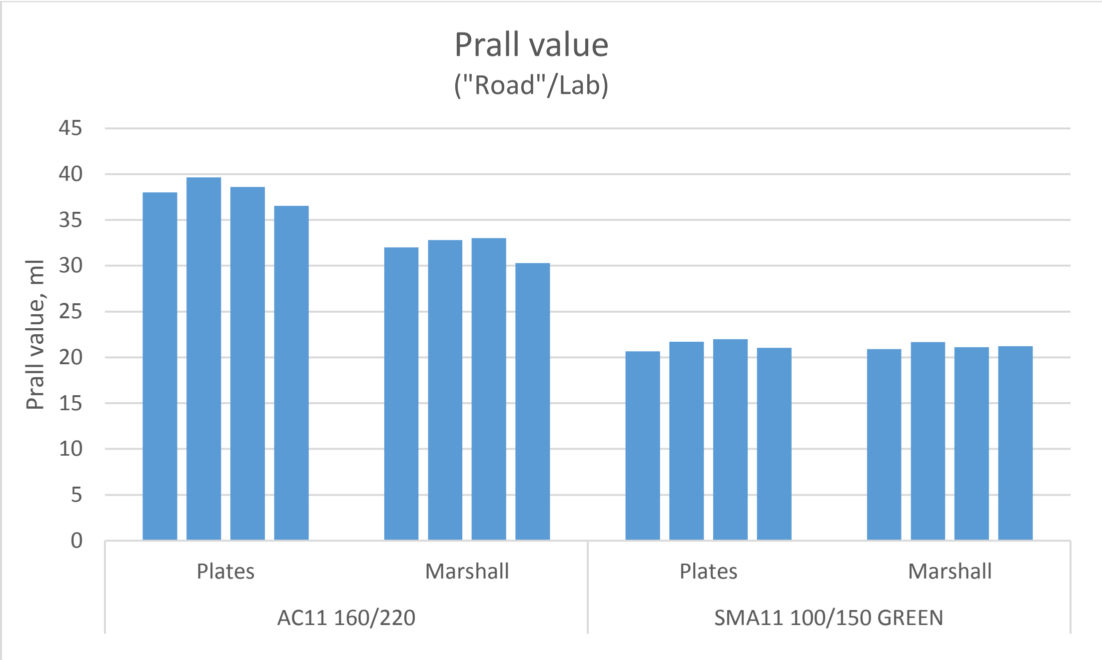


Figure 17 Prall values on Marshall specimens (cut surface) compared with cored samples from plates (uncut surface)

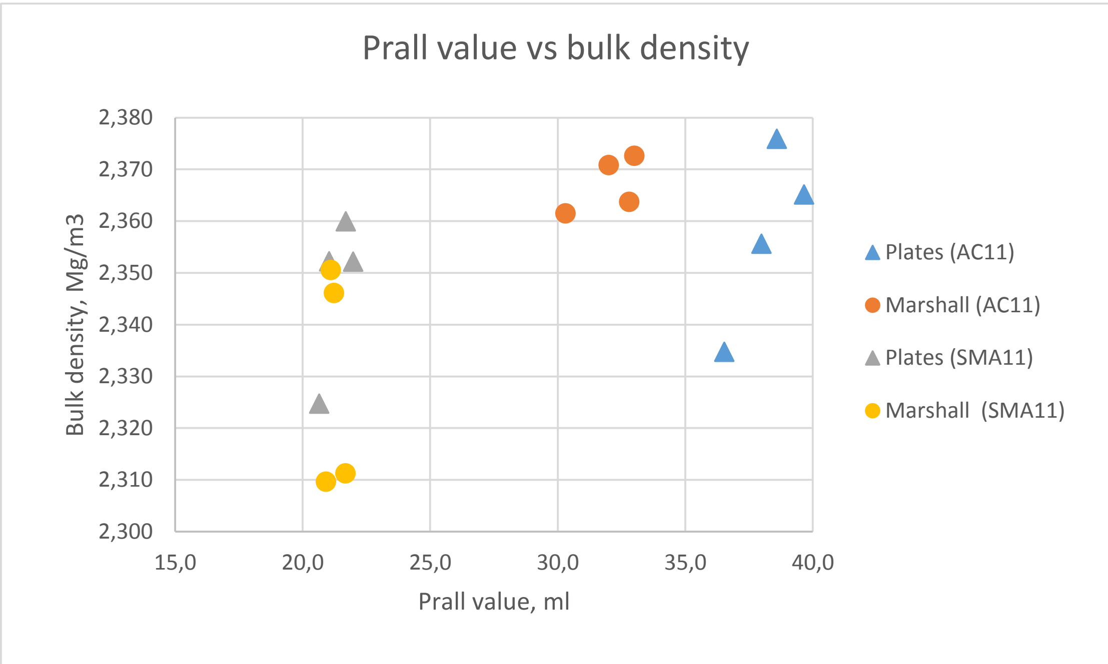


Figure 18 Prall value versus bulk density

3.4 Phase 2: Additional testing of temperature dependence

Samples from the same plates, used in chapter 3.3 above, where used for this Prall test at different temperatures (*Table 13-14 and Figure 19*). 2 mixes and 3 temperatures give a result where SMA shows no impact on temperature. For AC there where the same result at +8 and +11 °C, but higher values at +5 °C. Even here you can use the same explanation as for the Prall test in former chapter and the same independence of bulk density (*Figure 20*).

Table 13 AC11 160/220

Test temperature	**Individual values**				**Average**	**s**	**V-%**
+5 °C	38.0	39.7	38.6	36.5	38.2	1.3	3.4
+8 °C	32.2	34.5	34.5	36.4	34.4	1.8	5.1
+11 °C	31.0	34.0	32.8	35.9	33.4	2.1	6.1

Table 14 SMA11 100/150 GREEN

Test temperature	**Individual values**				**Average**	**s**	**V-%**
+5 °C	20.6	21.7	22.0	21.0	21.3	0.6	2.8
+8 °C	19.0	21.7	20.3	20.6	20.4	1.1	5.4
+11 °C	20.5	22.1	23.0	19.7	21.3	1.5	7.1

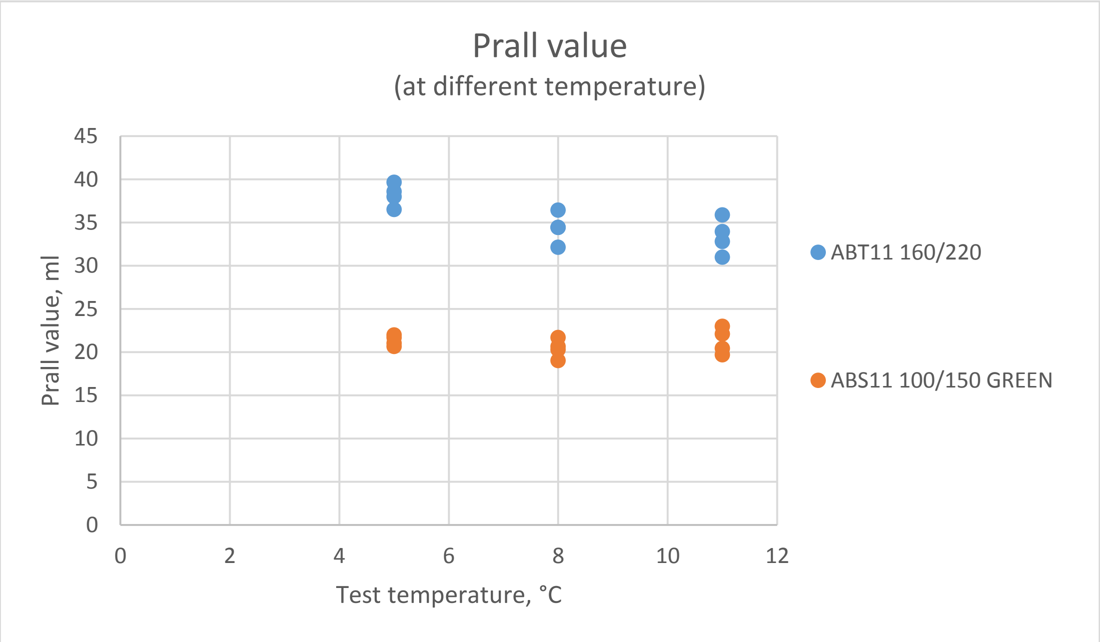


Figure 19 Prall value at different temperature

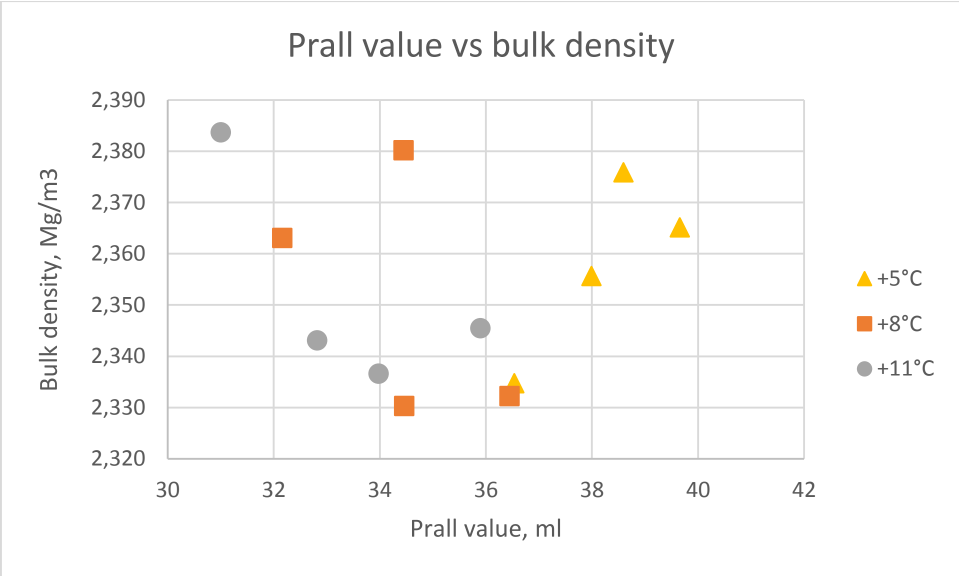


Figure 20 Prall value versus bulk density

4 Implementation and communication

The results and experiences obtained from this project and earlier research has been used during the work within 5 year review of EN12697-16 in CEN.

- Made corrections in the standard of known errors in both text and figures

The results will be implemented by:

- An updated reliable standard for determining of the abrasion value.
- Product standards with relevant levels of categories for Declaration of Performance of abrasion value.

5 Conclusions

The results from the first comparative testing gives a variation within laboratories (repeatability) around r = 20 % and variation between laboratories (reproducibility) around R = 26 %. The second comparative test gives better precision within laboratories (r = 15 %) but almost the same between laboratories (R = 27 %) compared to the first test. For a Prall value of 25 the respective variation would be about 4 and 7 units.

Decision to keep the standard values = 950 rpm/15 min. because the test at lower speed and longer time has not yielded better precision data for the method

After all tests has been performed in this project a quality of stainless steel sphere with HRC 58-65 was found on the market.

The project group suggested a change in the standard specifications to stainless steel spheres with HRC 58-65 which has the same density as HRC 52-55, but better quality and more in line with the previous described in the standard.

Observations:

- Comparative testing between laboratory compacted samples (Marshall) and cored samples from the road (Plates) gives less abrasion for cut samples of AC but no difference for SMA

- Test with different water temperature (5, 8 and 11 °C) gives differences for AC but not for SMA

6 Perspectives and recommendations

A new comparative testing with all laboratories dealing with this test method is recommended when the revised EN-standard is available.

It is incredibly important to maintain the Prall equipment in order to obtain relevant results

“Equipment that measures wear tends to also wear itself”

7 References

VTI Notat 22-2010. Development of the Prall method (Swedish)

VTI Utlåtande 759. Round Robin on Prall method. Cored samples from road (Swedish)

SBUF-Projekt 11904. Development of the Prall method (Swedish)

Annex 1

Basic data from the Round Robin Test
in phase 1 (four different mixes).

Bulk density
measured in each laboratory

Table: SMA 16 50/70 with aggregate AN <7 (Finland)

Lab	950 rev/min and 15 min (according to EN 12697-16)				800 rev/min and 30 min				950/15	800/30
	1	2	3	4	1	2	3	4	average	
1	2.323	2.334	2.325	2.334	2.334	2.337	2.334	2.317	2.329	2.331
2	2.304	2.304	2.321	2.312	2.322	2.326	2.330	2.303	2.310	2.320
3	2.327	2.329	2.337	2.324	2.330	2.290	2.337	2.323	2.329	2.320
4										
5	2.329	2.325	2.342	2.319	2.329	2.300	2.306	2.312	2.329	2.312
6	2.311	2.327	2.328	2.343	2.329	2.333	2.298	2.331	2.328	2.323
7	2.329	2.346	2.305	2.319	2.328	2.324	2.324	2.324	2.325	2.325
8	2.333	2.336	2.328	2.344	2.325	2.350	2.349	2.310	2.335	2.334
								m	2.326	2.323
								s	0.008	0.007
								V-%	0.335	0.311

Table: SMA 16 100/150 with aggregate AN <7 (Sweden)

Lab	950 rev/min and 15 min (according to EN 12697-16)				800 rev/min and 30 min				950/15	800/30
	1	2	3	4	1	2	3	4	average	
1	2.393	2.402	2.383	2.399	2.391	2.400	2.394	2.392	2.395	2.394
2	2.391	2.383	2.395	2.385	2.382	2.393	2.382	2.393	2.389	2.388
3	2.393	2.396	2.381	2.391	2.400	2.392	2.388	2.369	2.390	2.387
4										
5	2.381	2.388	2.369	2.374	2.379	2.371	2.384	2.398	2.378	2.383
6	2.391	2.387	2.380	2.406	2.388	2.385	2.379	2.392	2.391	2.386
7	2.392	2.398	2.384	2.387	2.397	2.396	2.384	2.379	2.390	2.389
8	2.387	2.392	2.302	2.397	2.390	2.396	2.386	2.400	2.370	2.393
								m	2.386	2.389
								s	0.009	0.004
								V-%	0.373	0.162

Table: AC 11 160/220 with aggregate AN <7 (Norway)

Lab	**950 rev/min and 15 min (according to EN 12697-16)**				**800 rev/min and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	2.433	2.457	2.458	2.478	2.442	2.449	2.465	2.476	2.457	2.458
2	2.461	2.45	2.439	2.463	2.462	2.456	2.423	2.451	2.453	2.448
3	2.467	2.433	2.459	2.462	2.464	2.426	2.475	2.455	2.455	2.455
4										
5	2.457	2.442	2.436	2.444	2.439	2.450	2.442	2.477	2.445	2.452
6	2.473	2.436	2.456	2.436	2.436	2.454	2.440	2.464	2.450	2.448
7	2.448	2.476	2.461	2.429	2.449	2.433	2.446	2.469	2.454	2.449
8	2.448	2.484	2.448	2.461	2.439	2.471	2.473	2.456	2.460	2.460
								m	2.453	2.453
								s	0.005	0.005
								V-%	0.201	0.193

AC 11 160/220 with aggregate AN <10 (Iceland)

Lab	**950 rev/min and 15 min (according to EN 12697-16)**				**800 rev/min and 30 min**				**950/15**	**800/30**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**average**	
1	2.562	2.575	2.567	2.570	2.588	2.589	2.588	2.589	2.569	2.589
2	2.569	2.576	2.568	2.570	2.569	2.573	2.578	2.576	2.571	2.574
3	2.579	2.576	2.577	2.576	2.576	2.580	2.577	2.577	2.577	2.578
4										
5	2.583	2.585	2.557	2.57	2.580	2.585	2.575	2.581	2.574	2.580
6	2.582	2.581	2.577	2.582	2.574	2.573	2.574	2.574	2.580	2.574
7	2.596	2.582	2.581	2.579	2.581	2.585	2.585	2.582	2.585	2.583
8	2.572	2.574	2.573	2.571	2.579	2.579	2.579	2.578	2.573	2.579
								m	2.575	2.579
								s	0.006	0.005
								V-%	0.219	0.203

Annex 2

Basic data and evaluation of bulk density measurements
from the Round Robin Test in Phase 1b (two different mixes).

With basic data means weight and dimension of all specimens,
including bulk density and water absorption.

Values for AC 11 160/220 from VTIs measurements on each specimen before sending them to the laboratory

VTI's initial values											
lab	specimen	Dimensions			Weight			Water			
		heigt		diff	dry	in water	ssd	temp	density	bulk density	water abs
nr	nr	mm -	mm +	mm	g	g	g	°C	g/cm³	Mg/m³	%
1	T03b	29,74	30,75	1,01	564,0	325,6	564,4	21,3	0,998	2,357	0,2
1	T04a	30,15	31,06	0,91	568,8	328,3	569,2	21,3	0,998	2,356	0,2
1	T04b	30,41	31,22	0,81	576,3	332,5	576,6	21,3	0,998	2,356	0,1
1	T05a	30,09	30,52	0,43	565,0	326,2	565,4	21,3	0,998	2,357	0,2
2	T07b	29,57	30,65	1,08	558,7	324,0	559,1	21,3	0,998	2,372	0,2
2	T08a	29,67	30,86	1,19	560,1	322,2	560,3	21,3	0,998	2,348	0,1
2	T08b	31,1	31,8	0,70	583,2	336,0	583,7	21,3	0,998	2,350	0,2
2	T09a	29,77	31,33	1,56	575,9	332,2	576,4	21,3	0,998	2,354	0,2
3	T09b	30,13	30,87	0,74	570,9	329,7	571,3	21,3	0,998	2,358	0,2
3	T16a	29,35	30,12	0,77	555,1	321,4	555,5	21,3	0,998	2,366	0,2
3	T11a	30,74	31,82	1,08	561,6	323,3	561,8	21,3	0,998	2,350	0,1
3	T11b	30,57	31,75	1,18	577,6	332,4	578,4	21,3	0,998	2,343	0,3
4	T10a	29,34	29,74	0,40	547,2	315,0	547,6	21,3	0,998	2,348	0,2
4	T16b	30,85	31,64	0,79	583,4	337,7	583,8	21,3	0,998	2,366	0,2
4	T17a	29,16	30,39	1,23	555,3	320,7	555,7	21,3	0,998	2,358	0,2
4	T18a	30,58	31,39	0,81	581,7	337,6	582,3	21,3	0,998	2,372	0,2
5	T20b	29	29,91	0,91	549,6	315,6	550,0	21,3	0,998	2,340	0,2
5	T21a	31,85	31,96	0,11	599,1	345,7	599,6	21,3	0,998	2,355	0,2
5	T21b	28,79	29,44	0,65	544,2	314,5	544,6	21,3	0,998	2,360	0,2
5	T22a	29,55	30,41	0,86	566,0	329,4	566,6	21,3	0,998	2,381	0,3
6	T12a	30,84	31,59	0,75	565,5	325,2	566,2	21,3	0,998	2,342	0,3
6	T31a	31,08	31,66	0,58	581,4	334,5	582,0	21,3	0,998	2,344	0,2
6	T13a	29,9	30,51	0,61	564,9	326,9	565,4	21,3	0,998	2,364	0,2
6	T13b	30,61	31,61	1,00	576,8	332,3	577,3	21,3	0,998	2,350	0,2
7	T18b	29,62	30,43	0,81	561,9	325,6	562,2	21,3	0,998	2,370	0,1
7	T19a	29,38	29,91	0,53	555,7	320,7	556,0	21,3	0,998	2,357	0,1
7	T19b	30,89	31,42	0,53	583,4	336,7	583,8	21,3	0,998	2,356	0,2
7	T20a	31,13	31,92	0,79	590,5	340,5	591,1	21,3	0,998	2,352	0,2
8	T05b	30,36	31,05	0,69	581,8	337,2	582,1	21,3	0,998	2,371	0,1
8	T06a	30,18	30,78	0,60	568,1	327,0	568,6	21,3	0,998	2,347	0,2
8	T06b	31,16	31,71	0,55	572,8	328,1	573,4	21,3	0,998	2,330	0,2
8	T07a	29,85	31,12	1,27	577,8	335,6	578,0	21,3	0,998	2,379	0,1
9	T24b	30,77	31,83	1,06	586,3	340,0	586,8	21,3	0,998	2,371	0,2
9	T25a	29,38	30,56	1,18	559,9	324,0	560,4	21,3	0,998	2,364	0,2
9	T25b	30,33	31,58	1,25	582,7	338,0	583,1	21,3	0,998	2,373	0,2
9	T26a	31,01	31,63	0,62	585,4	338,7	586,1	21,3	0,998	2,361	0,3

medel:	30,2	31,0	0,8	570,5	329,5	571,0	2,358	0,2
stdavv:	0,7	0,7	0,3	13,0	7,8	13,1	0,012	0,1
V-%	2,4	2,2	35,7	2,3	2,4	2,3	0,489	30,3
max	31,9	32,0	1,6	599,1	345,7	599,6	2,381	0,3
min	28,8	29,4	0,1	544,2	314,5	544,6	2,330	0,1

Values from each laboratory for AC 11 160/220

Values from all laboratories																Prall on VTI bulk density
lab	specimen	Dimensions		Weight			Water		bulk density		Prall					
		height	diameter	dry	in water	SSD	temp	density		water abs	before abrasion	after abrasion	abrasion value	dry weight after	dry before/ after	
nr	id	mm	mm	g	g	g	°C	g/cm³	g/ml	(%)	g	g	ml	g	ml	ml
1	T03b	30,1	101,7	564,0	324,9	564,5	20	0,998	2,350	0,2	564,7	489,3	32,1	488,2	32,6	32,0
1	T04a	30,5	101,6	568,8	326,2	569,2	20	0,998	2,337	0,2	569,7	488,4	34,8	487,2	35,3	34,5
1	T04b	30,7	101,6	576,2	332,1	576,6	20	0,998	2,352	0,2	577,0	496,7	34,1	495,6	34,6	34,1
1	T05a	30,2	101,6	565,0	325,7	565,5	20	0,998	2,352	0,2	565,7	481,3	35,9	479,7	36,6	35,8
2	T07B	29,5	101,5	558,8	323,9	559,1	21	0,998	2,371	0,1	559,6	464,9	39,9	463,1	40,7	39,9
2	T08A	29,7	101,5	559,8	322,3	560,1	21	0,998	2,350	0,1	562,2	464,5	41,6	461,8	42,7	41,6
2	T08B	31,1	101,5	583,3	336,4	583,8	21	0,998	2,353	0,2	584,5	491,4	39,6	488,0	41,0	39,6
2	T09A	30,5	101,6	575,9	332,2	576,3	21	0,998	2,355	0,2	577,0	488,0	37,8	485,5	38,9	37,8
3	T09b	30,1	101,7	570,9	329,3	571,0	20	0,998	2,358	0,0	571,7	496,2	32,0	494,7	32,7	32,0
3	T16a	29,5	101,7	555,1	318,8	555,2	20	0,998	2,344	0,0	555,7	467,3	37,7	465,5	38,5	37,4
3	T11a	29,9	101,7	561,5	323,0	561,7	20	0,998	2,348	0,1	562,3	476,4	36,6	475,3	37,1	36,6
3	T11b	30,8	101,7	577,6	331,8	577,8	20	0,998	2,344	0,1	578,7	497,5	34,6	496,2	35,2	34,7
4	T10a	29,0	101,7	547,2	314,8	547,6	23	0,998	2,345	0,2	548,0	464,0	35,8	462,6	36,4	35,8
4	T16b	30,7	101,8	583,4	337,1	583,5	23	0,998	2,362	0,0	584,0	505,0	33,4	500,2	35,5	33,4
4	T17a	29,4	101,7	555,0	320,3	555,2	23	0,998	2,357	0,1	555,5	474,0	34,6	471,8	35,5	34,6
4	T18a	30,6	101,7	581,5	336,6	581,7	23	0,998	2,367	0,1	582,5	479,0	43,7	476,9	44,6	43,6
5	T20B	29,4	101,7	549,6	315,4	549,8	20	0,998	2,340	0,1	550,7	460,2	38,7	458,8	39,3	38,7
5	T21A	31,9	101,8	599,1	345,2	599,3	20	0,998	2,353	0,1	599,8	510,4	38,0	509,3	38,5	38,0
5	T21B	28,9	101,7	543,9	313,8	544,1	20	0,998	2,357	0,1	544,8	459,1	36,4	457,7	36,9	36,3
5	T22A	29,8	101,6	565,8	329,1	566,1	20	0,998	2,383	0,1	566,6	481,7	35,6	480,3	36,2	35,7
6	T12a	30,4	101,7	565,4	325,0	565,7	25	0,997	2,342							
6	T31a	31,3	101,8	581,4	334,3	581,6	25	0,997	2,344							
6	T13a	30,2	101,7	564,9	326,7	565,1	25	0,997	2,363							
6	T13b	30,8	101,6	576,8	332,1	577,0	25	0,997	2,348							
7	T18b	29,8	101,6	561,7	324,9	562,3	21	0,998	2,362	0,3	562,5	465,8	40,9	464,2	41,6	40,8
7	T19a	29,7	101,6	555,6	320,2	556,2	21	0,998	2,350	0,3	556,2	451,8	44,4	449,8	45,3	44,3
7	T19b	31,2	101,6	583,3	336,2	584,1	21	0,998	2,348	0,3	584,1	484,4	42,5	482,2	43,4	42,3
7	T20a	31,6	101,6	590,2	339,7	591,0	21	0,998	2,344	0,3	591,0	486,2	44,7	483,3	45,9	44,6
8	T05b	30,7	101,5	581,7	337,3	582,0	21	0,998	2,373	0,1	582,5	497,0	36,0	495,6	36,6	36,1
8	T06a	30,4	101,7	568,0	327,0	568,3	21	0,998	2,349	0,1	568,9	484,9	35,8	483,5	36,3	35,8
8	T06b	31,4	101,5	572,8	328,2	573,3	21	0,998	2,333	0,2	573,8	488,1	36,7	485,6	37,8	36,8
8	T07a	30,4	101,6	577,7	335,3	577,8	21	0,998	2,378	0,0	578,3	496,8	34,3	495,9	34,7	34,3
9	T24b	30,8	102,1	586,3	340,0	586,8	21	0,998	2,371	0,2	587,4	511,5	32,0	510,2	32,6	32,0
9	T25a	29,4	102,2	559,9	324,0	560,4	21	0,998	2,364	0,2	560,7	483,1	32,8	482,2	33,2	32,8
9	T25b	30,3	102,1	582,7	338,0	583,1	21	0,998	2,373	0,2	583,5	505,1	33,0	504,3	33,4	33,0
9	T26a	31,0	101,9	585,4	338,7	586,1	21	0,998	2,361	0,3	586,2	514,7	30,3	513,3	30,9	30,3
	medel:	30,3	101,7	570,5	329,1	570,8			2,355	0,2	571,1	484,5	36,8	482,8	37,5	36,7
	stdavv:	0,7	0,2	13,1	7,9	13,1			0,012	0,1	13,6	16,5	3,8	16,5	3,9	3,8
	V-%	2,4	0,2	2,3	2,4	2,3			0,505	52,6	2,4	3,4	10,3	3,4	10,5	10,3
	max	31,9	102,2	599,1	345,2	599,3			2,383	0,3	599,8	514,7	44,7	513,3	45,9	44,6
	min	28,9	101,5	543,9	313,8	544,1			2,333	0,0	544,8	451,8	30,3	449,8	30,9	30,3

Values for SMA 11 70/100 from VTIs measurements on each specimen before sending them to the laboratory

VTI's initial values												
lab	Specimen	Dimensions			Weight			Water				
		heigt		diff	dry	in water	ssd	temp	density	bulk density	water abs
nr	id	mm -	mm +	mm	g	g	g	°C	g/cm³	Mg/m³	%
1	S21b	29,9	30,9	1,0	527,9	303,6	529,2	21,3	0,998	2,335	0,6
1	S07b	29,7	30,9	1,2	550,2	318,7	551,2	21,3	0,998	2,362	0,4
1	S30b	30,3	31,5	1,2	545,6	313,8	546,6	21,3	0,998	2,339	0,4
1	S08b	29,7	30,7	0,9	541,9	313,2	542,9	21,3	0,998	2,354	0,4
2	S13a	29,7	30,7	1,0	548,2	317,3	549,7	21,3	0,998	2,354	0,6
2	S13b	30,1	30,7	0,6	533,6	307,7	535,0	21,3	0,998	2,343	0,6
2	S14a	29,0	30,2	1,2	528,8	306,6	530,0	21,3	0,998	2,362	0,5
2	S30a	29,8	30,8	1,0	532,3	306,0	533,4	21,3	0,998	2,336	0,5
3	S14b	30,5	31,5	1,0	550,6	318,8	551,7	21,3	0,998	2,359	0,5
3	S15a	29,6	30,7	1,1	540,0	313,0	541,0	21,3	0,998	2,364	0,4
3	S15b	29,9	30,9	1,0	537,6	310,3	539,2	21,3	0,998	2,344	0,7
3	S16a	30,1	31,9	1,8	552,0	318,1	553,4	21,3	0,998	2,341	0,6
4	S22a	30,3	31,4	1,1	549,7	319,2	551,1	21,3	0,998	2,366	0,6
4	S22b	29,1	30,1	0,9	530,4	306,8	531,5	21,3	0,998	2,356	0,5
4	S23a	29,3	30,5	1,1	538,7	311,4	539,8	21,3	0,998	2,354	0,5
4	S24a	30,2	31,9	1,7	556,1	318,6	557,3	21,3	0,998	2,325	0,5
5	S12b	28,8	30,4	1,5	531,8	308,1	532,9	21,3	0,998	2,361	0,5
5	S28a	29,5	30,3	0,7	532,0	308,2	533,1	21,3	0,998	2,361	0,5
5	S28b	30,1	31,4	1,3	546,0	314,3	547,0	21,3	0,998	2,342	0,4
5	S29a	29,1	30,4	1,3	518,1	297,6	519,9	21,3	0,998	2,326	0,8
6	S16b	29,1	30,6	1,5	533,4	307,9	534,5	21,3	0,998	2,349	0,5
6	S02a	30,0	30,7	0,8	538,3	310,3	539,2	21,3	0,998	2,347	0,4
6	S18a	29,3	31,0	1,7	538,0	311,3	539,4	21,3	0,998	2,354	0,6
6	S18b	29,6	31,1	1,5	543,5	313,2	544,5	21,3	0,998	2,345	0,4
7	S25a	30,1	31,0	0,9	544,0	314,9	545,0	21,3	0,998	2,359	0,4
7	S25b	29,5	30,1	0,6	536,2	310,0	537,1	21,3	0,998	2,356	0,4
7	S26a	30,5	31,9	1,4	555,6	320,5	557,0	21,3	0,998	2,345	0,6
7	S26b	29,4	30,8	1,4	522,6	299,8	523,8	21,3	0,998	2,328	0,5
8	S09b	30,1	31,4	1,3	551,5	319,7	552,3	21,3	0,998	2,366	0,3
8	S10a	30,0	30,9	1,0	538,0	310,4	539,5	21,3	0,998	2,344	0,7
8	S21a	31,3	31,9	0,6	551,7	317,5	553,5	21,3	0,998	2,333	0,8
8	S11a	30,3	31,8	1,6	559,6	323,8	560,8	21,3	0,998	2,356	0,5
9	S06b	29,5	31,4	2,0	529,5	302,7	531,5	21,3	0,998	2,310	0,9
9	S24b	29,5	31,1	1,6	525,7	300,4	527,4	21,3	0,998	2,311	0,7
9	S27a	30,3	31,3	1,0	550,9	318,1	552,0	21,3	0,998	2,351	0,5
9	S27b	29,5	30,7	1,2	520,7	300,1	521,6	21,3	0,998	2,346	0,4
	medel:	29,8	31,0	1,2	539,7	311,4	541,0			2,347	0,5
	stdavv:	0,5	0,5	0,3	10,7	6,7	10,7			0,014	0,1
	V-%:	1,7	1,7	28,7	2,0	2,1	2,0			0,611	23,5
	max:	31,3	31,9	2,0	559,6	323,8	560,8			2,366	0,9
	min:	28,8	30,1	0,6	518,1	297,6	519,9			2,310	0,3

Values from each laboratory for SMA 11 70/100

Values from all laboratories																	Prall on VTI bulk density
lab	specimen	Dimensions		Weight			Water			bulk	Prall						
		height	diameter	dry	in water	SSD	temp	density	water abs	density	before abrasion	after abrasion	abrasion value	dry weight after	dry before/ after		
nr	id	mm	mm	g	g	g	°C	g/cm³	%	g/ml	g	g	ml	g	ml		ml
1	S21b	30,6	101,5	527,8	302,3	529,1	20	0,9982	0,6	2,323	529,4	485,8	18,8	482,5	20,2		18,7
1	S07b	30,5	101,5	550,2	314,4	551,0	20	0,9982	0,3	2,321	551,4	507,4	19,0	505,5	19,8		18,6
1	S30b	30,9	101,3	545,6	310,4	546,9	20	0,9982	0,5	2,303	546,9	498,8	20,9	497,0	21,7		20,6
1	S08b	30,5	101,4	541,9	311,3	542,7	20	0,9982	0,3	2,338	543,0	498,2	19,2	496,4	19,9		19,0
2	S13A	29,5	100,6	548,2	317,5	549,2	21	0,9981	0,4	2,361	549,5	494,7	23,2	491,1	24,7		23,3
2	S13B	29	100,4	533,5	306,9	534,8	21	0,9981	0,6	2,336	534,9	484,6	21,5	480,7	23,2		21,5
2	S14A	29	100,4	528,8	306,1	529,5	21	0,9981	0,3	2,363	529,8	468,1	26,1	464,8	27,5		26,1
2	S30A	29,5	100,5	532,4	306,6	533,9	21	0,9981	0,7	2,338	534,2	485,6	20,8	480,8	22,8		20,8
3	514b	30,6	101,6	550,6	317,7	551,0	20	0,9982	0,2	2,356	552,4	507,3	19,1	505,3	20,0		19,1
3	515a	29,7	101,4	539,9	311,1	540,5	20	0,9982	0,3	2,349	541,3	492,8	20,6	490,3	21,7		20,5
3	515b	30,2	101,5	537,5	308,9	538,1	20	0,9982	0,3	2,341	538,9	494,4	19,0	491,4	20,3		19,0
3	516a	31	101,6	551,9	316,6	552,6	20	0,9982	0,3	2,334	553,5	503,7	21,3	500,6	22,7		21,3
4	S22a	30,7	101,2	549,8	318,4	550,6	23	0,9976	0,3	2,362	551	499	22,0	496,3	23,2		22,0
4	S22b	29,7	101,5	530,5	306,6	531,3	23	0,9976	0,4	2,355	531,5	470,5	25,9	466,9	27,4		25,9
4	S23a	29,7	101,4	538,8	311,0	539,5	23	0,9976	0,3	2,352	540	487,5	22,3	483,7	23,9		22,3
4	S24a	30,8	101,5	556,2	319,4	556,6	23	0,9976	0,2	2,339	557,5	505	22,4	500,3	24,5		22,6
5	S12B	29,45	101,49	531,8	308,0	532,5	20	0,9982	0,3	2,365	532,9	479,8	22,5	477,6	23,4		22,5
5	S28A	29,87	101,49	532,0	307,7	533,3	20	0,9982	0,6	2,354	533,6	482,8	21,6	480,4	22,6		21,5
5	S28B	30,40	101,40	546,0	314,5	546,8	20	0,9982	0,3	2,346	547,5	499,1	20,6	496,4	21,8		20,7
5	S29A	29,63	101,60	518,1	297,9	519,9	20	0,9982	0,8	2,330	520,2	470,1	21,5	467,5	22,6		21,5
6	S16b	30,0	101,7	533,4	307,6	534,0	25	0,9971	0,3	2,349							
6	S02a	30,7	101,7	538,3	310,3	538,7	25	0,9971	0,2	2,350							
6	S18a	30,4	101,7	537,9	310,8	538,5	25	0,9971	0,3	2,355							
6	S18b	30,3	101,8	543,4	314,2	544,0	25	0,9971	0,3	2,358							
7	S25a	30,6	101,6	543,8	314,7	544,7	21	0,9981	0,4	2,360	544,8	484,2	25,7	481,6	26,8		25,7
7	S25b	30	101,6	536,0	309,5	537,2	21	0,9981	0,5	2,350	537,3	486,9	21,5	483,8	22,8		21,4
7	S26a	31,3	101,6	555,6	319,8	556,7	21	0,9981	0,5	2,341	557	502,4	23,3	498,7	24,9		23,3
7	S26b	30,4	101,6	522,4	299,3	524,0	21	0,9981	0,7	2,320	524,2	469,2	23,7	465,5	25,3		23,6
8	S09b	30,9	101,5	551,5	320,5	552,2	21	0,9981	0,3	2,376	552,5	506	19,6	503,9	20,5		19,7
8	S10a	30,7	101,2	537,7	311,8	539,1	21	0,9981	0,6	2,361	539,7	496,7	18,2	492,9	19,8		18,3
8	S21a	31,6	101,5	551,6	319,0	552,7	21	0,9981	0,5	2,356	553,6	505,8	20,3	502,3	21,8		20,5
8	S11a	31,4	101,3	559,5	324,4	560,2	21	0,9981	0,3	2,368	560,8	513,2	20,1	510,8	21,1		20,2
9	S06b	29,5	101,6	529,5	302,7	531,5	21	0,998	0,9	2,310	531,2	482,9	20,9	478,2	22,9		20,9
9	S24b	29,5	101,7	525,7	300,4	527,4	21	0,998	0,7	2,311	527,7	477,6	21,7	473,1	23,6		21,7
9	S27a	30,3	101,7	550,9	318,1	552,0	21	0,998	0,5	2,351	552,2	502,6	21,1	501,1	21,7		21,1
9	S27b	29,5	101,6	520,7	300,1	521,6	21	0,998	0,4	2,346	522,1	472,3	21,2	468,8	22,7		21,2
	medel:			539,7	311,0	540,7		0,998	0,4	2,345	541,3	491,1	21,4	488,0	22,7		21,4
	stdavv:			10,7	6,7	10,5		0,000	0,2	0,017	11,2	13,0	2,0	13,3	2,1		2,0
	V-%:			2,0	2,1	1,9		0,036	43,2	0,738	2,1	2,6	9,3	2,7	9,4		9,4
	max:			559,5	324,4	560,2		0,998	0,9	2,376	560,8	513,2	26,1	510,8	27,5		26,1
	min:			518,1	297,9	519,9		0,997	0,2	2,303	520,2	468,1	18,2	464,8	19,8		18,3

Figure over variations caused by different bulk density measurements on AC 11 160/220

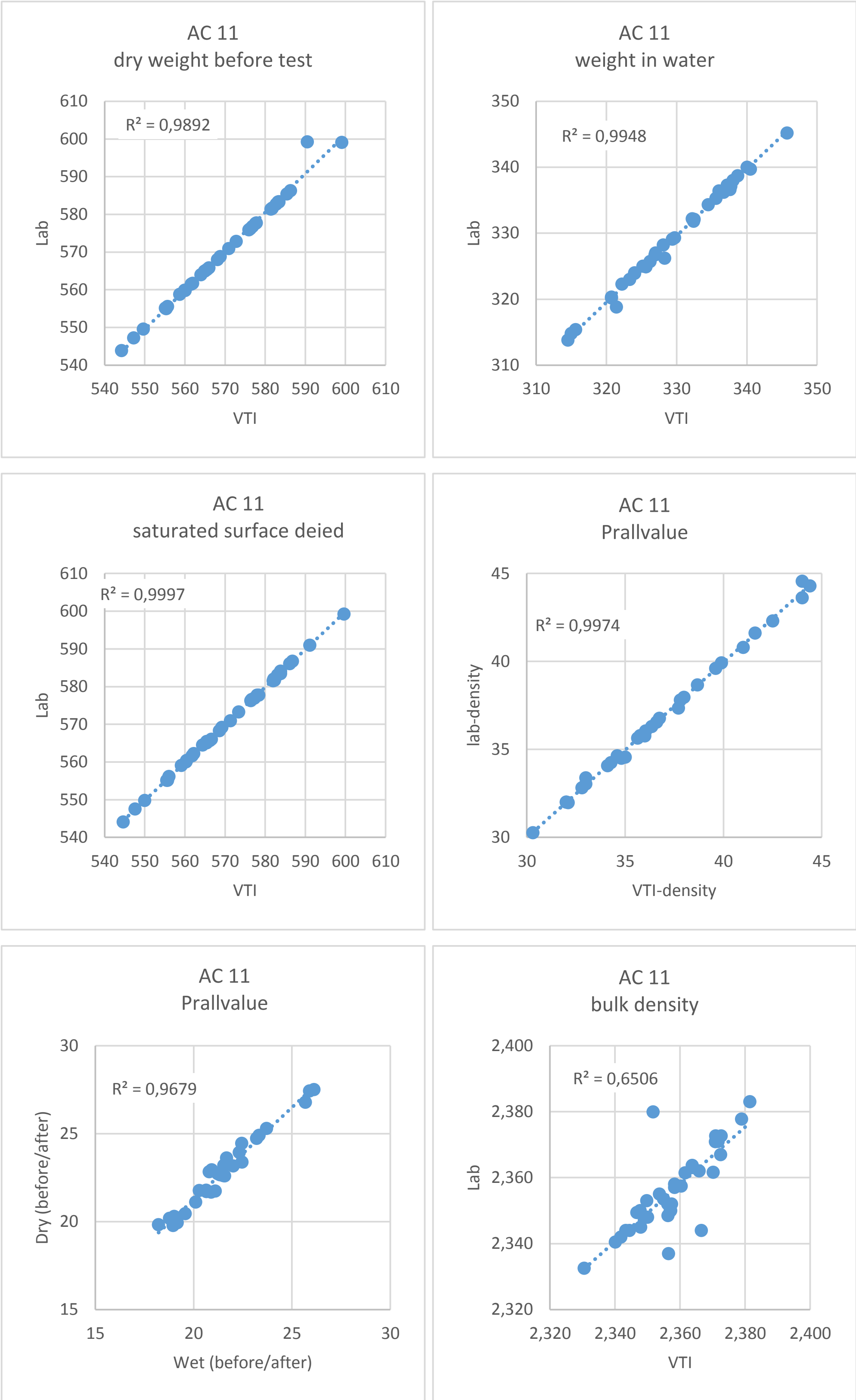


Figure over variations caused by different bulk density measurements on SMA 11 70/100