Prall tests to study the effect of mortar on the wear of Norwegian asphalt mixtures

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ABSTRACT

With the use of studded tires, the mineralogy of the aggregates used in asphalt mixtures is considered crucial for the wear resistance of the road surface. High strength of the coarse aggregates and adequate binder content are usually considered good requirements. However, field observations indicate that the mortar is the least wear resistant portion of the asphalt mixture. Being exposed to studded tires, the binder coating the coarse aggregates will be grinded off, and a significant part of the further wear takes place between the coarse particles. As the wear is caused by the studded tires, the Prall Test (Method A) is used to check the effect of the mortar. The purpose was to study how to improve the mortar to achieve both as little and as even as possible wear on the asphalt surface. In addition, the evenness of the worn asphalt surface was evaluated by calculating the area which is formed between the peak and the minimum of the surface texture. Three rock materials with different Nordic abrasion values were used for the stone skeletons of 19 asphalt mixtures. The mixtures varied thereby in their combination of rock materials in the fine and coarse aggregates. The paper shows the results of the Prall Test and the evaluation of the surface texture on the Prall tested specimens. The correlations of the results to the Nordic abrasion values are opposite of one another, indicating further research is needed to improve the wear characteristics of the asphalt mixture and keeping a low noise surface texture at the same time.

Keywords: Aggregate, Asphalt, Resistance to Wear (Studded Tyres), Surface Texture, Tyre/road noise

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ABSTRACT

With the use of studded tires, the mineralogy of the aggregates used in asphalt mixtures is considered crucial for the wear resistance of the road surface. High strength of the coarse aggregates and adequate binder content are usually considered good requirements. However, field observations indicate that the mortar is the least wear resistant portion of the asphalt mixture. Being exposed to studded tires, the binder coating the coarse aggregates will be grinded off, and a significant part of the further wear takes place between the coarse particles. As the wear is caused by the studded tires, the Prall Test (Method A) is used to check the effect of the mortar. The purpose was to study how to improve the mortar to achieve both as little and as even as possible wear on the asphalt surface. In addition, the evenness of the worn asphalt surface was evaluated by calculating the area which is formed between the peak and the minimum of the surface texture. Three rock materials with different Nordic abrasion values were used for the stone skeletons of 19 asphalt mixtures. The mixtures varied thereby in their combination of rock materials in the fine and coarse aggregates. The paper shows the results of the Prall Test and the evaluation of the surface texture on the Prall tested specimens. The correlations of the results to the Nordic abrasion values are opposite of one another, indicating further research is needed to improve the wear characteristics of the asphalt mixture and keeping a low noise surface texture at the same time.

1. INTRODUCTION

The wear on asphalt pavements can be reduced by increasing the amount and the maximum aggregate size (D_{max}) of the coarse aggregates. [1] However, on dense asphalt pavements, a reduction in maximum aggregate size gives a reduction in noise generation. [2] Thus, it is challenging to develop an asphalt mixture which is resistant against abrasion at the same time as it has noise reducing effect.
In the Nordic countries, most of the wear is caused by the use of studded tires during the winter time. The surface texture is changing rapidly, and it is observed that the mortar is usually worn away first. As a consequence, the coarse aggregates protrude from the pavement surface and form high amplitudes in the macro texture range (0.5-50 mm), which generates tire/road noise. [3] The bigger the maximum aggregate size, the more protrusion of the coarse aggregates, and the more tire/road noise is generated. Figure 1 illustrates the wear on a pavement surface before and after it is exposed to studded tires.

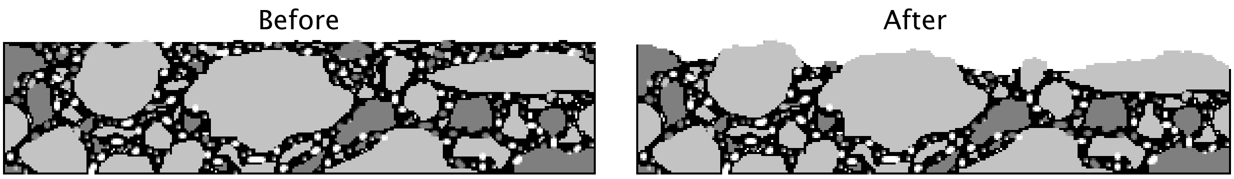


Figure 1: Pavement surface before and after exposure to studded tires

Since the mortar seems to be the weakest part of the asphalt mixture, the challenge is to find a rock material for the fine aggregates which strengthens the mortar. To avoid the coarse aggregates protruding, the abrasion characteristics of their rock material should be adjusted to those of the mortar. This is supposed to equalize the wear of the mortar and the coarse aggregates and to result in a more evenly worn asphalt surface. At the same time, the overall wear of the asphalt surface is required to be as low as possible after being exposed to studded tires.
In this study, 19 asphalt mixtures were developed using different combinations of three rock materials in their stone skeleton. The purpose was to balance the wear of the asphalt pavement and the evenness of the pavement surface texture. The quality of the aggregates is supposed to be crucial regarding the effect on the abrasion characteristics of the mortar and the coarse material. Therefore, the three rock materials differed amongst other things in their Nordic abrasion value, which reflects the resistance of the rock material against the abrasive action of studded tires. [4] To analyze the wear on the asphalt pavement caused by studded tires, all 19 asphalt mixtures were tested with the Prall Test (Method A). Afterwards, the Prall specimens were cut in two halves and the surface texture was analyzed on the cut surface of the specimen. Therefore, an area was calculated, which is formed between a 50 mmm long horizontal line touching the peak of the surface texture and a line retracing the surface texture.
The study was carried out to investigate whether the wear characteristics of an asphalt mixture can be improved by mixing rock materials with different characteristics in the fine and coarse fraction of the stone skeleton. The objective was to develop an asphalt mixture which provides a more even surface texture after the asphalt pavement has been exposed to studded tires. Thus, the surface texture can provide noise reducing characteristics over a long term.

2. CHOSEN MATERIALS

19 asphalt mixtures were developed. The most common asphalt mixture types in Norway are stone mastic asphalt (SMA) and asphalt concrete (AC). To get usable results, only these two mixture types were investigated during this study. The

D_{max} ranged from 8 to 16 mm. Since a reduction in maximum aggregate size results in noise reduction, D_{max} of 8 and 11 mm were dominating. Three types of rock material (A,B and C) were used differently in the stone skeletons to compose the mixtures. As bitumen, an unmodified 70/100 was used. The stone skeletons of the asphalt mixtures were accomplished by combining either one or two of the rock materials. When two rock materials where used in one asphalt mixture, one of them was used for the fine aggregates with aggregate size up to 4 mm and the other one was used for the coarse material with aggregate size above 4 mm.
Table 1 gives an overview of the tested asphalt mixtures with their D_{max} and the rock materials used for the fine and coarse aggregates.

Table 1: Asphalt mixtures with their D_{max} and the rock materials used for fine and coarse aggregates

Asphalt mixture types	D_{max}	Rock material: fine aggregates	Rock material: coarse aggregates	Notation
AC	8	A		AC8A
		A	B	AC8A/B
		B		AC8B
	11	A		AC11A
		A	C	AC11A/C
		A	B	AC11A/B
		C		AC11C
		C	A	AC11C/A
		B		AC11B
		B	A	AC11B/A
	16	A		AC16A
SMA	8	A		SMA8A
		A	B	SMA8A/B
		B		SMA8B
	11	A		SMA11A
		A	B	SMA11A/B
		C		SMA11C
		B		SMA11B
	16	A		SMA16A

Table 2 presents the different characteristics of the rock materials. The rock materials A and B were tested at Veidekke Industri. The results for the rock material C are taken from the homepage of the Geological survey of Norway (NGU).

Table 2: Characteristics of the rock materials

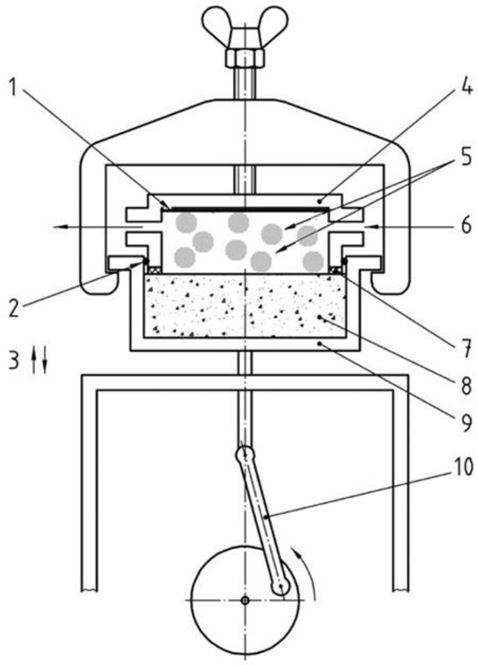
Test method	Rock material A (porphyry)	B (gabbro)	C* (monzonite)
Specific density [5]	2,614 g/cm^3	3,011 g/cm^3	2,72 g/cm^3
Flakiness index 4-8 mm [6]	26	9	-**
Flakiness index 8-11 mm [6]	13	3	-**
Micro-Deval value [7]	2	10	4,3
LA coefficient [8]	12 %	13,5 %	30,1 %
Nordic abrasion value [4]	3,9 %	11 %	13,7 %

* Values provided by [9]
** no values available

As Table 2 shows, the rock material A is most resistant against abrasion by studded tires, C is the least resistant one.

3. MEASUREMENT OF ABRASION DUE TO STUDDED TIRES

The 19 asphalt mixtures were tested with the Prall Test (Method A) at the central laboratory of the Norwegian Public Roads Administration (NPRA). The purpose of this test is to simulate the abrasive action of studded tires on the asphalt mixture. As the result, the loss of volume [ml] is recorded and reported as the Prall abrasion value (Abr_A). This value indicates the wear resistance of an asphalt pavement which is exposed to studded tires; the lower the value, the more resistant the pavement. The method is only used in the Nordic countries and is described in [10]. Figure 2 shows the setup of the Prall abrasion apparatus.



Key

1	Rubber plate
2	O-ring
3	Stroke
4	Lid
5	Steel spheres
6	Inlet/ outlet for cooling water
7	Flat rubber ring
8	Specimen
9	Sample collar
10	Connection rod

Figure 2: Prall abrasion apparatus, in general [10]

The test requires cylindrical asphalt specimens with a diameter of 100 mm and a height of 30 mm. At least three specimens of each asphalt mixture were prepared by the Marshal Mix Design, compacted by 50 blows on either side. Each Marshall Test specimen was cut in two halves, where each half made one Prall Test specimen. Prior to testing the specimens are cooled down to a temperature of 5 degree Celsius. Placed in the Prall Test chamber with 40 stainless steel spheres, the specimen is worn by abrasive action over the standard time period of 15 minutes. During testing the specimen is flowed with 0,2 liters of water per minute, at a temperature of 5 degree Celsius. 6 to 8 specimens were tested for all 19 asphalt mixtures. The Prall abrasion value for each asphalt mixture is calculated as the average value from all specimens of the respective asphalt mixture.

3.1. Changes in test equipment

The Prall Test was performed in two sets. The first set was tested in 2010, the second one in 2013. In 2012 the Prall abrasion apparatus was further developed and the requirements for the Prall Test were tightened. This resulted in a change of equipment at the laboratory. The most important development with the new test equipment was an automatic system to control temperature and quantity of the water which flows the specimen during testing. While the tests accomplished in 2010 were performed with the old equipment, the new revised equipment was used for the tests in 2013.

4. SURFACE TEXTURE EVALUATION

To achieve information on the worn surface, all specimens had to be analyzed regarding their surface texture after being tested by the Prall Test. However, in Norway, no standardized equipment exists to measure the texture of the asphalt surface on small specimens. The challenge was to find a simple method to evaluate the surface texture on the Prall Test specimens. In order to do that, at least three Prall Test specimens of each asphalt mixture were cut vertically into two half-moon shaped pieces of the same size (see Figure 3). The specimens were placed in the saw with no special consideration. Thus, the cutting edges are positioned randomly.

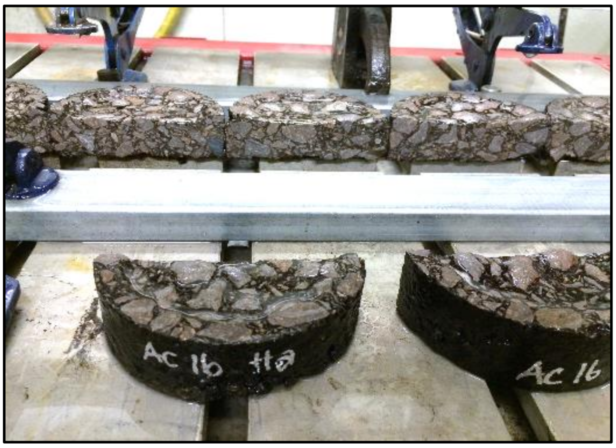


Figure 3: Cut Prall Test specimens

All cutting edges were photographed. The pictures were plotted in AutoCAD. The upper part of the cutting edge provides the surface texture of the specimen in form of a rugged line. This line was retraced in AutoCAD. In addition to this texture line, a horizontal line touching the peak of the surface line was drawn. Between the texture line and the horizontal line an area is generated, which is easily found in AutoCAD. The size of the area reflects the condition of the surface texture. The higher the value, the rougher the surface texture. A big area above the texture line reflects that the mortar is worn away and the coarse aggregates protrude. The smaller the area, the smoother the surface texture. Small values reveal a balanced wear of both, the fine and the coarse aggregates. In the following, the generated area will be named "Texture area".

4.1. Adjustments related to the test equipment

When the specimen is tested in the Prall Test chamber, the specimen is trapped in the test chamber by an O-ring with a flat rubber ring underneath (see Figure 2). [10] These rings cause an edge around the specimen which does not get in contact with the steel spheres under testing, and like that stays unworn. In addition, the part of the worn surface is rounded into these edges caused by the geometry of the steel spheres, which have a diameter of 11.50-12.01 mm (see Figure 4). Only 50 mm in the middle of the specimen were considered to properly reflect the abrasion by studded tires on the surface. The horizontal line was therefore drawn through the highest peak in this 50 mm section. Figure 4 visualizes the cut surface of the Prall Test specimen with both edges and roundings including their dimensions and the Texture area calculated.

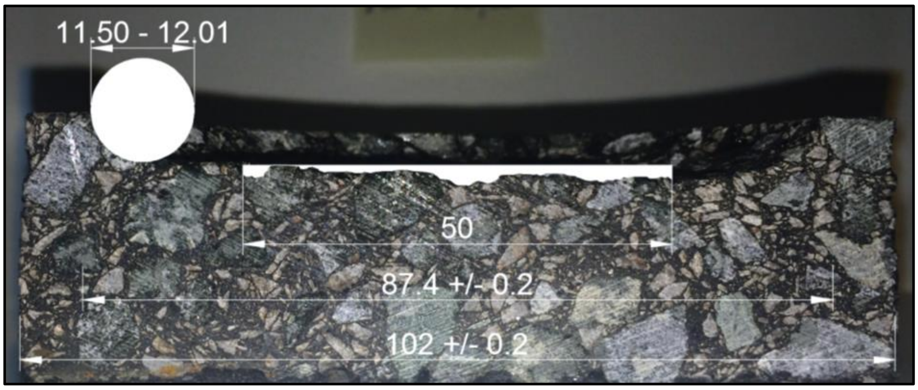


Figure 4: Cut Prall Test specimen as it is edited in AutoCAD to calculate the Texture area

5. PRALL TEST RESULTS

The results of the Prall Test are reflected by the Prall abrasion value (Abr_A), which is calculated by the following equation:

$$Abr_A = \frac{(M_1 - M_2)}{\rho_{bssd}} \quad (1)$$

where

Abr_A is the Prall abrasion value, [ml];
M_1 is the mass of the specimen with air dried surface, stored in water before testing, [g];
M_2 is the mass of the specimen with air dried surface, stored in water after testing, [g];
ρ_{bssd} is the bulk density of specimen according to 4.3.3 in NS-EN 12697-16:2004, [g/ml]. [10]

Figure 5 gives an overview of the Abr_A value for the 19 tested asphalt mixtures. The lighter bars emphasize the results for the asphalt mixtures tested with the new Prall Test equipment in 2013.

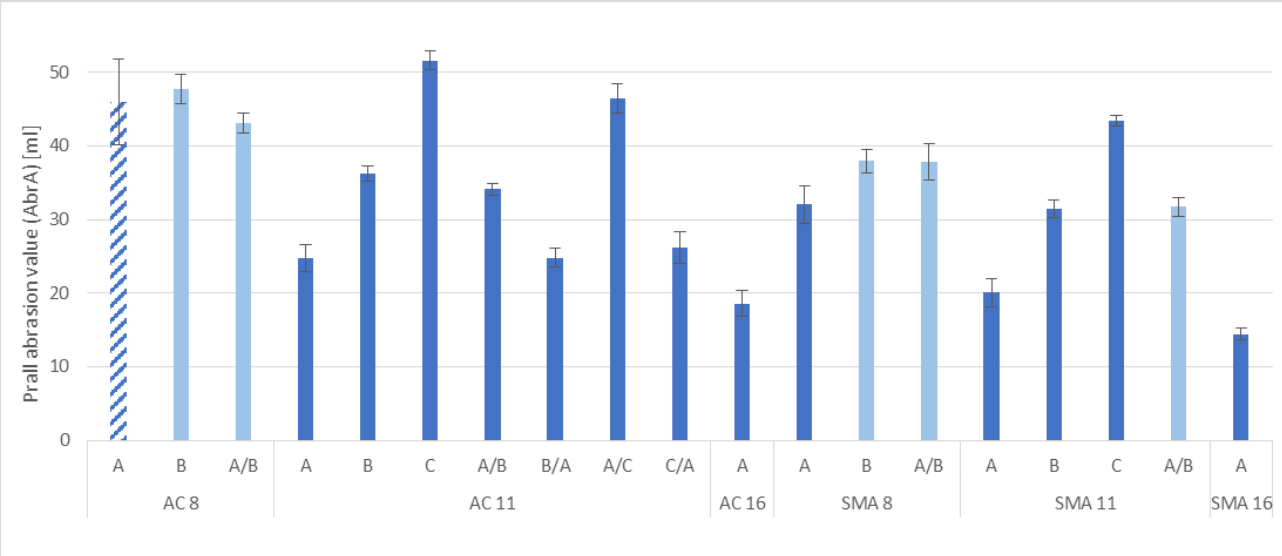


Figure 5: Prall abrasion value - overview

The graph illustrates that asphalt mixtures which include the strongest rock material A in the coarse fraction give the results with the lowest Abr_A. The highest values occur for the mixtures which include the rock material C.
However, the value for the AC8 with rock material A in both the fine and coarse aggregates, is questionable as it is higher than the value for the AC8 with A in the fine and B in the coarse fraction. Both the LA coefficient and the Nordic abrasion value in Table 2 reflect that the rock material B is weaker than the material A. Therefore, the Abr_A for AC8A should be lower than the Abr_A for the AC8A/B. Looking closer at the tested specimens for AC8A, it seems like the mixture failed during the Prall Test. Figure 6 shows a representative example for the specimens of the AC8A mixture after testing. Differently from specimens of the other mixtures, these specimens have a distinctive cavity which results in a high Abr_A. Caused by that, the results for the AC8A are not considered in the following discussions.

Figure 6: Cut specimen of AC8A after testing with the Prall Test

Looking closer at the asphalt mixtures with the same rock material in their stone skeleton, the results show the influence of the mixture type (AC or SMA) and D_{max} on the Abr_A. The graph clearly shows that the Abr_A decreases with an increase of D_{max}. It also shows that the values for AC mixtures are higher than the values for the respective SMA mixtures. The graph also shows that mixtures including only one rock material have a clear increase in Abr_A the higher the LA coefficient and the Nordic abrasion value of the rock material. For the mixtures including two rock materials, we get some improvement for the abrasion characteristics when using rock material in the fine fraction with a low LA coefficient and a low Nordic abrasion value. However, it is still the rock material used in the coarse fraction that primarily affects the results of the Prall Test.

6. RESULTS FROM SURFACE TEXTURE EVALUATION

The surface texture was evaluated for three specimens of each of the 19 asphalt mixtures, as described in chapter 4. The results reflect the average of the three calculated areas of each mixture. Figure 7 gives an overview of the results. As explained in chapter 5, the results for AC8A are not subject to the following discussions. Also here, the lighter bars emphasize the results for the asphalt mixtures tested with the new Prall Test equipment in 2013.

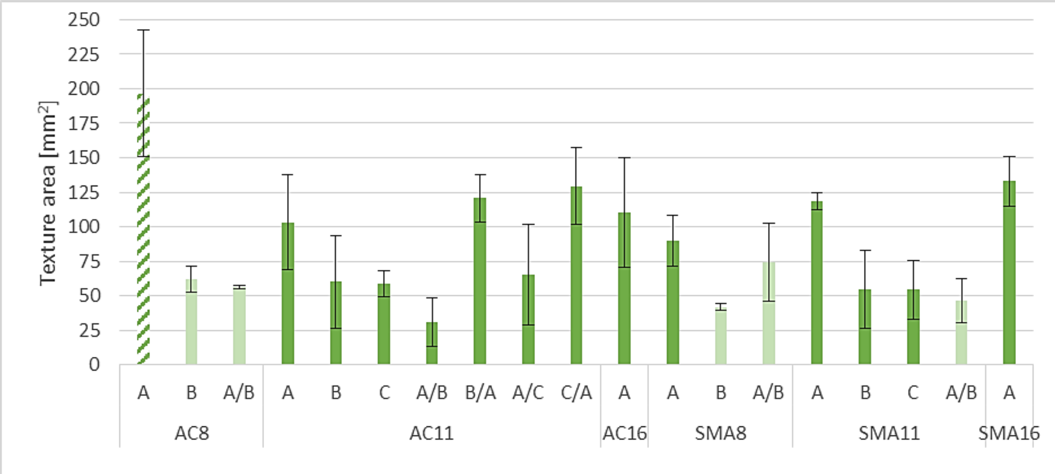


Figure 7: Texture area - overview

The results for the Texture area are generally widespread. The lowest values for the Texture area occur when the asphalt mixture includes rock material B in the coarse fraction. For mixtures with material A in the fine and coarse or only the coarse fraction, the area gets the highest values. The graph in Figure 7 also indicates an increase of the Texture area with an increase in D_{max} for the asphalt mixtures which include only one rock material in their stone skeleton. However, for mixtures with the rock material combination A/B, the Texture area decreases with an increasing D_{max}. This rock material combination also gives the lowest values for each asphalt mixture, irrespective of D_{max}.
Figure 7 includes the error bars which reflect the standard deviation for each asphalt mixture. The error bars show that the Texture areas for one asphalt mixture vary a lot, while the results are close to each other for another one.

7. DISCUSSION

By assembling the results for the Texture area and the Prall abrasion value in Figure 8, no obvious correlation can be found. The results differ a lot from each other for every asphalt mixture and from one to another.

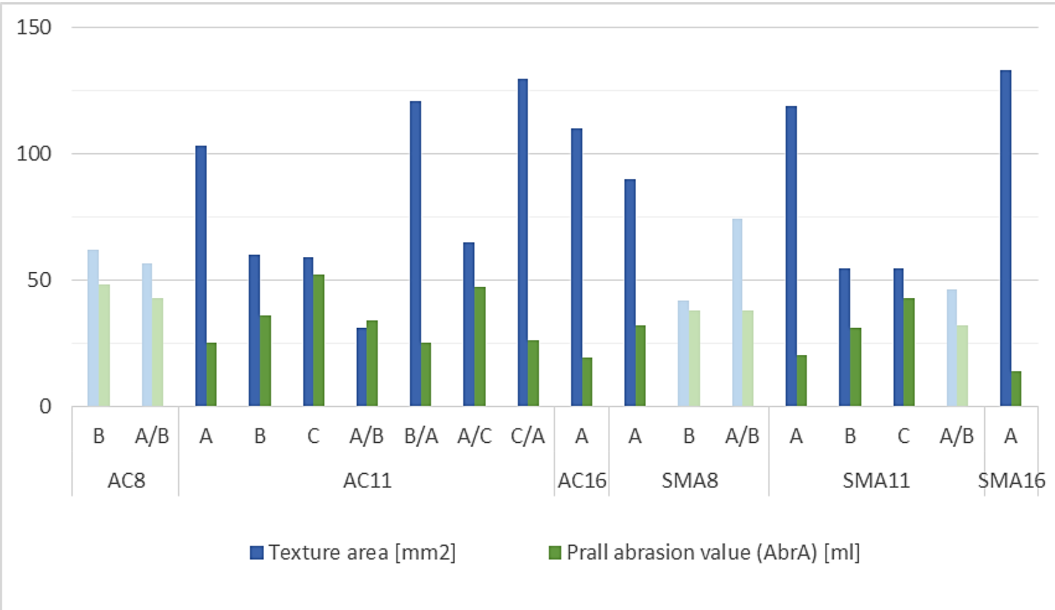


Figure 8: Assembling Prall abrasion value and Texture area

To obtain the best results relating to a sustainable low noise road surface, both the Abr_A and the Texture area should be as low as possible. The asphalt mixture that delivers relatively low values in both categories is AC11A/B. However, the mixtures that have lower values for Abr_A turn out to form a big Texture area in general.
Figure 9 and Figure 10 show the correlation for the Nordic abrasion values to the Abr_A and the Texture area for aggregates > 4 mm and < 4 mm, respectively. While Figure 9 visualizes a good correlation for the aggregates > 4 mm to both Abr_A and the Texture area, Figure 10 indicates that there is no correlation for the aggregates < 4 mm.

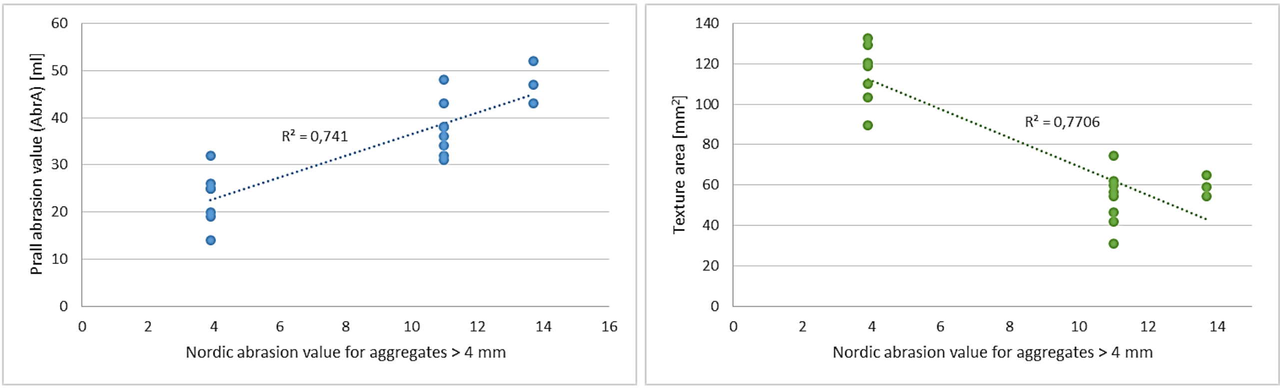


Figure 9: Correlations regarding the Nordic abrasion value for aggregates > 4 mm

The Nordic abrasion value for the aggregates > 4 mm seems to be decisive for both, the Prall abrasion value and the Texture area. However, the correlations are contrary for the Abr_A and the Texture area. The wear caused by studded tires is increasing for an increasing Nordic abrasion value. On the other hand, the surface gets smoother for the asphalt mixtures which includes the weaker material in the coarse fraction.

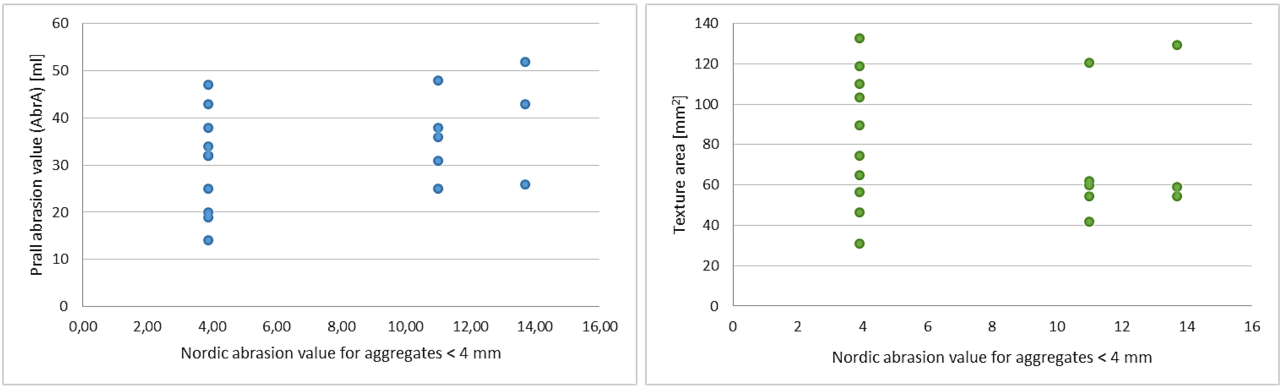


Figure 10: Correlations regarding the Nordic abrasion value for aggregates < 4 mm

Figure 10 visualizes that there is no correlation found for the abrasion characteristics of the aggregates < 4 mm neither to the Prall abrasion value, nor to the Texture area. The results are widespread and no trend is indicated.
The rock materials for the asphalt mixtures that have been used for the study, were chosen with the intention to get as big variations in the abrasion characteristics as possible. However, considering the requirements for the Prall abrasion value it is obvious that most of the asphalt mixtures are not usable in real road conditions.
Figure ***11*** shows the results of the Abr_A together with the requirements for low and high traffic roads, according to [12]. Only a few asphalt mixtures meet the requirements for the Prall abrasion value according to [12] for roads with an AADT >10000.

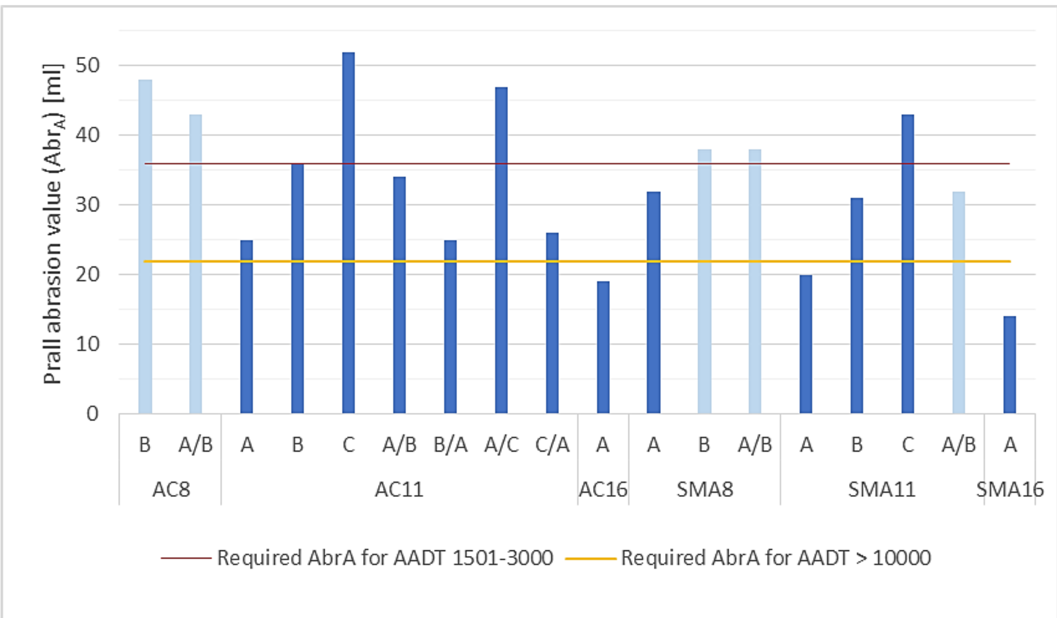


Figure 11: Results of Abr_A together with the requirements stated in NPRA's handbook N200

8. CONCLUSIONS

The results of the study verify that both the size and the quality mainly of the coarse aggregates in the asphalt mixture affect the Prall abrasion value. But also surface texture characteristics are essentially controlled by the characteristics of the rock material used in the fractions > 4 mm. Since the correlations for the Abr_A and the Texture area show opposite trends, it is difficult to find an asphalt mixture that is wear resistant and can obtain a low noise road surface at the same time after being exposed to studded tires. Achieving a balanced wear on the mortar and the coarse aggregates results in high total abrasion for the chosen rock material combinations in this study.

Further, it should be investigated how the Texture area reflects the texture characteristics of an asphalt mixture. The area above the surface only gives information about the smoothness of the surface texture. However, the surface texture should not only be smooth in order to reduce noise generating mechanisms. The Mean Profile Depth (MPD) is one of the texture characteristics that can be correlated to the noise characteristics of the surface texture. [2] One opportunity might be to calculate the MPD on the 50 mm section of the Prall Test specimens to find out more details about the texture characteristics. At the same time it should be investigated whether a section of 50 mm is sufficient to evaluate the surface texture regarding their noise characteristics.

Figure 7 shows that the Texture area can vary a lot from one specimen to another for some of the asphalt mixtures. These variations might be caused by the placement of the cutting edge on the specimen. On the cylindrical Prall Test specimen the surface texture varies in all directions. Thus, placing the cutting edge in another angle can change the results of the Texture area. More samples might be needed to get more reliable results.

9. ACKNOWLEDGEMENTS

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