Laboratory investigation of asphalt binder with and without crumb rubber modifier

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ABSTRACT Some countries around the world receive asphalt binder from different sources. The same asphalt binder grades or sources behave differently in the same environmental condition. This behavior can be attributed to the diversity of sources. Although all these sources of binders have to pass characterisation tests, some of these sources are quite sensitive to temperature variations. This research aims to study the consequence of the Crumb Rubber modification (CR) on the temperature susceptibility of the asphalt binders using traditional and Superpave techniques. Two asphalt binder grades were investigated: 60/70 was from New Zealand source and 80/100 was imported. The two binder sources were experimented on in the laboratory under three different conditions: unaged binder, short-term and long-term ageing. Furthermore, the response of the addition of 10% CR modifier was investigated under these various conditions. The results of this research clearly showed that the addition of the CR modifier led to reduced temperature susceptibility of the asphalt binder and improved resistance to thermal cracking at low temperatures.

KEY WORDS

Asphalt binder, temperature susceptibility, modification, crumb rubber and stiffness

INTRODUCTION

Asphalt binder ageing

It is widely acknowledged that the rheological properties of the asphalt binder have a direct influence on pavement performance. Once the Hot Mix Asphalt (HMA) productions and pavement applications take place, the rheological properties of the asphalt binder start to experience a change in their nature; consequently, asphalt binder is expected to have a critical condition over time (Robert *et al*. 1996).

The principal elements of asphalt molecules are carbon and hydrogen (Asphalt Institute 1994). Asphalt binder has a complex chemical composition that varies in response to the environmental conditions. Oxidation and physical hardening are the major factors that contribute to a change in the asphalt binder properties, which is clearly attributed to age hardening over the service life of the pavement, which consequently affects its behaviour (Bahia and Anderson 1995). Asphalt binder becomes brittle with age due to oxidation. Moreover, when asphalt pavement is exposed to a low temperature for a prolonged time, shrinkage and hardening occurs. Once asphalt binder has experienced hardening, the pavement structure is more likely to show cracking (Asphalt Institute 1994).

Asphalt binder temperature susceptibility

At a high temperature, asphalt binder behaves like a viscous liquid. Moreover, it is characterised as a Newtonian fluid that has a linear relationship between the force of resistance and its relative velocity. When the temperature drops or the pavement rapidly undergoes applied loads, the asphalt binder similarly acts as an elastic solid. Low temperatures cause the asphalt binder to become brittle; in addition, thermal cracking occurs when there is a low temperature and excessive load. Asphalt binder is deemed as a visco-elastic and thermoplastic material; it behaves completely differently when its temperature changes. As it is heated, it becomes fluid which would easily coat the aggregate; after cooling, it behaves like glue and holds the aggregate together (Asphalt Institute 1994). Temperature susceptibility is considered an important property of the asphalt binder. It can be defined as the rate of change of binder consistency as the temperature changes. Asphalt binder that is highly susceptible to temperature change could result in tender mix at high temperature because of the very low viscosity; similarly, very high viscosity could lead to thermal cracking at very low temperature (Roberts *et al*. 1996).

SCOPE OF RESEARCH

The main objective of this research project was to study the consequence of the Crumb Rubber modification (CR) on the temperature susceptibility of the asphalt binders using traditional and Superpave techniques. Two asphalt binder grades secured from two different sources were investigated: 60/70 and 80/100 imported; in addition, each asphalt binder source was modified with 10% (by weight of the asphalt binder) CR modifier. These asphalt binder samples were tested through three different conditions in order to simulate the real service life: unaged, rolling thin film oven test short-term aged and long-term aged. Unaged asphalt binder is subjected to transporting, manufacturing processes in its early life stages. Short-term ageing simulates the ageing during mixing, lay down and compaction of the pavement service life and the long-term ageing imitates the pavement performance over 7 to 10 years of service time or longer. Figure 1 shows a flow chart of the experimental design.

MATERIALS

The asphalt binders were provided by Fulton Hogan Limited, which brought them from Shell New Zealand Limited. Two asphalt binder sources were provided: 60/70 and 80/100 (imported), named in this research as asphalt binders A, B respectively The same sources were modified with 10% of CR. The CR modified asphalt binders were prepared by adding 10% of crumb rubber passing number 40 mesh size, and 5% of aromatic oil Tudalen 65, and 80% of asphalt binder.

$$PI = \frac{20 - 500A}{1 + 50A} \qquad \textbf{(1)}$$

Where, $A = \dfrac{Log\ Pen\, at\, T_1 - Log\ Pen\, at\, T_2}{T_1 - T_2}$

$$PVN = \frac{L - X}{L - M}(-1.5) \qquad \textbf{(2)}$$

Where, X= the logarithm of viscosity in centistokes measured at 135°C;
L= the logarithm of viscosity at 135°C for a PVN of 0.0; and
M= the logarithm of viscosity at 135°C for a PVN of -1.5.
L= log V= 4.25800-0.79670 log P
M= log V= 3.46289-0.61094 log P

METHODOLOGY

Figure 1 shows the testing programme that was followed. Each binder source with and without CR modifier was subjected to a number of laboratory tests through three stages: unaged, short-term and long-term aged binder. Penetration measurements were undertaken only for the unaged asphalt binder; however, viscosity measurements were conducted on unaged asphalt binders as well as artificially aged asphalt binders; BBR parameters were only measured for the artificially aged asphalt binders.

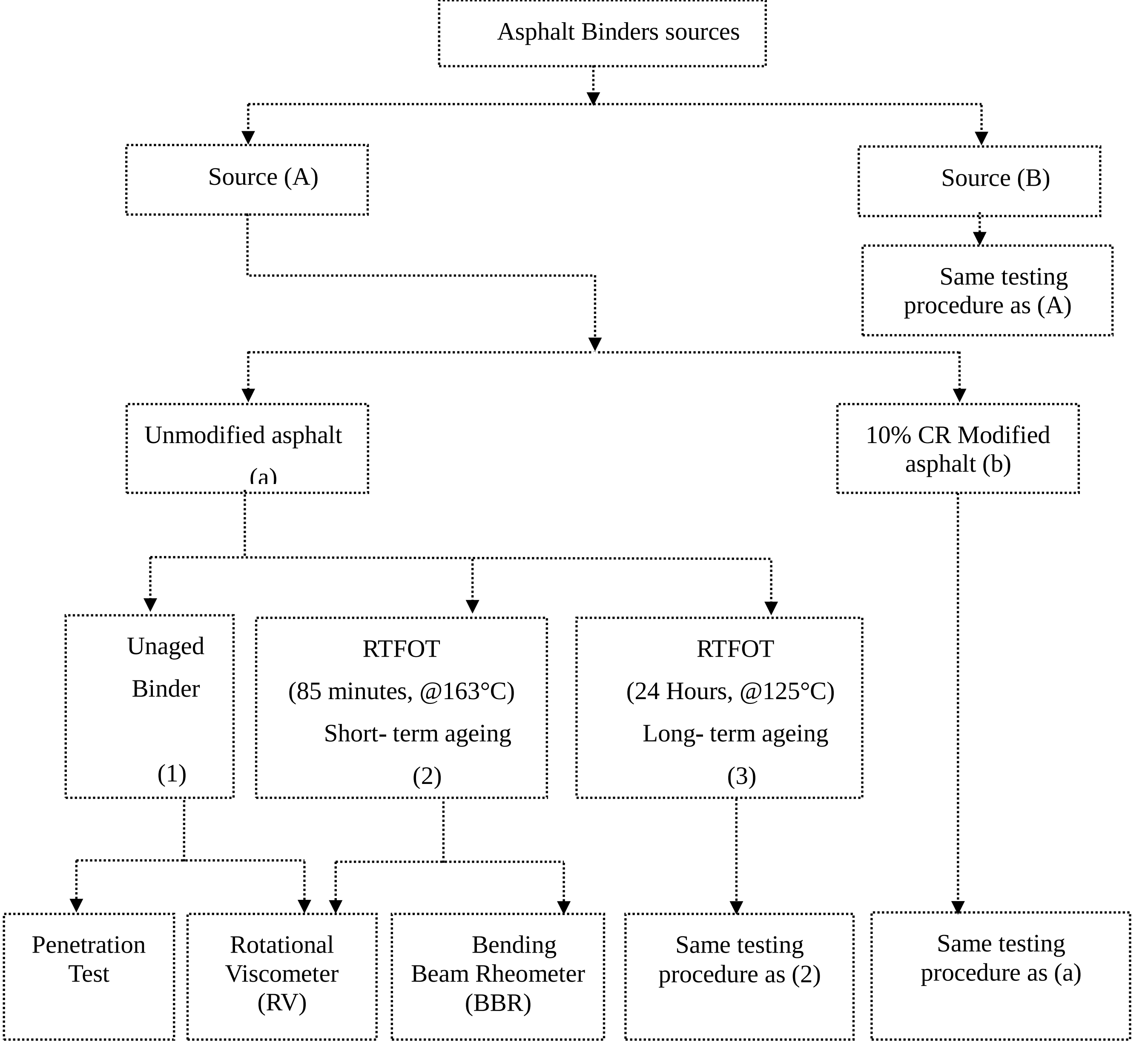

Figure 1: Experimental design.

The hardening of the asphalt binder starts to take place during the manufacture and construction of HMA pavement. This type of aging is called short-term ageing because it occurs at the beginning of the pavement's service life. The Rolling Thin-Film Oven Test (RTFOT) imitates short-term aging that the asphalt binder experiences in its early stage of life during manufacturing and placement (Robert *et al*. 1996). In order to simulate the long-term ageing that the HMA pavement is expected to experience during its service life, RTFOT was utilised for 24 hours at 125°C.

Traditionally there are three indexes that can be used to determine temperature susceptibility, viscosity temperature susceptibility (VTS), penetration viscosity number (PVN) and penetration index (PI). In the Superpave characterisation methods, the bending beam rheometer parameters, namely, creep stiffness and m-value are used to characterise the low temperature behaviour of the asphalt binder. Figure 2 displays the three apparatuses utilised to measures the temperature susceptibility parameters.

Viscosity measurements

All the unmodified binders and the10% CR modified asphalt binder sources artificially experienced short-term ageing in the RTFOT for 85 minutes at 163°C according to (ASTM D 2872-97). The Rolling Thin Film Oven Test equipment was also used to simulate the long-term ageing, but the RTFOT kept ageing the asphalt binders for 24 hours at 125°C. The viscosity was measured at different temperatures before and after short-term ageing as well as after long-term ageing, for determining the asphalt binder temperature susceptibility. The viscosity of the different sources of binders was measured by using the Brookfield rotational viscometer (RV). Table 1 and Table 2 summarise the viscosity results at different temperature for the two different sources for different ageing and modification conditions.

Penetration measurements

In order to find the Penetration Index (PI) and Penetration-Viscosity Number (PVN), the penetration test was conducted at three different temperatures (room temperature, 25°C and 30°C) for both the unmodified asphalt binders and the10% CR modified asphalt binder according to the (ASTM D5-06) standard. While the PI is only based on the penetration value at different temperatures, the PVN is based on both viscosity at 135°C and penetration at 25°C. This variety of testing temperatures is due to the specification of asphalt binder paving (Roberts *et al*. 1996). Those indexes are considered to examine the temperature susceptibility of the asphalt binder. PI and PVN were calculated using Equation 1 and Equation 2. The smaller the value of PI and PVN, the higher the temperature susceptibility of asphalt binder (Roberts *et al*. 1996).

Table 1: Summary of the viscosity versus temperature results and BBR's parameters of the 0% CR modified binder sources

Property	Temperature	Source A	Source B
Unaged binder			
Viscosity, Pa.s @	**100 ºC**	5.569	3.2496
	115 ºC	1.96033	1.12883
	135 ºC	0.6563	0.5083
	140 ºC	0.52293	0.3625
Short-term aged binder (RTFO) residue (163°C)			
Viscosity, Pa.s @	**100 ºC**	8.87533	3.8169
	115 ºC	2.49733	1.41467
	135 ºC	0.89167	0.49167
	140 ºC	0.6417	0.377
Stiffness (60 Sec). MPa (-20°C)		296	641
m-Value (60 Sec) (-20°C)		0.310	0.219
Long-term aged binder (RTFO) residue (125°C)			
Viscosity, Pa.s @	**135 ºC**	1.675	0.7
	140 ºC	1.251	0.545
	150 ºC	0.723	0.342
	163 ºC	0.404	0.2
Stiffness (60 Sec). MPa (-20°C)		353	551
m-Value (60 Sec) (-20°C)		0.272	0.253

Table 2: Summary of the viscosity versus temperature results and BBR's parameters of the 10% CRMA binder sources

Property	Temperature	Source A	Temperature	Source B
Viscosity, Pa.s@	**135 ºC**	2.26	**115 ºC**	4.10
	140 ºC	1.74	**135 ºC**	1.54
	145 ºC	1.48	**140 ºC**	1.25
Short-term aged binder (RTFO) residue (163°C)				
Viscosity, Pa.s@	**135 ºC**	4.49	**115 ºC**	6.35
	140 ºC	3.50	**135 ºC**	2.32
	145 ºC	2.75	**140 ºC**	1.82
Stiffness (60 Sec). MPa (-20°C)		238		350
m-Value (60 Sec) (-20°C)		0.301		0.333
Long-term aged binder (RTFO) residue (125°C)				
Viscosity, Pa.s @	**135 ºC**	4.02	**135 ºC**	2.13
	140 ºC	3.51	**140 ºC**	1.68
	145 ºC	2.71	**150 ºC**	1.10
Stiffness (60 Sec). MPa (-20°C)		200		277
m-Value (60 Sec) (-20°C)		0.289		0.308

BBR parameters measurements

In accordance with (ASTM D 6648-01), the BBR test was conducted on the RTFOT residues at -20°C for unmodified asphalt binders after short-term ageing as well as after long-term ageing, three duplicate beam samples (125x6.35x12.7mm) were tested after conditioning them in the methanol bath at the desired low temperature. Similarly, the same procedure was followed at -20°C for the 10% CR modified binders.

$$VTS = \frac{Log\,Log\,viscosity\ at\ T_2 - Log\,Log\,viscosity\ at\ T_1}{Log\,T_1 - Log\,T_2} \qquad \textbf{(3)}$$

Where, T1 and T_2 are the binder temperatures in Kelvin

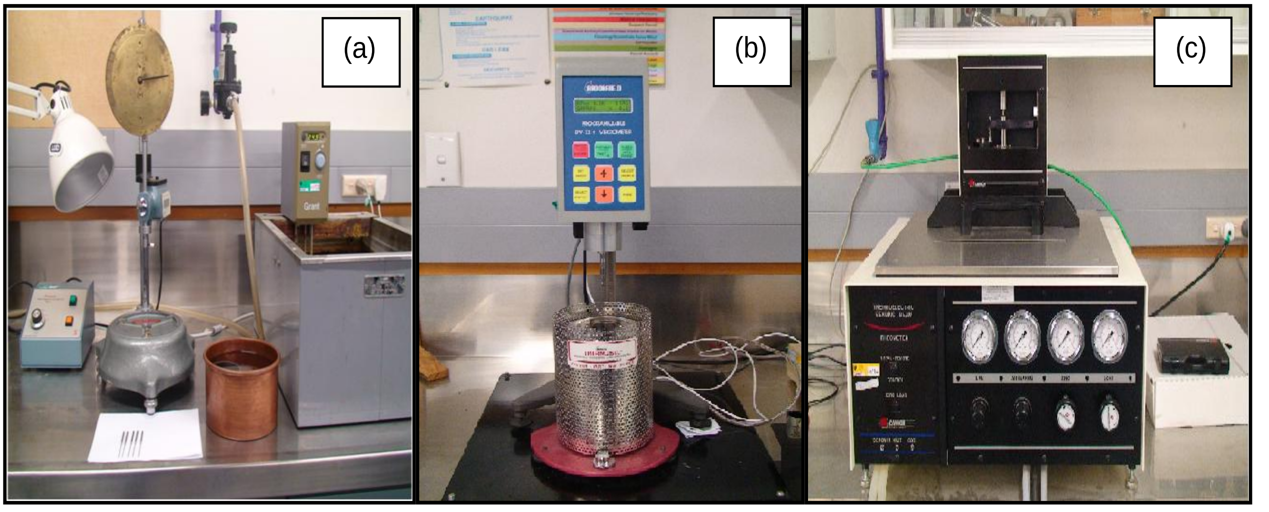

Figure 2: (a) Penetrometer, (b) Rotational Viscometer (VR), (c) Bending Beam Rheometer (BBR)

RESULTS AND DISCUSSION

Viscosity-temperature susceptibility index (VTS)

The Brookfield rotational viscometer was used to measure the viscosity of all unmodified asphalt binders and the 10% CR modified asphalt binder sources at different temperatures in order to study how they can be distinguished by using VTS parameters. Table 3 indicates for the VTS values, there was no major difference after subjecting unmodified asphalt binders to short-term and long-term ageing. This means that the temperature susceptibility of all the unmodified asphalt binder sources had no changes before and after ageing.

The 10% CR modified asphalt binders, however, displayed an improvement in VTS for unaged asphalt binders. A higher VTS value demonstrates high temperature susceptibility asphalt binder (Roberts *et al*. 1996). Table 3 shows that 10% CR modified asphalt binder source B had the highest VTS. There were significant differences in their VTS. Regardless of the asphalt binder sources, the VTS of short-term aged 10% CR modified asphalt binder and long-term aged 10% CR modified asphalt binder did not show significant differences among the asphalt binder sources. Generally, the asphalt binder sources showed significant improvement in terms of temperature susceptibility when they were modified with 10 % crumb rubber by weight. Equation 3 was used to calculate the VTS.

Table 3: Viscosity Temperature Susceptibility (VTS) with and without crumb rubber modification

Binder sources	**VTS of Source A**		**VTS of Source B**	
	0 % CR	**10 % CR**	**0 % CR**	**10 % CR**
Unaging	3.2	2.4	3	2.5
Short-term aging	3.3	2.5	3.2	2.5
Long-term aging	3.3	2	3.2	2.5

Penetration parameters

Penetration tests were conducted at three different temperatures, including room temperature, in order to study the behaviour of the different asphalt binder sources. Both unaged unmodified asphalt binders and unaged 10% CR modified asphalt binders were investigated. Temperature susceptibility parameters, PI and PVN, were measured. Table 4 summarises all the parameters for both the unmodified asphalt binder sources and the 10% CR modified asphalt binder sources.

Table 4: Penetration Index (PI) and Penetration-Viscosity Number (PVN) with and without crumb rubber modification

Binder sources	**Source A**		**Source B**	
	0 % CR	**10 % CR**	**0 % CR**	**10 % CR**
PI	**-0.88**	**0.98**	**-1.8**	**-0.35**
PVN	**-0.05**	**1.42**	**-0.24**	**1.41**

The asphalt binder that has a lower value of PI and PVN will have higher temperature susceptibility (Roberts *et al*. 1996). From this, the PI of the unmodified asphalt binder source B has the highest temperature susceptibility. Similarly, the PVN of the unmodified asphalt binders was presented showing a similar trend.

The CR modified asphalt binder has been found to significantly affect the temperature susceptibility of the various asphalt binder sources (Lee *et al*. 2008).Table 4 shows that PI and PVN were remarkably improved after the modification with the crumb rubber. Both PVN and PI methods showed a different temperature susceptibility order, however, all binder sources showed some improvement of the temperature susceptibility after the modification with crumb rubber. Figure 3 illustrates the relationship between penetration and temperature for both unmodified binder sources and 10% CR modified asphalt binder sources; the higher the temperature the higher the penetration.

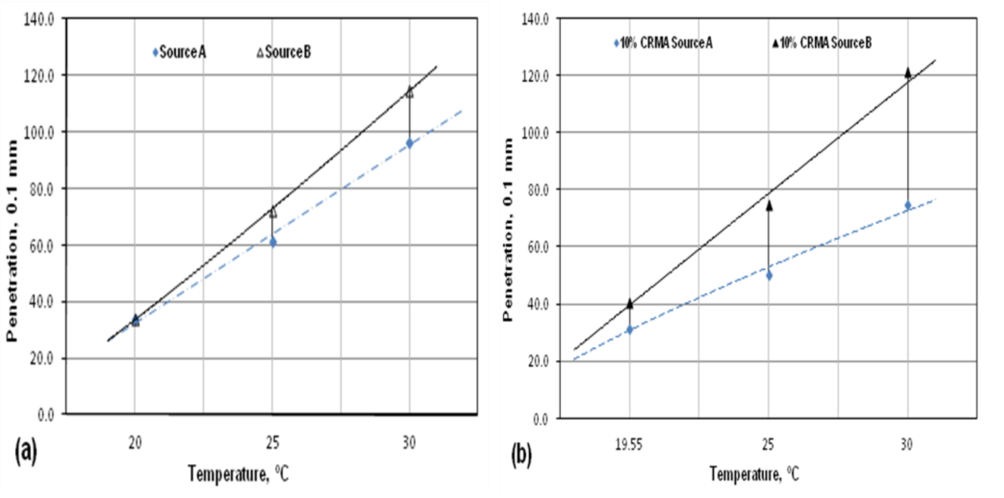

Figure 3: Penetration-Temperature relationship: (a) Unaged unmodified asphalt binders (b) Unaged 10% CR modified asphalt binders

Bending Beam Rheometer's parameters (BBR)

The BBR test is one of the Superpave tests that is able to imitate temperature and loading conditions. This test was conducted on the RTFOT residue after artificial short-term and artificial long-term ageing. Creep stiffness and m-value parameters were measured for both modified and unmodified asphalt binder sources at -20°C. Table 1 and Table 2 summarise the m-values and creep stiffness values.

From Figure 4, it can be seen that the m-value of the short-term aged asphalt binder source A decreased after being modified with 10% crumb rubber, but the m-value of source B was improved. However, regardless of the Superpave specification limit, the m-value of all the long-term aged asphalt binder sources had a significant improvement with the CR modifier.

Regardless of the modification, Figure 5 indicates an increase in the creep stiffness after a longer time of ageing of the asphalt binder source A, while source B showed a significant reduction in creep stiffness as ageing time increased. Asphalt binder source A behaved differently compared with source B; this was also observed for m-value. This discrepancy might be because of the waxy content and chemical composition of the asphalt. The molecular structure of the asphalt binder is affected differently with either heating or cooling due to differences in size and the chemical bonding type among asphalt binder sources (Asphalt Institute 1994). Generally, irrespective of the asphalt binder sources, 10% CR modified asphalt binders had a significant improvement in the creep stiffness that showed more resistance to thermal cracking at low temperatures.

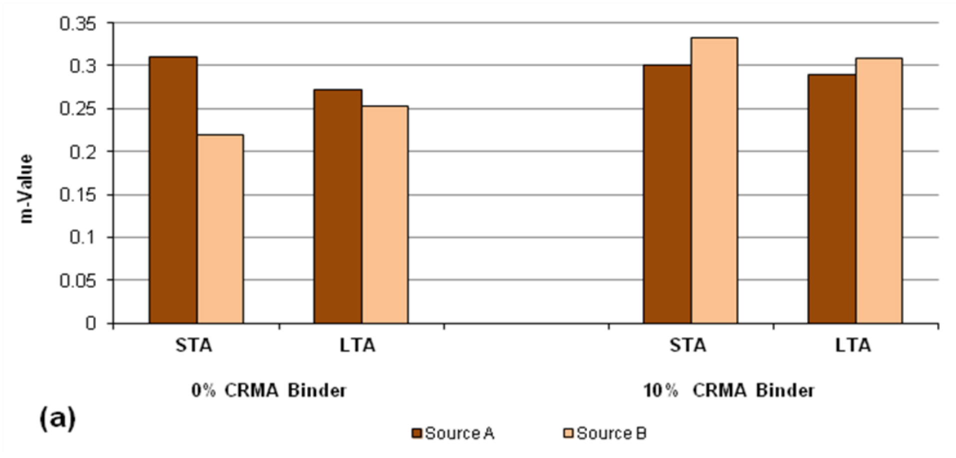

Figure 4: Effect of asphalt binders with and without CR modifier on m-value

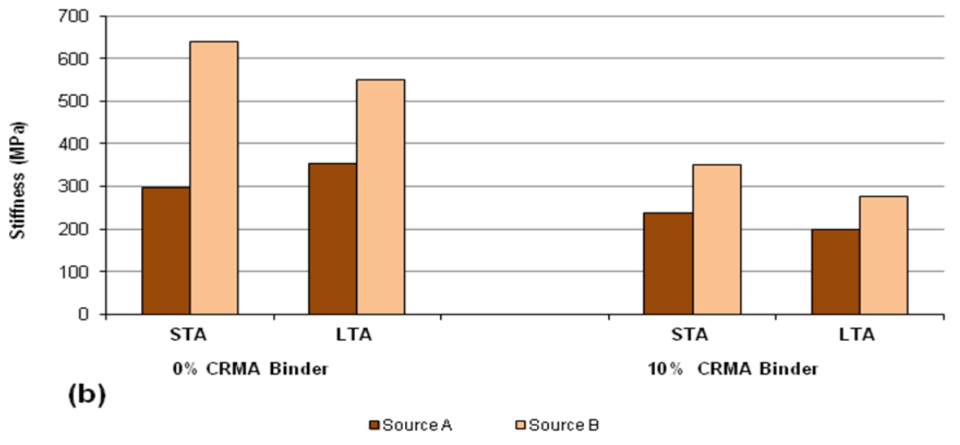

Figure 5: Effect of asphalt binders with and without CR modifier on creep stiffness

*STA: Short-term ageing, LTA: Long-term ageing

CONCLUSION

The investigation of the thermal characteristics of the New Zealand and overseas asphalt binders, with and without CR modifier, resulted in the following:

- The addition of the CR modifier significantly influenced the viscosity of the asphalt binder. High CR modifier content demonstrated higher viscosity of the asphalt binder which reduced the temperature susceptibility of the asphalt binder. This was observed not only after short-term ageing, but also after long-term ageing.

- For unmodified asphalt binder sources, the increase in viscosity due to long-term ageing was more pronounced compared to short-term ageing. However, for CR modified asphalt binder sources, the viscosity was lower for long-term ageing compared with short-term ageing.

- The improvement in both the m-value and creep stiffness was more influenced by the addition of crumb rubber.

- Better explanation of the asphalt binder behaviour could be achieved by investigating the effect of the molecular size on the rheological properties of the asphalt binders.

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