Effects of Filler Properties on the Rheological and Volumetric properties of Mastics and Asphalt Mixes

C. Thodesen* & P. Dehdezi
SINTEF Road and Railway Engineering, Trondheim, Norway

M. Mengede
Franzefoss Minerals AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud, Oslo, Norway

S. Anastasio
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT: This paper describes the effects of varying filler properties on the rheological properties of mastics and volumetric properties of asphalt mixtures. The main aim of the study was to evaluate how filler properties affect the rheological properties of the mastic that dictate asphalt performance (i.e. rutting, fatigue cracking and thermal cracking). An additional objective of the study was to evaluate some of the volumetric properties of the asphalt mixtures produced with the studied fillers, in particular to see how filler properties affect the compaction of asphalt mixtures.

The fillers used in this study were evaluated according to four common filler properties: Specific Surface Area (SSA), Rigden air voids, specific weight, and average particle size. The laboratory evaluation of the materials was divided into two main sections. First the four different mastics were prepared by blending filler and bitumen, subsequently rheological evaluations of these mastics were conducted using the Dynamic Shear Rheometer (DSR) and the Bending Beam Rheometer (BBR). Specifically, the performance grade (PG) of the mastics with regards to permanent deformation and cracking were evaluated. Next, asphalt mixtures were produced using the studied fillers to evaluate the volumetric properties of asphalt samples prepared with different filler types.

The results of the study indicate that the specific surface area of the filler is strongly correlated with permanent deformation susceptibility of the mortar. Whereby, increasing the specific surface area of the filler was seen to decrease the susceptibility of the pavement to permanent deformation. Weaker correlations were found for specific weight and average particle size for thermal cracking of asphalt pavements.

Some correlations were found linking the volumetric properties of the laboratory prepared asphalt samples with filler properties. However, in general these correlations were weaker than those between the mortar properties and the fillers. These findings suggest that some filler properties may affect asphalt pavement performance, whereby the largest effect is due to the modification of the bitumen due to the presence of the filler.

KEY WORDS: Asphalt, filler, specific surface area, Rigden air voids, particle size, rheology

1 INTRODUCTION

Fillers in asphalt can be defined as "finely divided mineral matter such as hydrated lime, rock dust, slag dust, hydraulic cement, fly ash or other suitable matter", where this definition typically refers to the size fraction smaller than 63μm (Taylor, 2007). Typically fillers are used to modify the properties of asphalt pavements by increasing their performance and durability. Another benefit of using fillers in the production of asphalt pavements lies in the fact that fillers may be used to lower the cost of production of the asphalt (Taylor, 2007).

When used in asphalt pavements, studies have shown that too much filler in the asphalt mixture can lead to cracking or fatigue problems due to increased stiffness, while too little filler can lead to bleeding of the bitumen from the mixture (Taylor, 2007). Therefore, using both the right quantity and type of filler is essential for the ultimate success of the pavement.

The most frequently used filler in asphalt is limestone (calcium carbonate) which is the general term for rocks where calcite, a form of calcium carbonate, is the predominant mineral. Other materials commonly used as fillers in asphalt include Portland cement and hydrated lime, which possess well documented properties with regards to mixture durability and reduced potential for moisture damage in asphalt (Tunnicliff and Root, 1995). In order to provide satisfactory properties in the finished asphalt, filler should (Kavussi and Hicks 1997):

- Not have adverse chemical reactions with bitumen
- Not possess hydrophilic surfaces to ensure good adhesion
- Not possess high porous particles which may lead to excessive stiffening through selective adsorption
- Contain a dense (well graded) particle size distribution

When bitumen is combined with a mineral filler a mastic is formed. This mastic can be viewed as the component of the asphalt mixture that binds the aggregates together and also the component of the asphalt that undergoes deformation when the pavement is stressed under traffic loading. The characteristics of the filler can significantly influence the properties of the mastic, and thus the filler properties can have significant effects on asphalt mixture performance (Osman, 2004). In some cases it has been noted that mastics with the proper amount and type of filler can absorb more damage than unmodified systems (Kim et al., 2002)

Studies have shown that the presence of fillers may affect the asphalt content in the mix, the workability during blending, and the final properties of the asphalt mixture (Zulkati et al., 2012). However, to date no studies have attempted to correlate the specific properties of the filler with asphalt mixture performance. Such information is important as it may allow road engineers to identify specific measurable properties of the filler and provide insight with regards to how the properties might affect the road structure.

In this study four commonly measured filler properties were evaluated in conjunction with asphalt properties, the filler properties studied were: filler specific surface area, Rigden air voids, specific weight, and particle size. The asphalt performance properties evaluated were mortar rheology and the asphalt mix volumetrics (air voids and voids filled with asphalt).

2 OBJECTIVE

The goal of this study was to examine the effects of filler properties on the rheological and volumetric properties of mastics and asphalt mixtures. Specific objectives within the study can be identified as follows:

- Characterization of the specific filler properties of four different filler types using specific weight, specific surface area, Rigden air voids, and average particle size
- Evaluate if filler properties affect mortar rheology
- Evaluate if filler properties affect volumetric properties

3 MATERIALS AND METHODS

3.1 Experimental plan

The experimental plan is illustrated in Figure 1, the plan illustrates how both binder testing and mixture testing were performed on the four mortars based on combining the same 70/100 binder with equal amounts of four different filler types.

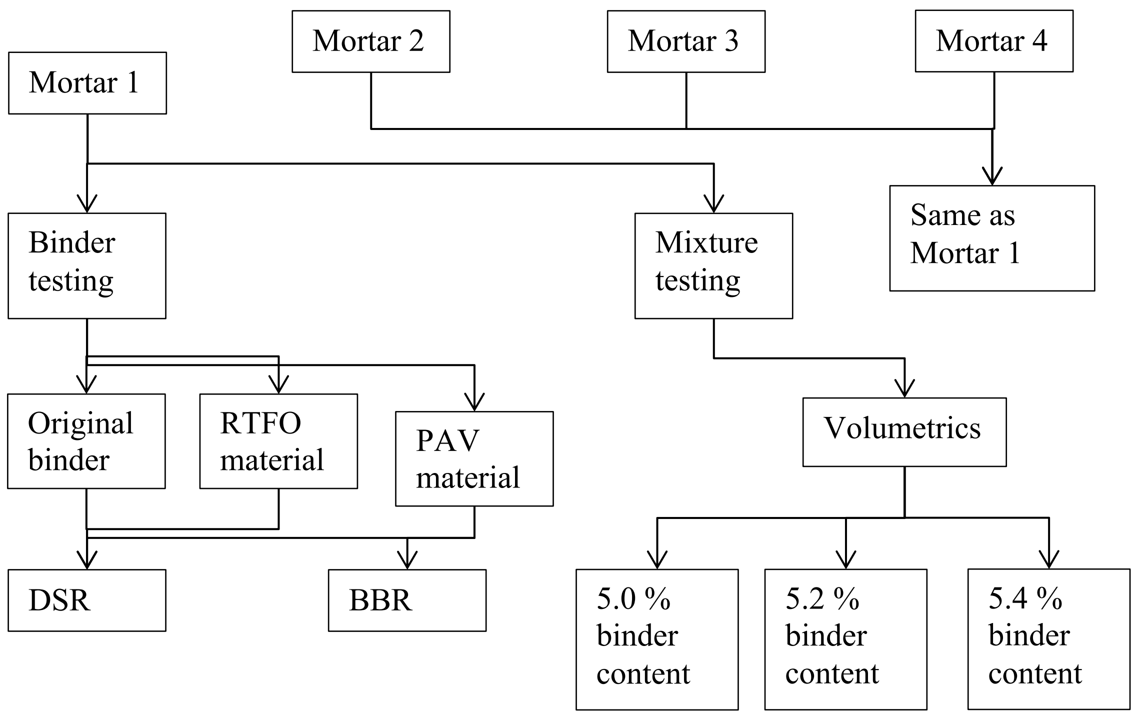

Figure 1: Experimental plan

3.2 Materials

The aggregate gradation used to produce Marshall samples is provided in Figure 2, the Ab11mixture type was selected as it is a commonly used asphalt mixture in Norway. The stone material was blended with a 70/100 binder and compacted at 150°C. The aggregate type was from Vassfjell, a commonly used aggregate for the production of Ab11 mixes.

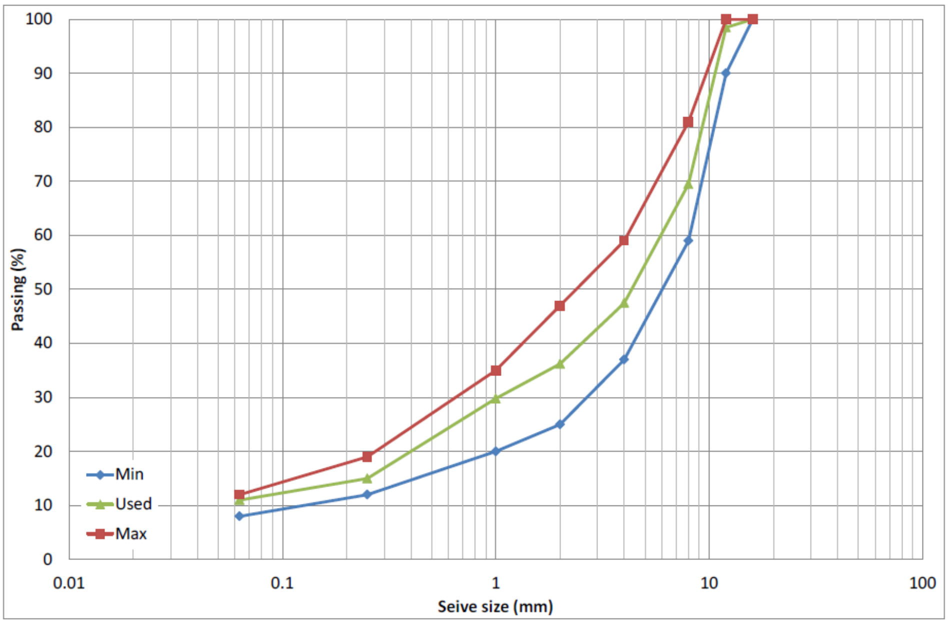

Figure 2: Aggregate gradation limits in Norwegian Ab11 mix along with aggregate gradation used in mixture testing

3.3 Mortar sample preparation

A mortar representative of the actual mastic in the asphalt mixture was prepared assuming that only the added filler would mix with all the bitumen in the asphalt mix to form the mastic component of the asphalt mixture. Based on this assumption and considering a 5% bitumen content by total mass of asphalt, all the percentage of filler in the Ab11 aggregate grading curve (Figure 2) was added to 70/100 Pen bitumen which resulted in a 50/50 bitumen/filler proportions by mass of mastic.

In order to reduce variability in the test results, the mastics were prepared using the following procedure (Osman, 2004):

- Place filler sample in an oven at 110±5°C for drying to a constant weight.
- Place the bitumen into an oven at 160±5°C, until it reaches a uniform temperature of 160°C. Stirring is needed from time to time.
- After preheating the bitumen and filler samples, remove each from its respective oven.
- Place the correct quantities of the dried filler sample and the heated bitumen into a sample container and place it in an oven at 160°C and hand mix with a spatula until the air bubbles escape. Care must be taken to prevent loss of fines during mixing. Stirring of the mixture is necessary to produce a homogeneous specimen.
- When the mastic appears visually homogenous, the mastic will be ready for testing.

3.4 PG binder grading

The four different mortar types were evaluated using rheological testing using a DSR and a BBR. The DSR and BBR are commonly used to measure the rheological characteristics of bitumens. Typically, dynamic tests are performed and the parameters that are determined are the complex modulus and phase angle from which the viscoelastic properties of the bitumen can be evaluated. The DSR has become an accepted test method for determining the dynamic mechanical properties of bitumen in the linear region (Osman, 2004; Taylor, 2007). The standard DSR test system consists of parallel metal plates, a temperature control chamber, a loading device and a control and data acquisition system. Two samples from each mastic were tested as Un-aged, RTFOT (short term aging), and PAV (long term aging) in order to grade the mastic for its performance at high and intermediate temperatures.

To evaluate the mortars at low temperatures BBR testing was conducted on the various mortars, this testing is done to determine its propensity to thermal cracking. The midpoint deflection of a simply supported prismatic and rectangular cross-section beam of bitumen subjected to a constant load applied to its midpoint is measured at different temperatures. Two PAV-aged samples from each mastic were tested in order to grade the mastic for its performance at low temperatures.

3.5 Mixture preparation and testing

Asphalt mixture samples were prepared using the Marshall method, the compaction temperature was 150°C and 2 x 50 blows was used as specified by Norwegian Public Road Administration specifications for Ab11 mixes. The air voids and voids filled with asphalt were subsequently evaluated, whereby the maximum theoretic density was determined using the Rice method.

4 RESULTS

4.1 Binder testing

The results of the rheological evaluation of the various mortar types are presented in the following section whereby the all the various stages of aged material as well as the various filler properties are illustrated in one chart. This has been done to provide an idea of how a specific filler property affects the mortar rheology over the lifecycle of the mortar. Whereby the original unaged binder illustrates the likelihood of permanent deformation due to filler properties towards the beginning of the pavement lifecycle. While on the other end of the spectrum the PAV aged material gives an indication of the effects of filler properties on thermal cracking towards the end of the pavement lifecycle.

4.1.1 Effects of filler Rigden air voids on mortar rheology

As seen in Figure 3, there is a very limited linear correlation between Rigden air voids and the failure temperature of the mortars. The R^2 values for the various correlations vary between 0.22 and 0.30, these findings indicate that Rigden air voids of fillers have very limited, if any effect, on the permanent deformation susceptibility of a pavement as well its susceptibility to thermal and fatigue cracking.

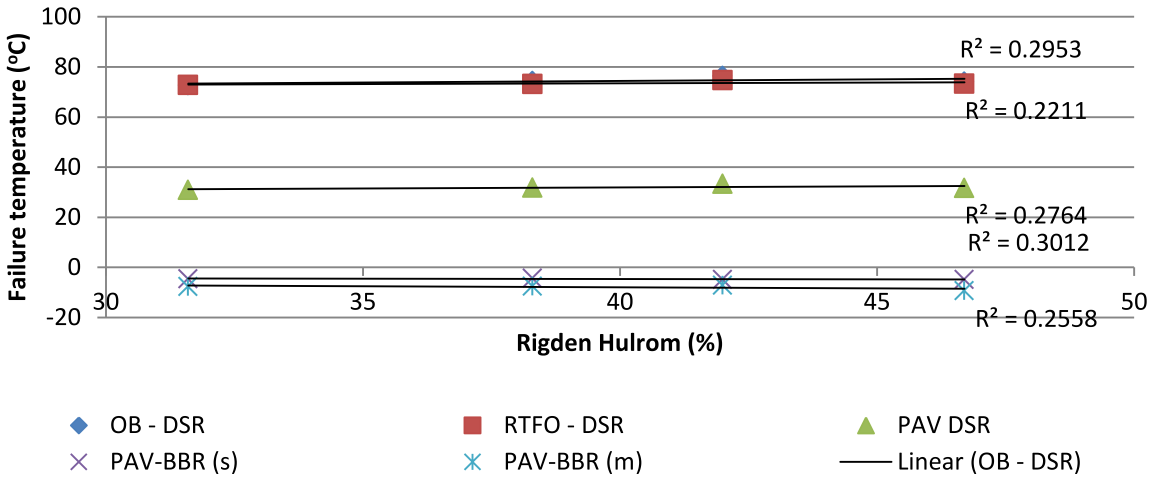

Figure 3: Effect of filler Rigden air voids on mortar rheology

4.1.2 Effect of filler surface area on mortar rheology

Figure 4 illustrates that there is a positive correlation between some types of binder properties and specific surface area of the filler used to create the mortar. The strongest correlations are found for the unaged binder (R^2=0.91), followed by the PAV aged material tested for fatigue cracking (R^2=0.86), and then followed by short term aged material evaluated for permanent deformation (R^2=0.73). Specific surface area of the filler and cold temperature cracking do not appear to be correlated.

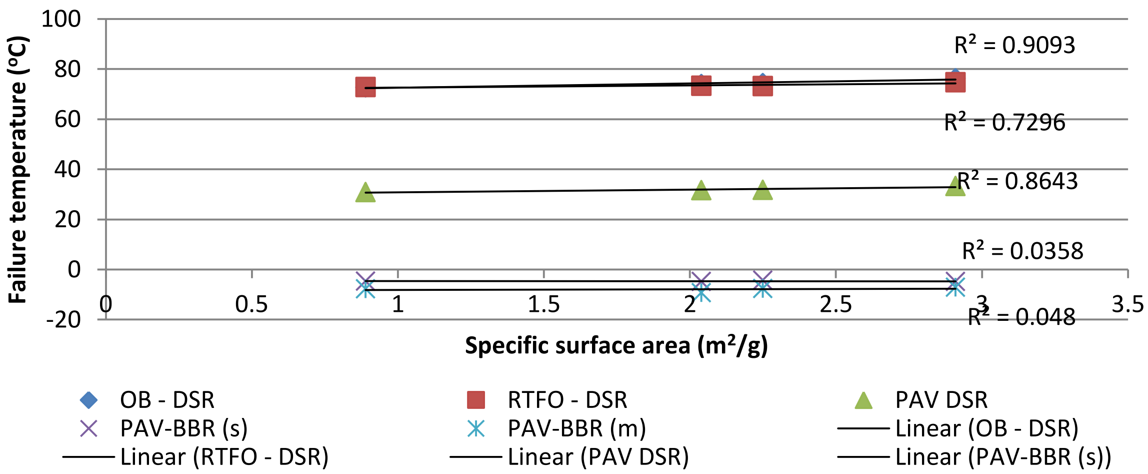

Figure 4: Effect of filler surface area on mortar rheology

These findings suggest that the mortar appears to be sensitive to the surface area of the filler used to modify it, whereby increases in specific surface area of the filler correspond to mortars which are slightly more resistant to permanent deformation and fatigue cracking.

4.1.3 Effect of filler specific weight on mortar rheology

Figure 5 indicates that there is a linear relationship between the specific weight of the filler and the m- value of the mortar as tested by the BBR. The m-value provides an indication of the susceptibility of the mortar to thermal cracking, and in this case suggests that the mortar's ability to resist thermal cracking increases slightly when heavier fillers are used to prepare the mortar. Otherwise, the specific weight of the mortar is shown to have very little effect on the rheological properties of the mortar.

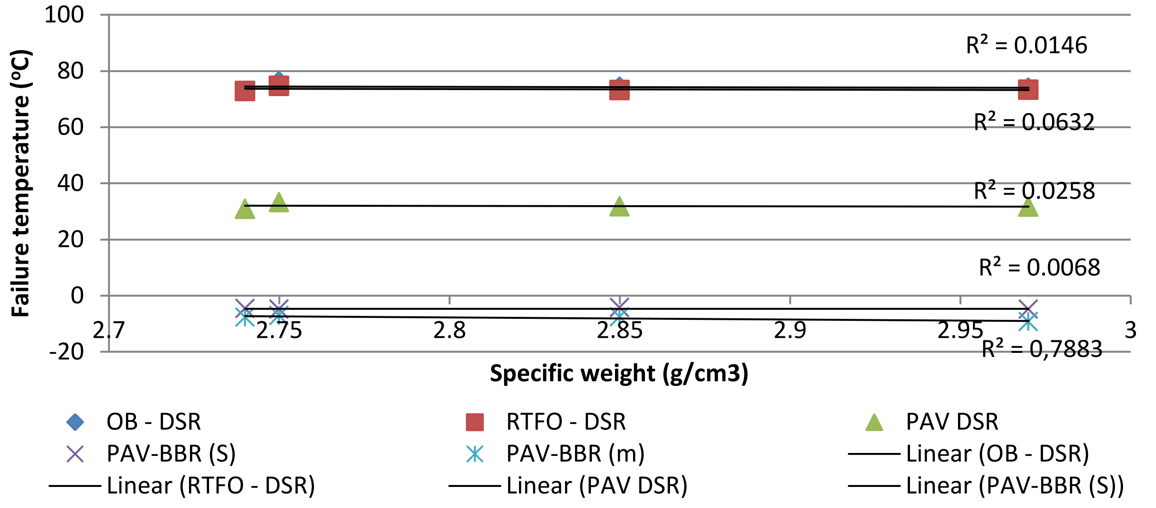

Figure 5: Effect of filler particle size on mortar rheology

4.1.4 Effect of filler particle size on mortar rheology

Figure 6 provides a summary of the test data with regards to the effect of filler particle diameter size on the failure temperature of the various mortar types. From this data set the strongest correlation was found for the stiffness of the mortars evaluated by the BBR on PAV aged material. The data suggests that as the average particle diameter of the filler in the mortar increases, its susceptibility to thermal cracking increases due increasing stiffness of the mortar. The average particle size of the filler does not appear to influence any of the other aging or rheological properties.

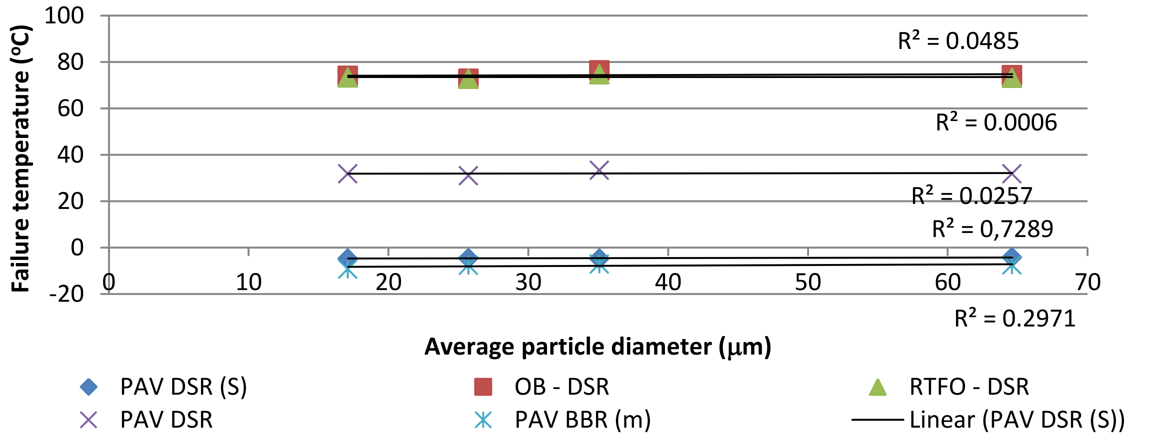

Figure 6: Effect of filler average particle diameter on mortar rheology

4.2 Mixture testing

Limited testing was conducted on Marshall prepared mixture samples, whereby the effects of the previously mentioned filler properties was evaluated with respect to the air voids and voids filled with asphalt of laboratory prepared Ab11 asphalt specimens. Only the results from the specific surface area testing are illustrated in figures, as this property was seen to be dominant in the mastic evaluation phase of the study.

4.2.1 Air voids

Figure 7 illustrates the effects of filler specific surface area on the air voids in the asphalt samples, the data suggests that there is a positive correlation between specific surface area and air voids in Ab11 mixes. In practice this means that asphalt mixes using fillers with higher specific surface areas may experience greater air voids than those using coarser filler types (for filler types with SSA between 0.5 and 4 m^2/g). Possible causes for this could be that fillers with more surface absorb more binder, thus decreasing the lubrication effect of the available binder during compaction.

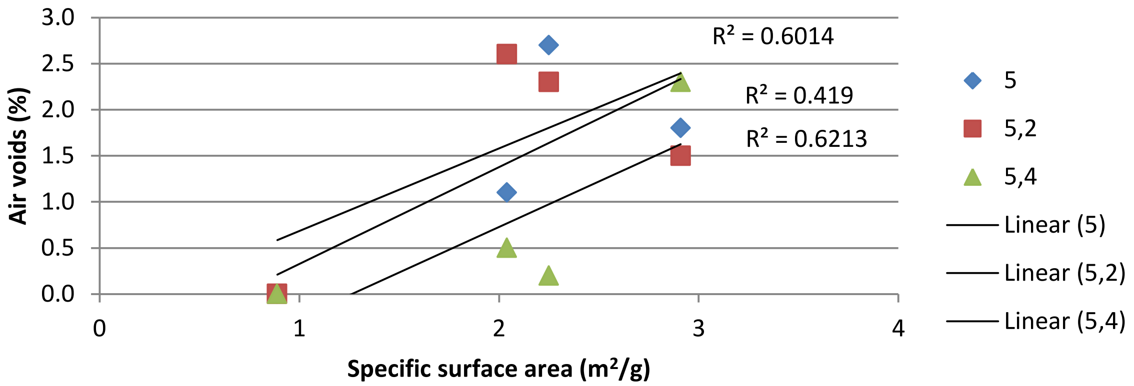

Figure 7: Effect of filler specific surface area on air voids

4.2.2 Effect of specific surface area on voids filled with asphalt

Figure 8 illustrates the effects of filler specific surface area on the development of voids filled with asphalt in Ab11 mixes. The data indicates that as the specific surface area of the filler increases the voids filled with asphalt in the asphalt mix tend to decrease.

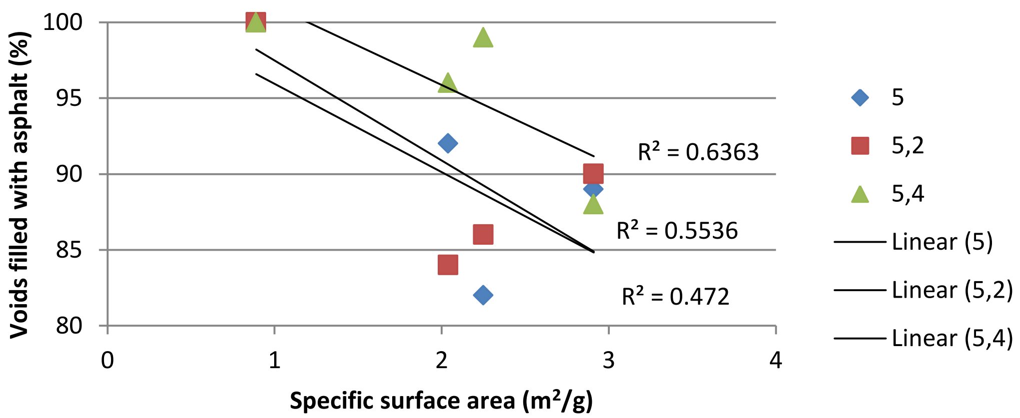

Figure 8: Effect of specific surface area on voids filled with asphalt

4.3 Summary

Using the R^2 value for the linear correlation between the various filler and asphalt/mortar properties it is possible to generalize and draw some conclusions on some of the findings of this study.

As shown in Table 1, few of the filler properties had significant correlations with the mortar properties. However, what can be seen is that the specific surface area of the filler was strongly correlated with permanent deformation properties as well as with intermediate temperature fatigue cracking. The average particle size and specific weight of the filler were seen to influence the thermal cracking of the mortar. However, the data indicates that these do so in different ways with the specific weight having a correlation with the m-value and the average particle size with the stiffness respectively.

Table 1: Summary of R^2 values for linear correlation of filler and mortar rheological properties

	R^2 value				
	Original binder	RTFO aged binder	PAV aged binder	PAV aged binder	PAV aged binder
	DSR	DSR	DSR	BBR (S)	BBR (m)
Specific surface area	0,91	0,73	0,86	0,04	0,05
Rigden air voids	0,30	0,22	0,28	0,26	0,30
Specific weight	0,01	0,06	0,03	0,01	0,79
Average particle size	0,05	0,00	0,03	0,73	0,30

Table 2 indicates that with respect to the volumetric properties it can be seen the specific surface area was consistently correlated with the air voids. However, the strength of the correlations between filler properties and volumetric properties was significantly weaker than those present for the mortar properties.

Table 2: Summary of R^2 values for linear correlation of filler and volumetric properties

	R^2 value					
	Air voids			VFA		
	5 % Binder content	5,2 % Binder content	5,4 % Binder content	5 % Binder content	5,2 % Binder content	5,4 % Binder content
Specific surface area	0,60	0,42	0,62	0,55	0,47	0,64
Rigden air voids	0,15	0,71	0,18	0,17	0,74	0,28
Specific weight	0,05	0,68	0,09	0,08	0,63	0,04
Average particle size	0,65	0,06	0,01	0,63	0,06	0,02

These findings suggest that specific surface area typically has the most influence on asphalt performance, where the contributions of increasing surface area tend to include the reduction of permanent deformation and intermediate temperature fatigue cracking. The data suggests that the specific weight of the filler as well as its average particle size can affect the thermal cracking properties of the pavement.

5 CONCLUSIONS

Studies have shown that the presence of fillers may affect the asphalt content in the mix, the workability during blending, and the final properties of the asphalt mixture. However, to date no studies have attempted to correlate the specific properties of the filler with asphalt mixture performance. Such information is important as it allows road engineers to identify specific measurable properties of the filler and provide insight with regards to how such properties might affect the road structure.

This paper provides data on how different filler types affect the rheological properties of mastics and volumetric properties of asphalt mixtures produced with these different types of added fillers. The main aim of the study was to evaluate rheological properties of the mastic as well as evaluating how volumetric properties of the asphalt mixtures vary when filler properties were varied. The filler properties studied were: specific surface area, Rigden air voids, specific weight, and particle size.

The results of the study indicate that the specific surface area of the filler is strongly correlated with permanent deformation properties of the mortar. Whereby, increasing the specific surface area of the filler was seen to decrease the susceptibility of the pavement to permanent deformation. Weaker correlations were found for specific weight and average particle size for thermal cracking of asphalt pavements.

Some correlations were found linking the volumetric properties of the laboratory prepared asphalt samples with filler properties. However, in general these correlations were weaker than those between the mortar properties and the fillers. These findings suggest that some filler properties may affect asphalt pavement performance, whereby the largest effect is due to the modification of the bitumen due to the presence of the filler.

REFERENCES

Kavussi, A. and R. G. Hicks (1997). Properties of bituminous mixtures containing different fillers. Proceedings of the Association of Asphalt Paving Technologists. 66: 153.

Kim, Y.-R., D. N. Little, and R. L. Lytton. (2002). Fatigue and Healing Characterization of Asphalt Mixtures. Journal of Materials in Civil Engineering, American Society of Civil Engineers

Osman, S. (2004). The role of bitumen and bitumen/filler mortars in bituminous mixture fatigue, University of Nottingham.

Taylor, R. (2007). Surface interactions between bitumen and mineral fillers and their effects on the rheology of bitumen-filler mastics. Doctor of Philosophy, University of Nottingham.

Tunnicliff, D. G., and R. E. Root(1995). NCHRP Report 373: Use of Antistripping Additives in Asphaltic Concrete Mixtures: Field Evaluation. TRB, National Research Council, Washington, D.C., 1995.

Zulkati, A., Diew, W., and Delai, D. (2012). Effects of Fillers on Properties of Asphalt-Concrete Mixtures. ASCE Journal of Transportation Engineering. July 2012, Vol. 138, No. 7 : pp. 902-910