Active filler's effect on in-situ performances of foam bitumen recycled mixtures

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Abstract

Cold recycling is one of the most employed rehabilitation techniques for asphalt pavements and it is becoming more and more important as saving of emissions becomes a priority in the reduction of the greenhouse effect. The main advantages of asphalt cold recycling techniques are the use of reclaimed materials and the fact that there is not need of aggregate heating to make the mixtures. This paper describes the evolution with time of *in situ* performances of different foam bitumen stabilized mixtures made with different active fillers (cement and lime), monitored during the first year from construction. Results are part of a more extensive research program aimed to investigate the effects of using lime as active filler in cold recycled mixtures. Mixtures have been raid down on a specifically designed trial section in Italy, close to Florence. Short term bearing capacity, immediately after construction, has been evaluated by means of LWD (Lightweight tests) while in the mid-term performance FWD tests have been performed after 24 hours, 14 days, 28 days and 9 months from construction. During these 9 months tests road was not opened to traffic, so the mixtures experienced almost 0 traffic (only construction traffic loads). This fact allowed to have the curing process without any influences than the temperature: it means same curing conditions for all mixtures. Subsequent FWD tests are still ongoing to evaluate the evolution over time of pavement bearing capacity due to traffic. Results obtained positively support the use of lime as active filler in the foamed bitumen stabilized material and allow to underline the effect of different active filler in the material behaviour, even if all the mixtures underline excellent performances under traffic loading. FWD tests are scheduled to be repeated every 6 months in order to monitor the stiffness evolution of the mixtures and evaluate the nature of traffic damage.

Keywords: word; Foam bitumen, bearing capacity, FWD, active filler, lime, cement

Introduction

Asphalt mixtures are the most common materials employed in the road pavements around the world and as all the materials used in constructions they face to sustainability challenges. However, using asphalt mixtures road agency have the answers for the main questions that sustainability of constructions generally raises about materials ("How to re-use it?" "How to manage it after demolition?"): asphalt mixtures can be fully recycled in plant or in field using hot recycling techniques or cold recycling techniques (1).

Considering greenhouse emissions, impact on traffic and fuel consumption, from the environmental point of view the most efficient technique is the in-place full-depth reclamation using a cold recycling technique. One of the most popular is the bitumen stabilization with foam bitumen or bituminous emulsions: most probably, the reason is that bitumen stabilized mixtures can be made with RA (Reclaimed Asphalt) aggregates from the bound layers mixed with the aggregates from the unbounded layers of pavement. Together with several advantages, the in-situ bitumen stabilization also brings some challenges. Among the problematics mainly discussed by pavement engineers and researchers it is how to manage active fillers. Active fillers are used in the bitumen-stabilized mixtures mainly for the following reasons:

- to facilitate the dispersion of bitumen in the mixture: active filler's particles catch the droplets of bitumen made by the blasting of the bubbles of foam bitumen or made by the flocculation of the emulsion's bitumen and take them in the mixture;
- to have a quicker strengthening of the mixture and consequently to obtain quickly the necessary bearing capacity of the layer (for this purpose is mainly used cement);
- to maintain control of the moisture content;
- to treat fine plastic particles in the aggregates.

In addition to previous tasks, sometime in the full depth reclamation it is necessary to stabilize clay particles raised in the unbounded layer from the subgrade. For this purpose, it is necessary to use lime and it generally means to have a blend of fillers (2): lime for stabilization of clay, cement to have quickly the necessary bearing capacity and mineral filler originally present in the granular material of unbounded layer.

The problems related with active fillers may be synthetized in the following questions:

- Which is the most appropriate active filler?
- What is the correct amount of active filler?
- In case of a blend of active fillers, what is the correct ratio between the components?

In spite of the fact that practical experience and some research gives the examples that assist with practical answers to the previous questions, from a scientific perspective, there are still unanswered questions. In particular, the relationship between active filler and performance of bitumen-stabilized material is unclear. Limited literature is available regarding the effect on long-term performance of cold recycled mixtures incorporating different blends of active fillers.

In an effort to develop a better understanding of the stiffness evolution of bitumen-stabilized materials over time, related to active filler or blends of active fillers used, a comprehensive research project was set by University of Pisa, University of Stellenbosch, University of Parma and University of Nottingham. This paper shows the results of a part of the project focused on the investigation of in field mid-term performances of fully recycled mixtures produced with foam bitumen and different blend of fillers made by cement, lime and mineral filler.

Six mixtures made with 100% of RAP and different amounts of foam bitumen and different ratios of lime, cement and mineral were used to build six consecutive sections in an experimental road. The performances of the mixtures were investigated over the time using Light Weight Deflectometer initially and Falling Weight Deflectometer successively.

The results obtained when all the mixtures may be considered fully cured allow to make some preliminary considerations and some fundamental hypotheses on foam bitumen stabilized mixtures; these hypotheses are under verification in the ongoing phases of the project, in particularly they will be verified considering weather and traffic effects.

Objective and scope

The objective of this research work is to investigate the evolution of performance properties of cold recycled mixtures made using foam bitumen technique, containing different blend of fillers, made with cement, lime and mineral filler, over time. Even though the in situ recycling can be considered the most appropriate technique for full depth recycling, in this case, in order to minimize the variability and keep under control all the different components, the mixtures were produced with a mobile mixing plant using only sieved RAP and laid down with a paver.

The comparison between the performance of different mixtures was based on the elastic modulus evaluated on the basis of deflectometric tests at different times after construction. All the tests were carried out using the FWD except for tests immediately after compaction undertaken with the Light Weight Deflectometer.

Because it was not clear from the beginning the evolution over time of performances and what effect may have the traffic load on curing of different mixtures, the pavement was completed and road opened to traffic after 9 months when it was possible to consider all mixtures fully cured with curing process independent from traffic load. During the 9 months a specific surface treatment was used to keep under protection the layer made with BSM (Bitumen Stabilized Material) against weather demage. LWD and FWD tests were made after 4 and 24 hours to evaluate immediate performance and further FWD tests were made after 28 days when the setting reaction of cement may be considered completed and after 9 months, before last paving operations and traffic opening, to evaluate the midterm performances. A multiple series of FWD tests campaign are will be made in the future in order to have a mid stage and long term evaluation of pavement performances and effect of traffic. On the other hand, laboratory evaluation of fracture properties of recycled mixtures are still ongoing.

Materials and investigation method

Materials characterization

Trial section comprises six foam bitumen stabilized mixtures with two different active fillers: lime and cement. In specific six different blends of filler (cement, lime and mineral filler) were used to keep constant the global amount of filler. In addition, to avoid differences made by the interaction between mineral filler and bitumen, the same limestone filler wash used for all the mixtures. Two fractions of RA aggregates (one coarse and one fine) have been selected to form the stone skeleton of the mixes, which results made with 100% RA aggregates. The two fraction have been mixed in order to have the same grading composition for all the mixtures analyzed.

(Figure 1 near here)

Percentage of bitumen in the RA resulted significantly different for the two fraction. Values obtained (the ones reported in the table below is the average of tests on multiple specimens) by means of laboratory tests are reported in the subsequent table.

(Table 1 near here)

The two fraction of RA have been mixed in order to reach the subsequent final grading composition, optimized following the Italian common practice regarding cold recycling mixtures. Black refers to curve obtained before binder extraction while white refers to grading composition after binder extraction.

(Figure 2 near here)

Compaction properties of the mixture has been evaluated by means of Modified Proctor tests: the optimum moisture content of the RA resulted 3.3% (Figure 3).

The total amount of filler in the mixes, both active and mineral filler, binder and ratio's blends of fillers were selected on the base on the common practice in Italy. A standard grade bitumen (penetration 70-100 dmm) was used for the foaming process.

The characteristics of the mixtures analyzed within the present research activity are reported in the subsequent table.

(Table 2 near here)

The amount of water added to the mixtures during the production phase was established using a common field practical approach. To do that the subsequent parameters have been taken into account:

- Moisture content of the RA around 1%;
- Optimum moisture content of the RA resulted, as reported before, around 3.3%;
- Total amount of filler in the mixes of about 4.5%.

On the basis of the previous mentioned parameters, the amount of water to be added to the mixtures (OMC Optimum Moisture Content) for production purpose was found to be 6%.

Trial field characteristics

Trial section was located on a constructing road near Florence (Italy) (Figure 1). The test pavement included a 17 cm base course made with foam bitumen stabilized material (study mixtures) placed over a lime stabilized subgrade. Compaction was extended until reaching the reference level of 100% the Modified Proctor density using a combi-roller (front rubber and rear metallic drum). The pavement structure has been completed before be opened at traffic: now it has 4 cm of asphalt concrete wearing course laid directly over the recycled layer. The entire pavement structure is not following the normal standard requirements: was specifically designed with the only aim to reach the stress and strain distribution under load allowing researchers to clearly underline the different performances of tested mixtures.

(Figure 4 near here)

Since the bearing capacity of subgrade may influence the effectiveness of the compaction of foamed bitumen stabilized layers, an extensive LWD tests campaign was carried out on recycled mixtures foundation, selecting the test location in order to have a widespread coverage of the test area. This approach is followed to control bearing capacity and compaction level achieved on the unbound layer and underline the presence of weakness area (3). Tests location used to characterize the pavement subgrade matched exactly that used for the analysis of foam bitumen stabilized mixtures. Results obtained in terms of average Surface Modulus are presented in the next graph (Figure 5).

Short term performance of foam stabilized mixtures were investigated performing LWD tests after 4 hours and FWD after 24 hours curing. Results obtained underline the well performances of the mixtures, exceeding the threshold stiffness values provided by the Italian Road Authority ANAS specification (4).

Further FWD tests were carried out after 14 and 28 days, when the setting reactions of cement may considered completed, and after 9 months, before last paving operations and traffic opening, to evaluate the midterm performances. Measured deflections are usually used for backcalculation process. This process is a mechanistic evaluation of pavement surface deflection basins that matches measured with calculated surface deflection basins (within a tolerable errors) by varying the associated layer moduli. The backcalculation process is usually iterative and normally done with software. The Method of Equivalent Thickness (MET, Odemark's structural transformation method) suggested by Ullidtz (4) was used to backcalculate layers moduli and evaluate their evolution over time. It was not clear from the beginning the evolution over time of performances and what effect may have the traffic load on curing of different mixtures, so the pavement was completed and the road was open to traffic after 9 months when it was possible to consider all mixtures fully cured with curing process independent from traffic load.

Since backcalculation process is mainly dependent on the thickness of the tested pavement layers a fundamental assumption needed to be made regarding the pavement structure. As reported by different authors (6) (7) (8), special care should be taken when analyzing thin layers (less than 10 cm). Huang (6) reports that "two agencies using the same computer program derived very different backcalculated results for the same pavement cross section. This is especially true for thin layers because the deflection basin is insensitive to their moduli and good match between computed and measured deflection can be obtained even if totally unreasonable moduli are derived for these thin layers". For this reasons, as suggested by the same author, engineering judgments should be used when analyzing deflection of pavement with thin layers.

Due to the limited AC thickness, in order to perform a reliable backcalculation analysis, the trial filed pavement was modeled as a two layers system: layer one combines the 4 cm wearing course with the recycled layer while layer two represented the subgrade half space. By combining together wearing course and recycled mixes in one single layer in the model, its layer modulus backcalculated from the analysis becomes a composite value with the contribution of both layers. However, the wearing course thickness is constant along all the test section; hence, the change in performance underlined by the different sections can only be attributed to the change in the stiffness of the recycled materials.

Materials temperature sensitivity analysis

During field tests variable pavement temperatures were experienced. In order to take account of changes in material's response under different climate conditions, future tests will be undertaken in different seasons thus in different temperature condition of the pavement. This involves the need to develop a procedure to correct moduli at test temperature to the 20°C reference value.

Previous research on cement treated mixtures with high content of RA aggregates underline a variation of layer moduli from tests carried out in different seasons (winter and summer), revealing a sort of temperature sensitivity due to only presence of RA (9). Regarding bitumen stabilized materials, Plati et. al (10) present a specific equation, based on laboratory results, to correct layer moduli to 20°C reference temperature. More recently the effect of temperature on Resilient Modulus of foam bitumen stabilized mixtures with different amount of RA aggregates have been investigated: results obtained underline that high percentage of RA aggregates could led to early fatigue in the pavement as well as permanent deformation (11).

Within the present research activity an innovative procedure to evaluate temperature variation of foam bitumen stabilized layer moduli is presented, basing assessment on FWD tests. The basic idea is to perform FWD tests in the same day (same curing level), on the same test location with significant difference in the pavement temperatures.

Measured deflection, recorded for each mixtures, have been back-calculated to estimate layer moduli and estimate their variation due to only temperature. Resulting moduli at different temperature were then used to calibrate a specific value for temperature sensitivity parameter “α” for each mixtures, provided by the generalized version of the equation for temperature correction provided by the Asphalt Institute (1) (12).

$$E_{Ts} = 10^{\alpha \cdot (T^2 - T_S^2)} \times E \qquad (1)$$

where E_{Ts} is the layer modulus at the reference temperature, E is the modulus at test temperature, T (°F) is the test temperature, T_S (°F) is the reference temperature and α is a temperature sensitivity parameter. Asphalt Institute suggest a value of $1.47362 \cdot 10^{-4}$ for α to be used for correction of new road asphalt mixtures layer moduli (12).

This kind of procedure was applied to all the mixtures in order to find six different values of α to be used for correction of foam bitumen layer moduli, evaluated during the previous mentioned four step of curing (24 hours, 14, 28 days and 9 months), at the 20°C reference temperature. To correct moduli evaluated on the complete pavement (after last paving operation) a single average value were used, taking into account both influence of the recycled layer and asphalt wearing course. Results obtained are reported in the next graph where the trend of temperature variation of recycled layer moduli is compared to the ones obtained using equation provided by Plati et al. (10), Asphalt Institute equation for new asphalt mixtures (Equation 1) (12) and equation provided by the HD 29/08 Standard for new constructed asphalt pavement (13).

(Figure 6 near here)

Results underline the significantly lower temperature sensitivity of the foam bitumen stabilized mixtures analyzed in this research work compared to variation typical of asphalt mixtures. Moreover trend seems to be comparable with the one provided by Plati at al. allowing to confirm the reduced temperature sensitivity of this kind of mixtures.

This behavior may have an important implication in pavement design; in warm climate areas, like the one experienced in Italy, stiffness variation over the year due to air temperature variation from cold to hot seasons can be considered quite low. On the basis of these results, regarding the temperature sensitivity, foam bitumen stabilized materials seems to performs more likely a “super-performing granular material” (14) than an asphalt concrete.

The resulting average moduli for each period of testing (E_{1t} at the test temperature) are presented in the next table together with average moduli at the 20°C reference temperature (E_{1ts}). The layer temperatures, measured through a thermometer placed on a drilled hole inside the pavement, are also reported.

The approach proposed involves some approximation and is probably the reasons of some scatter in the results obtained but is needed in order to have performances directly comparable.

Results and discussion

Back-calculated layer moduli of test carried out before wearing course laying operation (9 months from construction) are reported in the next graph comparing values obtained on each mixtures for the four series of tests carried out at different curing time. Results are organized to show both values obtained on each test location (8 tests location per mixture) and average values for the four curing level. LWD tests results on the subgrade are also presented in order to underline its influence on recycled mixtures performances.

Deflectometric tests after compaction (LWD tests after 4 hours from compaction) are required by the Italian prescriptions to evaluate soundness of construction work in terms of compaction achieved. For instance, the Italian Road Authority ANAS require to have Surface Modulus provided by LWD tests greater than 45 MPa after 4 hours from compaction (4). Since mixtures compaction may influence the stiffness growth of mixtures containing cementitious binder (15), LWD average modulus obtained after 4 hours from compaction are also presented.

All the tests have been carried before opening to traffic, during the first nine months from construction. For this reason all the mixes can be considered completely cured in the same manner, without any influence of traffic load on the curing process and without traffic post compaction effect. This avoid the introduction of additional variables related to the traffic influence on the curing process and the possibility to have different behaviors with different active filler and different strengthening process. Moduli reported in the next graphs are all corrected to 20°C reference temperature, applying the procedure previously reported.

(Figure 7 near here)

(Figure 8 near here)

(Figure 9 near here)

(Figure 10 near here)

(Figure 11 near here)

(Figure 12 near here)

After 9 months of curing, without traffic effect, performance of the mixes appear to be almost the same except for mixture 5F who shows the lowest value of layer moduli. This is probably due to the effect of subgrade weakness (Figure 5) to compaction effectiveness, as also confirmed by the lowest value of surface modulus (LWD test) after 4 hours from construction.

To compare the performance evolution over time of all the mixtures analyzed and evaluate the influence of the different blends of active fillers, the layer moduli at different curing time are plotted together in the subsequent graph.

Results presented below show that mixtures stiffness increase rapidly in the first 14 days of curing, except for mixture 5C, and remain almost stable in the next period. Moreover, the increase of stiffness appears to be lower for mixtures with a high content of cement (2.5%) than the others. Presence of lime seems to reduce the rate of stiffness increase when blended with a high content of cement (mixture 5C) while without cement the mixtures stiffness increase very quickly in the first period (Mix 5E, Mix 3A and Mix 5F). Mixtures with a high content of cement (2.5%, Mix 5D and Mix 5C) have the higher stiffness at the end of curing (9 month) even if the rate of stiffness growing seems to be lower: this is especially true for Mix 5C and is probably due to the presence of lime. These results led to consider the behavior of mixtures with 2.5% of cement more likely a continuously bound material able to increase stiffness over time as an only effect of curing. On the other hand, mixtures with low content of cement appear to behave like an non-continuously bound materials capable of increase stiffness rapidly in the very short term period (14 days) and remain almost constant after that.

To further analyze the influence on mixtures behavior of using lime with/instead of cement, a comparison have been made between the subsequent mixtures:

3B (2% foam bitumen FB, 1% cement C, 0% lime L, 3.5% mineral filler MF)

3A (2% foam bitumen FB, 1% cement C, 2% lime L, 1.5% mineral filler MF)

and

5D (3% foam bitumen FB, 2.5% cement C, 0% lime L, 2% mineral filler MF)

5E (3% foam bitumen FB, 0% cement C, 2% lime L, 2.5% mineral filler MF)

(Figure 13 near here)

(Figure 14 near here)

The comparison underline that both couple of mixtures have almost the same trend of stiffness evolution and the ultimate bearing capacity is of the same order of magnitude. This confirm that, at the end of 9 months of curing, the use of lime in combination with cement (mixtures 3B-3A) or as a substitution of cement (mixtures 5D-5E) led to comparable results in terms of layer moduli.

From a general point of view, the order of magnitude of layer moduli appear to reasonable, according the common practice experience for road type as the one we used in this case to place the trial field. For instance, assuming 20 years as the service life horizon, the allowable commercial traffic magnitude reach 3 million passages. This value, according to the Italian experience on roads of the same importance, appear to be reasonable.

All these comments regarding performance that was evaluated after only 9 months from construction (without traffic). To verify these assumptions the trail section will be monitored in the future in order to evaluate the mid stage and long term performances of the mixtures. Special regard will be devoted to the effect of traffic and the consequent failure of the material in terms of fatigue cracking (reduction of stiffness for a continuously bound material) or in terms of permanent deformation (stiffness increase over time for a unbounded or un-continuously bonded material) (9).

Summary and conclusions

In the present study, a comparison between foam recycled mixtures with cement and lime and different amount of active fillers has been analysed. Results are based on FWD tests carried out on a specifically designed trial section monitored within the first year. Even if the investigated technique is appropriate for full depth recycling, to minimize the variability and to keep under control all the different components to have as much as possible homogeneous mixtures, all the mixtures were produced with a mobile mixing plant using only sieved RA aggregates and laid down with a paver.

It was not clear from the beginning the evolution over time of performances and what effect may have the traffic load on curing of different mixtures, so the pavement was completed and the road was open to traffic after 9 months when it was possible to consider all mixtures fully cured with curing process independent from traffic load. During the 9 months, the layer made with BSM was protected by weather effects with a specific surface treatment. LWD and FWD tests were made after 4 and 24 hours to evaluate immediate performances and further FWD tests were made after 14 and 28 days when the setting reaction of cement may considered completed and after 9 months, before last paving operations and traffic opening, to evaluate the midterm performances.

To compare moduli obtained in different temperature conditions an innovative procedure, based on FWD tests was followed allowing authors to correct moduli at the 20°C reference temperature. Results obtained underline the lower temperature sensitivity of the foam bitumen stabilized mixtures compared to what is typically expected for asphalt mixtures; the moduli variation with temperature result however comparable with that provided by other authors and specifically devoted to foam recycled mixtures. From a practical point of view, these results allow consideration of the stiffness variation over the year due to air temperature variation from cold to hot seasons quite low. Regarding the temperature sensitivity, foam bitumen stabilized materials seems to performs more likely a “super-performing granular material” (9) than an asphalt concrete.

After 9 month curing, without traffic effect, no significant differences in mixtures performances can be recognized, except for mixture having a weaker subgrade (Mix 5F). The rate of stiffness growth seems to be quicker in the first period (14 days) remaining stable after that. This is especially true for mixtures with no or low content (1%) of cement. Percentage stiffness growth of mixtures with high content of cement (2,5%) is lower than other mixes even if, after 9 months of curing, the absolute moduli are higher than mixtures with low or no content of cement. Furthermore, the presence of lime in those mixtures (Mix 5C) seems to further reduce the rate of stiffness growth. These results led to conclusion that the behavior of mixtures with 2.5% of cement is more likely to be that of a “continuously bound” material, able to increase stiffness over time as the primary effect of curing. On the other hand, mixtures with low content of cement appear to behave like a non-continuously bound material capable of increase stiffness rapidly in the very short-term period (14 days) and remain almost constant after that. Moreover, the comparison between mixtures 3B-3A and 5D-5E underline that both couple of mixtures have almost the same trend of stiffness evolution and the ultimate bearing capacity is still comparable. This confirm that, at the end of 9 months of curing, the use of lime in combination with cement (mixtures 3B-3A) or as substitution of cement (mixtures 5D-5E) can led to equivalent results in terms of layer moduli.

For all of the analyses, differences in the rate of cement gain between cement and lime active fillers, should be considered in conjunction to the curing (moisture reduction) of the bitumen stabilized material. Moreover, the order of magnitude of layer moduli, from a general point of view, appear to reasonable. For instance, assuming 20 years as the service life horizon, the allowable commercial traffic magnitude reach 3 million passages.

Results obtained at this stage of the research allow to confirm that the use of lime instead of cement led to equivalent results in term mixtures bearing capacity. Moreover, layer moduli seems not to be negative affected by the use of a cement/lime active fillers blend. This led to conclude that, from a practical point of view, lime can be used instead of cement when excess water content in the mixtures need to be reduced (in plant recycling) or in combination with cement when presence of clay particles require stabilization (in situ recycling).

To verify these assumptions and evaluate the possible reduction of brittleness due to presence of lime, the trail section will be monitored in the future in order to evaluate the long-term performances of the mixtures. Especially regard will be devoted to the effect of traffic and the consequent type of damage in the material.

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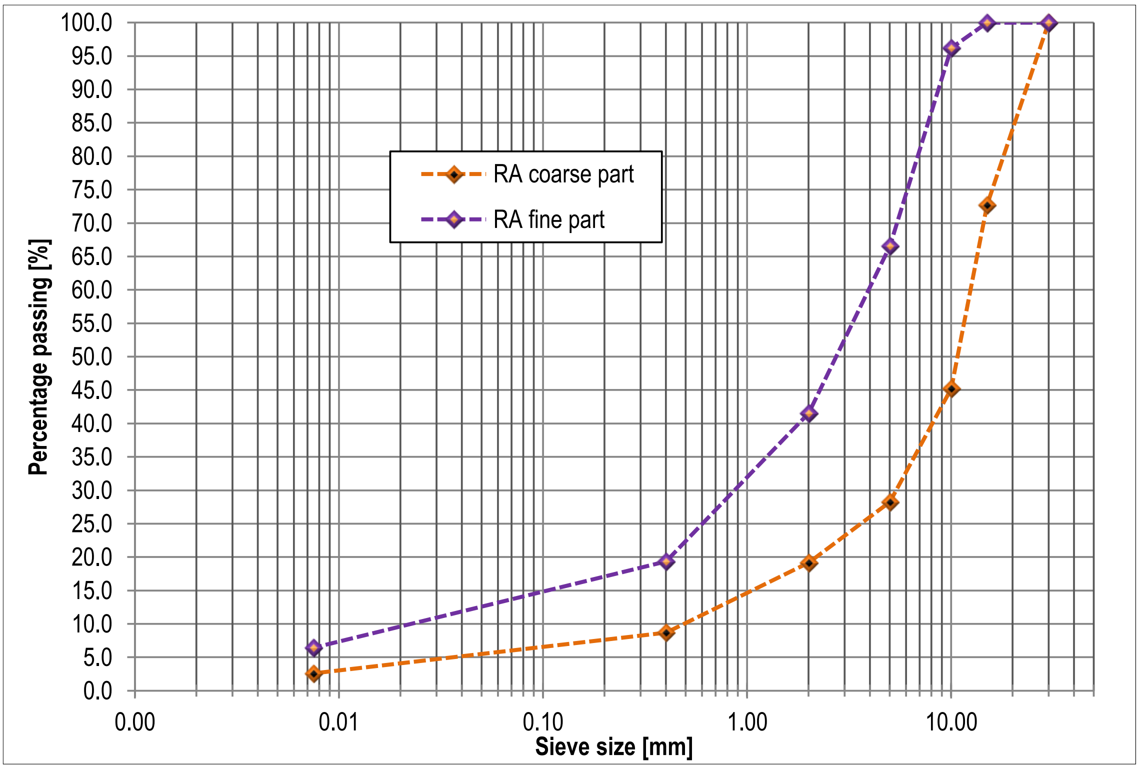

Figure 1. RA grading composition of RA fraction used to produce the recycled mixtures.

Table 1. RA percentage of bitumen for coarse and fine part.

Specimen	Average percentage of bitumen (on the dry weight of the aggregate)
RA coarse aggregates	4.4%
RA fine aggregates	7.1%

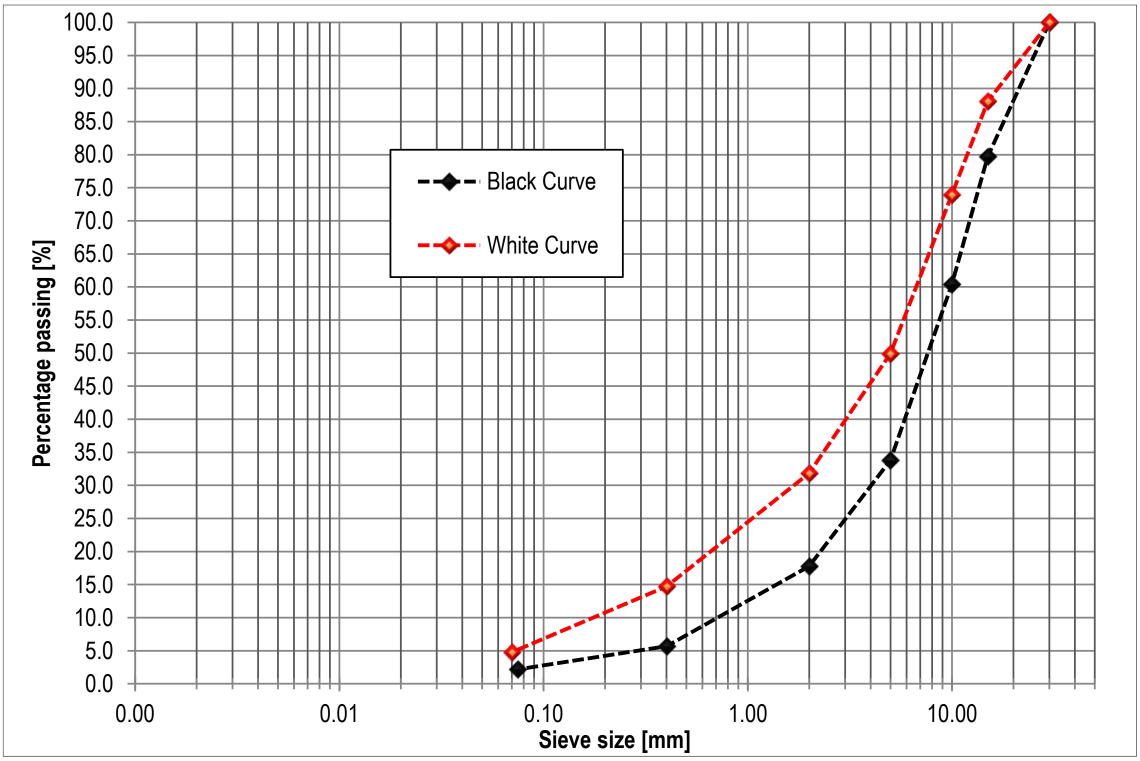

Figure 2. RA mixture sieve size distribution before (black) and after the extraction (white) of the binder.

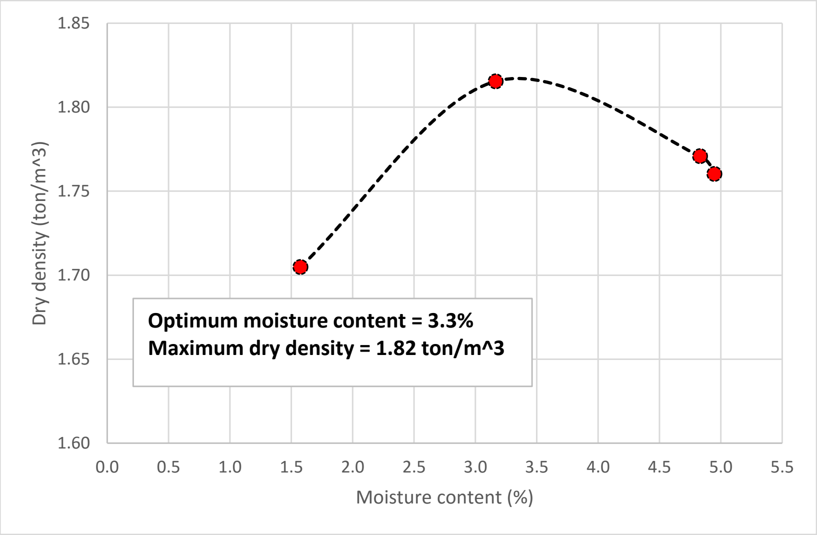

Figure 3. RA optimum moisture content evaluation.

Table 2. Recycled mixtures composition.

Mix ID	**% foam bitumen**	**% cement**	**% lime**	**% mineral filler**
3A	2	1.0	2.0	1.5
3B	2	1.0	0.0	3.5
5C	3	2.5	2.0	0.0
5D	3	2.5	0.0	2.0
5E	3	0.0	2.0	2.5
5F	3	0.0	3.0	1.5

Figure 4. Trial section location and organization of the different mixtures analysed.

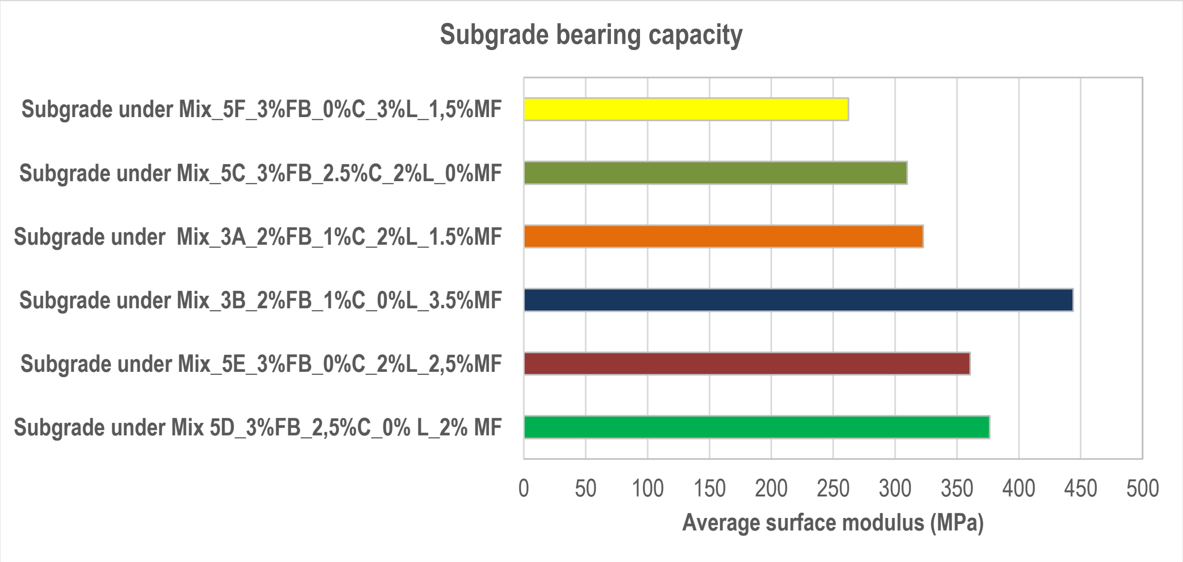

Figure 5. Average surface modulus of the subgrade.

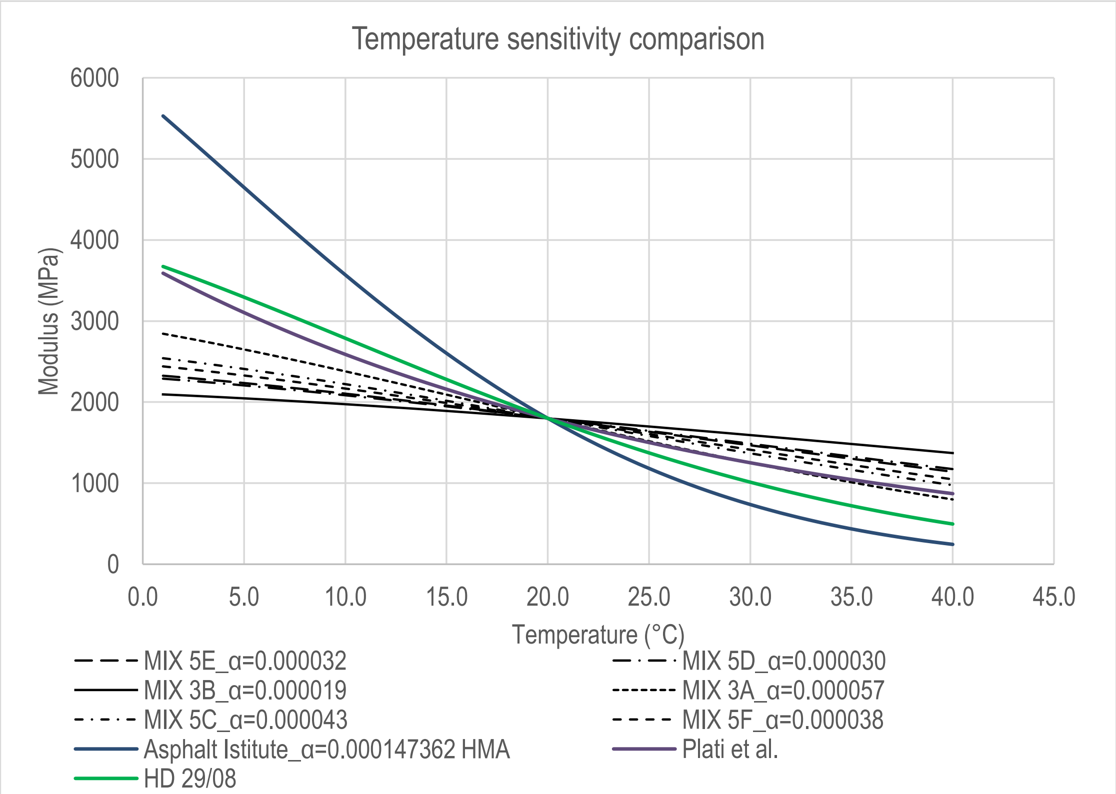

Figure 6. Temperature sensitivity of foam bitumen stabilized mixtures.

Table 2. Temperature variation of foam bitumen layer moduli.

Curing time	**Mix 5D_3%FB_2,5%C_0% L_2% MF**					**Mix_5E_3%FB_0%C_2%L_2,5%MF**				
	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)
24 hours curing	842	24.9	1.09	0.000030	919	573	25.3	1.11	0.000032	634
14 days curing	1322	27.8	1.16	0.000030	1531	1588	27.6	1.16	0.000032	1846
28 days curing	1487	17.3	0.96	0.000030	1423	1690	17.5	0.96	0.000032	1619
9 months curing	1421	30.0	1.21	0.000030	1722	1291	30.6	1.24	0.000032	1608
Curing time	**Mix_3B_2%FB_1%C_0%L_3.5%MF**					**Mix_3A_2%FB_1%C_2%L_1.5%MF**				
	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)
24 hours curing	1057	25.5	1.06	0.000019	1126	834	26.2	1.24	0.000057	1035
14 days curing	1600	27.3	1.09	0.000019	1743	1431	26.5	1.26	0.000057	1799
28 days curing	1812	17.8	0.98	0.000019	1770	1842	18.3	0.95	0.000057	1746
9 months curing	1508	27.8	1.10	0.000019	1654	1185	28.7	1.36	0.000057	1615
Curing time	**Mix_5C_3%FB_2.55C_2%L_0% MF**					**Mix_5F_3%FB_0%C_3%L_1,5%MF**				
	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)	E_{1t} (MPa)	T(°C)	E_{1t}/E_{1ts}	α	E_{1ts} (MPa) (@20°C)
24 hours curing	898	26.3	1.18	0.000043	1061	581	26.4	1.16	0.000038	674
14 days curing	980	26.4	1.18	0.000043	1159	1171	26.2	1.16	0.000038	1353
28 days curing	1318	18.4	0.96	0.000043	1269	1314	18.5	0.97	0.000038	1274
9 months curing	1376	29.6	1.30	0.000043	1789	957	31.1	1.31	0.000038	1258

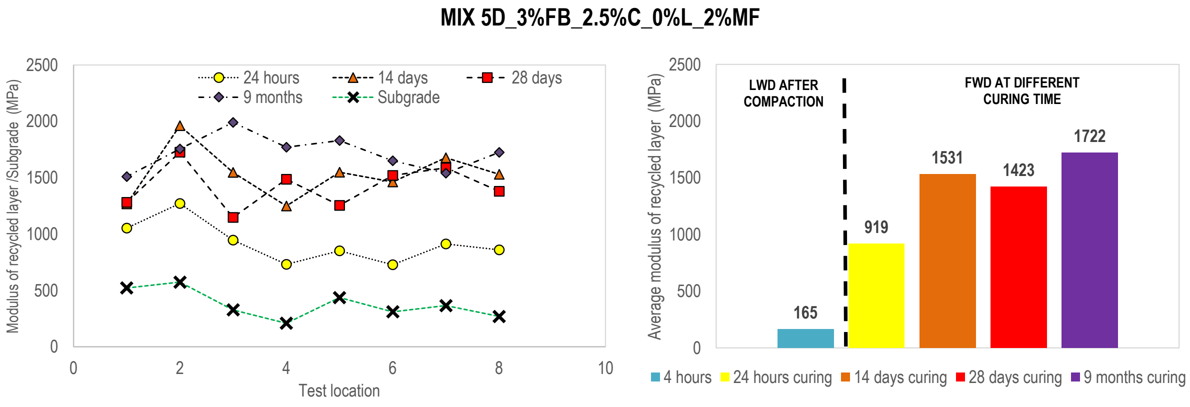

Figure 7. Performance over time: Mixture 5D.

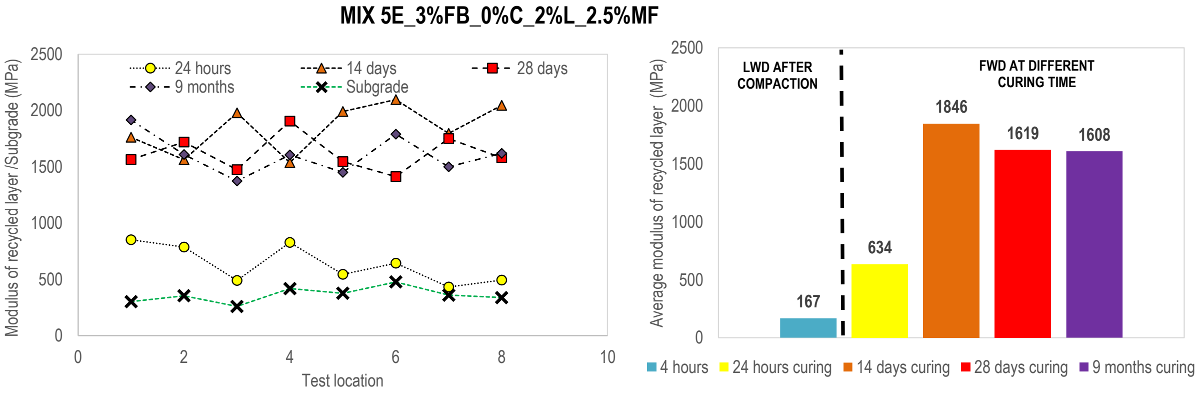

Figure 8. Performance over time: Mixture 5E.

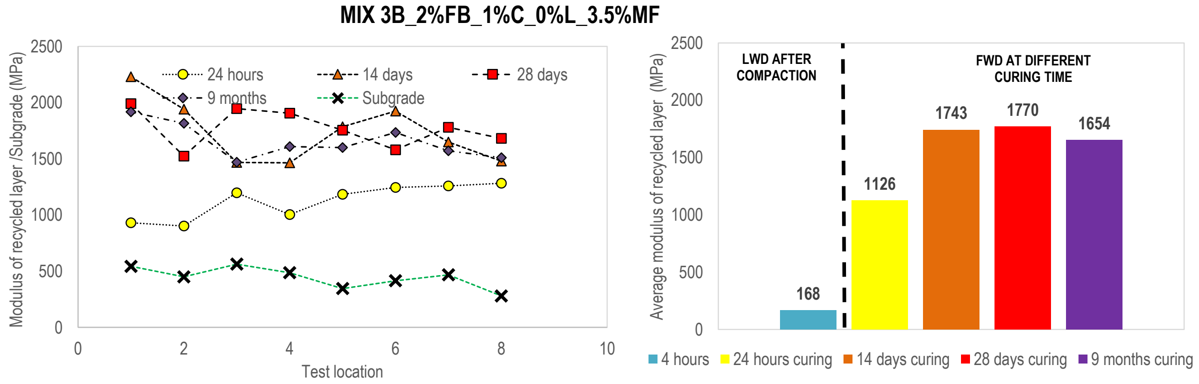

Figure 9. Performance over time: Mixture 3B.

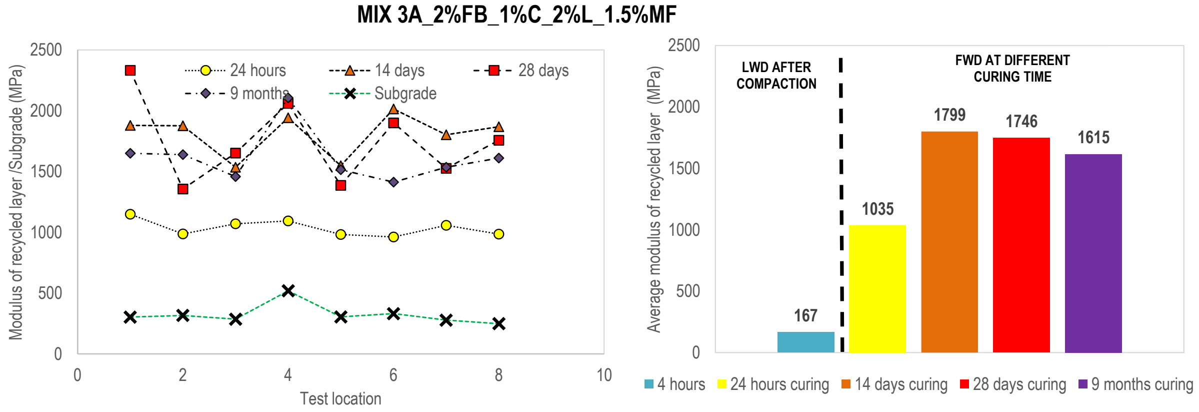

Figure 10. Performance over time: Mixture 3A.

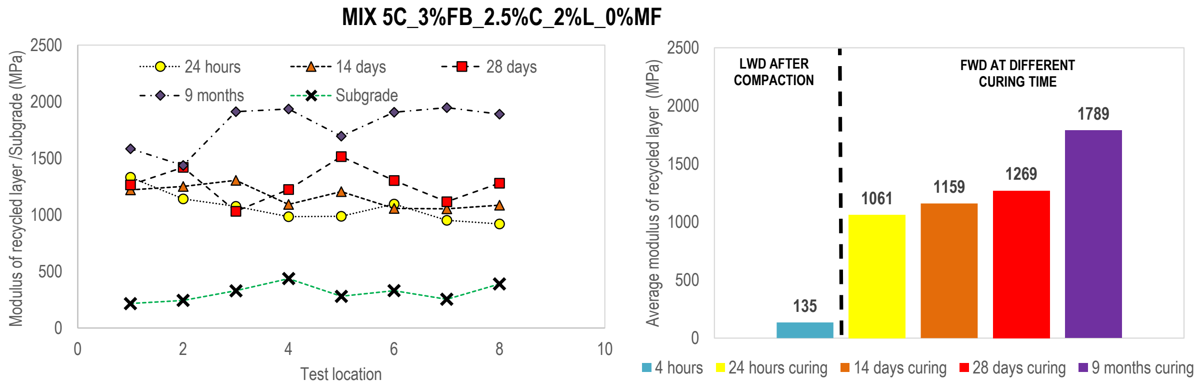

Figure 11. Performance over time: Mixture 5C.

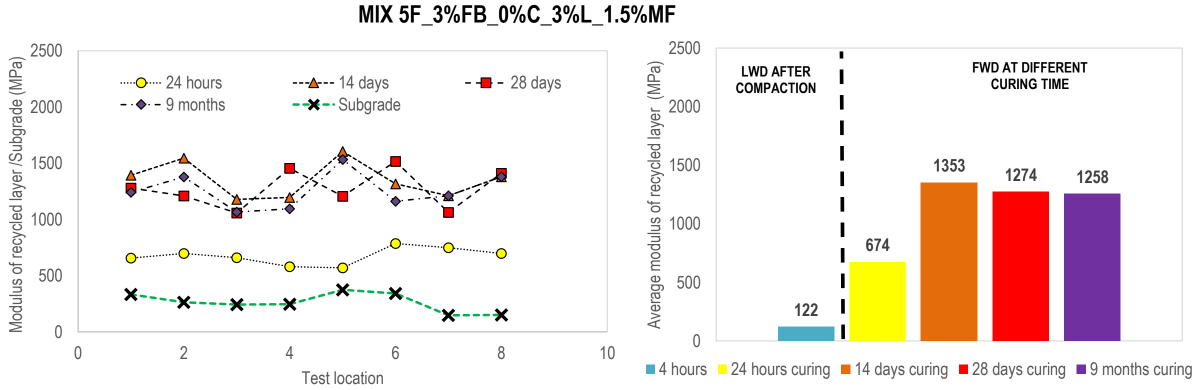

Figure 12. Performance over time: Mixture 5F.

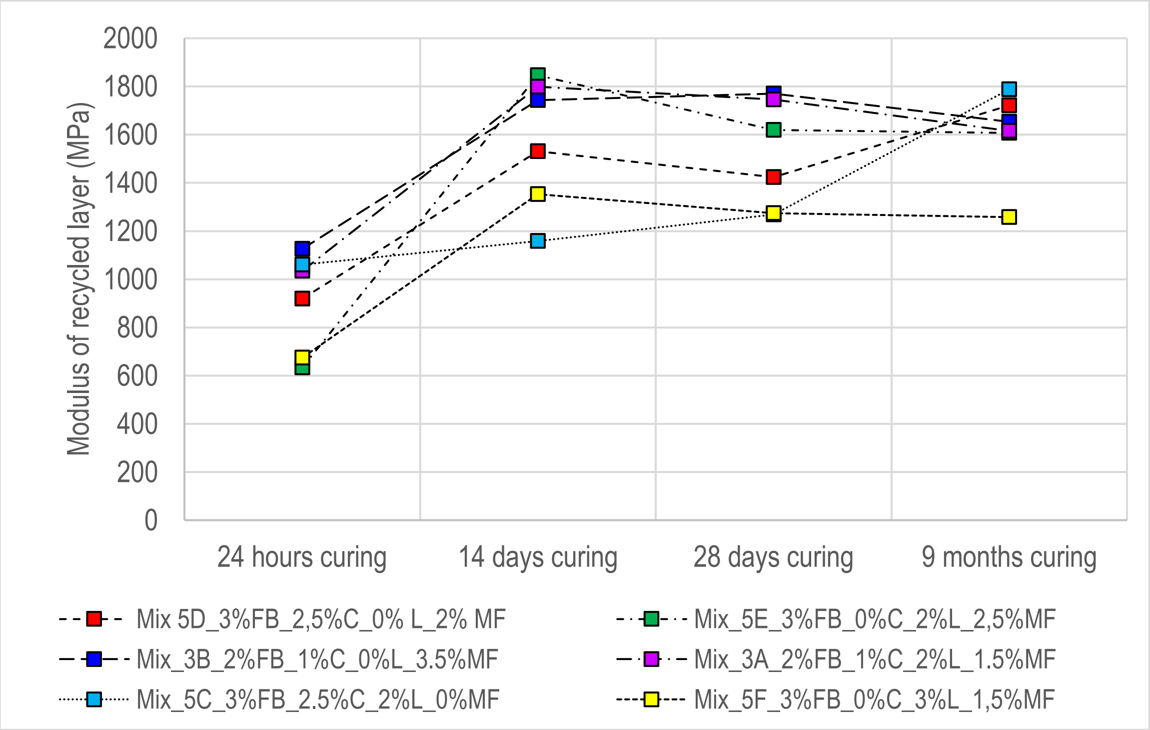

Figure 13. Comparison of mixtures performance over time.

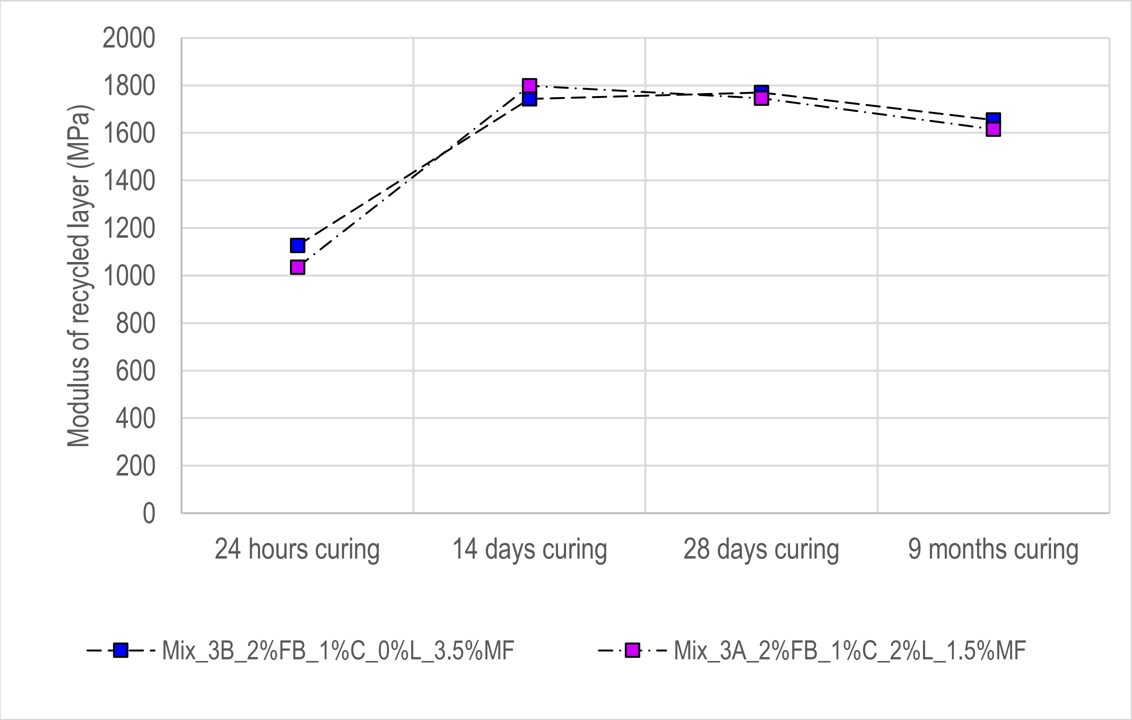

Figure 14. Comparison between mixtures 3B and 3A performance over time.

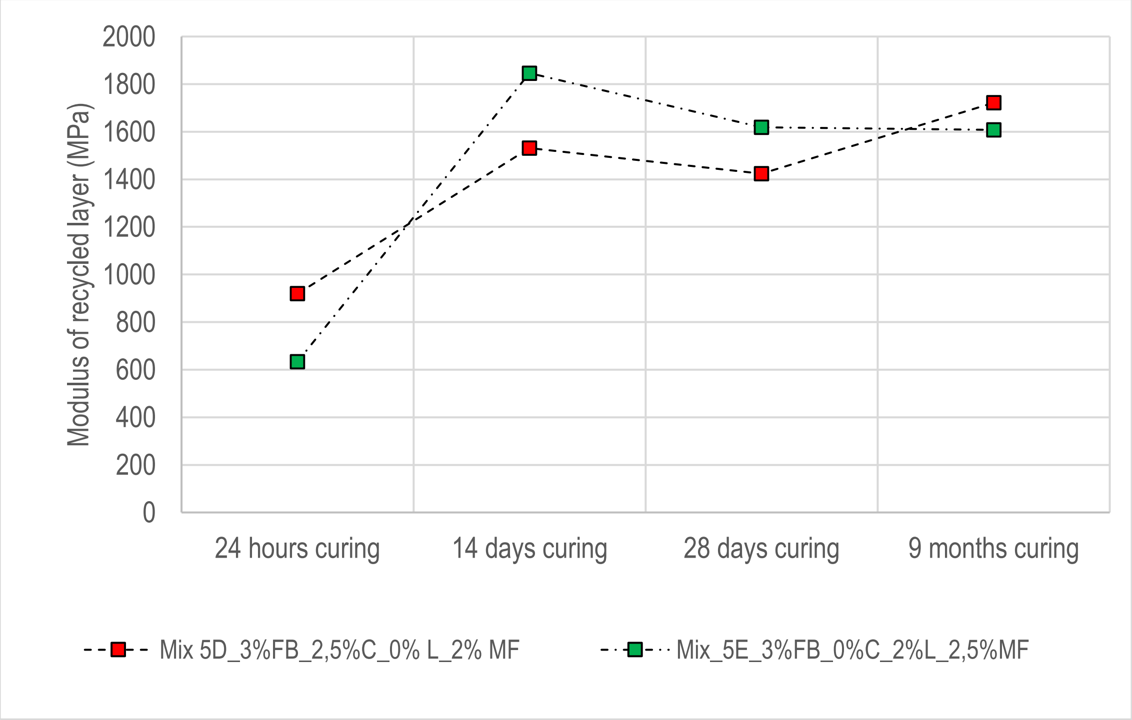

Figure 15. Comparison between mixtures 5D and 5E performance over time.