Asphalt pavement wear by studded tires – Effects of aggregate grading and amount of coarse aggregate

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ABSTRACT

Studded tires cause mechanical wear of asphalt pavements in the northern European countries, which leads to substantial problems with air quality and noise in urban areas. Experience show that the pavements wear resistance is among other factors dependent on amount and maximum size (D) of the coarse aggregate (> 4 mm). To reduce noise from pavements, one measure is to reduce the maximum aggregate size (D) in the pavements. However, this can increase the production of particulate matter from pavement wear. In this study, the effects of maximum aggregate size (D) and amount of coarse aggregate on pavement wear were investigated using a large-scale indoor Road simulator operated by the Swedish National Road and Transport Research Institute (VTI) and small-scale asphalt testing equipment (Prall) at The Norwegian University of Science and Technology (NTNU). Two types of asphalt pavements were tested; asphalt concrete (AC) and stone mastic asphalt (SMA). This study has clearly shown that the lower the aggregate size, the lower is the wear resistance of the asphalt pavement and the higher is the dust production. In addition, SMA pavements are more resistant to wear by studded tires compared to AC pavements due to the higher amount of coarse aggregates contained in SMA mixes.

The Norwegian Wear Parameter (NWP) is used in this study as an indicator of the wear potential of different asphalt pavements.

Keywords: Aggregate, Dust, Resistance to Wear (Studded Tyres), Total Particulate Matter, Tyre/road noise

1. INTRODUCTION

Road wear caused by studded tires has been the dominant mechanism of distress and the cause of rut development on high traffic Nordic roads (average annual daily traffic AADT > 3 000). This has resulted in huge repaving costs of roads and shorter lifespan of asphalt pavements. Over several decades, stricter regulations, development of more environmentally friendly winter tires, studs that wear the road surface less, and durable asphalt pavements has resulted in an 80 % decrease in the pavement wear as seen in Table 1. SPS is the pavement wear in g/km caused by a passenger car with studded tires on all four wheels.

Table 1: Reduction in specific studded tire wear (SPS) [1]

Year	SPS (g/km)
1970	25-30
1980	20
1990	12-15
2000	5-10

However, many cities and towns in Norway suffer from poor air quality, especially in winter during the studded tire season (October-April) due to dust pollution to which road wear is considered to be a significant contributor. In addition, noise from road traffic is a huge problem in urban areas.

Experience shows that a pavement's wear resistance is, among other factors, depending on amount and maximum size (D) of coarse stone aggregates. The maximum aggregate size, D, is defined as the upper limit for the aggregate grading; however, oversize materials are accepted within certain limits [2]. To counteract the wear from a high percentage of studded tires in Norway, pavements with D of 16 mm have been used because of their good wear resistance. The use of studded tires is decreasing, though, and today D of 11 mm is preferred mainly because of lower costs and lower noise potential. Even pavements with D of 8 mm and 6 mm are being tested to achieve the advantages of smaller D, namely lower noise emissions and reduced rolling resistance [3]. However, the reduction in D can lead to increased rutting and dust generation from the pavements [4,5] and lower expected service life as can be seen in Figure 1 and 2. The predicted pavement life in these figures is obtained by extrapolating measured rutting data from the Norwegian pavement management system, PMS. The difference between expected service life for pavements with D=11 mm compared to D=16 mm is 4-5 years for 50 % of the road lengths with AADT > 3 000.

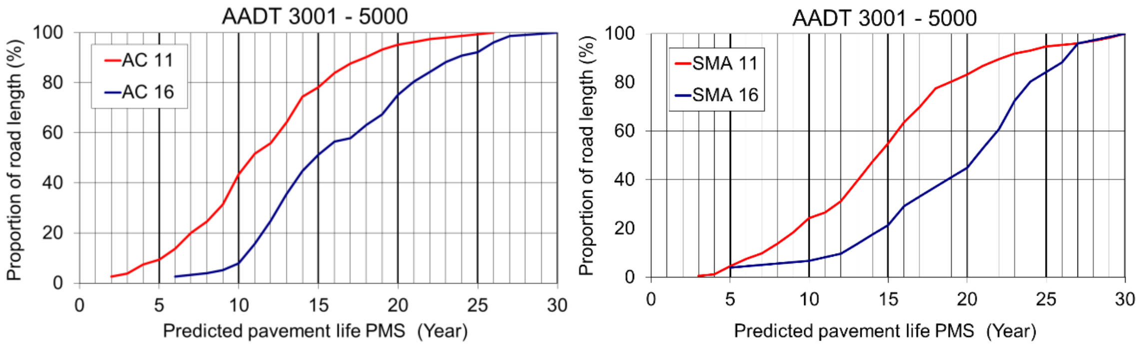

Figure 1: Predicted pavement life in years of AC and SMA pavements with D 11 and 16 mm in Eastern Norway with AADT 3 001-5 000 [6]

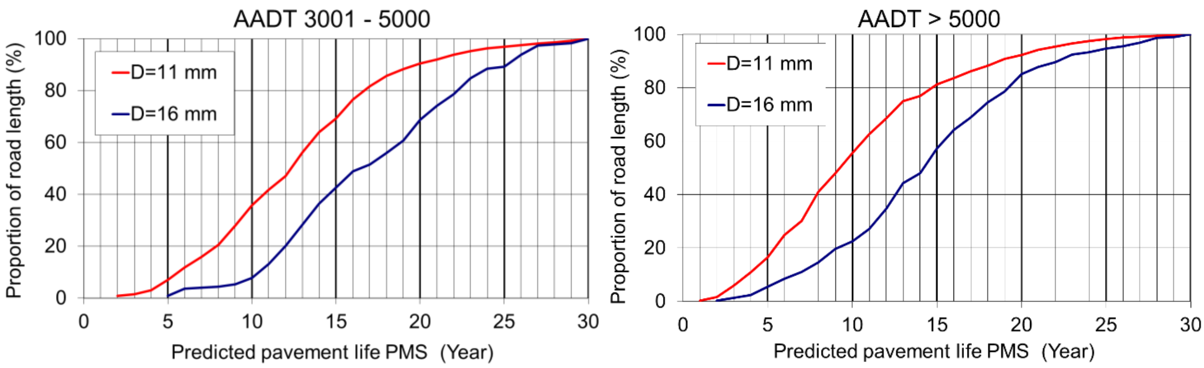

Figure 2: Predicted pavement life in years of all pavements with D 11 and 16 mm in Eastern Norway with AADT > 3 000 [6]

Asphalt concrete (AC) and stone mastic asphalt (SMA) were chosen in this study since they are the most common pavement types used on roads with heavy traffic (AADT > 3 000 vehicles per day) in the Nordic countries. SMA is a wear resistant pavement with SPS (specific studded tire wear) around 5-10 g/km for a passenger car with studded tires, while AC has SPS around 15-20 g/km as seen in Table 2. SMA consists of a coarse aggregate skeleton bound with a mastic consisting of crushed rock fines, filler and bitumen. The essential requirement for a successful SMA is the gap grading with high amount of coarse aggregate (> 4 mm). The AC has a more continuous aggregate grading, with relatively high amount of material < 4 mm, which gives a stable aggregate skeleton. The use of SMA compared to AC has reduced the pavement wear up to 20 % in some parts of Norway [7], and given about 40 % longer service life [8]. A study from 2006 estimates the difference in predicted lifetime between AC and SMA pavements is 1-2 years for AADT 3 000-10 000, as seen in Figure 3.

Table 2: Typical values for wear resistance for different asphalt pavement types (SPS) [9]

Pavement type	SPS (g/km)
Stone mastic asphalt (SMA)	5-10
Asphalt concrete (AC)	15-20
Topeca	< 15
Porous asphalt	18-25
Asphalt concrete with more gravel	15-30

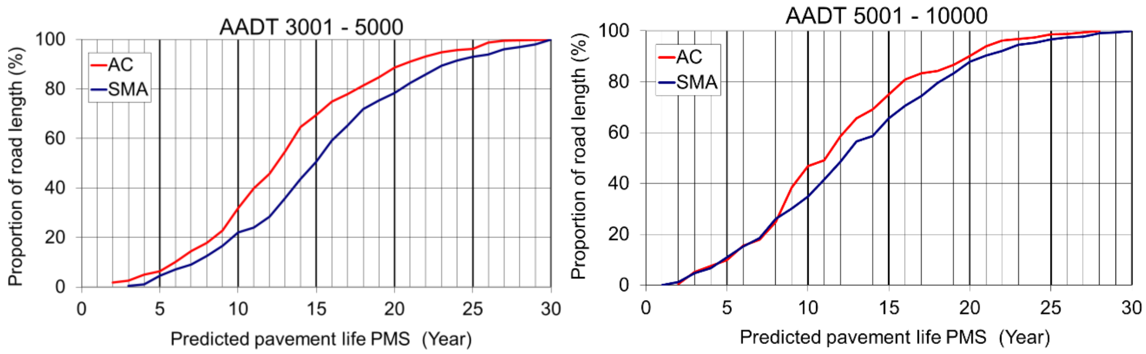

Figure 3: Predicted pavement life in years of AC and SMA pavements in Eastern Norway with AADT > 3 001 [6]

The aim of this study was to investigate how different aggregate grading and amount of coarse aggregate in asphalt pavements influence the pavement wear caused by studded tires.

2. MATERIALS AND METHODS

In this study the effects of maximum aggregate size (D) and amount of coarse aggregate (aggregate size > 4 mm) were investigated with regard to pavement wear using the large scale indoor Road simulator at the Swedish National Road and Transport Research Institute (VTI), and the Prall equipment at The Norwegian University of Science and Technology (NTNU). The objective of this study was to determine the difference in the amount of wear generated from two different types of asphalt pavements (asphalt concrete, AC, and stone mastic asphalt, SMA) with different D (6, 8, 11 and 16 mm).

2.1 Prall

The Prall equipment was used for testing asphalt samples from AC and SMA pavements with varying maximum aggregate size D. The Prall method is described in EN 12697-16:2004 [10]. It was developed to determine wear resistance of asphalt concrete, but has also been used for other asphalt mixtures. The apparatus is shown in Figure 4. The pavement sample (height 30 mm and diameter 100 mm, conditioned in water at 5ºC) is put in a test chamber with 40 steel balls (12 mm in diameter). The steel balls hammer the sample driven by a stay rod which rotates with 950 rotations per minute, and cooling water is flushed through the chamber (2 liter/minute). Studies at VTI have shown a correlation between the studded tire wear on the road and Prall test of R^2=0.89-0.96 [11,12]. The test is normally performed on four test specimens, and the average wear value is calculated. The wear (S) is expressed as:

$$S = (m_1 - m_2)/\gamma$$

Where:

m_1 = mass of original test specimen (g)
m_2 = mass of test specimen after testing (g)
γ = density of tested material (g/cm^3)

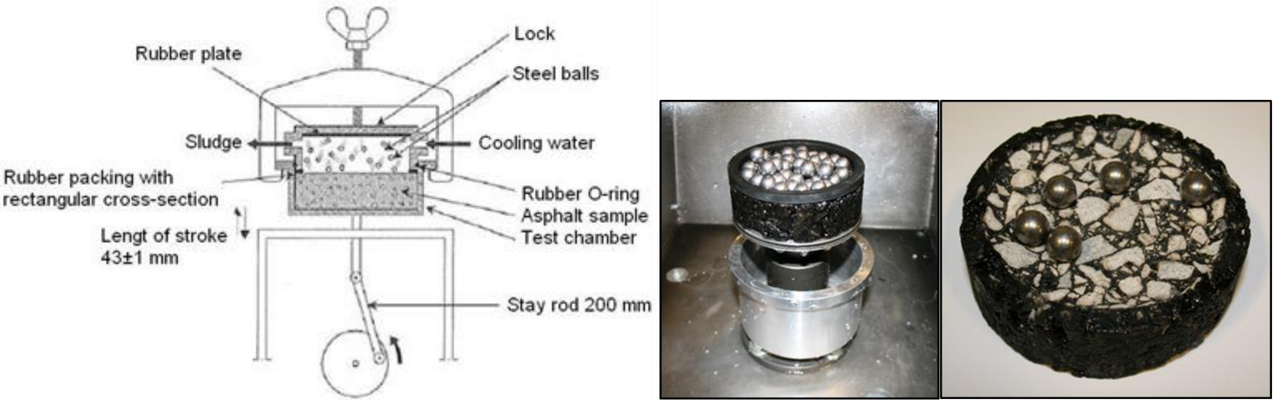

Figure 4: Prall apparatus (figure adopted from EN 12697-16:2004, photos by Brynhild Snilsberg)

2.2 Road simulator

The Road simulator at VTI was used to accelerate and simulate the pavement wear. The machine has four electrically powered wheel axles mounted on a central rotating axle with a counter clockwise movement. The rotating speed is adjustable up to 70 km/h (Figure 5). To move the wheels over the whole width of the track, the central axel has an eccentric movement. The diameter of the test ring is approximately 6 m, and the machine is located in a closed room with controlled ventilation. In this machine wear particles from pavement and tires can be studied separately, without interference of particles from exhaust and other sources [13]. The machine is an accelerated test facility and pavement types, car tires, friction materials, driving speeds and temperatures can be varied. Asphalt plate samples are made in the laboratory under controlled conditions, and these plates are glued to the circular track, run over by four wheels. Earlier studies at VTI have shown very good correlation between the studded tire wear on the road and in the machine [14]. A correlation factor of R^2=0.96-0.98 has been reported [11]. The method is described by EN 13863-4:2004 [15].

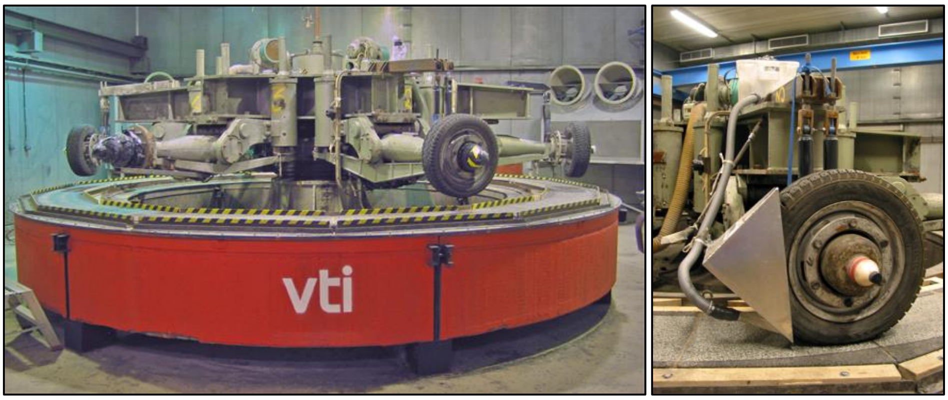

Figure 5: Road simulator and dust sampling setup (photos by VTI)

The tires used in the Road simulator study were studded tires (Nokian Hakkapellitta 4). The tests were performed with speed 20-70 km/h and temperature -6 to 6ºC [16].

2.3 Asphalt

The material tested in the Road simulator was SMA with D of 11 and 8 mm (SMA 11 and SMA 8). The SMA aggregate composition was 88 % Durasplitt (mylonite), 5 % Lyngås gravel (glacifluvial deposit), and 7 % Breivik filler (limestone) with 6% bitumen 70/100, fiber and amin. The composition of SMA 11 and SMA 8 is shown in Table 3. Durasplitt is a wear resistant rock material frequently used in Norway on pavements with high traffic volumes. The rock has fine/moderate mineral texture and a Nordic abrasion value (A_N) of 6.1 [17].

Table 3: Asphalt composition (%), Road simulator

Pavement	Aggregate > 4 mm (%)	Aggregate > 2 mm (%)
SMA 8	37	69
SMA 11	52	72

The Prall samples were produced in the laboratory. The aggregate composition was Vassfjell (gabbro and greenstone), Heggberget gravel (river gravel), and Hylla filler (limestone) with bitumen 70/100, fiber and amin. The asphalt composition is shown in Table 4. Vassfjell is a moderately wear resistant rock material much used in the Trondheim area.

The rock has medium/coarse mineral texture and an A_N of 12.5. The gravel has A_N of 13.9. A combined A_N value for the aggregate is 12.57 which is used in the further analysis.
For each of the asphalt material four asphalt cores were tested in the Prall apparatus.

Table 4. Asphalt composition (%), Prall

Pavement	Aggregate > 4 mm (%)	Aggregate > 2 mm (%)	Filler 0-0,5 mm (%)	Binder 70/100 (%)	Void (%)
AC 6	17	37	5	6.1	7.2
AC 8	27	48	5	5.9	2.3
AC 11	46	64	5	5.6	1.5
SMA 6	13	60	8	6.6	4.2
SMA 8	49	64	8	6.4	2.1
SMA 11	55	66	7	5.8	0.3

The void content is often lower for asphalt samples produced in laboratory, since it is easier to control the temperature, compaction equipment and time in the laboratory compared to in situ. High void content in asphalt pavements increases the potential for rutting. The rutting will increase when the void content in dense asphalt types exceed 4.5-5 % [1,7] or when the void content is below 3 % [18]. In Norway, dense asphalt with low void content is often used mainly because of studded tire wear, and a void content of between 2-6 % is accepted for AC and SMA [2].

3. RESULTS AND DISCUSSION

3.1 Prall

The result from the Prall testing is shown in Figure 6. The bars are average values from four samples of each asphalt mixture. A high value indicates an asphalt mixture with poor wear resistance. The standard deviation is displayed on the figure, ranging from 0.73-4.10. According to this figure, AC pavements are less wear resistant than SMA pavements, and a lower D leads to increased pavement wear. The rate of change is higher for SMA pavements than for AC pavements.

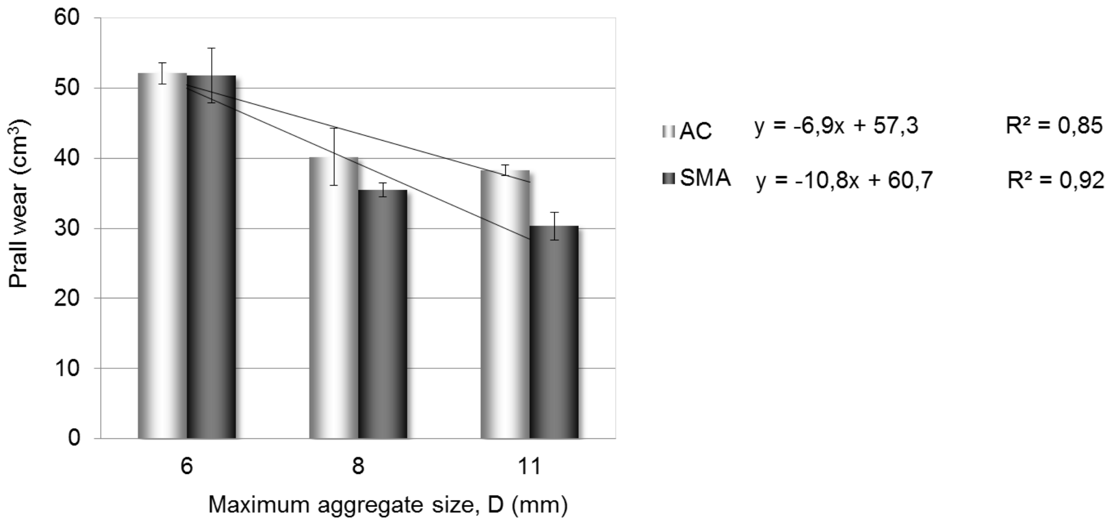

Figure 6: Average Prall wear (cm^3)

Table 5. Prall requirements in Norway [2]

	AADT				
	≤ 1 500	1 501-3 000	3 001-5 000	5 001-10 000	> 10 000
Maximum allowed Prall wear (cm^3)		36	28	25	22

According to requirements set by The Norwegian Public Roads Administration shown in Table 5, none of these pavements can be used on high traffic roads (AADT > 3 000) in Norway. Only SMA 8 and 11 can be used with AADT 1 501-3 000. For AADT < 1 500 there are no requirements for Prall value.

3.2 Road simulator

Figure 7 shows result of mean wear measurement with laser at the Road simulator for SMA pavements with three different aggregate types and D of 8, 11 and 16 mm. The data includes measurement conducted earlier by VTI (blue and orange dots) [19]. The quartzite has an A_N of around 6, porphyry between 4-5, and mylonite 6.1. The results show a clear downward trend in mean wear with increasing maximum aggregate size for all three aggregate types.

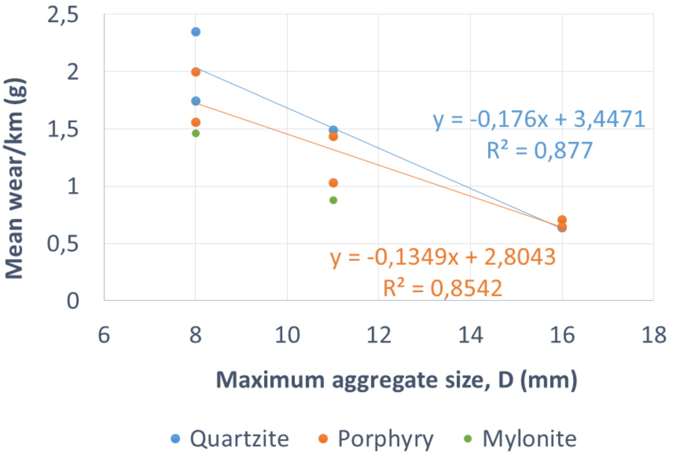

Figure 7: Mean wear from the Road simulator for three different aggregate types and maximum aggregate sizes D = 8, 11 and 16 mm

3.3 Norwegian wear parameter (NWP)

Earlier studies has shown the importance of the amount of aggregate > 4 mm [4] for pavement wear, and a parameter named Norwegian wear parameter (NWP) has been defined to express the effect of the amount of coarse aggregate on pavement wear. NWP is expressed as follows:

*NWP (4 mm) = Nordic Abrasion value/Aggregate > 4 mm * 100*

This relationship applies to dense asphalt types. However, at D ≤ 6 mm the amount of aggregate > 4 mm is low and an alternative is to use the amount of aggregate > 2 mm to define NWP:

*NWP (2 mm) = Nordic Abrasion value/Aggregate > 2 mm * 100*

Figure 8A presents the calculated NWP for the different pavements types tested in the Prall. The maximum aggregate size, D, ranges from 6-11 mm. The Nordic abrasion value is the same for all of these pavements (12.57). As can be seen in the figure, pavements with high amount of aggregate material > 4 mm has a much lover NWP value, and the difference between them is small. Figure 8B show that both AC11, SMA 8 and 11 have an amount of coarse aggregate > 45 %.

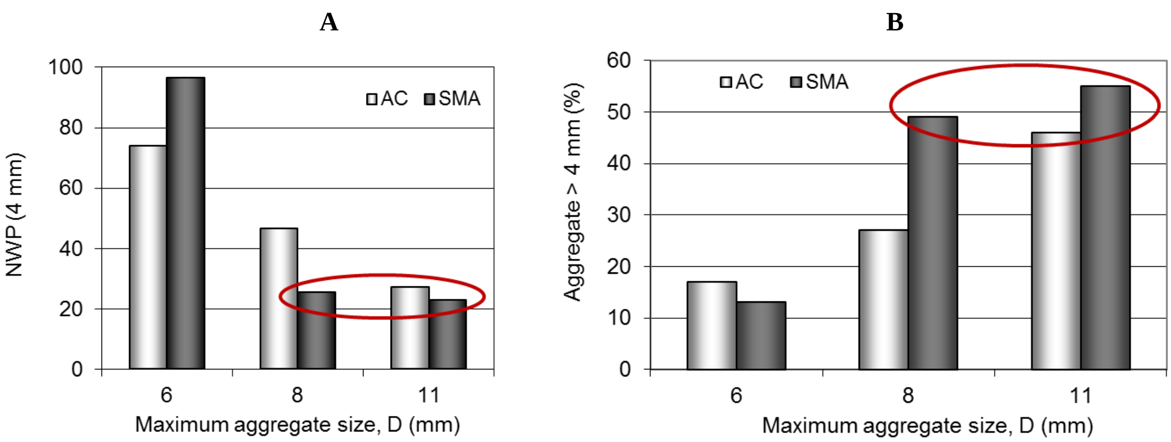

Figure 8A: NWP (4 mm) for D = 6, 8 and 11 mm
Figure 8B: Amount of aggregate > 4 mm in the asphalt samples tested in Prall

The quality of aggregate material is also important for the wear resistance of the asphalt pavement. In Figure 9 a comparison of NWP for two different aggregate materials with significant difference in abrasion value (12.57 and 6.1) are shown. The aggregate quality can offset the effect of reduced maximum aggregate size as shown in the figure.

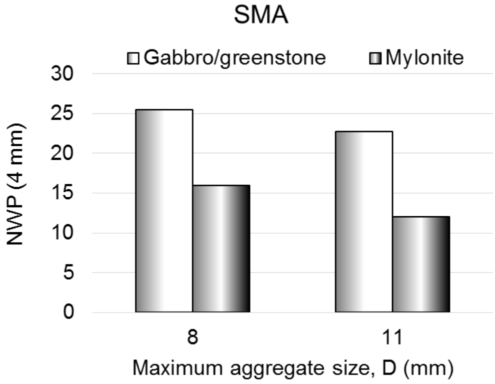

Figure 9: NWP (4 mm) for D = 8 and 11 mm with different mill value

If we plot the NWP against the Prall values, as shown in Figure 10, we can observe that the NWP can be a good indicator of the resistance to wear for continuously graded asphalt mixtures such as AC. However, for gap-graded mixtures like SMA, a significant change in the NWP does not produce so significant change in the resistance to wear. NWP correlates well with the different pavement types tested, as can be seen from Figure 10. Note that only three aggregate sizes for each pavement type were tested in this study and as such the data is not big enough to draw conclusions regarding the correlation.

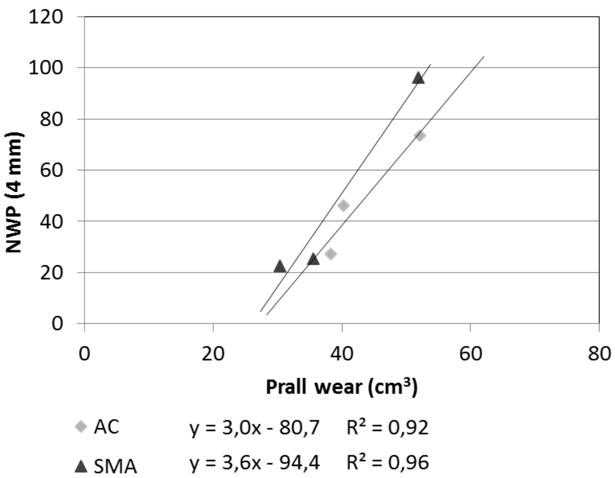

Figure 10: NWP (4 mm) as a function of Prall wear for each asphalt mixture

The Nordic wear parameter is only dependent on the amount of aggregate > 4 mm and aggregate quality, and not the asphalt type. If we plot the NWP against Prall values for both mixes tested, we can obtain a more general correlation between the NWP and the wear resistance. This is shown in Figure 11. As can be seen from the figure, the correlation with the Prall is quite good (R^2=0.88).

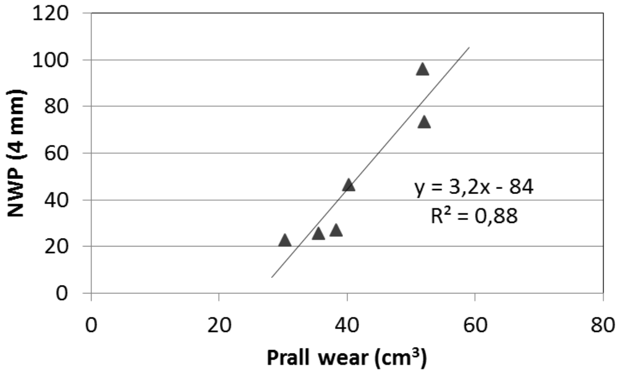

Figure 11: NWP (4 mm) as a function of Prall wear for AC and SMA

The mixes used in the Road simulator were made from a different aggregate type (Durasplitt/mylonite) which is stronger than the Vassfjell aggregate (gabbro/greenstone) that was used to produce samples for the small-scale laboratory testing (Prall). This makes it difficult to directly compare the results from the Road simulator to that of Prall. However, since the focus of this study is the effect of aggregate grading and the amount of coarse aggregate, the two studies are used to show the correlation between these two factors and wear resistance.

4. CONCLUSION

Results from this study regarding the effect of maximum aggregate size on resistance to wear of asphalt materials showed that the lower the aggregate size, the lower is the wear resistance of the asphalt pavement. A result of lower wear resistance is also higher dust production from studded tire wear.

Regarding the effect of aggregate grading, the results show that AC pavements are more susceptible to studded tire wear and will therefor produce more dust than SMA pavements.

The amount of coarse aggregate (rock material > 4 mm) is important for asphalt pavement resistance against wear by studded tires. However, the wear resistance of the material < 4 mm may become more important when reducing D since it will constitute a larger part of the total rock material even though this was not tested in this study. To reduce wear and dust generation from asphalt pavements one should select wear resistant rock materials, both for the aggregate and the mortar fraction. This applies particularly to areas with a lot of traffic noise where there is a desire to use low-noise asphalt pavements with smaller D.

The Norwegian Wear Parameter can be used to give an indication of the wear potential of different pavement types, regardless of the grading, since only the Nordic abrasion value and amount of aggregate > 4 mm are needed.

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