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LIFE TIME PREDICTION FOR LOW ENERGY AND ECOLOGICAL EFFECTS BITUMINOUS MIXTURES

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Abstract: Road surfaces with low temperature bitumen are usually used due to the lower energy consumption and environmental considerations. This paper presents a study of the performance of low temperature bitumen, in particular, the long- term behavior and life-time prediction of some low-temperature bitumen. Six bitumen mixture samples were tested with different modifiers such as synthetic Cecabase (C), Sasobit (S), Greenseal (G) and Advera (A) wax. Pavement performance prediction in terms of fatigue cracking and surface rutting is essential for any mechanistically-based pavement design method. In this study full-scale Accelerated Pavement Testing (APT) has been used to simulate field conditions and Equivalent Standard Axles (ESAs). Fatigue response was also analyzed in the laboratory. This paper focus on developing a life time prediction model based on rutting and fatigue to describe the stable and unstable performance of six tested low energy bitumen mixtures.

Keywords: Life Time prediction, fatigue, rutting, foamed bitumen, warn mixtures, Reclaimed Asphalt Pavement.

1 INTRODUCTION

Hot mix asphalt (HMA) is the most usual material for road construction. HMA requires heating of aggregates and bitumen to 160 °C or sometimes more [1]. Due to high production temperatures, HMA is highly energy-consuming due to the high temperature of the mixture production and is a source of greenhouse gas emissions affecting the environment [2].

Foamed bitumen is a hot bituminous binder that has been temporarily converted from a liquid state into a foam state by the addition of a small percentage of water and pressurized air. Foam bitumen has been used as a stabilizing agent in pavement since 1956 [3]. After modification its production process from injecting steam to cold water into hot bitumen in 1976 [4], and also introducing new machineries in the market in mid-1990 [5], numerous road and highway stabilization and recycling projects performed using this technology [6].

Warm Mix Asphalt (WMA) is produced at temperatures between 100 °C and 140 °C. Lower processing temperatures can be achieved using chemical additives or by reducing bitumen viscosity through organic modifiers such as synthetic Cecabase (C), sasobit (S), Advera(A) or greenseal (G) wax. The Cecabase (C), sasobit (S), Advera (A) and greenseal (G) have a significant influence to the rheological characteristics of bitumen, enhancing its performance in service temperatures (by increasing its viscosity below 100 °C and elevating softening point temperature). At the same time, Cecabase (C), Sasobit (S) and Advera (A) and

Greenseal (G)wax decreases bitumen viscosity in temperatures exceeding 100 °C, permitting lower compaction temperatures to be used [7].

2 BITUMEN MATERIALS

The objective of this research is to study the performance of asphalt mixtures prepared with some WMA technologies, A, C, G and S in comparison with a reference HMA mixture [8]. Bitumen AC B 16S was used for the reference mixture. Recycled/Reclaimed Asphalt Pavement (RAP) was also tested[8].

It was used the standard method for determining the Optimus bitumen Content with the ASTM D6927-15 Standard Test Method for Marshall Stability and flow test. All samples were cylindrical specimens compacted using a gyratory compactor. The specimens were prepared based upon the laboratory mixture design, i.e. at optimum binder content (between 4% and 6% of aggregate mass) and an aggregate water content of about 4.5%. The specimens were cured at 40°C for 3 days to simulate approximately 6 months of field curing as proposed by [9].

The response of bitumen to stress is dependent on both temperature and loading time and the degree to which their behavior is viscous and elastic is a function of both temperature and loading time.

Table 1 explains in detail the composition of the 6 mixtures tested in this research.

Table 1. Composition of the mixtures under study.	REF-HOT Kg	FR-PACK Kg	FR-WAX Kg	FR-WATER Kg	WATER+RAP Kg	PA PACK Kg
Bitumen 250/330				1215	0.945	
Bitumen 70/100					2.16	
Bitumen 35/50				4995		
Bitumen 50/70	6.2	6.21	6.21			4.462
Filler	5.1	5.13	5.13	5.13		3.8
0/4	54.8	54.81	54.81	54.81	22.275	40.6
Gravel 4/8	29.1	29.025	29.025	29.025	9.315	21.5
Gravel 8/11	16.7	16.74	16.74	16.74	12.285	12.4
Gravel 11/16	23.1	23.085	23.085	23085	20.52	17.1
Cecabase		0.02484				
Sasobit			0.1863			0.138
Bithaftin			0.006			0.0046
RAP					67.5	

3 MIX DESIGN

Sasobit is a long chained synthetic wax (chain lengths ranging between 40°C to 115°C carbon atoms) that is produced using the Fischer-Tropsch (F-T) process. Sasobit forms a lattice structure inside the asphalt binder at temperatures below its melting point which improves the stability of asphalt mixtures and causing a reduction in the viscosity of binder. The addition of sasobit additive significantly assists in lowering the amount of air voids within mixes in most cases [10].

Cecabase is the reference modifier for Warm Mix Asphalt (WMA). Cecabase brings workability and easier compaction of the mix, even with Reclaimed Asphalt Pavement (RAP) that is also under study in this research .

Advera is a synthetic zeolite that is formed of alumni-silicates and released as the temperature rises above 100°C upon the introduction of the additive to the mixture simultaneously with the binder .

Another tested material in this study, RAP, has several advantages, most notably, the preservation of natural and economic resources, thus it is considered an environmentally friendly practice.

The test results indicate clearly that the use of these additives in the modified bitumen will result in a significant increase in rutting resistance, on the one hand, and will enable paving at lower temperatures due to a significant reduction of bitumen viscosity. Table 2 summarizes the mixtures temperatures for all the tested mixtures.

Table 2. The following table shows data about the mixture temperatures.

Code	REF-HOT	FR-PACK	FR-ZEO	FR-WAX	PA-HWAM	PA-PACK
Formule	AC B 16S	AC B 16S	AC B 16S	AC B 16S	AC B 16S	AC B 16S
Addit.	-	Cecabase RT	Advera	Sasobit	Fluxant (LEA1)	Greenseal
Addit. Dosing	-	0.4% bitume	0.25% / coated	3% / bitumen	0.4% / bitumen	1% / bitume
Aggreg. Temp	160 °C	130 °C	130 °C	130 °C	150 °C	130 °C
Sand Temp	160 °C	130 °C	130 °C	130 °C	150 °C	130 °C
Filler Temp	160 °C	130 °C	130 °C	130 °C	150 °C	130 °C
Bitume Temp	155 °C	130 °C	130 °C	130 °C	150 °C	130 °C

4 OPTIMUM BITUMEN CONTENT

For determining the optimum bitumen content was used the ASTM D6927-15 Standard Test Method for Marshall Stability and flow test. Asphalt mixtures were compacted using a Marshall compactor and tested for stability, bulk density and air voids. Indirect tensile strength test was carried out also to measure the tensile strength of compacted asphalt mix [11][12][13].

In order to prepare the laboratory mixes, mixing aggregates with foam bitumen, made of specimens of 101 mm in diameter and 65 mm height, were compacted applying Marshall Hammer at 65 blows per sample sides with about 5% by volume void content. The mixture compacity (%) is shown in figure 2.

Marshall test was performed to determine the percentage of optimum bitumen content. Figure 1 summarizes the test results for the optimum bitumen content of all the mixtures.

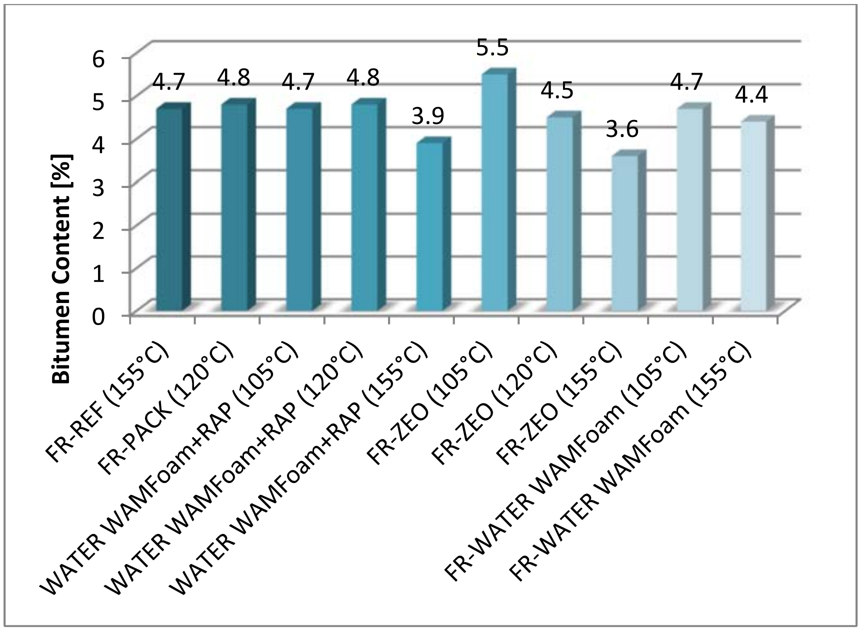

Figure 1. Marshall test results for all the mixtures in the study.

The air-void content of the mixes in the study, determined from Marshall-compacted specimens, was notably different with the reference mix having significantly lower air-void content than the mixes with additives. The reference mix had the lowest air-void content and the Sasobit mix the highest air-void content. The obtained data suggests that the binders in the WMA mixes at the lower compaction temperature were stiffer/more viscous than the reference mix binder at the higher temperature.

The tests showed that the Marshall stability of the reference mix was significantly higher than the mixes with additives or RAP [1].

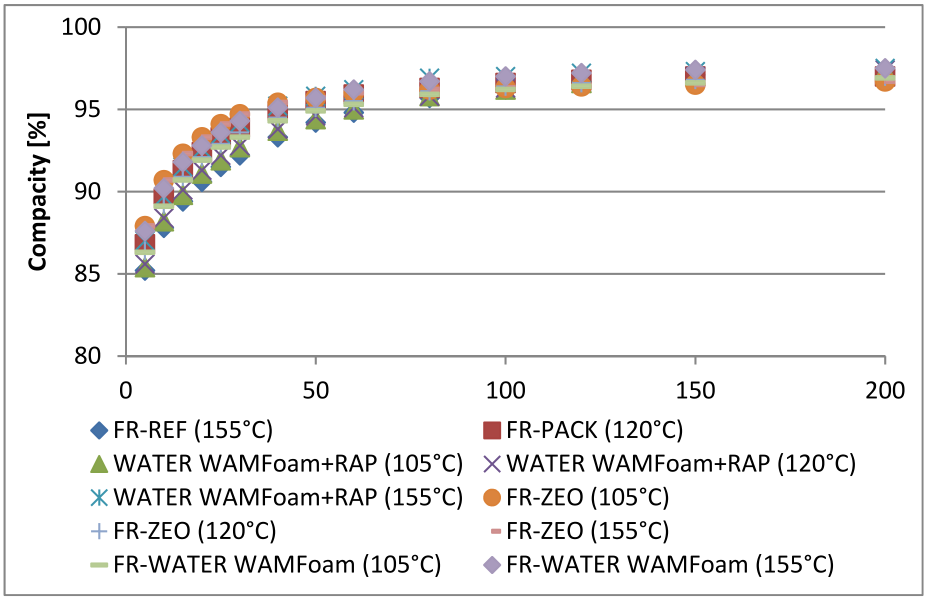

Figure 2. Mixture compacity (%)

4.1 Preliminary ageing method and tests

The ageing method performed in the lab was the following:

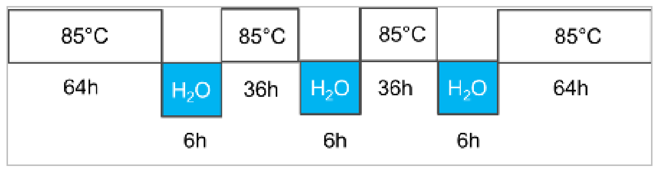

Figure 3. Long-term ageing of compacted laboratory samples.

Samples were in the oven at 85°C during 64 h, 36 h, 36 h and 64 h in between of the hot treatment the samples were in water at ambient temperature three times during 6h per time.

5 MASTER CURVES

In this study, asphalt mixture samples were subjected to accelerate short and long-term ageing. The goal was getting asphalt mixtures that were representative of “in-service conditions”. This requires laboratory conditioning procedures to simulate binder conditions immediately after construction and after in-service ageing.

5.1 Short-Term Ageing

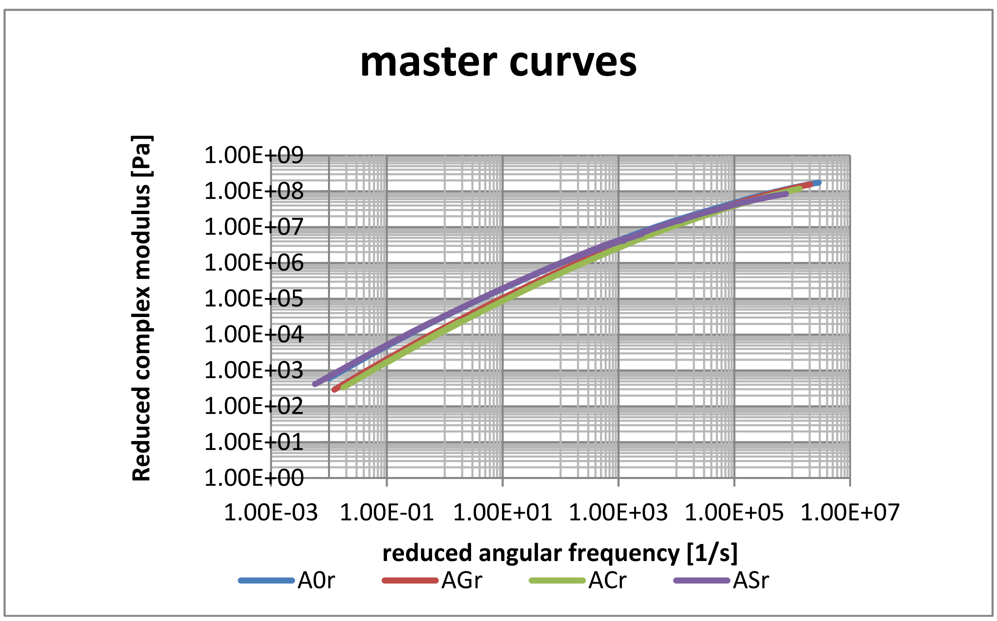

Figure 4. Master curve for short term ageing

The study uses RTFO (Rolling Thin Film Oven Test) for Short Term Ageing.[15]. Figure 4 shows the results of the master curves under short term aging. RTFO simulates asphalt aging during the asphalt production and pavement construction according the obtained data and the reduced angular frequency that can be seen in Figure 4 where A 0r is the reference mixture, AGr is the mixture with Greeseal, ACr is the mixture with Cecabase and ASr is the mixture with Advera, we can say that:

There was no apparent big difference between the complex modulus of the reference, Advera and Cecabase mixes although the complex modulus of the reference mix was slightly higher than the other two mixes. However the master curve of the Sasobit mix was above the other three mixes.

Phase angle increased with increasing loading frequency for all mixes. There was no neither apparent big difference in the phase angle master curves for the reference, Advera and Cecabase mixes. The master curve of the Sasobit mix crossed the other three master curves approximately between 2.0 Hz and 5.0 Hz; hence, higher loading frequency in the Sasobit mix appears to have smaller phase angles than the other three mixes and higher phase angles at lower loading frequencies.

5.2 Long-Term Ageing

In this study PAV (Pressure Ageing Vessel) was used to simulate long-term ageing [16]. Figure 5 shows the results of the master curves under long term aging. PAV simulates asphalt aging under service life of the pavement. High temperature increases the rate of ageing. Increased pressure makes oxygen available to asphalt molecules thereby increasing rate of ageing [17][18]. According the obtained data and the reduced angular frequency that can be seen in Figure 5 where A 0r is the reference mixture, AGr is the mixture with Greeseal, ACr is the mixture with Cecabase and ASr is the mixture with Advera we can conclude that for long term ageing, all the master curves for the bitumen under study are quasi identical especially for high frequencies, except for Sasobit. Sasobit has been identified to have an antioxidant effect on the rate of ageing.

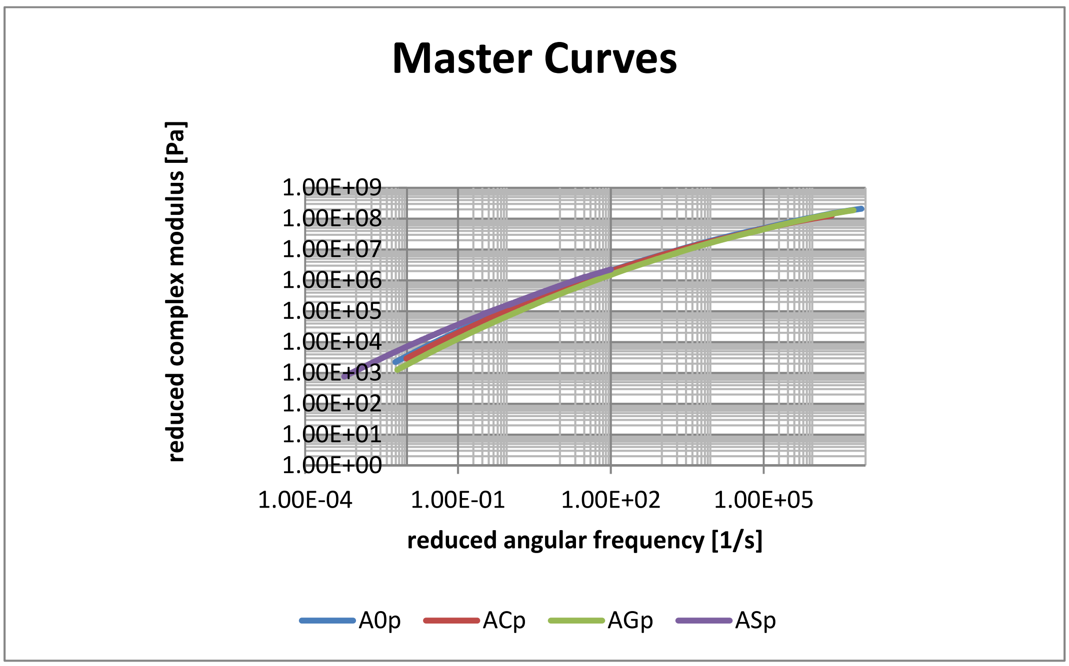

Figure 5. Master curve for long term ageing

6 EXPERIMENTAL DATA FOR FATIGUE

Data for the six mixtures were obtained in lab tests and were used to develop the fatigue life prediction of the mixtures.

Fatigue tests were performed with the four point beam fatigue test. The tested WMA specimens showed a shorter fatigue life than the reference HMA. Mixtures containing RAP were studied and results showed that WMA mixtures allow RAP to be produced at lower temperature (up to 35°C lower) without a decrement of the main properties of the bitumen in terms of fatigue, rutting, or moisture susceptibility [19][20].

6.1 Fatigue Life Prediction

Fatigue live is calculated in the lab and Figure 6 and Figure 7 present the fatigue lives versus increment axle loads for different asphalt mixtures under study for both short term ageing and long term ageing [21]. The figures show that fatigue live decrease dramatically with increasing the increment axle load, especially when the axle load exceeds 3000 N for fatigue life.

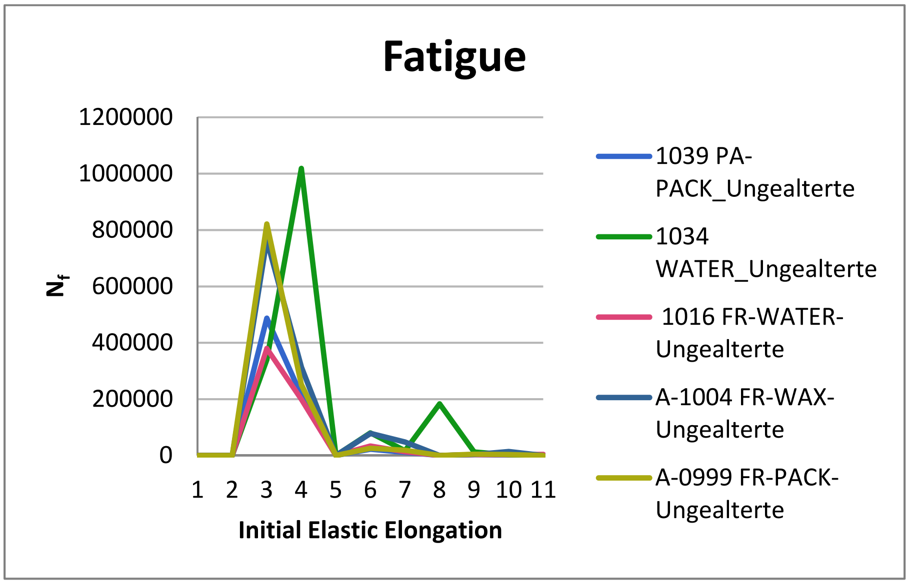

Figure 6. Fatigue test results for the samples.

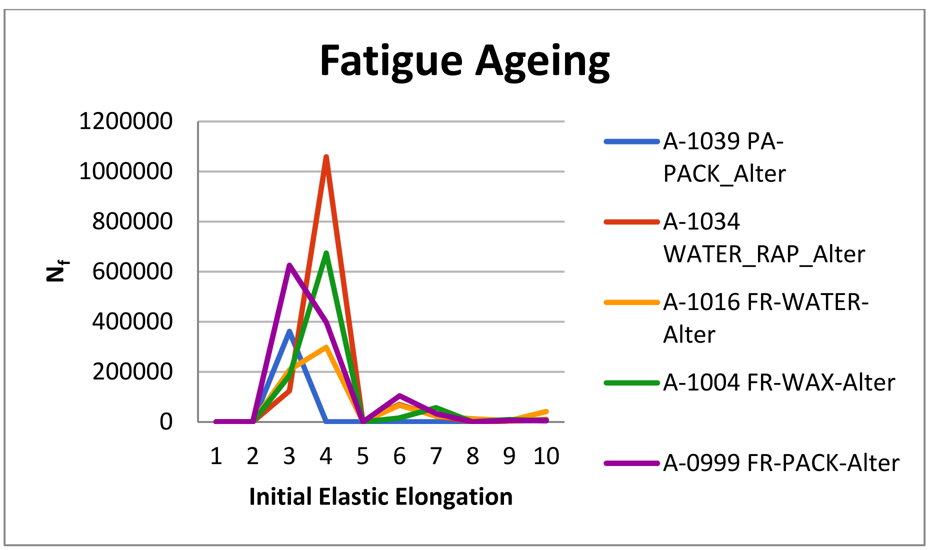

Figure 7. Fatigue test results for the samples with an ageing treatment.

7 EXPERIMENTAL DATA FOR RUTTING

Rutting is strongly influenced by traffic loads, but changes in temperature or high temperatures can also influence on it. In this study it has been analyzed six samples under aged and unaged conditions and the purpose of this test was to determine the rut resistance for WMA and compare the results with the control mixture (HMA). Rutting behavior for mixtures under study is compared and shown in figures 8 and 9.

It was found that WMA PA- PACK made with Sasobit and Bithaftin, with the quantities described in table 2, showed the highest rutting depth under unaged conditions. This is because as it has already mentioned in the study the asphalt ageing is higher at higher temperature. Aging also results in a higher stiffness of the bitumen.

Rutting test shows that all the WMA produced at temperatures within 105°C and 120°C have higher rutting depth compared to reference HMA; and the rest of the WMA samples (except PA-PACK that has the highest rutting) have quite comparable rutting depth after 8000 loading cycles compared with HMA of reference (REF-HOT). It was found that PA-PACK WMA made with Sasobit and Bithafin produced at 120 °C has the highest rutting .

Higher numbers of cycles indicate better rutting-resistance. As expected, the rutting-resistance capacity decreased with increasing temperature and stress level. In ageing conditions the lowest deep mixture would be REF-HOT and later FR PACK and WATER RAP almost with the same results although a light resistance to rutting is shown the FR PACK. As it can be seen in the figure 4 the Sasobit mix had deepest rutting compare to the other mixes and the reference mixture at the same number of cycles. This indicates that the use of these additives and lower production and compaction temperatures do not help significantly in the influence in rutting [22].

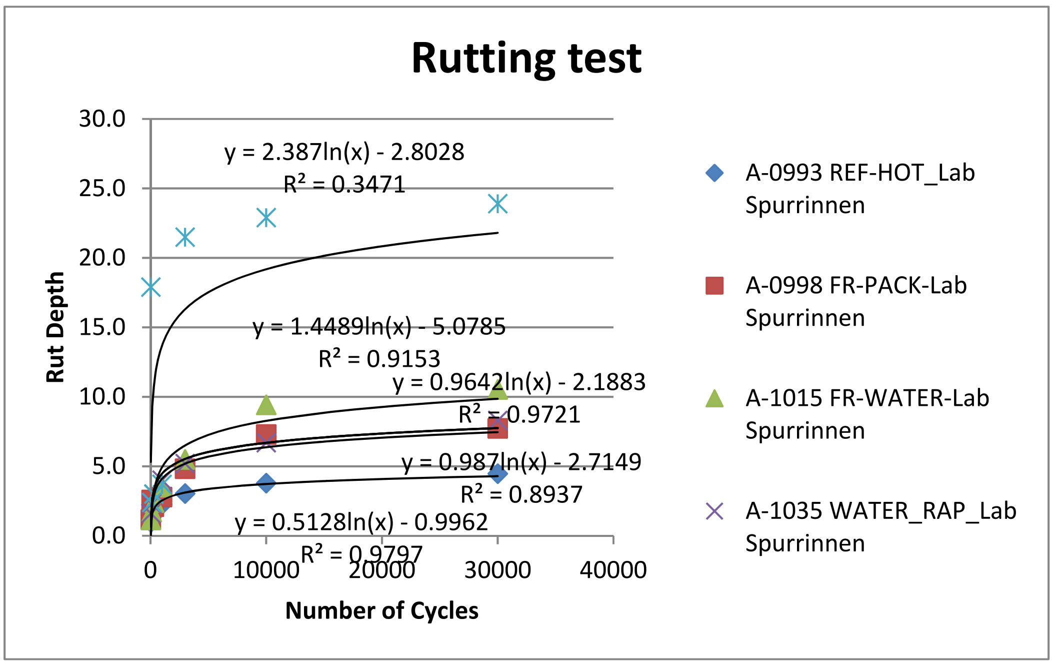

Figure 8. Rutting test results for the mixtures under study.

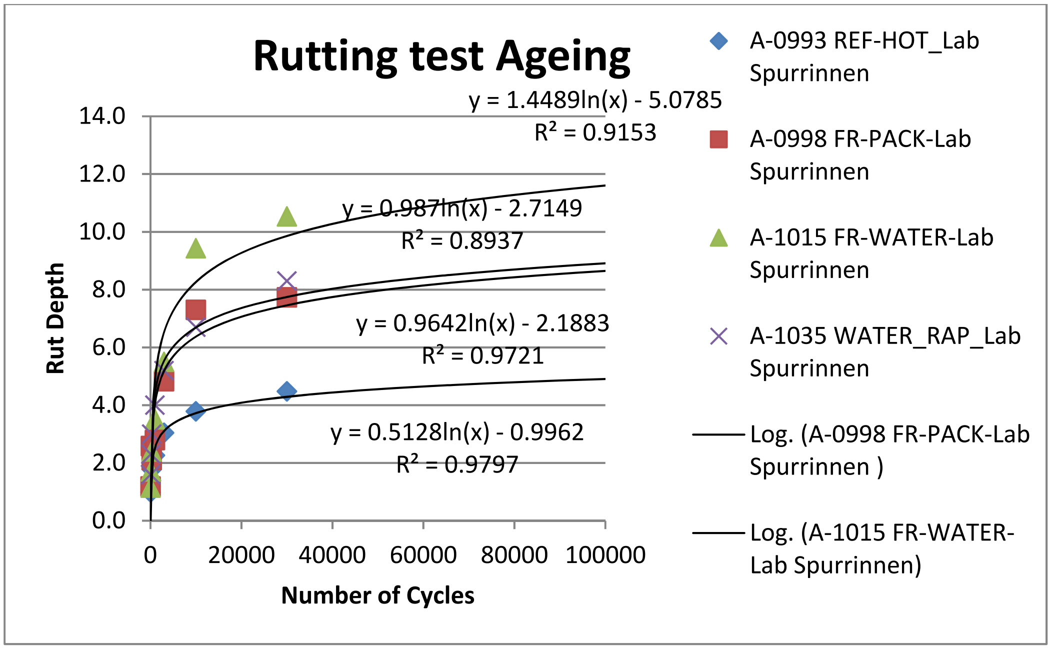

Figure 9. Rutting test results for the mixtures under ageing conditions.

8 THE PAVEMENT DESIGN LIFE

Pavement design is performed taking into account minimum load repetitions to produce structural damage in the pavement. The main reason for this structural failure in the pavement is both fatigue and rutting. Fatigue failure is stronger than rutting failure and it occurs at earlier stages so fatigue is usually consider being the failure that governs pavement design. Look Figure 6 and figure 7.

We can say that the total damage of a pavement can be written in the following form taking into account all the possible damages that a pavement can suffers [23]. D will be one in the fracture.

[1] $D = \sum_{n=1}^{n=n} \frac{n_i}{N_i}$

D_i is the cumulative damage and N_i is the minimum number of load repetitions to produce either fatigue (N_f) or rutting (N_r) failure in the pavement. But to quantify the damage in the pavement we have to take into account the different stress levels of every type of damage, because we must take into account the proportion of life time consumed in every type of damage because for instance fatigue has a bigger effect than other damages that can suffer the pavement especially in the beginning of the service time of the pavement. This means that this formula would not be right in the case of the pavement if we do not take into account this bigger stress level in the fatigue. The stress level can be taken into account in the following form:

[2] $D = \sum_{n=1}^{n=n} \frac{n_i \times s_i}{N_i \times S_i}$

Where s_i is stress, or the proportional stress, associated to every type of damage (fatigue, rutting,…). In the case of this research where only fatigue and rutting have been taken into account for the life time prediction the formula used for the calculation of the total damage is:

[3] $D = \frac{n_f \times s_f + n_r \times s_r}{N_T \times S_T} = \frac{n_f \times 2{,}3 + n_r \times 0{,}7}{N_T \times S_T}$

According to this formula the results of this research for the life time prediction of the bitumen under study are the following showed in figure 10. This study want to point up that the calculation of the damage in the pavement is accumulative but not all the factors (rutting, fatigue…) has the same contribution to the total damage and in fact the biggest contribution for the total damage comes from fatigue.

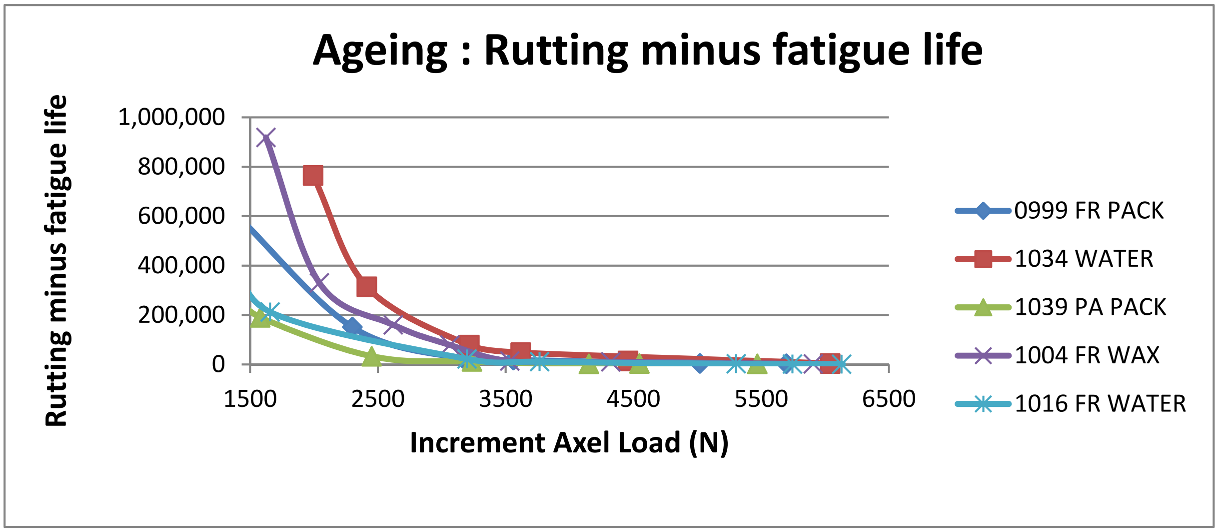

Figure. 10. Rutting minus fatigue life, Ageing.

It is remarkable the different results for fatigue and rutting were in the first case the modifiers affect positively the mixture but in rutting the use of modifiers, RAP is a big disadvantage to rutting. This can make think about the use of these bitumens in cold weather were rutting is especially critical.

Test results of the pavement life prediction according the accumulative damage of both fatigue and rutting for different low energy bitumen show better results in life time service for foam bitumen with RAP and bitumen modified with sasobit in a high percentage than when bitumen is modified with lower quantity of sasobit or modified with cecabase.

9 CONCLUSIONS

- Fatigue has the most important contribution for the total damage of the pavement although the total damage is an accumulative damage of all the possible damages in the pavement.
- The test results of the pavement life prediction according the accumulative damage of both fatigue and rutting indicate a longer life time service for foam bitumen with RAP inclusions and bitumen modified with sasobit in a high percentage than when bitumen is modified with a lower quantity of sasobit or modified with cecabase. These results are especially important taking into account the bad rutting resistance that shows the modified reference bitumen in this research. This indicates the benefits in fatigue that gives the modified bitumen with WMA and RAP.
- The test results indicate that most WMA improved thermal cracking resistance of asphalt with the exception of Sasobit and the zeolite additives. Sasobit tended to stiffen the binder in the laboratory. The modified bitumen with Sasobit reduced the ageing rate of the binder in the PAV as the waxy WMA additive behaved as an antioxidant. In general terms the tests showed that WMA technologies resulted in a softer binder except in the case of sasobit as modifier.
- In general terms we can say that rutting resistance of WMA mixtures is a concern because all results in this research show a significantly higher rutting for all the tested modified bitumen with sasobit and cecabase, and also for the foam bitumen and RAP bitumen inclusion compared to the HMA reference mixture. Rutting test shows that all the WMA produced at temperatures within 105°C and 120°C have higher rutting depth compared to reference HMA. It was found that PA-PACK, modified bitumen with Sasobit and Bithafin produced at 120 °C has the highest rutting.

- Rutting resistance is still better in the performance of HMA mixtures than in RAP mixtures. RAP content is a significant factor that affects alligator cracking while the incorporation of WMA additives impact on the rutting of the AC layer and it is statistically significant for the cecabase mixtures.
- With the obtained results with very bad obtained data for rutting in the modified bitumen in this study we can conclude that the suitability of the studied WMA technologies for use in pavements located in hot climate regions needs to be further investigated.

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