ASSESSMENT OF WATER AND TEMPERATURE SUSCEPTIBILITIES OF COLD RECYCLED BITUMINOUS EMULSION MIXTURES USING THE NAT IN THE ITSM MODE OF TESTING

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ABSTRACT

Energy efficiency, cost effectiveness and the need to minimise the impact of construction activities on the environment are major drivers responsible for cold recycled asphalt mixtures being considered as alternatives to hot mixtures in road works. However such mixtures are still regarded in some quarters as second class asphalt mainly because of durability problems. The indirect tensile stiffness modulus (ITSM) of such materials under the individual or combined effects of water and temperature is considered a good indicative property for assessing durability. The work reported herein involved the assessment of five cold bituminous emulsion mixtures (CBEMs) for ITSM under the effects of water and temperature. The five CBEMs were constituted such that the control specimens contained 100% virgin aggregate (VA), while the remaining four contained reclaimed asphalt pavements (RAP) with residual bitumen of varying penetrations of 5, 10, 15 and 20dmm. An aggregate gradation containing RAP, 5mm granite dust and granite mineral filler in the proportion 65:30:5 respectively was used for the RAP CBEMs. Bitumen emulsion content of 6.5% and pre-wetting water content of 1.5% were applied while the CBEMs were manufactured in the gyratory compactor at temperatures of 20^0C and 32^0C. The results of the water and temperature susceptibility tests indicated that irrespective of the CBEM type and the condition of curing and testing temperature for ITSM, CBEMs prepared at 32^0C consistently performed better than those prepared at 20^0C even at an ITSM test temperature of 40^0C, and overall, the RAP CBEMs performed better than the VACBEM. A trend which indicates that as the penetration of residual bitumen in RAP CBEMs increases, performance similarly increases was observed. These results suggest that problems associated with durability could be minimised when adequate quality control measures based on laboratory results are put in place and followed on site during production and the laying of such materials as road pavement layer.

Keywords: RAPs, Cold Asphalt, Durability, ITSM

INTRODUCTION

It is now a common knowledge that cold recycled asphalts are sustainable materials for road works. It has been reported that they are better off than hot asphalts in terms of energy efficiency, cost effectiveness and in the degree of impact on the environment when used for road rehabilitation works (Hakim and Fergusson, 2010; Thanaya, 2003; FHWA, 1997). However such mixtures are still regarded in some quarters as second class asphalt mainly because of durability problems. Soenen et al (2000) describe durability as the resistance of a material to changes caused by environmental exposure or the capacity of a material to keep its (original) properties over time. Durability of bituminous pavements is often affected by environmental factors (Needham, 1996). Carswell et al (2008) and Airey (2003) commented that durability of asphalt pavements is a major issue and that it is a fairly complex problem because it involves a number of parameters, with binder ageing and moisture damage considered as prominent.

Though presently, there is no universally accepted test for assessing the durability of cold recycled asphalts, the stiffness responses of such materials under the individual or combined effects of water and temperature could serve as good indicative tests for assessing their durability. The Indirect Tensile Stiffness Modulus (ITSM) test is the common means of measuring this property of bituminous mixtures in the UK. In fact the ITSM test has been reported as the most frequently conducted test in the Nottingham Asphalt Tester (Wu, 2009). Apart from being inexpensive, the test is simple and can be quickly conducted compared to other traditional means of testing the stiffness modulus of bituminous mixtures. Brown (1995) reported that up to 100 specimens can be tested for ITSM in a working day. Meanwhile, ascertaining temperature susceptibility of bituminous materials also gives a good knowledge of such materials in service under extreme conditions. Naturally bitumen is temperature susceptible i.e. becomes brittle at low temperatures and gets increasingly less viscous and ready to flow at high temperatures. While low temperatures make such materials susceptible to cracking they are prone to rutting at high temperatures. Under such hot conditions too, oxidative ageing is enhanced especially when the mixture is highly porous. This work examines the durability of the cold recycled asphalt mixtures in respect of water susceptibility, and their temperature susceptibility.

EXPERIMENTAL PROGRAMME

This study required ascertaining the temperature and water susceptibilities of cold recycled asphalt mixtures by the stiffness test as indicative of the durability of the materials. For stiffness, the Indirect Tensile Stiffness Modulus (ITSM) Test in line with BS DD 213: 1993 ITSM (Jacobson, 2002) was followed using the Nottingham Asphalt Tester (NAT). The Cooper Research Technology Gyratory Compactor was used for the compaction of the CBEM materials. A detailed account of the procedure followed for the manufacturing of the specimens is reported by Oke (2011). For the temperature susceptibility, the study examined the effects of CBEM material type, mixing and compaction temperature and compactive effort on the stiffness properties of the materials. Four specimens were studied at each observation level. In order to reduce variations, the same sets of specimens were tested for ITSM at each of the chosen testing temperatures of 20^{0}C, 30^{0}C and 40^{0}C. For the water susceptibility test, two protocols were used for the test. The first involved soaking specimens in water at 20^{0}C for 24hrs followed by testing for ITSM. The ITSM tests were conducted at 20^{0}C (mild condition) first and then at 30^{0}C (severe condition) after specimens had been conditioned for 2hrs at that temperature. Prior to soaking, the specimens were tested dry at 20^{0}C for ITSM. The second protocol similarly involved soaking specimens at 30^{0}C for 24hrs. These were followed by ITSM testing at 30^{0}C (severe condition) first and then at 20^{0}C (mild condition) after the specimens have been conditioned at that temperature for 2hrs. Similarly, four specimens were studied at each level of observation. It is worth mentioning that prior to soaking, vacuum saturation of all the specimens was carried out at a pressure of 140mbar for 10 minutes. Meanwhile, from physical observation, the vacuum saturation seemed not to have affected the specimens since none of the specimens bulged or collapsed/disintegrated in the process.

MATERIALS TESTED

Five cold bituminous emulsion mixtures (CBEMs) were tested during this exercise as follows:

1. VACBEM - 100% virgin binder and aggregates
2. 5dmmCBEM - 65% RAP (recovered pen = 5dmm)
3. 10dmmCBEM - 65% RAP (recovered pen = 10dmm)
4. 15dmmCBEM - 65% RAP (recovered pen = 15dmm)
5. 20dmmCBEM - 65% RAP (recovered pen = 20dmm)

The CBEMs listed in 2 to 5 were constituted in the ratio 65:30:5 for RAP, fine aggregate (5mm) and filler respectively and the RAP was made in the laboratory (Oke et al, 2010) from aged 20mm Dense Bitumen Macadam (DBM) with 4.25% binder content. The VACBEM was similarly constituted except that the RAP was replaced with virgin aggregate and the gradation used was 20mmDBM (TRRL and DFID, 2002). Granite aggregates were used throughout. The choice of aggregate and RAP ageing was made to reflect conditions in Nigeria which was the subject of a wider study of which this work formed part. Tests were conducted at 20, 30 and 40^{0}C. The pre-wetting water content was 1.5% by aggregate mass and 6.5% of cationic bitumen emulsion (with water/bitumen ratio of 2:3) was used in all the mixtures. The penetration and softening point of the residual bitumen in the emulsion were determined as 48dmm and 51.4^{0}C respectively. Mixing and compaction temperatures of 20^{0}C and 32^{0}C were maintained throughout to simulate typical low and high ambient temperatures in the tropics. All the specimens were compacted in the gyratory compactor using 100 and 200 gyrations, 600kPa pressure and a 1.25^0 angle of gyration. The materials were either conditioned to intermediate life (40^{0}C over 72hrs) or fully cured (60^{0}C over 96hrs) conditions following extrusion after 24hrs in the mould. For each condition, four specimens were tested and the quoted values are averages of the four.

TEST RESULTS

Table 1 details a summary of the ITSM results along with the respective average air void contents of the specimens for the temperature susceptibility of the cold recycled asphalts. Tables 2 and 3 detail the summary of ITSM results along with the respective average air void contents of the specimens for Protocols 1 and 2 for the water susceptibility test.

Table 1 Summary of ITSM Results for Temperature Susceptibility of CBEMs

CBEM Condition	Testing Condition	VA CBEM	5dmm CBEM	10dmm CBEM	15dmm CBEM	20dmm CBEM
I.L. (32,100)	ITSM @20^{0}C (MPa)	2424	2071	2280	2387	2448
	ITSM @30^{0}C (MPa)	1298	1058	1265	1486	1248
	ITSM @40^{0}C (MPa)	591	483	512	631	501
	Ave. Air voids (%)	17.6	16.5	15.1	12.9	12.9
I.L. (20,100)	ITSM @20^{0}C (MPa)	1982	1869	1459	1773	2127
	ITSM @30^{0}C (MPa)	852	934	705	1007	1109
	ITSM @40^{0}C (MPa)	378	386	317	388	467
	Ave. Air voids (%)	18.7	18.7	19.9	17.2	15.9
I.L. (32, 200)	ITSM @20^{0}C (MPa)	2428	2190	2383	2378	2510
	ITSM @30^{0}C (MPa)	1195	1108	1307	1260	1333
	ITSM @40^{0}C (MPa)	495	442	444	585	493
	Ave. Air voids (%)	15.7	15.8	14.1	12.5	11.5
I.L. (20,200)	ITSM @20^{0}C (MPa)	1526	1623	1483	1817	2335
	ITSM @30^{0}C (MPa)	576	682	778	1014	1124
	ITSM @40^{0}C (MPa)	313	317	298	377	455
	Ave. Air voids (%)	19.1	18.4	18.3	15.8	14.5
F.C. (32,100)	ITSM @20^{0}C (MPa)	2704	2267	2752	3085	3665
	ITSM @30^{0}C (MPa)	1389	1306	1576	1920	1663
	ITSM @40^{0}C (MPa)	550	441	606	694	702
	Ave. Air voids (%)	17.2	16.3	15.9	13.3	13.0
F.C. (20,100)	ITSM @20^{0}C (MPa)	2110	1631	1729	1930	2620
	ITSM @30^{0}C (MPa)	1108	723	944	1094	1337
	ITSM @40^{0}C (MPa)	451	378	391	430	581
	Ave. Air voids (%)	19.6	19.0	19.6	18.6	16.5
F.C. (32, 200)	ITSM @20^{0}C (MPa)	2860	2584	3216	3557	3900
	ITSM @30^{0}C (MPa)	1502	1374	1732	1839	1816
	ITSM @40^{0}C (MPa)	644	482	738	752	667
	Ave. Air voids (%)	17.7	15.3	13.3	12.6	11.9
F.C. (20,200)	ITSM @20^{0}C (MPa)	2174	1814	1787	2006	2826
	ITSM @30^{0}C (MPa)	1046	926	994	1137	1404
	ITSM @40^{0}C (MPa)	463	436	408	413	555
	Ave. Air voids (%)	18.1	18.1	18.7	17.3	15.3

Note: ***F.C.*** *= Fully Cured;* ***I.L.*** *= Intermediate Life*
Numbers in parenthesis = mixing and compaction temperature in ^{0}C, *number of gyrations.*

DISCUSSION ON TEMPERATURE SUSCEPTIBILITY OF CBEMs

From Table 1, the relevant results for intermediate life of curing show that the ITSM responses for the CBEMs were generally below 2500MPa irrespective of testing temperature. This observation is not unexpected as the CBEMs are still evolving at this point. The CBEMs did not follow a distinct trend at intermediate life when compared to those that had

Table 2 ITSM Results of Water Susceptibility of CBEMs for Protocol 1

CBEM Condition	Testing Condition	VA CBEM	5dmm CBEM	10dmm CBEM	15dmm CBEM	20dmm CBEM
I.L. (32,100)	At 20⁰C Dry	2368	2089	2169	2360	2474
	At 20⁰C to 20⁰C Wet	1170	1422	1655	2263	2169
	At 20⁰C to 30⁰C Wet	390	422	496	685	661
	Air voids (%)	17.3	16.4	15.7	13.3	11.8
I.L. (32,200)	At 20⁰C Dry	2478	2203	2395	2381	2486
	At 20⁰C to 20⁰C Wet	1147	1430	1687	2251	2315
	At 20⁰C to 30⁰C Wet	358	436	576	638	697
	Air voids (%)	16.6	15.2	14.1	12.2	10.3
F.C. (32,100)	At 20⁰C Dry	2546	2183	2659	3016	3670
	At 20⁰C to 20⁰C Wet	1435	1554	2061	2707	2869
	At 20⁰C to 30⁰C Wet	489	529	813	939	1093
	Air voids (%)	18.7	16.3	16.3	13.5	13.1
F.C.(32,200)	At 20⁰C Dry	2918	2531	3173	3652	3949
	At 20⁰C to 20⁰C Wet	1616	1893	2562	3008	3680
	At 20⁰C to 30⁰C Wet	634	621	866	1238	1419
	Air voids (%)	16.7	16.1	13.4	12.9	12.0

Table 3 ITSM Results of Water Susceptibility of CBEMs for Protocol 2

CBEM Condition	Testing Condition	VA CBEM	5dmm CBEM	10dmm CBEM	15dmm CBEM	20dmm CBEM
I.L. (32,100)	At 20⁰C Dry	2402	2075	2153	2340	2495
	At 30⁰C Dry	948	1108	1079	1352	1426
	30⁰C to 30⁰C Wet	267	391	522	706	624
	30⁰C to 20⁰C Wet	479	908	1089	1486	1502
	Air voids (%)	17.1	16.2	16.0	12.9	12.1
I.L. (32,200)	At 20⁰C Dry	2485	2146	2379	2336	2500
	At 30⁰C Dry	1360	1067	1315	1357	1544
	30⁰C to 30⁰C Wet	273	569	670	777	778
	30⁰C to 20⁰C Wet	607	1173	1372	1550	1811
	Air voids (%)	17.2	16.2	15.0	12.9	11.6
F.C. (32,100)	At 20⁰C Dry	2608	2253	2730	3027	3655
	At 30⁰C Dry	1520	1188	1515	1690	1620
	30⁰C to 30⁰C Wet	588	601	852	1055	1067
	30⁰C to 20⁰C Wet	1485	1373	1778	2264	2603
	Air voids (%)	16.8	16.9	15.0	12.9	12.1
F.C.(32,200)	At 20⁰C Dry	2901	2575	3105	3654	3901
	At 30⁰C Dry	1476	1254	1609	1884	1882
	30⁰C to 30⁰C Wet	658	816	847	1152	1372
	30⁰C to 20⁰C Wet	1359	1641	1966	2319	2859
	Air voids (%)	15.8	15.1	14.3	12.9	11.8

*Note: **F.C.** = Fully Cured; **I.L.** = Intermediate Life*
Numbers in parenthesis = mixing and compaction temperature, number of gyrations

been fully cured. Also the effect of mixing and compaction temperature is not as clear as observed for the fully cured condition.

ITSM responses tested at 20^{0}C for fully cured CBEMs mixed and compacted at 32^{0}C were generally above 2500MPa (with the exception of the 5dmmCBEM) irrespective of the compactive effort applied. However, the responses dropped to around 1500MPa for ITSM tests conducted at 30^{0}C and further down to around 650MPa for tests conducted at 40^{0}C on the same specimens. The 5dmmCBEM showed the least good performance for the three test temperatures.

The results confirm the superiority of CBEMs prepared at 32^{0}C compared to those of 20^{0}C. Irrespective of the CBEM type, the condition of curing and testing temperature for ITSM, CBEMs prepared at 32^{0}C consistently performed better than those prepared at 20^{0}C even at ITSM test temperature of 40^{0}C.

Overall, the results indicate that all the materials prepared at 32^{0}C, 100 gyrations have least loss in ITSM which suggests just enough compactive effort along with appropriate temperature for preparation of CBEMs. More importantly, the VACBEM as observed here indicates that it has the highest temperature susceptibility.

DISCUSSION ON WATER SUSCEPTIBILITY OF CBEMs

A close inspection of the Tables 2 and 3 indicate that the VACBEM has the poorest performance for the severe conditions irrespective of the preparation method though with an exception to materials prepared at 32^{0}C, 200 gyrations in Protocol 1, where it indicates a slightly better ITSM response than the 5dmmCBEM. For Protocol 2 which simulated the recovery of the CBEMs after experiencing a severe condition, the ITSM responses indicated a poor recovery in stiffness for the VACBEM compared to the others except for materials prepared at 32^{0}C, 100 gyrations where it performed reasonably well though only a little better than the 5dmmCBEM. For the two protocols, materials prepared using the higher compactive effort clearly performed better than those with less compactive effort except for the intermediate life in Protocol.

Although the two protocols have proved useful by clearly ranking the CBEMs, Protocol 2 appeals more as it also simulates and assesses performance after the recovery process of the CBEMs which is very important for performance in service. However in order to ascertain this, percentage in loss for each individual CBEM was further investigated. The percentage loss was relative to the ITSM response at 20^{0}C (dry).

Tables 4 and 5 detail the percentage losses in ITSM of the CBEMs as a result of the combined damaging effects of water and temperature. The table for Protocol 1 indicates a clear and logical trend for all the CBEMs. For all the conditions investigated here, the VACBEM clearly indicate the worst performance recording the highest losses both for the severe and mild conditions. In fact for the mild conditions, values as high as 52% loss were observed for VACBEM, while the 5dmmCBEM which is next in rank recorded a little above 30% loss for the same conditions. For the higher compactive effort, the 20mmCBEM consistently recorded the least loss i.e. the best performance for the severe condition of testing irrespective of the curing condition applied on the CBEMs. Materials prepared at 32^{0}C and 200 gyrations (fully cured) were clearly ranked for both the mild and severe conditions of testing in a logical order starting with VACBEM up the range to the 20dmmCBEM, the 15dmmCBEM contrary to logic recorded the overall best performance. The results indicated that CBEMs prepared at this level have the best resistance under severe conditions.

The Figures 1 to 4 for Protocol 2 detail responses for both temperature susceptibility and water damaging effects on the CBEMs. This has been purposely done in order to ascertain the effectiveness of the temperature susceptibility test at being able to rank the materials. It is obvious from the figures that measurements for the temperature susceptibility did not follow a clear order compared to the water damaging test. Although the trend for the severe condition here were not completely consistent with the observations made for CBEMs prepared at 32^{0}C, 200 gyrations, overall again, the VACBEM indicated the worst performance for both the severe and mild conditions (recovery path) with the 15dmmCBEM still having the best performance.

For the recovery process in Protocol 2, the VACBEM achieved a significant improvement for materials prepared at 32^{0}C, 100 gyrations just as the RAP CBEMs. The recovery path for other conditions was generally poor for the VACBEM while it was rather impressive for the RAP CBEMs. The poor performance of the VACBEM could have been partly as a result of its high air void content, while the lower air voids of the RAP CBEMs could have been partly responsible for their better performance. More importantly, it is believed that the residual bitumen in the severely aged

Table 4 Results of Percentage Loss in ITSM due to Water Susceptibility for Protocol 1

CBEM Condition	Percentage Loss Description	VA CBEM	5dmm CBEM	10dmm CBEM	15dmm CBEM	20dmm CBEM
I.L. (32^oC, 100)	Percentage Loss in ITSM from 20^oC Dry to 20^oC Wet	50.6	31.9	23.7	4.1	12.3
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	83.5	79.8	77.1	71.0	73.3
I.L. (32^oC,200)	Percentage Loss in ITSM from 20^oC Dry to 20^oC Wet	53.7	35.1	29.6	5.4	6.9
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	85.6	80.2	75.9	73.2	72.0
F.C. (32^oC,100)	Percentage Loss in ITSM from 20^oC Dry to 20^oC Wet	43.6	28.8	22.5	10.3	21.8
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	80.8	75.8	69.4	68.9	70.2
F.C. (32^oC,200)	Percentage Loss in ITSM from 20^oC Dry to 20^oC Wet	44.6	25.2	19.2	17.6	6.8
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	78.3	75.5	72.7	66.1	64.1

Table 5 Results of Percentage Loss in ITSM due to Water Susceptibility for Protocol 2

CBEM Condition	Percentage Loss Description (%)	VA CBEM	5dmm CBEM	10dmm CBEM	15dmm CBEM	20dmm CBEM
I.L. (32^oC, 100)	Percentage Loss in ITSM from 20^oC Dry to 30^oC Dry	60.5	46.6	49.9	42.2	42.8
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	88.9	81.2	75.8	69.8	75.0
	Percentage Loss in ITSM from 20^oC Dry to 30^oC -20^oCWet	80.1	56.2	49.4	36.5	39.8
I.L. (32^oC,200)	Percentage Loss in ITSM from 20^oC Dry to 30^oC Dry	45.3	50.3	44.7	41.9	38.2
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	89.0	73.5	71.9	66.8	68.9
	Percentage Loss in ITSM from 20^oC Dry to 30^oC -20^oCWet	75.6	45.4	42.3	33.7	27.6
F.C. (32^oC,100)	Percentage Loss in ITSM from 20^oC Dry to 30^oC Dry	41.7	47.3	44.5	44.2	55.7
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	77.4	73.3	68.8	65.2	70.8
	Percentage Loss in ITSM from 20^oC Dry to 30^oC -20^oCWet	43.0	39.0	34.9	25.2	28.8
F.C. (32^oC,200)	Percentage Loss in ITSM from 20^oC Dry to 30^oC Dry	49.1	51.3	48.2	48.5	51.7
	Percentage Loss in ITSM from 20^oC Dry to 30^oC Wet	77.3	68.3	72.7	68.5	64.8
	Percentage Loss in ITSM from 20^oC Dry to 30^oC -20^oCWet	53.2	36.3	36.7	36.6	26.7

*Note: **F.C.** = Fully Cured; **I.L.** = Intermediate Life*
Numbers in parenthesis = mixing and compaction temperature, number of gyrations

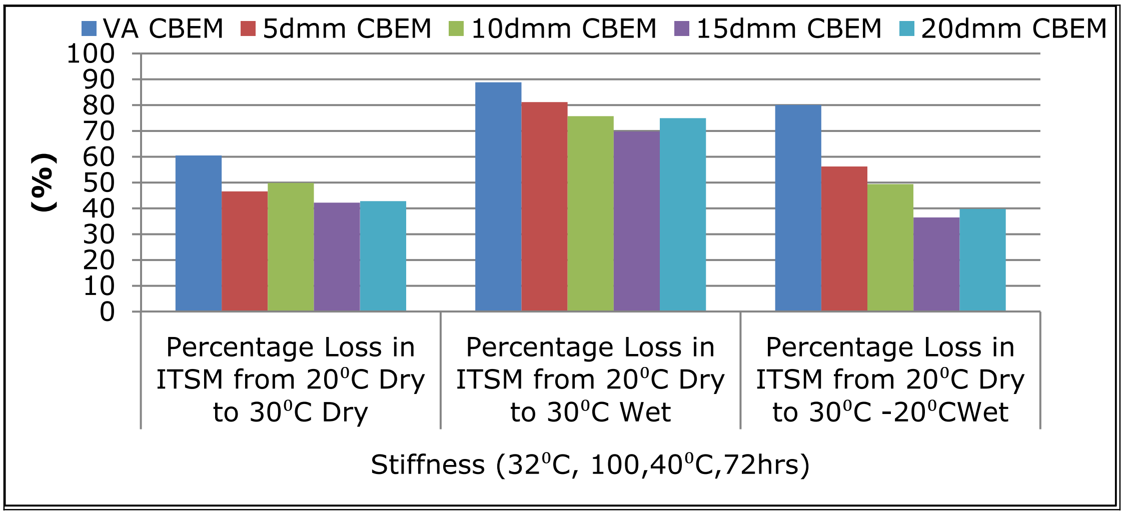

Figure 1 Water Susceptibility of CBEMs at Intermediate Life Condition Mixed and Compacted at 32^{0}C, 100 gyrations (Protocol 2)

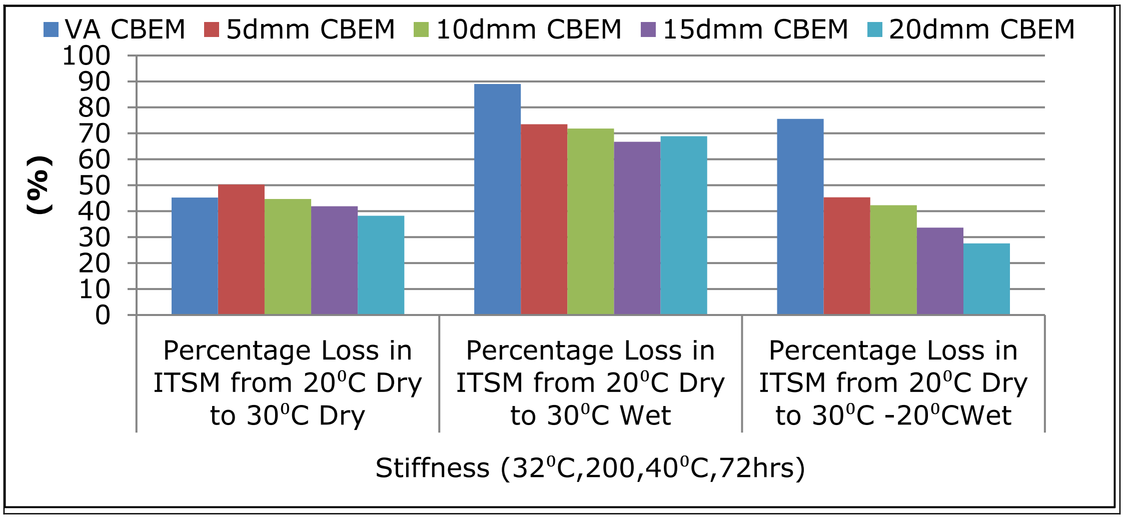

Figure 2 Water Susceptibility of CBEMs at Intermediate Life Condition Mixed and Compacted at 32^{0}C, 200 gyrations (Protocol 2)

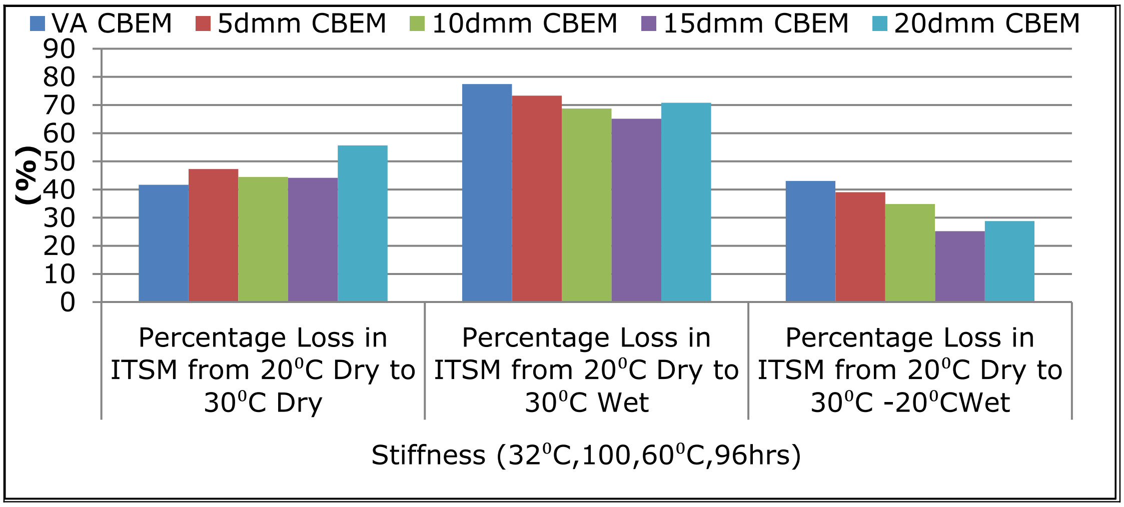

Figure 3 Water Susceptibility of CBEMs at Fully Cured Condition Mixed and Compacted at 32^{0}C, 100 gyrations (Protocol 2)

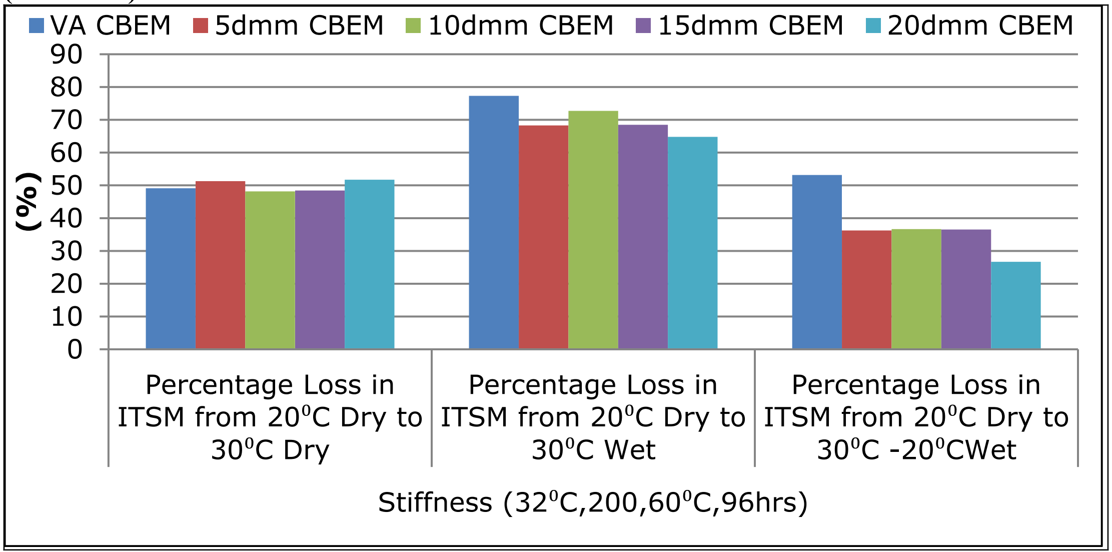

Figure 4 Water Susceptibility of CBEMs at Fully Cured Condition Mixed and Compacted at 32^{0}C, 200 gyrations (Protocol 2)

RAPs that constitute the RAP CBEMs could possibly have been rejuvenated thus providing a larger volume of active binder. This must have been responsible for the impressive performance observed for these RAP CBEMs in the recovery process and generally in being able to reasonably contain the water damaging effects when compared to the VACBEM. Comparing the results obtained here with the results of the temperature susceptibility tests, it is however likely that those CBEM materials prepared at 20^{0}C might not have been able to contain the water damaging effects as those prepared at 32^{0}C did. While this is an interesting area for future investigations, the two water susceptibility protocols as conducted here have been able to rank the CBEMs compared to the temperature susceptibility tests.

CONCLUSION

- ITSM responses tested at 20^{0}C for fully cured CBEMs mixed and compacted at 32^{0}C were generally above 2500MPa (with the exception of the 5dmmCBEM) irrespective of the compactive effort applied.
- The responses dropped to around 1500MPa for ITSM tests conducted at 30^{0}C and further down to around 650MPa for test conducted at 40^{0}C on the same specimens.
- Irrespective of the CBEM type, the condition of curing and testing temperature for ITSM, CBEMs prepared at 32^{0}C consistently performed better than those prepared at 20^{0}C even at an ITSM test temperature of 40^{0}C.
- The CBEM materials prepared at 32^{0}C, 100 gyrations have least loss in ITSM due to high temperature which implies just enough compactive effort along with appropriate temperature for preparation of CBEMs.
- VACBEM as observed here shows the highest temperature susceptibility.
- The RAP CBEMs performed better than the VACBEM in water susceptibility.
- In Protocol 2 where recovery was monitored after the CBEMs were subjected to severe conditions, the VACBEM performed poorly compared to the other CBEMs.
- The poor performance of the VACBEM could have been partly caused by its high air void content, while the lower air voids of the other CBEMs could have been partly responsible for their better performance. More importantly, it is believed that the residual bitumen in the severely aged RAPs that constitute the RAP CBEMs is possibly being rejuvenated thus causing the RAP CBEMs to have larger volume of active binder. Furthermore, the performance could similarly be linked to the possible changes in the volumetrics of the RAP CBEMs as a result of the softening of the residual bitumen in the RAP and not necessarily rejuvenation.

- A trend which indicates that as the penetration of residual bitumen in RAP CBEMs increases, performance similarly increases was observed.

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