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Effect of Various Additives on the Low Temperature Performance of Petroleum Based Asphalt Binders

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Abstract: Transverse cracking is a prevalent problem that occurs in asphalt pavement binders in cold climates and diminishes the integrity of the road as well as shortens the life span of the road leading to premature failure. Current specification for testing petroleum asphalt binders for transverse and low temperature cracking is not elaborate enough to accurately model the engineering behaviour of the binders. Besides, neat asphalt derived from petroleum crude oil does not seem to perform well at certain low temperatures without some modification to it. Thus, a study was to be undertaken to determine the low temperature behaviour of 60-70 penetration neat binder modified with traditionally used materials such as Crushed Lime Stone Powder (CLP), Hydrated Lime (HL) and Cellulose Oil Palm Fiber (COPF) at temperatures 0 °C, -5 °C and -10 °C. The study was carried using the state of the art Bending Beam Rheometer (BBR) to assess the stiffness value, m-value and deflection level. The tests were performed in accordance with AASHTO T 313-12 specification. The results of the penetration, rotational viscosity and softening point showed that all of the modified binder specimens are within the required range. However, the performance assessments on the modified petroleum binders with additive materials showed a varied nature with CL powder being the best and the COPF the lowest. It was also observed that the crushed lime stone powder had an increase in stiffness, reduction in deflection and m-value.

Key words: Asphalt binder, additives, BBR, stiffness, m-value, deflection.

1. Introduction

The most prevalent distress found in asphalt pavements built in cold weather climates is low temperature crack. When the temperature drops the restrained pavement tries to shrink. The tensile stresses are elevated to an unsustainable point at where cracks occur. Based on laboratory test and finite element simulation, it was concluded that thermal crack could be avoided by using softer binders and higher binder contents [1, 2]. In Malaysia and other developing countries, asphalt is used on more than 94% of road surfaces. In many countries only asphalt roads are in service and there are no rigid pavements at all [3].

On the average, 6% of asphalt is used for the construction of flexible pavement in the world's highways. It was to determine the feasibility of utilizing the local Malaysian industrial and by-products wastes such as steel slag, ceramic waste, coal fly ash, limestone, and rejected ceramic raw material as mineral fillers [4]. Research by others showed how strength of additives named Chained Interlocked Plastic Beads (CIPB) can positively reduce fatigue and rutting in Stone Mastic Asphalt (SMA) mixtures [5].

There are many approaches to define and evaluate the fatigue strength of asphalt mixtures such as the traditional method, by using stress or strain against number of cycles (S-N plot), the dissipated energy approach, and visco-elastic continuum damage method. However, there is not a clear or specific standard that states which one is the best method to compare the performance between various bituminous mixtures, although a good attempt was made using a Crack Meander (CM) technique developed by [6].

A series of investigations are carried out by distinct researchers around the world in a bid to figure out the problem and put out solution that would eliminate or reduce it to the bearable minimal of such cracking, which automatically increases the pavement's life. It

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looks like no one yet came out with a full system of approach that enables the engineers to design a pavement that is low temperature crack-free. However, several researches have provided comprehensive approach background to the problem.

The introduction of the recent known Superpave specification tried to analyze this issue by introducing a limit for low temperature to be used with asphalt binders. However, extensive research that was carried out in related areas of study has made it known that testing of binder alone is not sufficient enough to predict accurately the low temperature cracking performance in the field. Testing of asphalt mixtures with different additives is necessary to obtain a reliable performance prediction. In order to increase the life of bituminous pavement, the quality of bitumen needs to be enhanced and modified [7]. There are numerous factors that can affect asphalt low temperature cracking, which consist environmental-related factors materials and structure. Out of the material factors, the characteristics or physical properties of the bitumen binders are very important [6, 8-11].

As part of the research effort in the Civil Engineering Department of Universiti Putra Malaysia, a study was carried out on how an additive affects the performance of asphalt binder at low temperature. The objective(s) of this study is to identify the physical properties of asphalt binder before and after modification with different additives in terms of binder stiffness, m-value and deformations.

2. Materials and Method

The selected 60-70 penetration asphalt binder was modified with four different fine materials namely Crushed Lime Powder (CLP), Hydrated Lime (HL), and Cellulose Oil Palm Fiber (COPF). CLP and HL were used in the form of 75 micron sizes while the COPF size was between 75 and 100 micron. The percentages were selected based on their densities and the optimum usage and performance in the asphalt mixtures. The 60-70 neat asphalt binder and the additive modified binders were tested for their penetration and softening point temperature values in compliance with the local authority specifications.

Each of the modifiers was blended with the neat asphalt binder at three different proportions of 1%, 2%, and 3% to be tested at 3 different low temperatures of 0 °C, -5 °C and -10 °C. A total of 81 specimens were prepared a test matrix of 3 modifiers × 3 proportions × 3 temperatures × 3 replicas. The control samples without any modifiers were also tested for comparison purpose. Table 1 below shows the summary of the binder and the additives used in the study.

2.1 Asphalt Binder-Additive Blending

The various proportions of the additives were selected based on the suitability and workability of the mixture. An in-house procedure was in the blending of CLP, HL and COPF in the 60-70 penetration neat binder. The asphalt binder was heated to a temperature of 165 °C and the various additives were blended with specific percentages using a motorized stirrer. The temperature was maintained at 165 °C with 1,000 Rounds per Minutes (RPM) for 30 minutes each. A total of 9 test matrixes were created with 3 additives and 3 percentages of them.

2.2 Laboratory Testing Program

The additive modified asphalt specimens are moulded into miniature beams measuring 0.246 × 0.492 × 5.000 inches (6.25 × 12.5 × 127 mm) in accordance with the superpave procedure and ASTM

Table 1 Summary of the materials used in the study.

No.	Additives	Proportions	Binder
1	Crush lime powder (CLP)	(1%, 2%, 3%)	60-70
2	Hydrated lime (HL)	(1%, 2%, 3%)	60-70
3	Loose fiber (F)	(0.1%, 0.2%, 0.3%)	60-70

D6648. The prepared samples are as shown in Fig. 1. This Bending Beam Rheometer (BBR) was set up for the test. The asphalt sample was then placed and simply supported at two points 4.02 inches (102 mm) apart in a controlled temperature fluid bath. The beam was loaded at the midpoint with a 0.22 lb (100 g) load under normal gravity conditions. This produced a force of 0.22 lb (0.98 N). The asphalt beam deflections were measured at 8, 15, 30, 60, 120 and 240 seconds as per ASTM D6648. The beam stiffness, often called "creep stiffness", was calculated based on these time durations. A stiffness master curve was then fitted to these points. Two (2) sets of asphalt beams for each matrix were tested. Fig. 1 shows the BBR equipment set up and Fig. 2 shows the BBR asphalt binder beam sample.

2.3 Data Analysis

The preparation stage of the analysis involves a devising a good form in which to produce the data so that it could be readily analyzed and provide a fair summary of the study. The data are presented in the form of the graphs and charts for easy reference.

2.4 Data Collection and Laboratory Testing

Data from one hundred and eleven (111) specimens were collected from binder tests, and 30 were to be determined the physical properties of the neat binder and modified binders with the selected materials while 81 samples tested determine the performance of binder using different additives at low temperature with respect to the proportions used. Table 2 below shows detailed information of the type of tests, numbers of additives and samples prepared for each test proportion.

Fig. 1 BBR equipment setup.

Fig. 2 BBR beam on the supports.

Table 2 Asphalt-additive blending matrix.

Tests	No. of specimens	% of additives	No. of additive
Penetration	10 samples	0%, 1%, 2%, 3%	3
Viscosity	10 samples	0%, 1%, 2%, 3%	3
Softening point	10 samples	0.0%, 0.1%, 0.2%, 0.3%	3
BBR	81 specimens	1%, 2%, 3%	4

3. Results and Discussion

3.1 Physical Properties Modified Binders

The values of the penetration test ranged between 45 mm and 69.67 for the tested asphalt binders and the asphalt binder without any additives was observed to have the highest penetration. The Hydrated Lime modified asphalt binder at three percent (HL 3%) had the lowest penetration. The specimen without additives fulfilled the Public Works Department's (JKR) requirement that requires a penetration range of 60-70. The other additive modified asphalt binders lowered the penetration values considerably. Table 3 shows penetration test of the 60-70 modified asphalt binders.

The rotational viscosity asphalt binder without any additives carried out at 135 °C had values ranging from 2,431.0 cP to 781.9 cP which is the highest among the rest of the modified binders. However, the viscosities of CLP at various percentages at 135 °C did not show any significant difference while at 165 °C there seems to be slight variations. The HL modified binder showed a higher viscosity range with 691.0 cP at 135 °C and 301.5 cP at 165 °C (Table 4).

The COPF modified binder gave a value of 610.8 cP at 0.3% fiber which is quite close to the HL modified binder. However, there is something to observe here on the COPF viscosities at 165 °C where the values of 142.1, 166.8 and 152.9 cP are rather close. This seems to be a good performance with the initial viscosities being high and varied according to the percentage of fibers used but at 165 °C which is close to the required asphalt mixing temperature, the viscosities are very close regardless of the percentage of fibers used. From the industry point of view, there will be no additional cost involved in heating up the asphalt binders to higher temperatures as can be seen in other modifiers used in the study.

The softening value for all the blended asphalt specimens is s shown in Table 5. The results showed that CLP with 1% had the lowest value for softening point while COPF with 0.3% had the highest value. This indicates that the petroleum binder modified with COPF tends to give a higher softening point temperature with higher viscosity and engineering properties. The viscosity temperature plots for the Neat, CLP, HL and COPF binders are as shown in Figs. 3-6, respectively.

3.2 Bending Beam Rheological Properties

3.2.1 Stiffness of CLP Modified Binder

The stiffness values for blended asphalt binder with Crush Lime Powder samples ranged from 4.2316 MPa to 43.6915 MPa. The m-values ranged from 0.5092 to 0.9225 while the deflection values were found to be between 1.815 mm and 6.558 mm. The superpave standard requirements recommend that the stiffness of an asphalt binder to be less than 300 MPa and

Table 3 Summary of penetration results for 60-70 blended asphalt binder.

Sample name	1st trial (mm)	2nd trial (mm)	3rd trial (mm)	Average (mm)
NB	68	69	72	69.7
CLP 1%	69	69	65	67.7
CLP 2%	62	62.5	60	61.5
CLP 3%	57	55	58	56.7
HL 1%	65	68	63	65.3
HL 2%	69	63	60	64.0
HL 3%	43	46	46	45.0
F 0.1%	57	60	64	60.3
F 0.2%	56	53	51	53.3
F 0.3%	49	46	45	46.7

Table 4 Summary of viscosity results for 60-70 blended asphalt binder.

Sample name	135 °C (cP)	165 °C (cP)
NB	2,431.0	781.9
CLP 1%	436.0	181.5
CLP 2%	426.3	200.1
CLP 3%	426.0	216.6
HL 1%	555.6	301.5
HL 2%	555.6	301.5
HL 3%	691.0	600.7
F 0.1%	467.6	142.1
F 0.2%	510.6	166.8
F 0.3%	610.8	152.9

Table 5 Summary of results of softening point temperatures.

Sample name	Temp. 1st reading (°C)	Temp. 2nd reading (°C)	Ave. Temp. (°C)
NB	47.5	48.4	48.0
CLP 1%	47.2	48.3	47.8
CLP 2%	49.0	49.2	49.1
CLP 3 %	50.0	50.8	50.4
HL 1%	49.3	50.4	49.9
HL 2%	51.9	52.6	52.5
HL 3%	53.0	54.2	53.6
F 0.1%	56.0	57.0	56.5
F 0.2%	58.3	59.0	58.7
F 0.3%	60.1	60.9	60.5

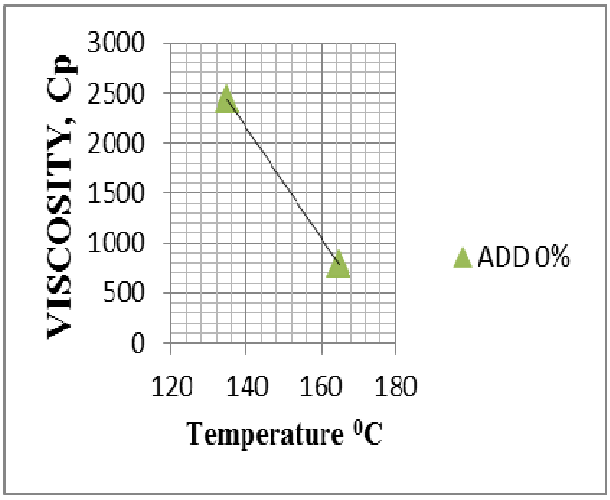

Fig. 3 Rotational viscosity for neat binder.

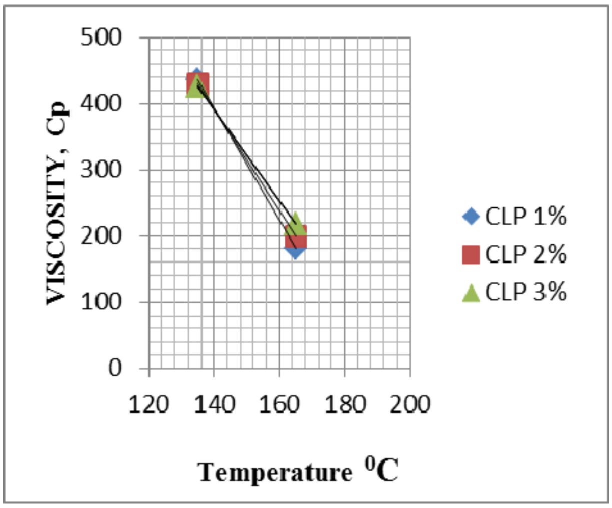

Fig. 4 Rotational viscosity for CLP 1%, CLP 2%, CLP 3%.

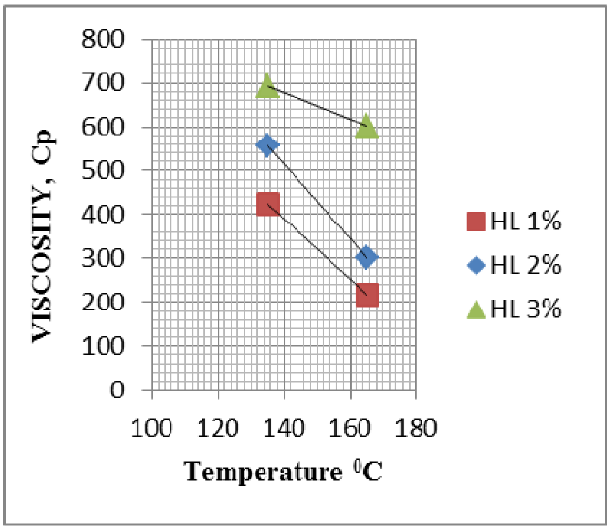

Fig. 5 Rotational viscosity for HL 1%, HL 2%, and HL 3%.

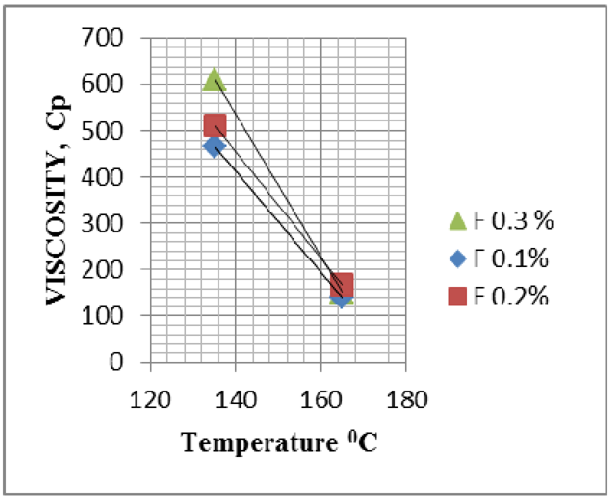

Fig. 6 Rotational viscosity for F 0.1%, F 0.2%, F 0.3%.

therefore all of the blended asphalt binder specimens with CLP met the requirement. The observed m-values are also greater than the minimum of 0.300. Although all samples met the requirements the AASHTO T313-12 states that the tests are not valid for beams of an asphalt binder that deflects more than 4 mm or less than 0.08 mm when tested in accordance with this method. Going by this specification it was noted that these following specimens did not fall into the acceptable range (CLP 1%, CLP 2%, and CLP 3%) while other specimens tests are acceptable. Table 6 below shows percentage of CLP and stiffness values and Fig. 7 shows the relationship between percentage of CLP and stiffness.

3.2.2 Stiffness of HL Modified Binder

The stiffness values for hydrated lime blended asphalt binder samples ranged from 12.8 MPa to 107.9 MPa, the m-values ranged from 0.643 to 0.324, while the deflection values were between 5.8307 mm and 0.740 mm. As elaborated in the above section the superpave standard requirement recommends the stiffness value of asphalt binders to be less than 300 MPa. Therefore it was observed that all of blended specimens with HL met the superpave requirement. The m-values are also found to be greater than 0.300. The following specimens were found to fall into the unacceptable range (0CLP 1%, 0CLP 2%, 0CLP 3%) while other specimens results are acceptable. This is as shown in Table 7 and Fig. 8.

Table 6 Percentage of CLP and stiffness.

CLP (%)	St @ 0 °C (MPa)	St @ -5 °C (MPa)	St @ -10 °C (MPa)
1	4.231	12.9	33.1
2	14.452	22.8	35.4
3	15.006	35.3	43.7

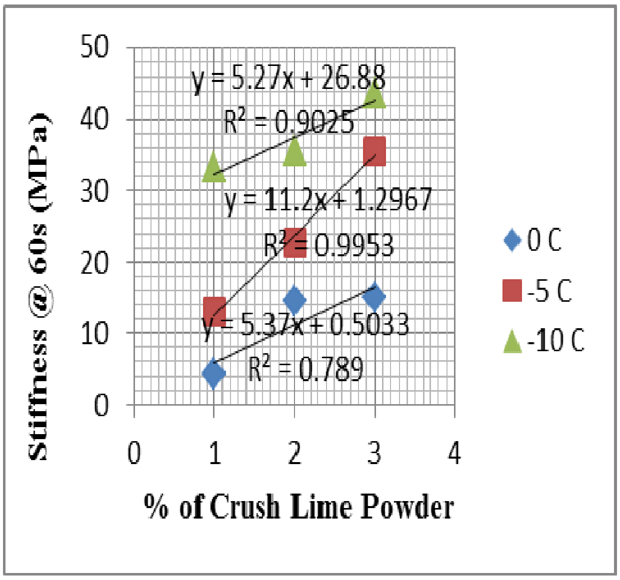

Fig. 7 Relationships between percentage of CLP and stiffness at various temperatures.

Table 7 Percentage of HL and stiffness.

HL (%)	St@ 0 °C (MPa)	St @ -5 °C (MPa)	St @ -10 °C (MPa)
1	13.750	31.771	39.654
2	14.129	34.236	91.459
3	15.866	44.729	107.851

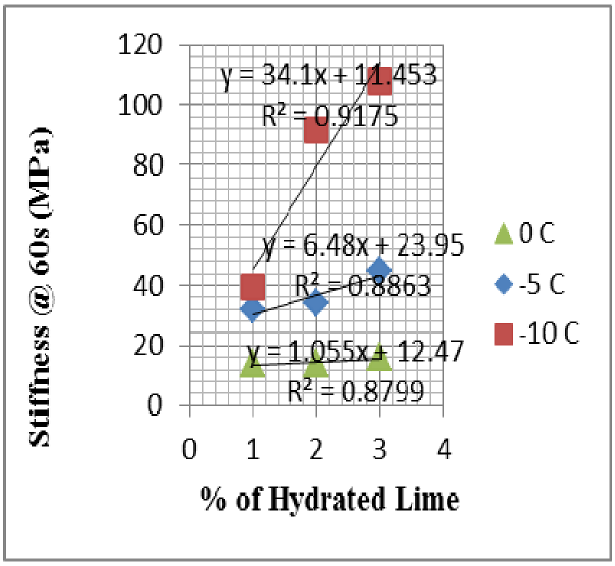

Fig. 8 Relationship between stiffness and percentage of HL at various temperatures.

3.2.3 Stiffness of OPCF Modified Binder

The stiffness values for blended asphalt binder with Loose Fiber samples were observed to be from 15.8 MPa to 81.8 MPa, the m-values ranged from 0.595 to 0.315, while the deflection values were determined to be between 5.078 mm and 0.967 mm. All of the tested COPF specimens met the superpave stiffness requirement of less than 300 MPa and the m-values are also greater than 0.300 for all samples while only the sample with 0.1% of fiber did not fall within the acceptable range values as compared with others. This can be observed in Table 8 and Fig. 9.

From the series of data collected from the laboratory test, it was observed that an increase in the percentage for all additives will lead to increase in stiffness of the asphalt binder, it is however advised to use asphalt binder with a moderate stiffness value.

3.4 Relationship between m-Value and Percentage of Asphalt for CLP, HL and OPCF

It was observed that all additives used in the

Table 8 Percentage of fiber and stiffness values.

Fiber (%)	St @ 0 °C (MPa)	St @ -5 °C (MPa)	St @ -10 °C (MPa)
0.1	15.755	23.535	60.058
0.2	23.476	41.408	68.990
0.3	32.208	74.527	81.829

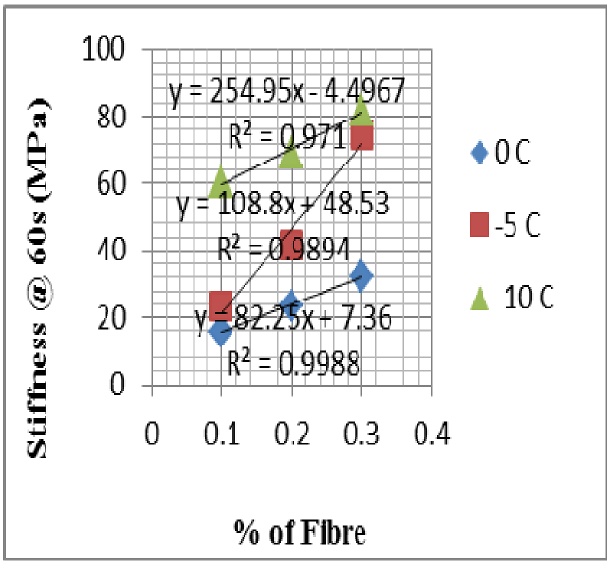

Fig. 9 Relationships between percentage of COPF and stiffness at various temperatures.

modification of the 60-70 asphalt binder showed similar performance and trends irrespective of the proportions of additives involve and it was also noted that increase in percentage of all additives used in this study led to a reduction of m-value whereby the m-value is known to be the absolute value of the slope of the logarithm of stiffness curves versus the logarithm of the time, since a lower m-value indicates lesser ability to relax stresses. Tables 9-11 and Figs. 10-12 show the relationship between the percentage of all blended specimens and the m-value.

3.5 Relationship between Deflection and CLP, HL, Fiber

From the series of data collected from the laboratory test, it was observed that an increase in the

Table 9 Percentage of CLP and m-value.

CLP (%)	m-Value @ 0 °C (MPa)	m-Value @ -5 °C (MPa)	m-Value @ -10 °C (MPa)
1	0.6427	0.4704	0.6888
2	0.5950	0.4540	0.4911
3	0.5790	0.4308	0.4539

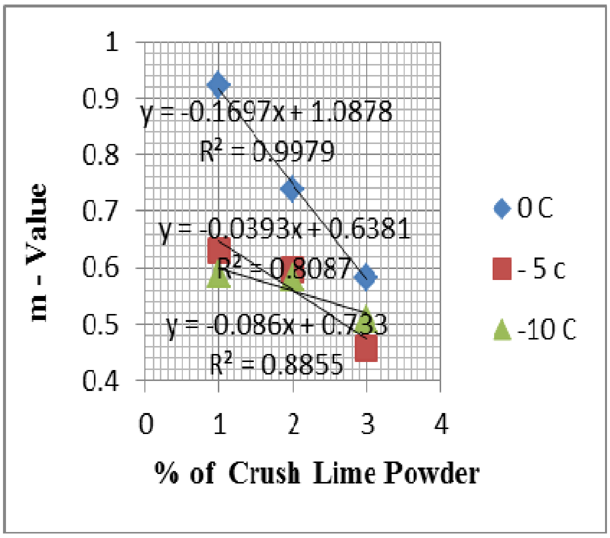

Fig. 10 Relationship between m-value and percentage of CLP at various temperatures.

Table 10 m-Value and percentage of HL.

HL (%)	m-Value @ 0 °C (MPa)	m-Value @ -5 °C (MPa)	m-Value @ -10 °C (MPa)
1	0.923	0.629	0.588
2	0.739	0.597	0.582
3	0.583	0.457	0.509

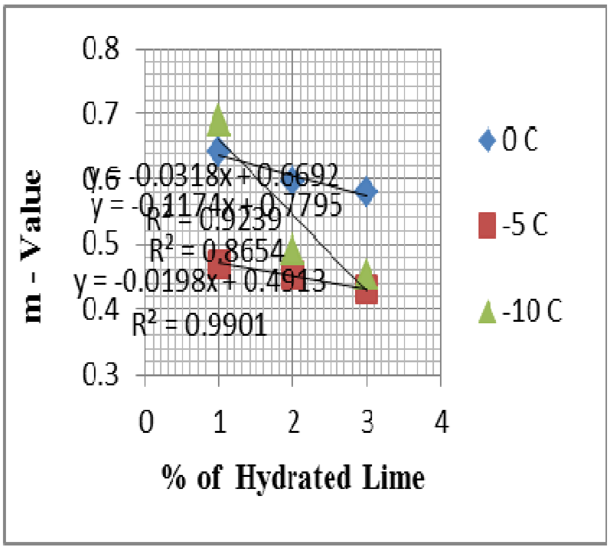

Fig. 11 Relationship between m-value and percentage of HL.

Table 11 Percentage of additives and m-value for fiber.

Fiber (%)	m-Value @ 0 °C (MPa)	m-Value @ -5 °C (MPa)	m-Value @ -10 °C (MPa)
1	0.595	0.467	0.489
2	0.518	0.402	0.434
3	0.484	0.365	0.415

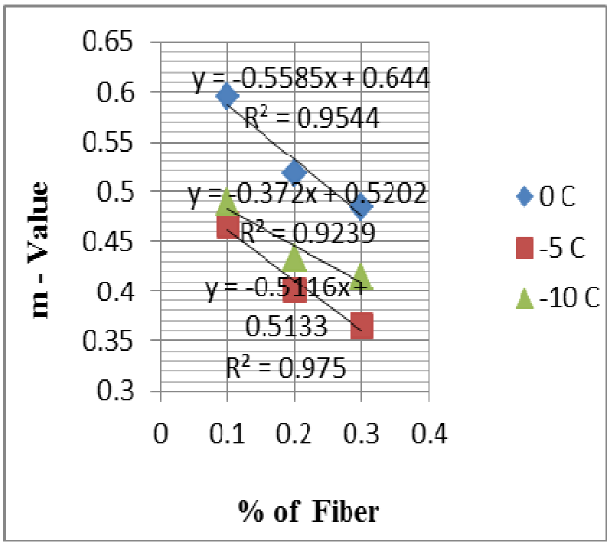

Fig. 12 Relationship between m-value and percentage of COPF at various temperatures.

percentage for all additives will decreased the deflection. In all the tested specimens, CLP showed a great potential in improving the strength and noticeably reducing the deflection. Tables 12-14 and Figs. 13-15 show the relationship between the percentage of blended specimens and deflection.

Table 12 Percentage of CLP and deflection.

CLP (%)	Deflection @ 0 °C (MPa)	Deflection @ -5 °C (MPa)	Deflection @ -10 °C (MPa)
1	6.558	2.514	2.009
2	5.746	2.412	0.862
3	5.375	2.012	0.740

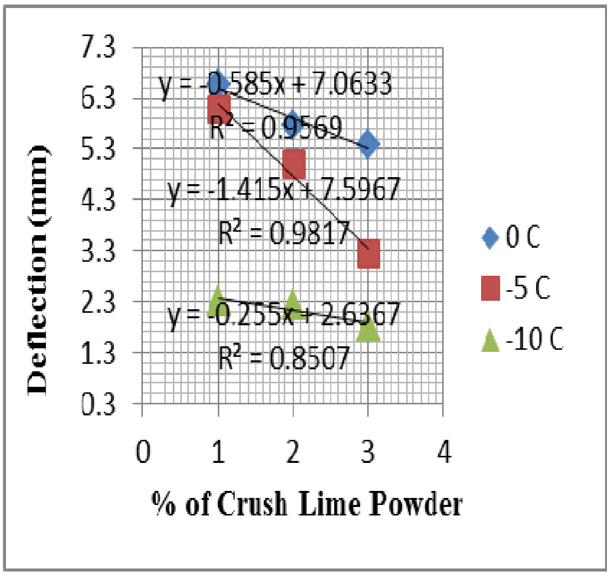

Fig. 13 Relationships between deflection and CLP.

Table 13 Percentage of HL and deflection.

HL 1 (%)	Deflection @ 0 °C (MPa)	Deflection @ -5 °C (MPa)	Deflection@ -10 °C (MPa)
1	5.831	2.514	2.009
2	5.687	2.412	0.862
3	5.0768	2.0116	0.7397

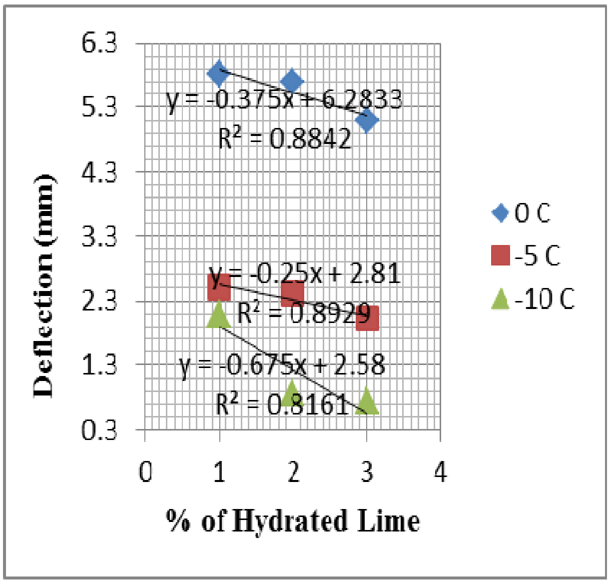

Fig. 14 Relationship between deflection and percentage of HL at various temperatures.

Table 14 Percentage of fiber and deflection.

Fiber (%)	Deflection @ 0 °C (MPa)	Deflection @ -5 °C (MPa)	Deflection@ -10 °C (MPa)
1	5.1	3.4	1.3
2	4.6	2.0	1.3
3	4.0	1.2	1.0

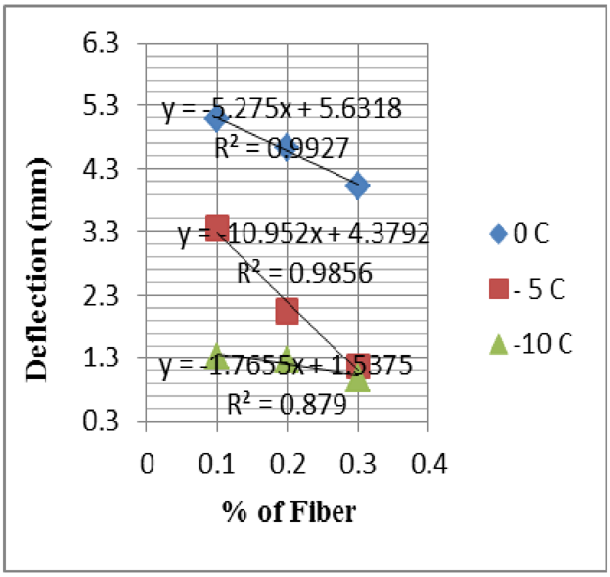

Fig. 15 Relationships between deflection and COPF at various temperatures.

3.6 Relationship between Temperature and Stiffness

Irrespective of the additives blended with the asphalt binder, it was observed that drop in temperature would lead to increase in the stiffness of the binder, for a specimen this relationship was clearly noted. Since a higher creep stiffness value indicates higher thermal stress, a minimum creep stiffness value of 300 MPa was specified by superpave. Tables 15-17 and Figs. 16-18 show the relationship between drop in temperature and stiffness of the blended BBR specimens.

3.7 The Relationship between Temperature and m-Value

A reduction was noted in m-value whenever there is a drop in temperature for all specimens. Tables 18-20

Table 15 Temperature and stiffness for CLP.

Temp. (°C)	CLP 1%, St (MPa)	CLP 2%, St (MPa)	CLP 3%, St (MPa)
0	4.2	14.5	15.0
-5	12.9	22.8	35.3
-10	33.2	35.4	43.7

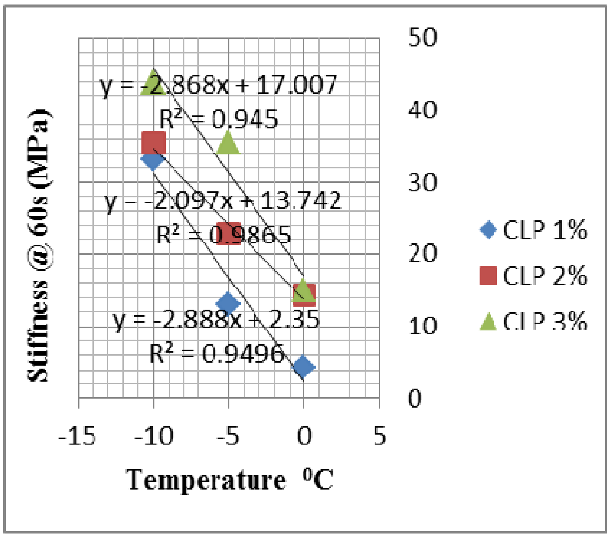

Fig. 16 Relationship between temperature and stiffness for CLP at various temperatures.

Table 16 Temperature and m-value for HL.

Temp. (°C)	HL 1%, m-value	HL 2%, m-value	HL 3%, m-value
0	0.643	0.595	0.579
-5	0.470	0.454	0.431
-10	0.449	0.361	0.324

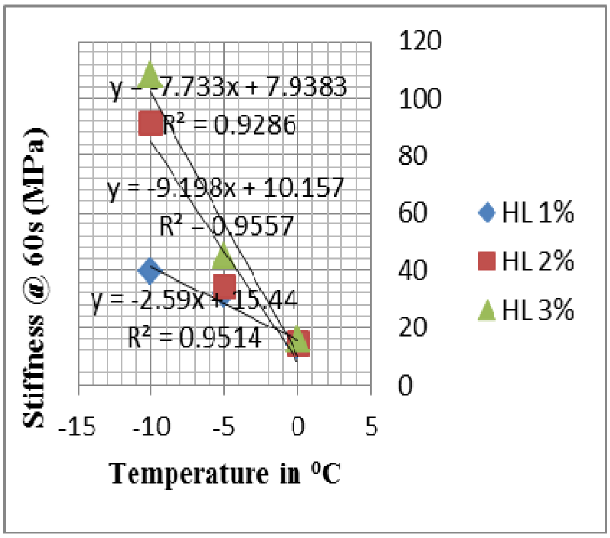

Fig. 17 Relationship between temperature and stiffness for HL at various temperatures.

Table 17 Temperature and stiffness for fiber.

Temp. (°C)	F 0.1%, St (MPa)	F 0.2%, St (MPa)	F 0.3%, St (MPa)
0	15.755	23.5	32.2
-5	23.5	41.4	74.5
-10	60.1	69.0	0.3

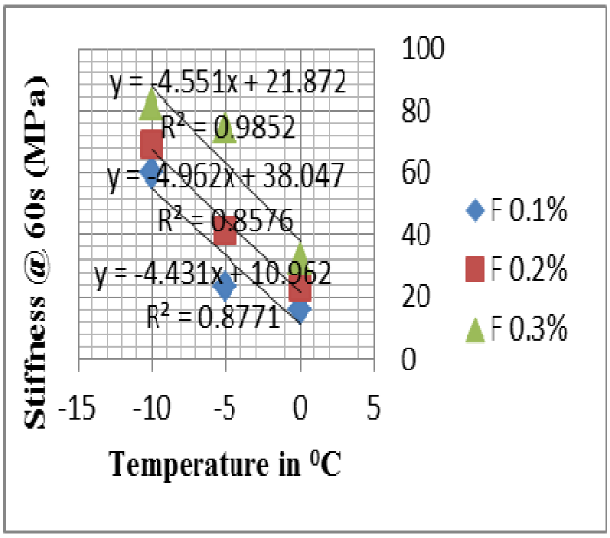

Fig. 18 Relationship between temperature and stiffness for COPF at various temperatures.

Table 18 Temperature and m-value for CLP.

Temp. (°C)	CLP 1%, m-value	CLP 2%, m-value	CLP 3%, m-value
0	0.923	0.739	0.583
-5	0.629	0.597	0.457
-10	0.588	0.582	0.509

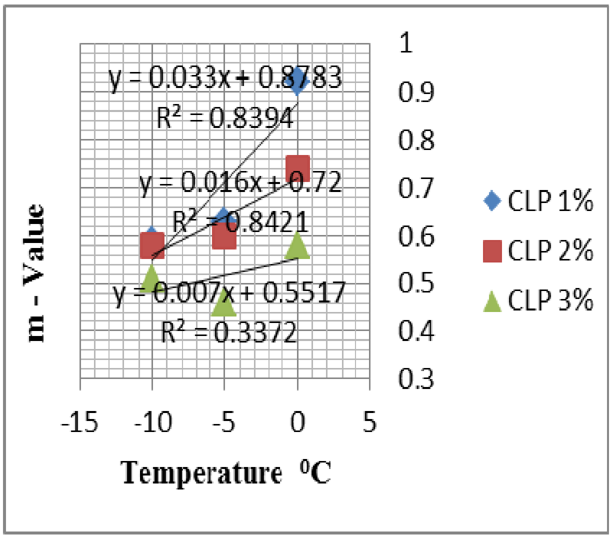

Fig. 19 Relationship between temperature and m-value for CLP at various temperatures.

Table 19 Temperature and stiffness for HL.

Temp. (°C)	HL 1%, St (MPa)	HL 2%, St (MPa)	HL 3%, St (MPa)
0	13.8	14.1	15.9
-5	31.8	34.2	44.7
-10	39.7	91.5	107.9

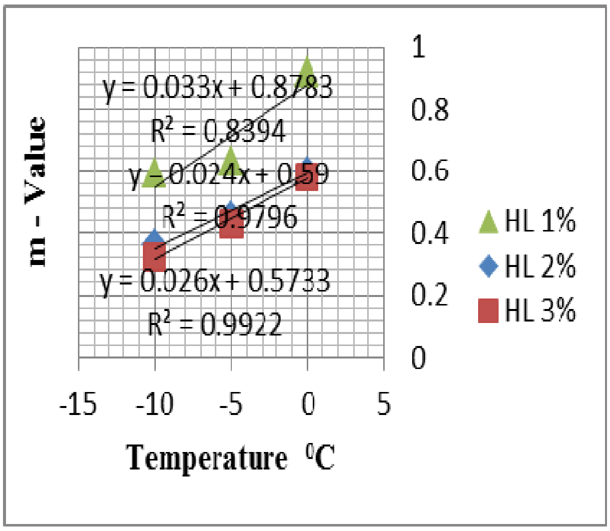

Fig. 20 Relationships between temperature and m-value for HL at various temperatures.

Table 20 Temperature and m-value for COPF.

Temp. (°C)	m-Value (HL 1%)	m-Value (HL 2%)	m-Value (HL 3%)
0	0.595	0.518	0.484
-5	0.467	0.402	0.365
-10	0.389	0.334	0.315

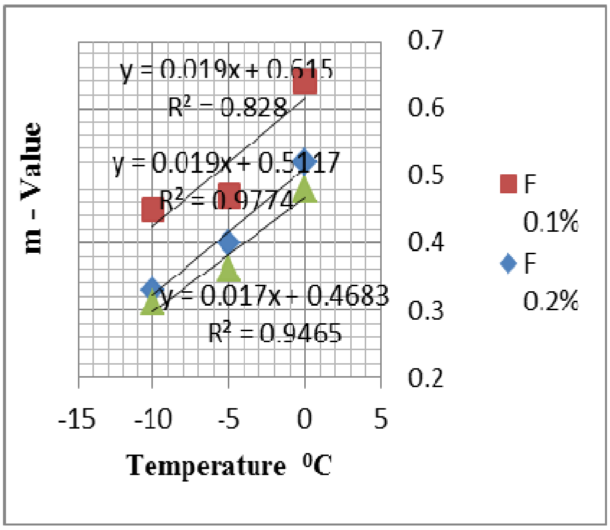

Fig. 21 Relationship between temperature and m-value for COPF at various temperatures.

and Figs. 19-21 show the relationships between the additive modified binder specimens and m-value.

3.8 Relationship between Temperature and Deflection

It was observed that a drop in temperature tends to reduce the deflection on the binder regardless of the additives used in the blending of the asphalt. Tables 21-23 and Figs. 22-24 show the relationship between temperature and deflection for all blended BBR specimens.

Table 21 Temperature and deflection for CLP.

Temp. (°C)	CLP 1%, deflection (mm)	CLP 2%, deflection (mm)	CLP 3%, deflection (mm)
0	6.658	5.746	5.375
-5	6.074	4.987	3.240
-10	2.319	2.246	1.815

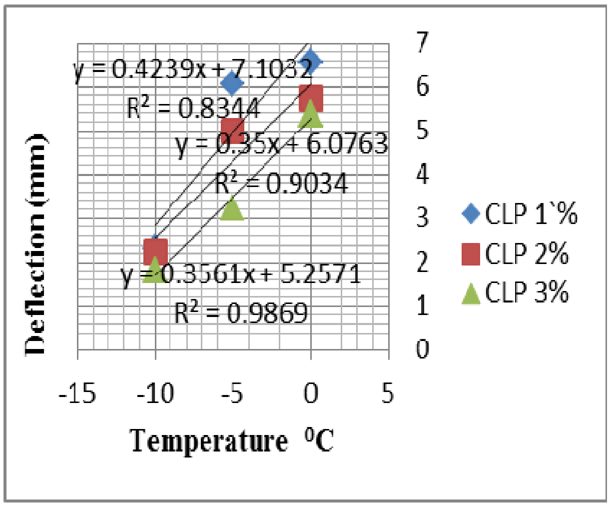

Fig. 22 Relationship between temperature and deflection for various CLP proportions.

Table 22 Temperature and deflection for HL.

Temp. (°C)	HL 1%, deflection (mm)	HL 2%, deflection (mm)	HL 3%, deflection (mm)
0	5.831	5.687	5.077
-5	2.5141	2.412	2.012
-10	2.009	0.862	0.740

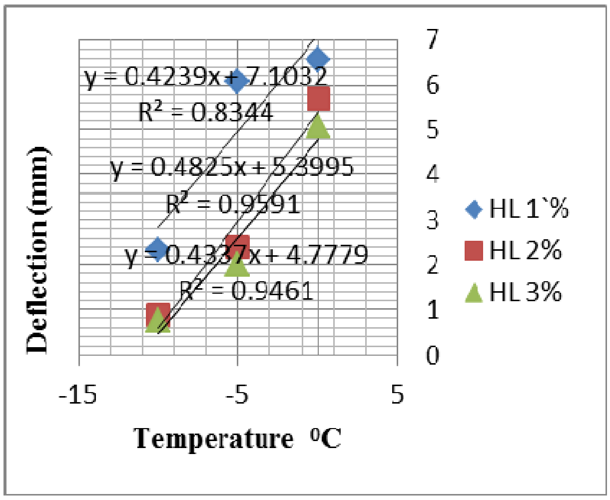

Fig. 23 Relationship between temperature and deflection for HL at various proportions.

Table 23 Temperature and deflection for COPF.

Temp. (°C)	HL 1%, deflection (mm)	HL 2%, deflection (mm)	HL 3%, deflection (mm)
0	5.078	4.629	4.023
-5	3.360	2.036	1.171
-10	1.323	1.262	0.969

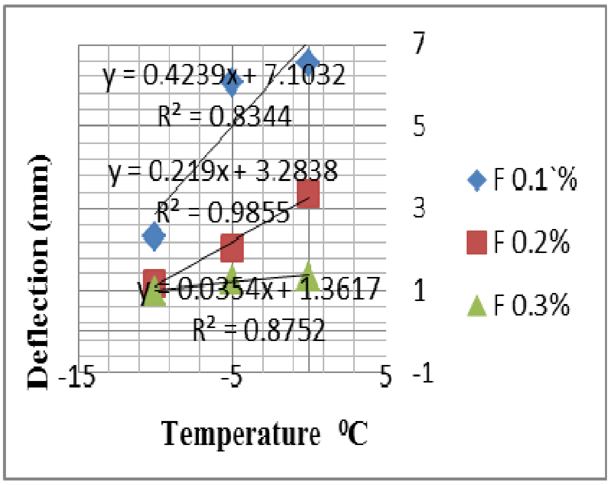

Fig. 24 Relationship between temperature and deflection for various proportions.

3.9 Relationship between Stiffness and Deflection

It was observed that an increase in stiffness will lead to a decrease in the deflection of the blended asphalt binder; this was noted in all tested specimens. Tables 24-26 and Figs. 25-27 show the relationship between stiffness and deflection for all blended specimens.

3.10 Comparison of Stiffness Performance of Various Additive Modified Binders

When the asphalt binder was tested at 0 °C among all specimens with respect to the proportion of additives, it was noted that fiber at 0.3% has the highest value of stiffness while CLP at 1% has the lowest stiffness, at 0 °C fiber generally has the highest stiffness value in all categories of proportions, fiber has exhibited the highest strength of increasing the stiffness of binder despite the fact that it has the lowest content of additives, while generally CLP has shown the lowest ability of increasing the stiffness at 0 °C. Fig. 28 shows the comparison between additives using the stiffness of the additive modified BBR specimens.

Table 24 Stiffness and deflection for CLP.

Def. (mm)	St @ 0 °C (MPa)	Def. (mm)	St @ -5 °C (Mpa)	Def. (mm)	St @ -10 °C (Mpa)
5.831	13.8	2.514	31.8	2.009	39.6
5.687	14.1	2.412	34.2	0.862	91.5
5.077	15.9	2.012	44.7	0.740	107.9

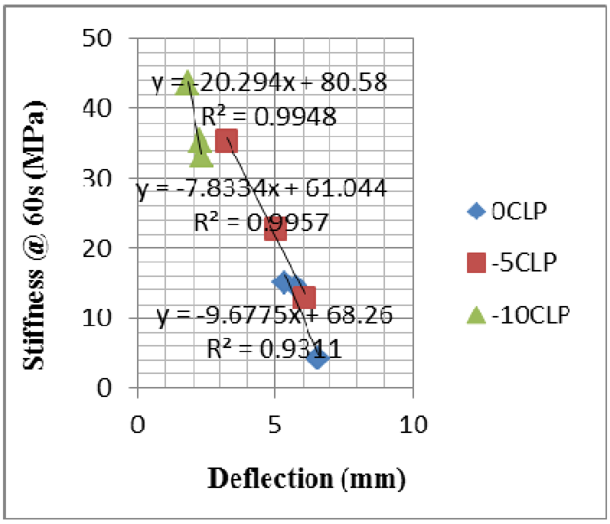

Fig. 25 Relationships between stiffness and deflection for CLP at various temperatures.

Table 25 Stiffness and deflection for HL.

Def. (mm)	St @ 0 °C (Mpa)	Def. (mm)	St @ -5 °C (Mpa)	Def. (mm)	St @ -10 °C (Mpa)
5.830	13.8	2.514	31.8	2.009	39.7
5.687	14.1	2.411	34.2	0.619	91.5
5.077	15.9	2.012	44.7	0.740	107.9

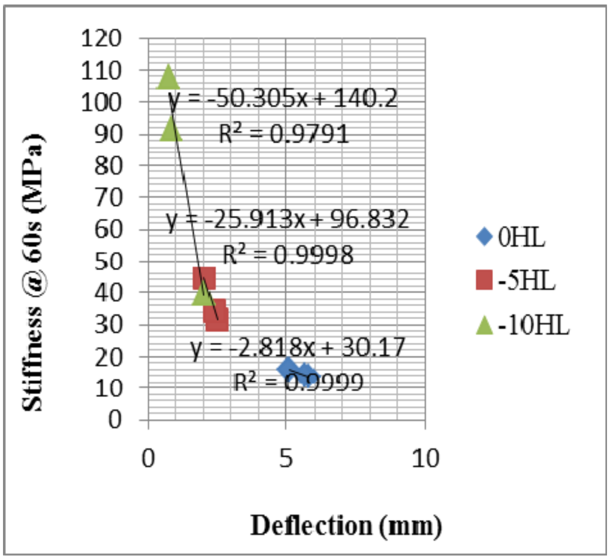

Fig. 26 Relationship between stiffness and deflection for HL at various temperatures.

Table 26 Stiffness and deflection for fiber.

Def. (mm)	St @ 0 °C (MPa)	Def. (mm)	St @ -5 °C (MPa)	Def. (mm)	St @ -10 °C (MPa)
5.078	15.755	3.360	23.535	1.323	60.0578
4.629	23.476	2.036	41.408	1.262	68.9904
4.023	32.208	1.171	74.527	0.969	81.8291

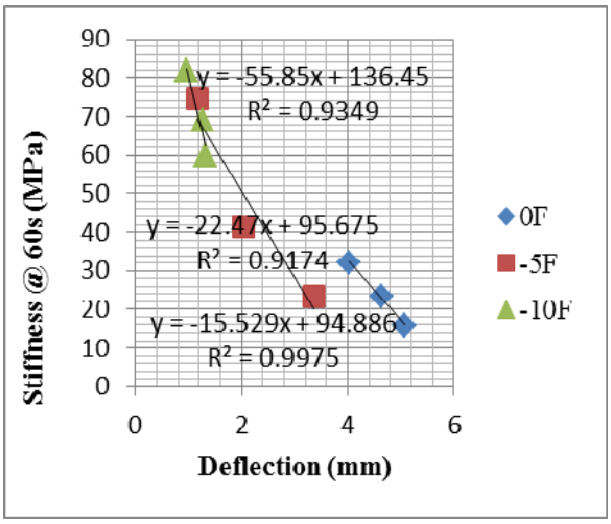

Fig. 27 Relationship between stiffness and deflection for COPF at various temperatures.

At -5 °C similar performance was observed with the binder that was tested at 0 °C, fiber at 0.3% still has the highest stiffness value while CLP at 1% also has the lowest stiffness value while HL at 3% has the second highest value of stiffness while CLP at 3% tested at this temperature shows a noticeable improvement in terms of the stiffness compared to stiffness at 0 °C and -5 °C, this implies that at 3% of CLP or above there might be significant increase in the thermal stress on the binder when tested at a lower temperature.

It has been established that a higher value is a clear sign of higher thermal stress on the binder, so judging from the available data, it was observed that Crushed Lime Powder has a better performance than Hydrated Lime and Fiber, although all the blended binders with additives meet the minimum requirements of having a stiffness value less than or equal to 300 MPa. Fig. 28 below shows the performance of the various modified binders at the three temperatures chosen for this research work.

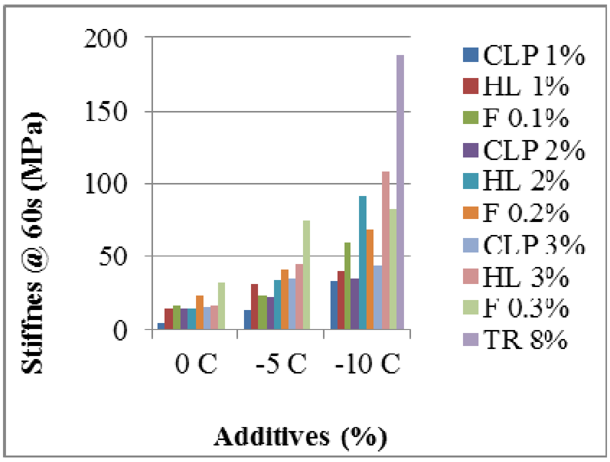

Fig. 28 Comparisons between performances of modified binder using deflection.

3.11 Comparison of Performance between Additives Using the m-Value

Testing modified binders at 0 °C shows that CLP at 1% and 2% has the highest m-value, while at 3%, the m-value and HL were almost the same, also at all categories fiber has the lowest m-value when testing at 0 °C. At -5 °C, CLP at 1% has the highest m-value, while fiber at 3% has the lowest m-value while at -10 °C, CLP 1% has the highest value but was just slightly higher than the CLP at 2% while TR at 8% has the lowest m-value, and fire has the second lowest value. Fig. 29 shows the performance of modified binders using m-value for the analysis.

According to superpave specification lower m-value can be linked to less ability of the binder to relax the thermal stresses that act on it, in all temperatures CLP seems to have the best performance when compared to the other additives, Fig. 29 shows the performance of modified binders using m-value for the analysis.

3.12 Comparing Performance Using Deflection

Testing modified binder at 0 °C using deflection as our point of analysis shows that CLP at 1% has the highest value of deflection; CLP 2% is slightly higher than HL 2%, while at -5 °C CLP at 1% also has the highest value of deflection, CLP at 2% has the second highest deflection value while fiber has the lowest

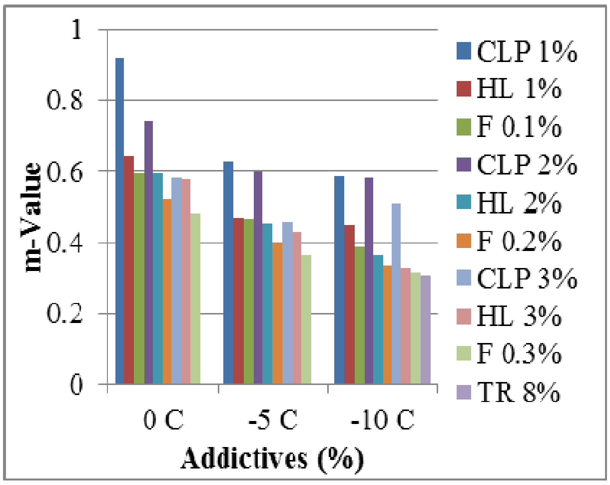

Fig. 29 M-value performance of modified binders at various temperatures.

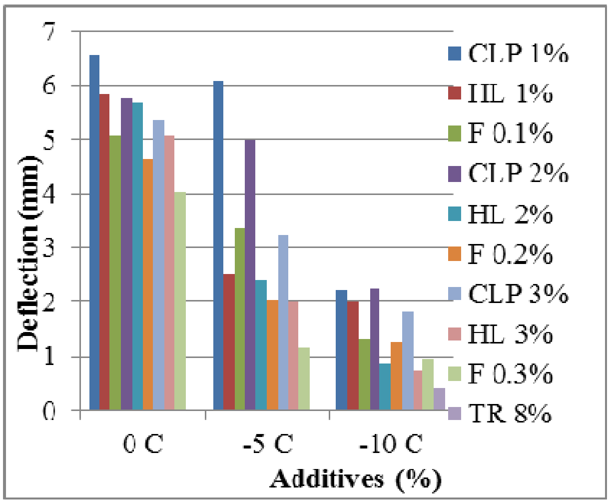

Fig. 30 Comparison of deflection performance between additives at various temperatures.

Table 27 Overall performance ranking of additives modified binders.

Name	Stiffness (MPa)	m-Value	Deflection (mm)
CLP	1	1	1
HL	2	2	2
Fibre	3	3	3

value of deflection. At -10 °C, CLP 2% slightly higher than CLP 1%, the both experience the uniform loading, while TR at 8% has the lowest value of deflection while fiber at 3% has the second lowest level of deformation of binder, Fig. 30 shows the comparison between modified asphalt binder specimens using deflection, so with respect to performance at low temperature, high deflection is an good indication that the binder modified binder can distribute the thermal stress that it was subjected when the temperature drops based on this we can conclude CLP has the best performance at low temperature. The figure shows the chart of performance of the modified binder that was analyzed by deflection. Table 27 shows the overall performance ranking of additives.

4. Conclusions and Recommendations

4.1 Conclusion

Three additives namely Crush Lime Powder (CLP), Hydrated Lime (HL), and Oil Palm Cellulose Fiber (OPCF) were blended with 60-70 penetration binder separately to evaluate the low temperature performance potential in terms of stiffness, m-value and deflection. From the results obtained, the following outcomes were observed.

It is evident from the laboratory tests that an increase in all additives used for this study under constant loading led to an increase in the creep stiffness of the asphalt binders under the controlled variables used for this study such as the proportions of additives and temperature. This observation was noted in all additives regardless of the proportions with the test temperatures of 0 °C,-5 °C, and -10 °C.

The penetration values were reduced as the proportion of additives was increased while the viscosity increased. The softening point temperatures increased and can be related to the increase in stiffness. Basically, the trend noticed with the creep stiffness is that as the proportion of additives increased, the m-value decreased and also the deflection decreased in all of the specimens. Temperature is a very important parameter or component used in this study for the assessment of the performance of modified binder without considering the proportion of blended additives. All evidences from the laboratory report point to an increase in creep stiffness whenever the temperature drops even with the exemption of all additives, this indicates an increase in thermal stress whenever the temperature goes down that eventually leads to a reduction in the ability of the binder to relieve the thermal stresses that acts on it.

In addition, the m-values and the deflection are also reduced because of stiffer binder due to sudden drop in temperature. It was also observed that the additives used in this study also played an important role in decreasing the deflection or deformation of the binder when subjected to constant loading at low temperatures.

The various additive modified binders were ranked from the highest to the lowest. The Crushed Lime Powder categorically performed better than Hydrated Lime and Oil Palm Cellulose Fiber. CL exhibited the lowest thermal stress on binder at all temperatures and also showed the highest m-value which further supports the theory of having the best performance.

All the tested specimens fulfilled the minimum specified requirement of a creep stiffness value less than or equal to 300 MPa and a minimum m-value of 0.300. The ranking of the additives from the best performance to the worst performance at low temperatures is as shown in Table 27.

4.2 Recommendations

Based on the preliminary study carried on the various additives, it is recommended that more laboratory tests are carried out for the optimization of additives to be added to the mixture to achieve a better field performance. This implies that the percentage of additives would be able to strike a balance between the creep stiffness, m-value and deflection.

References

[1] Foulkes, M. D., and Kennedy, C. K. 1986. "The Limitations of Reflection Cracking in Flexible Pavements Containing Cement Bound Layers." In *Proceedings of International Conference on Bearing Capacity of Roads and Airfields*.

[2] Hu, S., Zhou, F. J., and Scullion, T. 2011. "Factors that Affect Cracking Performance in Hot-Mix Asphalt Mix Design." *Transportation Research Record: Journal of the Transportation Research Board* 2210: 37-46.

[3] Isacsson, U., and Zeng, H. 1996. "Low-Temperature Cracking of Polymer-Modified Asphalt." *Materials and Structures* 31: 58-63.

[4] Jakarni, F. M., Muniandy, R., Hassim, S., and Mahmud, A. R. 2010. "Analysis of Stone Mastic Asphalt (SMA) Slab Dimensions for Evaluation of the Newly Developed Roller Compactor (Turamesin)." *Pertanika J. Sci. & Technol.* 18 (1): 13-22.

[5] Kheradmand, B., Muniandy, R., Law, T. H., and Solouki, A. 2015. "A Laboratory Investigation on the Rheological Properties of Aged and Unaged Organic Wax Modified Asphalt Binders." *Petroleum Science and Technology* 33 (7): 757-64.

[6] Mahdi, M. J., Muniandy, R., Yunus, R., and Aburkaba, E. 2013. "Effect of Short Term Aging on Organic Montmorillonite Nanoclay Modified Asphalt." *Indian Journal of Science and Technology* 6 (11): 5434-42.

[7] Aziz, M. B. A., Muniandy, R., Abdullah, K., Mahmud, A. R., Khalid, K., and Ismail, A. 2010. "Preliminary Determination of Asphalt Properties Using Microwave Techniques." *ARPN Journal of Engineering and Applied Sciences* 5 (11).

[8] Muniandy, R., Akhir, A. B. C., Hassim, S., and Moazami, D. 2014. "Laboratory Fatigue Evaluation of Modified and Unmodified Asphalt Binders in Stone Mastic Asphalt Mixtures Using a Newly Developed Crack Meander Technique." *International Journal of Fatigue* 59: 1-8.

[9] Muniandy, R., Aburkaba, E. E., Hamid, H., and Yunus, R. 2009. "An Initial Investigation of the Use of Local Industrial Wastes and By-Products as Mineral Fillers in Stone Mastic Asphalt Pavements." *ARPN Journal of Engineering and Applied Sciences* 4.

[10] Muniandy, R., Jafariahangari, H., Yunus, R., and Hassim, S. 2008. "Determination of Rheological Properties of Bio Mastic Asphalt." *American J. of Engineering and Applied Sciences* 1 (3): 204-9.

[11] Muniandy, R., and Huat, B. K. 2006. "Laboratory Diameteral Fatigue Performance of Stone Matrix Asphalt with Cellulose Oil Palm Fiber." *Am. J. Appl. Sci.* 3 (9): 2005-10.

[12] Nadzrol, F. A. 2014. "Performance of Stone Mastic Asphalt Mixture Reinforced with Newly Developed Interlocking Chained Plastic Beads." Ph.D. thesis, Universiti Putra Malaysia, Malaysia.