Effect of Aggregate Mineralogy on Permanent Deformation

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ABSTRACT: Permanent deformation of asphalt road surfaces is a critical issue in Nordic countries. The progression of this phenomenon is accentuated by the particular combination of harsh climatic conditions and heavy loading cycles. In fact, the pavement is exposed to temperature fluctuations of up to 80 °C throughout the year, and to a total traffic volume up to 5000 million vehicles thus causing severe distresses and shortening the pavement lifetime. Therefore, it is necessary to assess how each characteristic of the bituminous mixture and its components affects the performance of the pavement.

This study analyzes the relationship between the mineralogical composition of the aggregates and the permanent deformation of the wearing course. In particular, the silicon dioxide (SiO_2) content has been selected as distinguishing factor in the selection of the stone material, and used as control parameter to evaluate the pavement behavior when subjected to heavy loadings at high temperature.

Four asphalt mixtures have been designed with the same type of binder and different Norwegian aggregates having differing aggregate mineralogical properties. Subsequently the mixtures have been subjected to the Wheel Track test at 50 °C in order to identify the resulting permanent deformation. Depending on the aggregate mineralogy the test results will determine the relation between the mineral content in the material and the correspondent rut depth after 10 000 cycles, thereby indicating the dependency of the asphalt material permanent deformation resistance on the aggregate mineralogy.

KEY WORDS: Mineralogy, Permanent deformation, Wheel Track.

1 INTRODUCTION

The deterioration process of a pavement is influenced by factors such as bitumen type and air voids content. Other factors including temperature, applied load and environmental conditions may also affect the service life thus causing severe distresses. Although the effect of binder properties on the mixture has been widely studied, the contribution of the mineral aggregate characteristics to improve the capacity of the asphalt surface to withstand weather has not been extensively considered (Sousa, Pais et al. 1998).

Mineral aggregates are the skeleton of the asphalt mixture, and thus provide a significant amount of the structural support to the asphalt pavement. Encompassing approximately 95 % of the mixture volume, aggregate properties have a direct and significant effect on the performance of asphalt pavements (Chen and Liao 2002). Hitherto, wear from studded tires has been used as parameter for the selection of aggregates but the mechanical resistance of a pavement can also be related to the chemical interaction between the stone surface and the other components; Ribeiro, Correia et al. (2009) measured the adsorption of asphaltenes and asphalts on a stone material, their results indicate that the presence of silicon dioxide (SiO_2) hinders the interaction process with the asphaltenes probably because of the absence of aluminum in its structure although the resistance and hardness of some stones may be related to the silicon content. Other researchers (Liu and Jia 2011) associate the weakness of the bond between bitumen and aggregates with high content of SiO_2 to the affinity between the surface charges of the materials. In particular Liu and Jia (2011) indicate repulsion of the electric charges on the surface of the two materials due to the acidic nature of this stone material as a reason of non-adhesion between binder and silicon dioxide. A more exhaustive research about the influence of the mineral may lead to a better understanding of the damage mechanism, which would prevent premature distress and save maintenance and rehabilitation costs.

In the process of evaluating the mechanical resistance of an asphalt mixture, permanent deformation is considered a critical factor. Rutting has historically been used as a primary criterion for structural performance evaluation in many pavements design methods and represents a serious safety issue for road users. Pavement rutting can, in fact, lead to driving safety problems such as hydroplaning and skidding (Archilla and Madanat 2001; Fwa, Pasindu et al. 2012). Therefore, the wheel track test is recognized as a suitable test to estimate a relation between stone material characteristics and pavement performance. Moreover, in the future this test will be used as performance parameter in Norway.

It is always difficult to isolate the important parameters when doing research on aggregates: by using different materials several parameters will differ and it is not always easy to evaluate which is the important factor. This research will be mainly limited to the investigation of the deformation of the mixture depending on its mineralogical composition as result of the application of a moving load. Although the influence of binder properties on the behavior of a pavement is of unquestioned importance, in order to circumscribe the variables affecting the mixture performance to the stone materials' sphere, binder properties will not be considered.

2 EXPERIMENTAL PLAN

In this study, four dense graded Ab 11 mixtures with the same binder and filler, but different stone materials were compared. The resistance to permanent deformation as function of the aggregate mineralogy was evaluated through the wheel track test conducted on compacted samples.

2.1 Materials

Aggregates used in the Trøndelag region (Norway) as pavement construction materials, were selected to design four asphalt mixtures using aggregates from four local quarries: Fossberga, Lauvåsen, Steinkjer and Vassfjell. For each material the mineralogical composition was determined through an XRD analysis at Department of Geology and Mineral Resources Engineering of the Norwegian University of Science and Technology of Trondheim, Norway. In order to collect a sample of material that represents the whole pallet, between 5-10 kilos of stone aggregates underwent 1000 revolutions in the Los-Angeles (LA) drum, then 15 g of material were collected from the resulting fines (< 0,125 mm) and sent to the laboratory for the analysis. Table 1 shows a summary of the test results, and in particular the quartz content and the amount of other minerals representative for the stone; as "others" are accounted all the other minerals as clinochlore, microcline and actinolite, present in lower percentage. Particle shape analysis was carried out in terms of flakiness index (FI) according to NS-EN 933-3:2012 (CEN 2012), in Table 2 are listed the resulting value for each aggregate type and the correspondent LA abrasion value (CEN 2010).

Table 1 Mineralogical composition of the stone material.

		Fossberga	Lauvåsen	Steinkjer	Vassfjell
Quartz	(%)	37,20	21,25	48,20	1,20
Muscovite	(%)	15,10	12,32	18,30	0,00
Microcline	(%)	10,10	2,45	15,20	5,80
Albite	(%)	35,00	30,35	18,30	18,10
Other	(%)	27,80	48,40	33,50	76,10

Table 2 Shape index and Los Angeles abrasion value of the stone material.

		Fossberga	Lauvåsen	Steinkjer	Vassfjell
Aggregates					
FI	(%)	24,18	29,88	19,20	18,96
LA abrasion	(%)	15,90	19,20	20,90	14,40

The mixture design was performed for each aggregate type using the Marshall and Gyratory method according to the Norwegian specifications for dense graded Ab 11 mixtures (StatensVegvesen 2011). A conventional 70/100 binder, widely used in Norway, was used, and a binder content of 6,00%, 5,90%, 5,80% and 5,10% respectively was determined.

2.2 Testing procedure

The wheel track test was performed to evaluate the susceptibility of the asphalt mixtures to deform under dynamic load depending on the mineralogy of the aggregates. As evaluation criterion, the maximum depth of the rut formed by repeated passes of a loaded wheel at constant temperature has been used.

Two square samples for each mixture, 30,50 cm width and 4,00 cm thickness, were prepared and compacted with a roller compactor in accordance with NS-EN 12697-33 (CEN 2007A). The wheel track tests were conducted at 50°C using small-size equipment following the procedure B in air (CEN 2007B). The equipment used comprehends two wheels that can be used to test two samples in parallel, guaranteeing the same testing conditions. After a period of minimum four hours of conditioning at testing temperature, 20 000 passes (10 000 cycles) of the loaded wheel were allowed on each specimen at a speed of 26,5 cycles/min. Rut depths were measured every 100 wheel passes.

After the test is completed, given the final rut depth (RD_{air}), it is possible to calculate:

- the mean proportional rut depth (PRD_{air}) using the following equation:

$$\mathrm{PRD_{AIR}} = \frac{\mathrm{RD_{AIR}}}{\text{height of the sample}} 100$$

where,
$\mathrm{PRD_{air}}$: proportional rut depth at 10 000 cycles [%]
$\mathrm{RD_{air}}$: rut depth at 10 000 cycles [mm]
height of the sample: 40 mm.

- the wheel track slope ($\mathrm{WTS_{AIR}}$) calculated using:

$$\mathrm{WTS_{AIR}} = \frac{(d_{10000} - d_{5000})}{5}$$

where,
$\mathrm{WTS_{AIR}}$: wheel track slope [mm⁄1000 load cycles]
d_{10000}: rut depth after 10 000 load cycles [mm]
d_{5000}: rut depth after 5 000 load cycles [mm].

All the previous results were calculated as average of the two specimens tested per each mixture.

3 RESULTS

The wheel track test was used to directly evaluate if the mineralogy of the aggregates affects the resistance of the mixtures measured in terms of permanent deformation. Two slabs were compacted and tested per mixture according to NS-EN 12697-22 (CEN 2007B).

Table 3 and Figure 1 illustrate the results obtained from the test. An air voids content of about 3% was obtained in all the samples except for the Fossberga slabs where higher air voids are measured. The higher final rut depth of these tests, compared with the others, might have been influenced by this factor. The values illustrated in Figure 1 were collected at intervals of 400 passages, instead of 100, in order to improve the readability of the figure. The results are distributed within 8,71 % and 11,90 % $\mathrm{PRD_{air}}$ corresponding in all cases to a maximum AADT of 5000 according to the Norwegian specifications (StatensVegvesen 2011).

Table 3 Wheel track test results and volumetric analysis after testing. The values are the average of two samples.

Mixture	RDair	PRDair	WTSair	Specific density	Air voids
	(mm)	(%)	(mm/1000)	(g/cm3)	(%)
Ab 11 Fossberga	5,07	11,90	0,14	2,45	3,31
Ab11 Lauvåsen	3,78	8,98	0,10	2,45	2,92
Ab11 Steinkjer	4,30	10,18	0,12	2,45	2,81
Ab11 Vassfjell	3,71	8,71	0,10	2,73	3,13

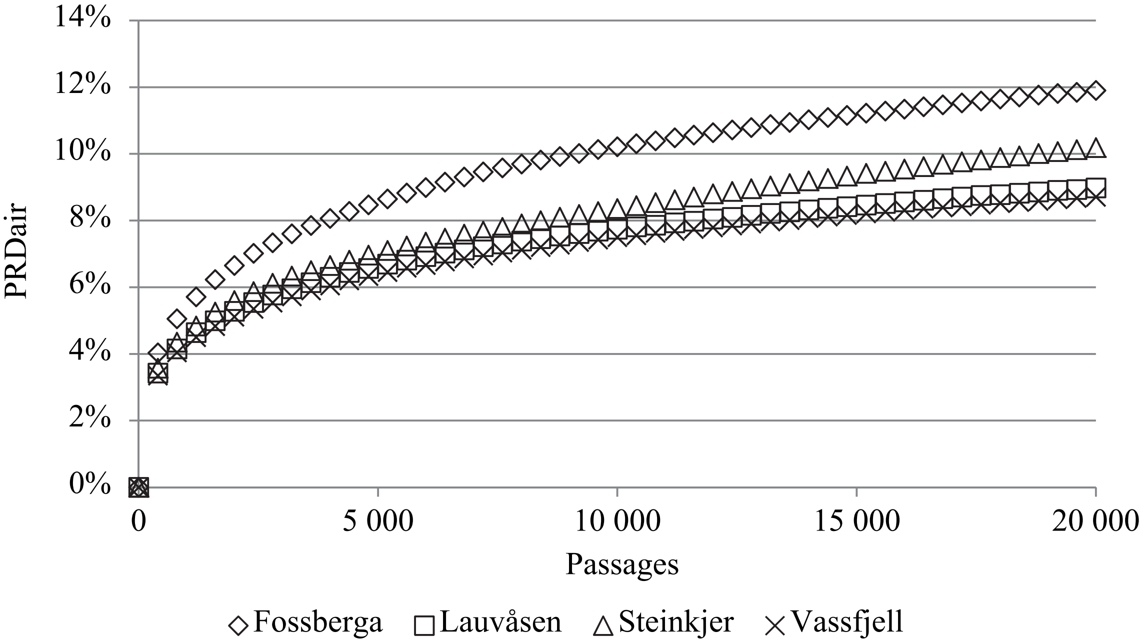

Figure 1 Wheel track test results expressed in terms of mean proportional rut depth (PRDair) versus the number of passages of the loaded wheel.

In the following analysis of results, PRD_{air} and WTS_{air} values are compared with the mineralogy of the aggregates. Figure 2 illustrates gradual worsening of rutting resistance with increasing quartz content in the mix. Lauvåsen and Vassfjell, the mixtures whose aggregates have the lower quartz content, show the lower rut depth after 20 000 passages of the the wheel.

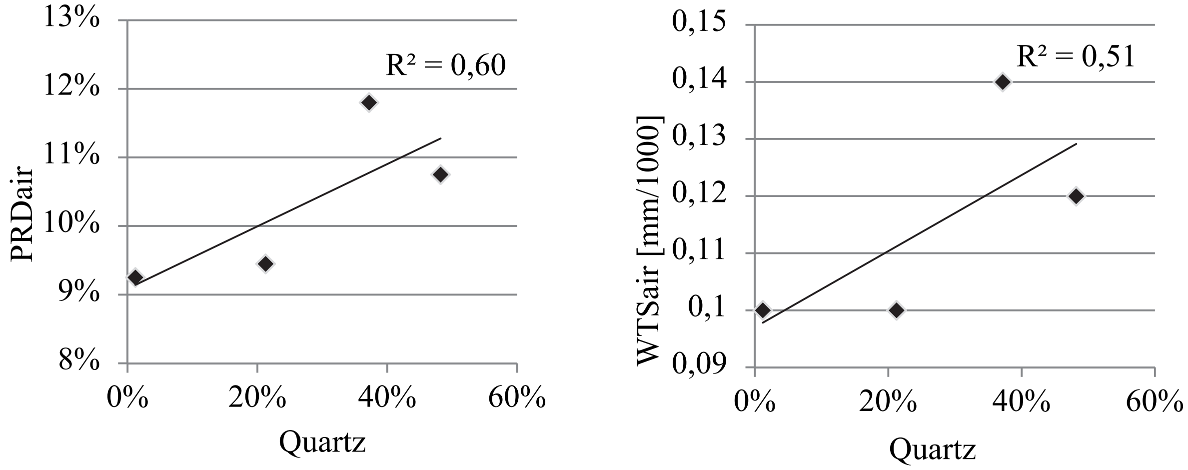

Figure 2: PRD_{air} and WTS_{air} resulting from the wheel track test compared with the quartz content of the mineral aggregates.

In Figure 3 and Figure 4, where the proportional rut depth has been compared with microcline and muscovite, a similar trend is found in both cases. However, a low coefficient of determination is found for both PRD_{air} and WTS_{air} ($R^2 \approx 0{,}47$ and $R^2 \approx 0{,}40$ respectively).

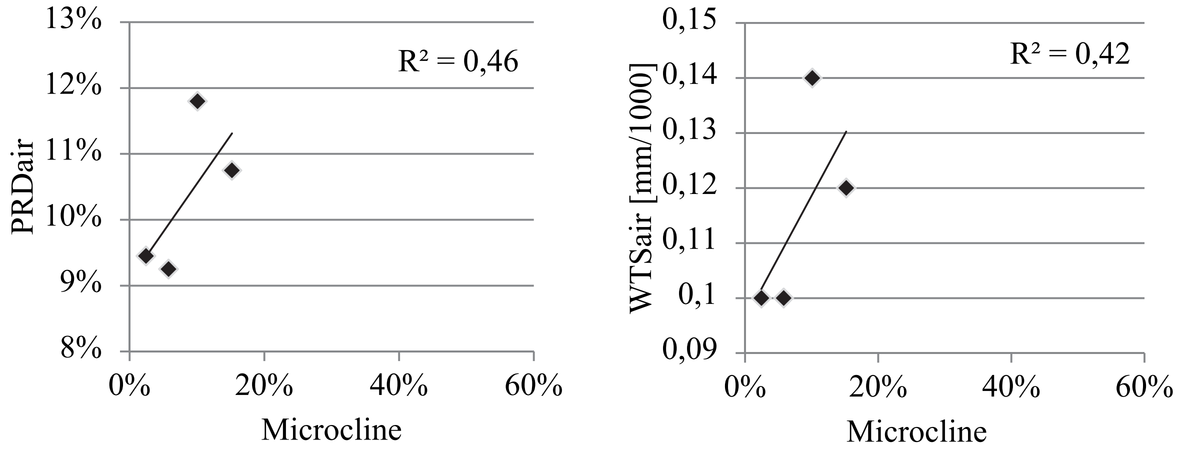

Figure 3 PRD$_{air}$ and WTS$_{air}$ resulting from the wheel track test compared with the microcline content of the mineral aggregates.

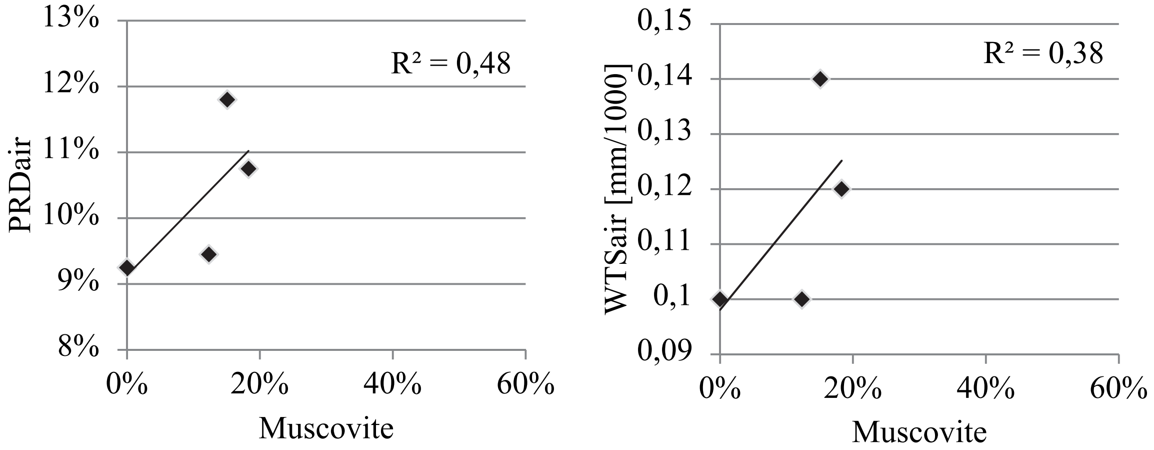

Figure 4: PRD$_{air}$ and WTS$_{air}$ resulting from the wheel track test compared with the muscovite content of the mineral aggregates.

No relevant correlation has been individuated as dependent from the alibite content of the stone materials (Figure 5).

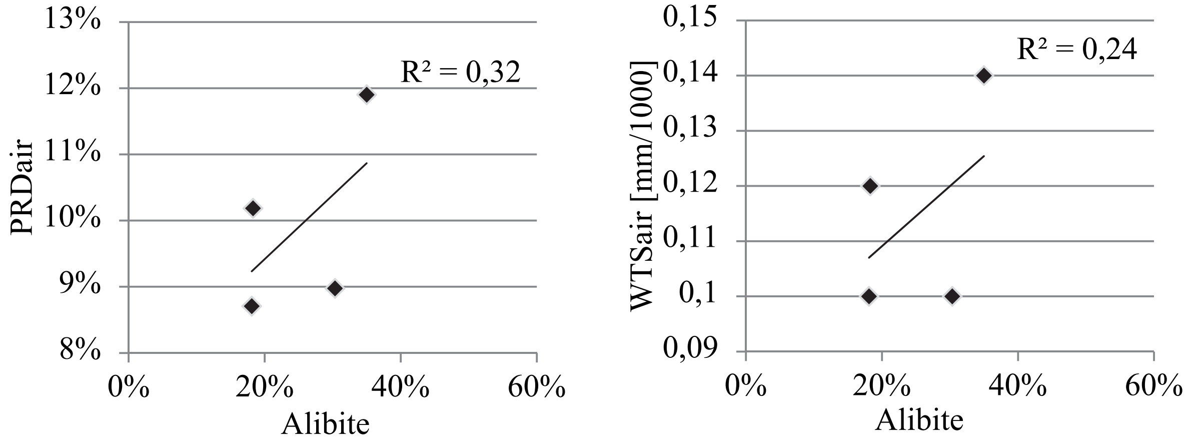

Figure 5: PRD$_{air}$r and WTS$_{air}$ resulting from the wheel track test compared with the alibite content of the mineral aggregates.

A high correlation is instead encountered between the final rut depth and the total content of all the other minerals (as clinochlore, microcline and actinolite, Figure 6). The samples with lower content of the above mentioned minerals showed a better performance in terms of proportional rut depth and vice versa. However, a careful analysis has not yet provided a direct relation between the minerals present in lower percentage in the aggregates and the wheel track test results.

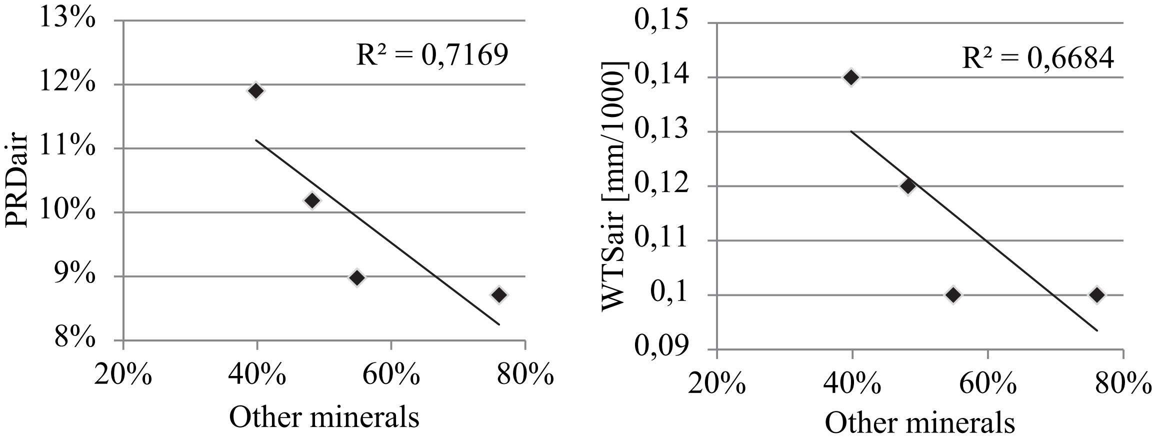

Figure 6: PRD_{air} and WTS_{air} resulting from the wheel track test compared with the muscovite content of the mineral aggregates.

In Table 4 the R^2 values derived from the approximation of the previous results are listed, compared with both PRD_{air} and WTS_{air}, with linear models. The resultant coefficient of determination is generally higher when considering the PRD_{air}, except for the alibite case. This suggests that the typology of the stones has a major influence in the firsts phases of the test, where, according to Sousa, Craus et al. (1991Sousa, Craus et al. (1991), the sample is mainly subjected to an additional compaction. The WTS_{air} does not result influenced because, as it was earlier defined, it represents the increment rate of the PRD_{air} in the second half of the test.

Table 4: Comparison between R2 values derived from the approximation of the results with linear models.

Parameter	R^2	
	PRD_{air}	WTS_{air}
Quartz	0,60	0,51
Albite	0,23	0,24
Muscovite	0,46	0,42
Microcline	0,48	0,38
Other	0,74	0,67

Furthermore even if the set of stone material does not comprehend a wide range in terms of flakiness index, the results of the wheel track test have been compared with the shape index in Figure 7. They do not appear to be directly related with it. As the flakiness index, the rut depth does not show any dependence with the Los Angeles abrasion values (Figure 8).

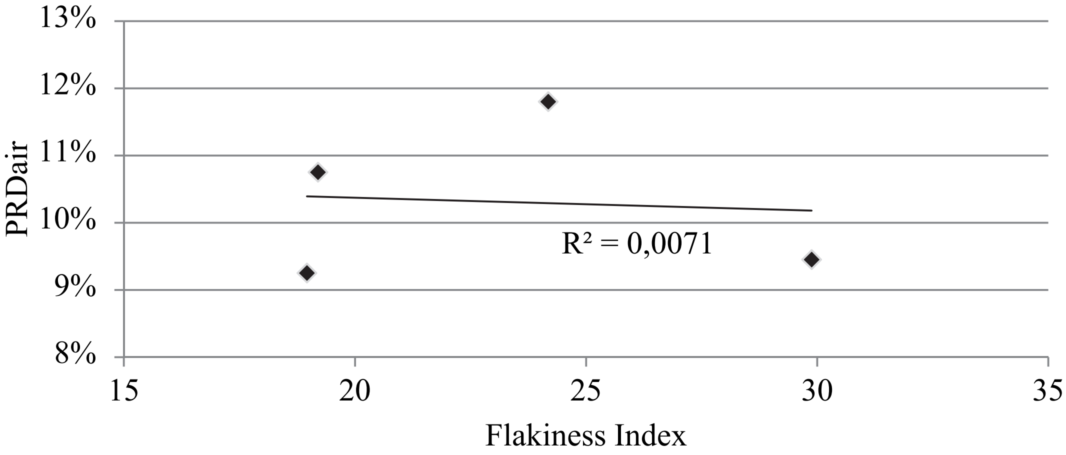

Figure 7: Wheel track test results compared with the flakiness index of the aggregates.

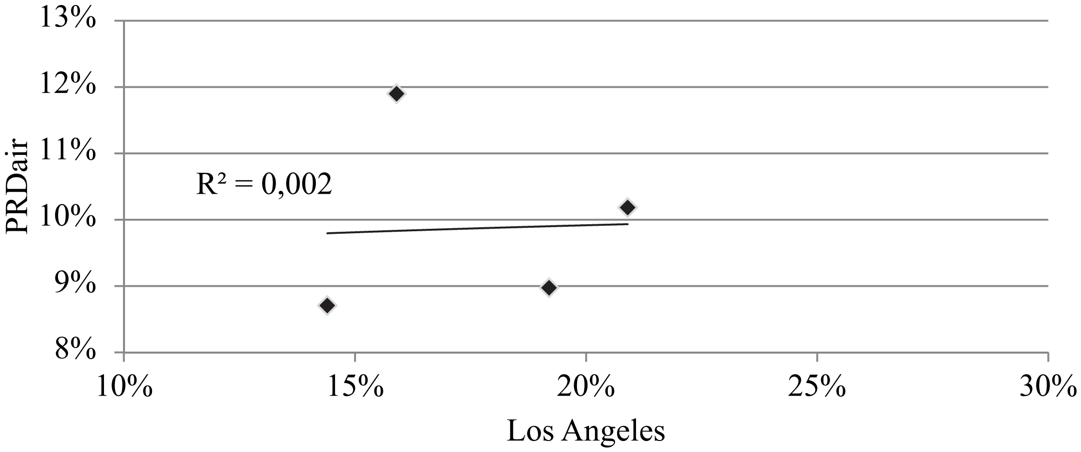

Figure 8: Wheel track test results compared with the Los Angeles abrasion value of the aggregates.

4 CONCLUSION

This paper investigated the effect of aggregate mineralogy on permanent deformation of asphalt mixtures. The results suggest that the type of minerals contained in the aggregates can interfere with the performance of the mixture. In this experimental work, a relevant correlation has been detected between the quartz content and the rut depth resulting from the wheel track test while alibite, contained in high percentages in the different materials, did not show any particular impact. Instead, the sum of all the other minerals contained in smaller percentages, has been found to be determinant. However, the mineralogy of the aggregates has a higher effect on the first stages of the rutting than on the entire test. The flakiness index and Los Angeles abrasion value did not show any influence on the results.

Even though binder content, air voids content, and other properties of the mixtures might have interfered with the test results, the mineral composition of the stone material should be considered as relevant parameter during the pavement design process as factor that may enhance the mixture capacity to withstand load application. Further experiments on this topic might include a wider selection of materials and tests.

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