EVALUATION OF BITUMEN-RUBBER ASPHALT MANUFACTURED FROM MODIFIED BINDER AT LOWER VISCOSITY

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ABSTRACT

In South Africa, crumb tyre-modified bitumen commonly known as bitumen-rubber binder has viscosity limits specified by the current edition of TG1: The Use of Modified Bituminous Binders in Road Construction. As the crumb rubber is 'digested', the viscosity of the bitumen-rubber binder inevitably falls below the minimum specification, and such binder is contractually unacceptable for use. A bitumen rubber asphalt mix was manufactured using a single aggregate grading and bitumen-rubber binder specifically engineered to have a viscosity below that of the current TG1 specification. The mix was then evaluated in the laboratory using traditional Marshall design properties. The effect of change in binder viscosity on the optimum binder content was also investigated. The results obtained from this study demonstrate that further research studies are needed for low viscosity bitumen rubber and its applications in South Africa. Overall, the study provided insight into the behaviour of the low viscosity bitumen rubber for its use in road pavement construction.

1 INTRODUCTION

Bitumen-rubber blends are constituted by mixing bitumen, granulated reclaimed rubber tyre (15 - 25%) and a diluent (3 - 7%) or aromatic oil (3 - 7%) at high temperature (180 - 220ºC) (Horak 1984). The rubber particles swell initially as they absorb aromatic oils and/or aromatic fractions from the bitumen, resulting in an initial increase in viscosity. The rubber particles consist of a cohesive three dimensional network of polybutadiene and polyisoprene as a result of the sulphur – sulphur cross-linkages introduced by the vulcanization process during the manufacture of the tyres. The aromatically 'peptized' rubber particles are further dispersed and incorporated into the binder as the sulphur – sulphur linkages become thermally dissociated, resulting in a breakdown of the three dimensional network. As the rubber phase is dispersed within the bitumen phase, this process promotes a further increase in the viscosity of the bitumen-rubber blend with time. In the asphalt industry, this process is known as 'digestion' or 'reaction' of the rubber particles.

As the digestion of the bitumen-rubber blend proceeds, the thermal dissociation of the sulphur bonds leads to ever increasing dissociation of the three dimensional network of the polymer phase. A point is reached whereby the decrease in viscosity in the rubber phase due to loss of the three dimensional network provided by the sulphur links exceeds the increase in viscosity due to dispersion of the rubber phase. The bitumen-rubber blend therefore reaches a maximum viscosity, whereafter the viscosity decreases with time. This is illustrated in Figure 1.

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According to TG 1 (The Use of Modified Bituminous Binders in Road Construction), bitumen-rubber blends have a minimum specification of 2000 dPa.s for seal and asphalt mix-grade blends. Once the minimum specification limit (illustrated in Figure 1) has been reached, the bitumen-rubber blend is labelled ‘over-digested’. The viscosity behaviour of the blend beyond the specification is not well documented. The decrease in viscosity beyond the specification limit has been represented by two alternate possibilities, A or B. Traditionally, in South Africa, further use of the ‘over-digested’ blend has been restricted to mixing it with a fresh blend of bitumen-rubber up to a maximum proportion of 20% ‘over-digested’ blend into the fresh blend. One disadvantage of this approach is that the rate at which the over-digested binder is disposed of can be less than the rate of accumulation of the over-digested binder, especially during times of inclement weather.

This paper focuses on an investigation conducted for the possible use of ‘over-digested’ bitumen-rubber (i.e, ‘low-viscosity bitumen-rubber) in medium continuous hot-mix asphalt. The mix properties were compared with typical South African medium continuous mixes with standard bitumen rubber and 60/70 penetration grade bitumen.

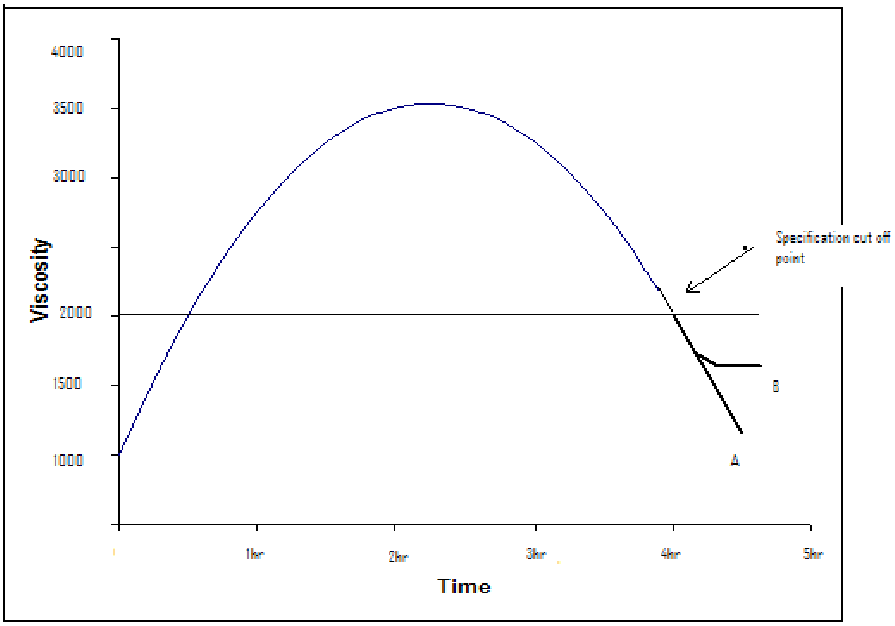

Figure 1: Viscosity-time specification for bitumen rubber

2 BITUMEN TESTING AND TEST RESULTS

Two different bitumen-rubber samples were received from Tosas for testing. The first batch of sample was a standard bitumen-rubber based on the specification requirements of TG 1, whereas the second batch, namely low-viscosity bitumen-rubber was a non-standard sample according to viscosity specifications of TGG1. In addition, tests were conducted on 60/70 penetration grade bitumen. The 60/70 bitumen was supplied by Much Asphalt. Table 1 presents detailed test results for the two bitumen-rubber samples. Values highlighted (bold) in the table do not conform to the TG1 requirements. Table 2 presents results obtained for the 60/70 penetration grade binder. It can be seen that all the test results of the 60/70 binder complied with the SANS specifications.

Table 1: Bitumen-rubber Properties

Property		Test Method	Standard Bitumen-Rubber	Low-Viscosity Bitumen-Rubber	Requirements of TG 1[2]
Softening Point (˚C)		MB-17	62	55	55 - 65
Viscosity @ 190˚C (dPa.s)		MB-13	25	**16**	20 - 50
Compression Recovery (%)	5 min	MB-11	83	**71**	> 80
	1 hr		84	**69**	> 70
	4 day		50	35	-
Resilience @ 25˚C (%)		MB-10	29	14	13 - 40
Flow (mm)		MB-12	30	**66**	10 – 50

Table 2: 60/70 penetration grade bitumen-rubber properties

Test	Test Method	Bitumen Sample	Specification SANS 307 (2005)
Penetration (10-1mm)	ASTM D5	65	60 – 70
Softening Point (˚C)	ASTM D36	48.8˚C	46 - 56
Viscosity @ 60 ˚C (Pa.s)	ASTM D4402	189	140 - 250
Viscosity @ 135˚C (Pa.s)	ASTM D4402	0.39	0.22 – 0.45
Spot Test (% Xylene)	AASHTO T102	Negative	30 max
After Rolling Thin Film Oven Treatment (RTFOT)			
RTFOT: Mass Change (%m/m)	ASTM D2872	0.08	0.3 max
Viscosity @ 60 ˚C: % of original	ASTM D4402	213	300 max
Softening Point (˚C)	ASTM D36	53.0	48 min.
Increase in Softening Point (˚C)	ASTM D36	4.2	7 max
Retained Penetration (10-1mm) % of 0riginal	ASTM D5	(44) 67	55 min.

2.1 Ageing characteristics of the bitumen rubber binders

Two ageing conditions were used to evaluate the viscosity of the standard and low viscosity bitumen rubber binders. For the short-term ageing condition, approximately 800g bitumen-rubber in a one litre tin of diameter 125 mm was placed in a forced-draught oven at 190˚C for a period of approximately 6 hours. The same sample size and setup as the short-term ageing was used for the long-term ageing except for ageing period of 48 hours instead of 6 hours.

The standard laboratory viscosity test (Brookfield Viscosity - ASTM D4402 2006) and field viscosity test (Rion “hand-held” viscometer: MB-13) were conducted on both blends of bitumen-rubber. Figures 3 and 4 show the test results for the standard bitumen-rubber and low viscosity bitumen-rubber, respectively. Figure 5 shows the test results for the long-term ageing for both blends of bitumen-rubber. These figures show the extent of changes in viscosity with time for the two types of bitumen-rubbers. The viscosities of the binders did not show significant change for the short term ageing. Detailed discussions on the test results are presented in next section (section 3).

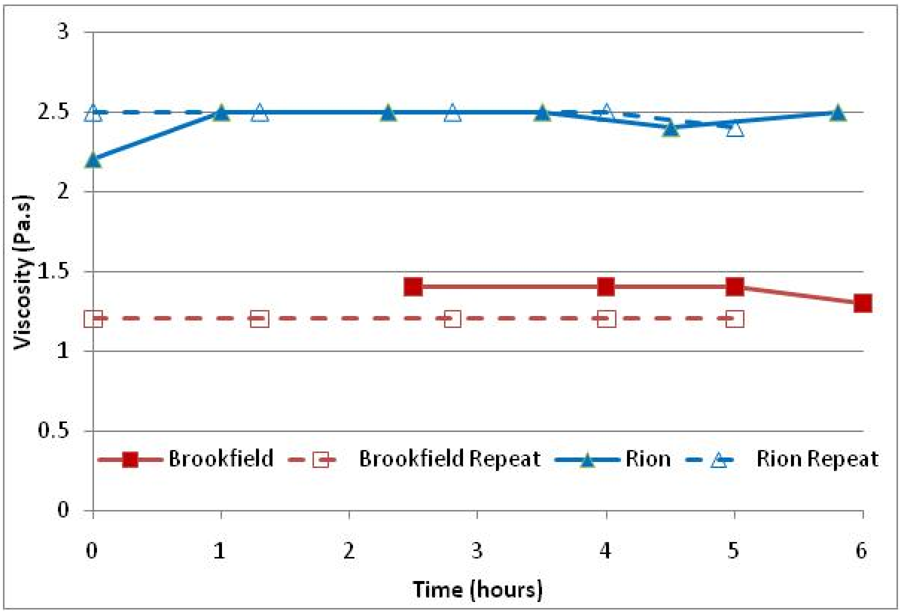

Figure 3: Short-term viscosity changes for the standard bitumen-rubber

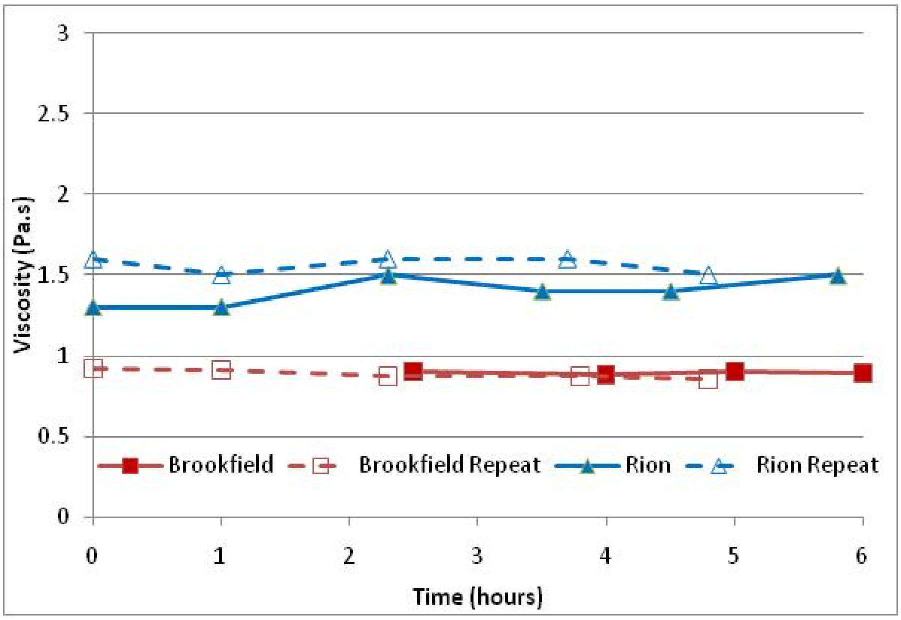

Figure 4: Short-term viscosity changes for the low viscosity bitumen-rubber

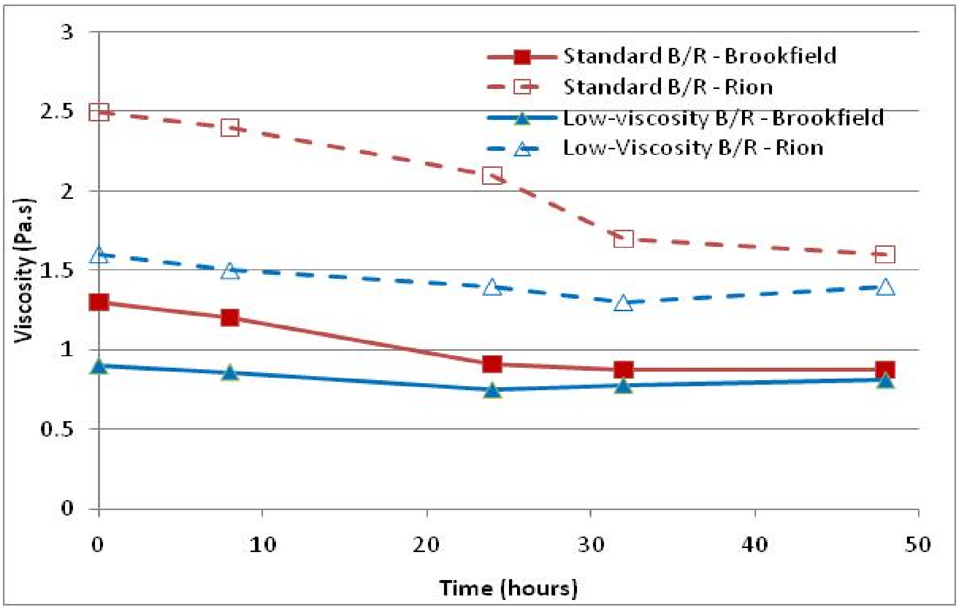

Figure 5: Long-term viscosity changes for the tow types of bitumen-rubber

3 DISCUSSION OF THE BINDER CHARACTERISTICS

Prior to the start of the study, it was suspected that the binder viscosity would influence the optimum binder content of the bitumen-rubber mix. The extent of change in viscosity with time for the bitumen-rubber binder was not known, and hence the effect of ageing (and viscosity change) of the binder on optimum binder content was not known. The effect of possible delays during the hot mix asphalt production, and the effect that such a delay may have on the initial mix design, motivated the studies on change in viscosity with time at high temperature.

The results of the ageing studies refer to heat changes only. No high shear mixing took place during the ageing study. It is important to remember that ageing in a plant may give different results when circulation with a gear pump simulates high shear mixing.

The short- and long-term ageing results in Figures 3 to 5 indicate that the absolute values obtained from the Brookfield and Rion viscometers differ significantly from each other by a factor that is dependent on the viscosity range of measurement. This is in agreement with previous experience, and such differences are to be expected when using these two different measuring systems to characterize a two-phase system such as bitumen-rubber. The results do indicate, however, that the readings from the Brookfield viscometer display greater repeatability than those of the Rion viscometer.

The viscosity changes resulting from the long-term ageing (Figure 5), answer the question posed in the introduction as to the nature of the viscosity change in Figure 1. The viscosity change (in the absence of high shear mixing) approximates that of curve B in Figure 2, showing little change over time once a certain level of ‘over-digestion’ has been reached. Figure 5 indicates that with long-term ageing, the viscosity may even start increasing eventually as the base bitumen starts stiffening with oxidative ageing.

4 HOT-MIX ASPHALT TESTING

As mentioned earlier, a medium continuous asphalt mixes three different binders were investigated in this study. The three mixes were:

- Medium-continuous with 60/70 penetration-grade bitumen (COLTO);
- Medium-continuous with standard bitumen-rubber binder conforming to the requirements of TG 1 (SABITA Manual 19);
- Medium-continuous with low-viscosity bitumen-rubber binder, the properties of which are less stiff than the requirements of TG 12 (SABITA Manual 19).

Three asphalt briquettes were manufactured for each binder content and each mix to determine the optimum binder content using the Marshall design method (Mathew and Rao 2007).

4.1 Mix sample preparation

Figures 6 and 7 present the grading results of the 60/70 penetration-grade and bitumen rubber binder mixes, respectively. Overall, the grading results were reasonable when compared to the target and the specification limits grading. Note that Figure 7 presents the grading results for both blends of the two bitumen-rubber samples.

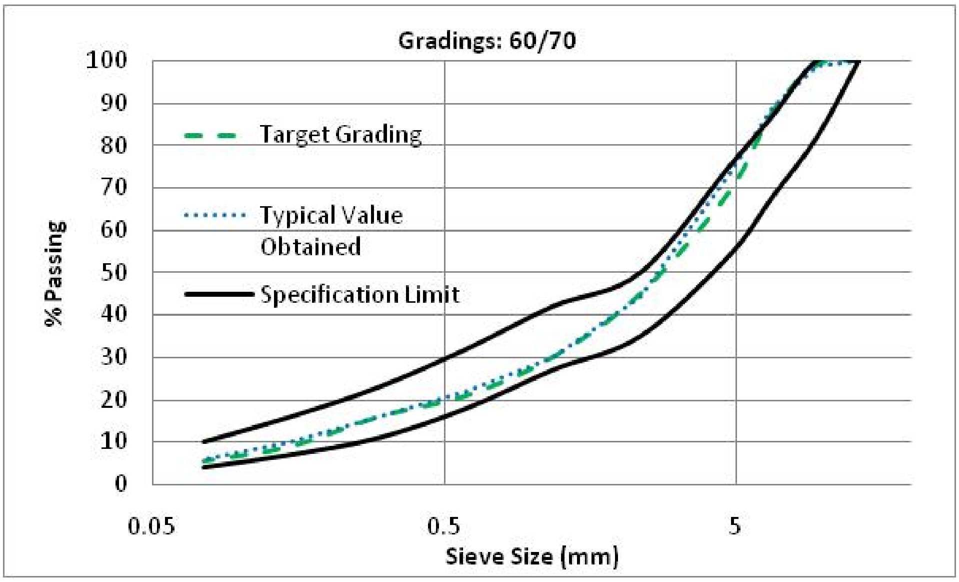

Figure 6: Aggregate grading results for the 60/70 penetration-grade mix

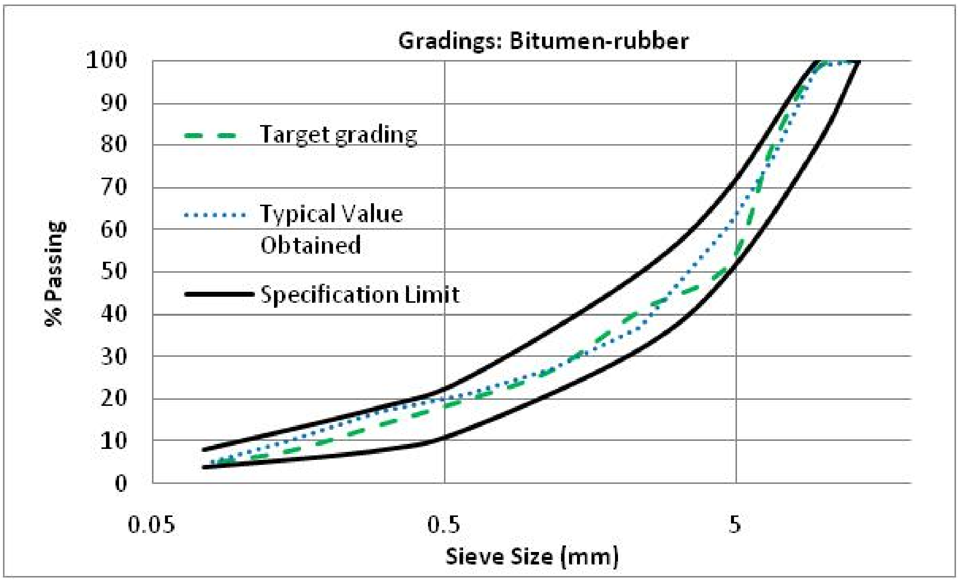

Figure 7: Aggregate grading results for the bitumen-rubber binder mix

5 MIX PROPERTIES AND OPTIMUM BINDER CONTENT

5.1 Determination of optimum binder content

Figures 8 to 10 present the plots of different mix properties (BRD, voids content and Stability) against binder contents for the 60/70 pen binder, standard bitumen-rubber and the low viscosity bitumen rubber, respectively. Notably, the Marshall stabilities obtained for the medium continuous mix using 60/70 penetration-grade bitumen, were comparable in data values to those obtained from the bitumen-rubber mixes. Generally, the Marshall stabilities for medium continuous mix using 60/70 penetration-grade bitumen should have been significantly higher in value than the bitumen-rubber mixes.

The binder content requirement of the bitumen-rubber mix using the low-viscosity bitumen-rubber binder was significantly lower compared to that of the ‘standard’ bitumen-rubber binder. This confirmed the earlier assertion that the optimum binder content could be affected by the viscosity of the bitumen-rubber binder.

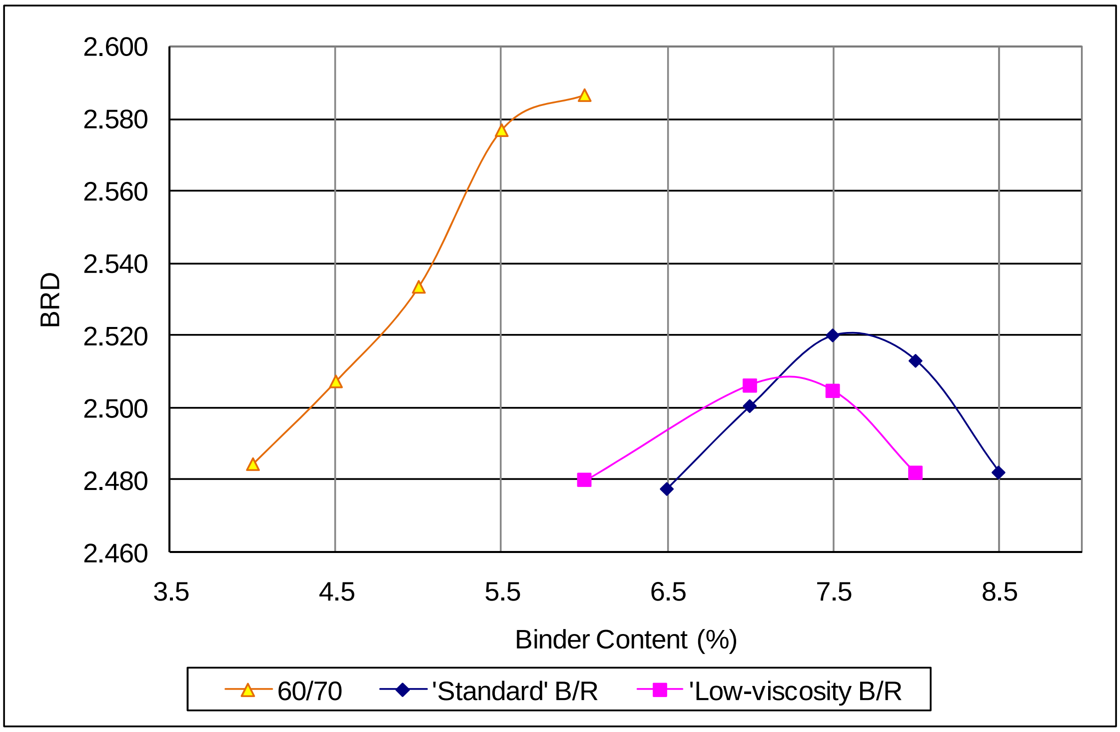

Figure 8: BRD versus binder contents for the three binders

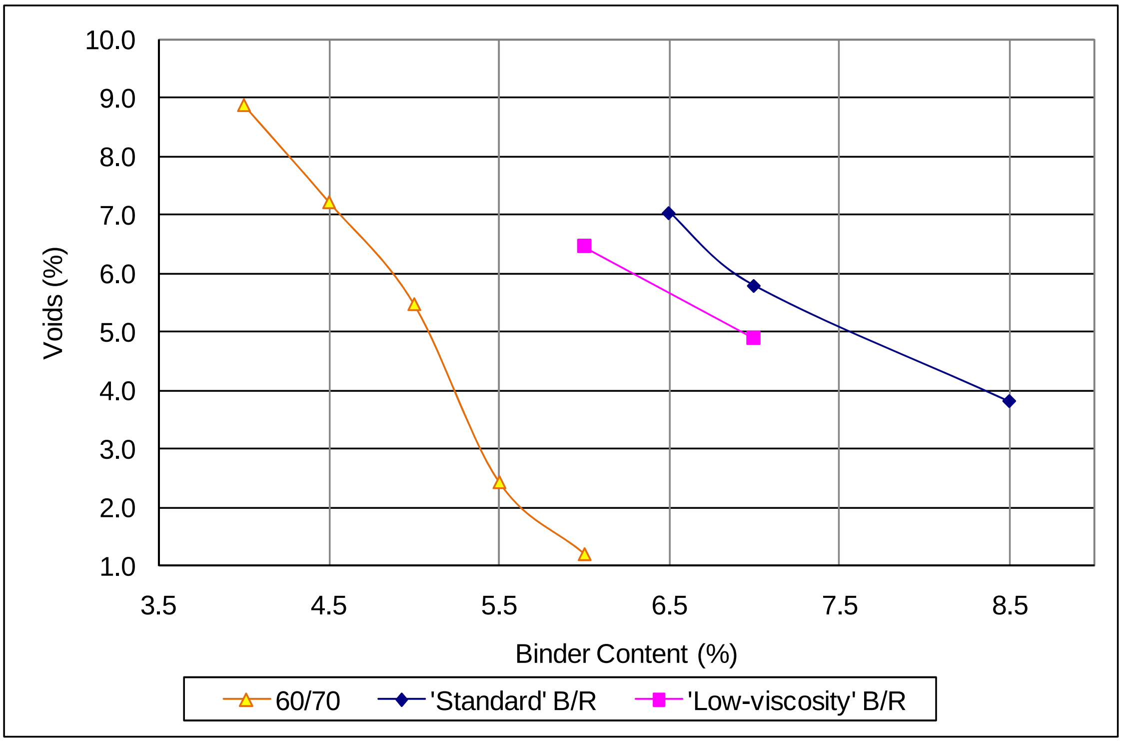

Figure 9: Voids content versus binder contents for the three binders

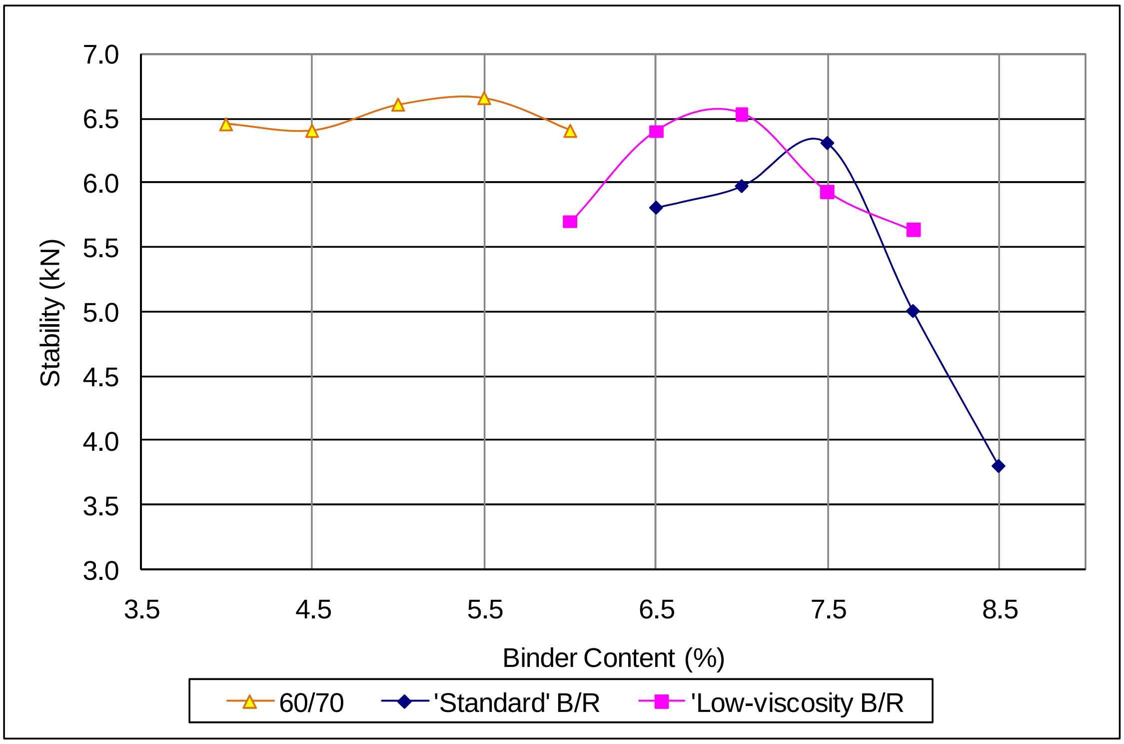

Figure 10: Stability versus binder contents for the three binders

5.2 Mix properties and standard mix specifications

Ten briquettes were compacted at optimum binder content for each mix using the Marshall compaction method. Six briquettes were for each mix compacted using 47 blows per side in accordance with the modified Lottman test procedure (ASTM 4867 2009). The remaining four briquettes for each mix were compacted with 75 blows per side to determine the ITS and the Marshall strength properties based on TMH1 C12T, and TMH1 C2 procedures, respectively. Table 3 shows the analysis results of the compacted briquettes for the three mixes compared with COLTO and SABITA specifications. As seen in Table 3, none of the three mixes meets the two major specification requirements in South Africa.

These results might be indicative of the quality of the mixes, the quality of manufacture/compaction and/or the testing carried out. It is a common knowledge that bitumen-rubber mixes give low ITS and Marshall stability results. However, some researchers believe that these low values are not necessarily a prediction of poor performance.

Table 3: Properties of medium continuous (MC) mix at optimum binder content

Properties	MC 60/70 binder	MC standard bitumen-rubber	MC low-viscosity bitumen-rubber	MC60/70 (COLTO/TRH 8)	MC bitumen-rubber (SABITA Manual 19)
Marshall Stability (kN)	10.4	6.8	5.8	8 – 18	8 min
Flow (mm)	4.1	5.1	6.0	2 – 4	2 – 5
ITS (kPa)	676	317	293	800 min	600 min
Modified Lottman (%)	62	50	63	N/a	75 min
MTRD	2.716	2.605	2.621	3 – 6	2 – 6
Average voids	5.7	3.3	4.2		

6 CONCLUSIONS

From a binder performance point of view, the presence of polymer in the low-viscosity bitumen-rubber binder should give acceptable (or even superior) performance compared to the performance of 60/70 penetration-grade bitumen. Some researchers have shown that significant resilience and elastic properties remain within bitumen-rubber even after 32 hours of over-digestion (Mac Carron 1986). This study initiated a comparative study of the binder and mix characteristics using standard bitumen-rubber, low-viscosity bitumen-rubber and a standard 60/70 penetration-grade bitumen.

Based on the findings from this study, additional repeat tests are recommended for the low viscosity bitumen rubber sample to ensure greater confidence in its future use in South Africa. In addition mechanical property tests including resilient or dynamic modulus, permanent deformation and fatigue characteristics tests are recommended for a medium continuous mix with the standard bitumen rubber, low viscosity rubber and typical 60/70 penetration grade binder. This may provide insight into the behaviour of the low viscosity bitumen rubber for its use in road pavement construction. Overall, this study provided the basis for further research and studies in low viscosity bitumen rubber and its applications in South Africa.

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