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INVESTIGATING EFFECTS OF AMINE BASED MODIFIER ON RECYCLED ASPHALT SHINGLES BLENDING

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ABSTRACT

A laboratory study was conducted to investigate the effects of Amine based modifier on rheological characteristics of particle filled viscous medium such as asphalt binder in presence of Recycled Asphalt Shingles (RAS). In this study, virgin asphalt binder (PG 64-22), three different percentages (20, 30 and 40%) of tear-off shingles and modifiers; Rediset, Evotherm and Bio-binder were used. The tear-off shingles acquired from local reroofing company in Greensboro, North Carolina; were finely grinded (85% passing of sieve # 200). The virgin binder and different percentages of RAS were then blended at 180°C using shearing speed of 400 rpm. Following that themixture was blended with 1.5% of Rediset, 0.5% of Evotherm and 5% of bio-binder. The properties of the blended binder were studied using the Rotational Viscometer (RV) equipped with two different spindle types:- One was Smooth Cylindrical spindle (SC4-27D) and the other one was Vane spindle (V 73). The analysis showed that the viscosity was increased with increasing the RAS percentage. Furthermore, the viscosity measured by vane spindle was continuously higher than the value measured by smooth spindle; however the difference between the two measurements reduced as the blending were improved using modifiers. Moreover, temperature found to be the main contributor to reduction of the viscosity in both spindles cases. In addition the coefficient of variation was significantly lower in the case of vane spindle, indicating that the vane spindle could be more appropriate in measuring viscosity of particle filled viscous medium such as RAS asphalt. Based on the experimental result an empirical index called blending index was introduced in this study to measure the blending behavior and status for modified mixtures. As expected it was found that the blending index increases as the temperature and rotational speed increases. In other word, higher temperature and shearing rate could enhance blending resulting in higher blending index. The blending index was further used as a laboratory measure to compare effectiveness of various additives in enhancing blending of RAS modified mixtures. It was shown that among three modifiers used in this study, the bio-binder was more effective to increase the blending index.

Keywords: Asphalt Binder, Recycled Asphalt Shingle (RAS), Recycled Asphalt Pavement (RAP), Hot Mix Asphalt (HMA), Modifiers, Theology, Spindle

1. INTRODUCTION

Environmental measures are becoming more dominant factors in decision making process of infrastructure and construction projects. In addition because of the fact that the global crude oil price has increased rapidly in the past decades, liquid asphalt price has grown up dramatically to the extent that the price of asphalt increased from $235/ton in 2004 to more than $635/ton in April 2013 (DOT, 2013). As a product derived from petroleum distillation, asphalt is becoming less available because the coking technologies allows refineries produce synthetic fuel from asphalt. This in turn, reduces the supply of asphalt available for road

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construction (Cleveland, 1993). Increasing concern for sustainable development and emphasis on materials conservation; re-use and recycling encouraged number of government and highways agencies to commission research and investigations to characterize and ultimately optimize. Recycled materials have to provide added value, i.e., similar performance to conventional materials as well as demonstrating cost effectiveness, in order to be acceptable (Widyatmoko, 2008). That is why pavement industry is emphasizing more and more on recycling of used asphalt resources while looking for substitutes for virgin asphalt (Fini *et al*., 2011a). Recycle materials could be crumb rubber, polymers, Recycled Asphalt Pavement (RAP), Recycled Asphalt Shingles (RAS), etc which provides attractive alternative solution to address the scarcity of the natural/virgin materials. Among these resources the use of RAS in road construction has been receiving more and more attention in recent years to reduce the consumption of the virgin asphalt binder.

In the construction and rehabilitation of asphalt pavements, large amounts of natural resources are used as aggregates and binders. These resources are limited and therefore the incorporation and reuse of bituminous aged asphalt is important and justified either by environmental issues or by economical. In US, more than 11 million tons of asphalt roofing materials are removed from roof every year (From Roof to Road, CIWMB). Among them 10 million tons from post-consumer (tear-off) and 1 million tons from post-consumer (manufacture scrap) which is the huge amount that will goes in waste. In fact, Roofing Asphalt Shingles (RAS) has been used in paving practices since early 1990's as a portion of aggregate but in recent it has been used as binder in Hot Mix Asphalt (HMA). To date, some of the state agencies have allowed RAS to be used with certain maximum percentages in Hot Mix Asphalt (HMA). The maximum allowed percentage of RAS in most states has been around 5% by weight of the total aggregate. Some states limit allowable RAS type to only manufacture scrap, while other allow for application of tear-offs as well. For example, following the supplemental specification issued in 2011, the state of Ohio allowed the use of either manufacture's RAS or tear-off RAS depending on the particular pavement course (DOT, 2011). **Figure 1** shows the states that currently allows the utilization of RAS in HMA.

Many past studies showed that introduction of shingles into asphalt mixture can increase the stiffness of the mixtures which can in turn promote pavement resistance to rutting.

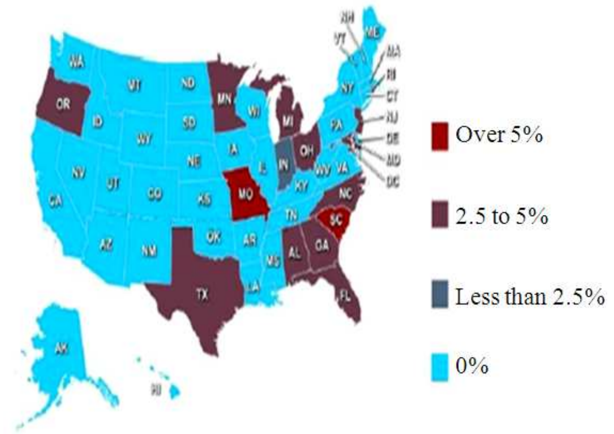


Fig. 1. Allowable percent of RAS in HMA (Scholz, 2010)

In addition application of roofing shingles can lead to reduction of virgin asphalt consumption required to produce HMA mixture. Laboratory studies indicated that incorporating shingle in asphalt mixture tends to improve temperature susceptibility and rutting resistance as well as fatigue life of pavement (Ali *et al*., 1995).

To studied the effect of introducing of the roofing shingles on the engineering properties of HMA by Burak and Ali (2004); and he found that the Marshall Stability values was increased when 1% shingle is introduced into the mixture. Moreover, the increased percentage shingle cause decreased the stability values. It has been also showed that at the concentration of up to 5% shingle, the stability values of mixture are still higher than the minimum value of the specification criteria; therefore, the resulting mixture meets the specification criteria. In addition, it has been reported that by incorporating 5% shingle in pavement construction, contractors can reduce the construction cost by $2.79/ton (Brock and Shaw, 1989). It has been further reported that introduction of shingles into asphalt can cause a significant increase in the stiffness of the asphalt binder (Foo *et al*., 1999). The use of shingle in a HMA mixture will generally improve the rutting resistance; however the mixture may show lower fatigue life and lower thermal cracking resistance. In such cases it has been recommended that the use of an appropriate softer virgin binder or modifiers to improve the fatigue and low temperature performance of the mixture.

There have been several studies on how to facilitate application of RAS without compromising workability and mechanical properties of the mixture including application of softer binder, mechanical grinding and wet processing as well as introduction of bio-binder to enhance workability (Mogawer *et al*., 2012). Grinding to ultra-fine particle size and blending with asphalt binder through a wet process has been reported to be effective in facilitating application of high percentage of RAS (Elseifi *et al*., 2012). In the wet process, the ground RAS is blended with the binder at high temperature prior to mixing with the aggregates. The proposed wet process allows for a better control of the chemical and physical reaction which occurs in the binder blend. Results of the rheological and stability testing indicate that RAS percentage as much as 20% can successfully used through a wet process.

From this study it was found that the aged RAS is the main constituent to increase the viscosity of the mixture which cause many distress on the pavement during preparation, compaction, mixing etc. So to address this issue many other softer binders also called modifiers has been in practices. As example Sasobit, Rediset, evotherm, bio- binder etc. And modifier have been used according to its properties and design guidelines. In order to establishing a design method suitable for a warm recycled mix has been studied in recent time through different test method. Dinis-Almeida *et al*. (2012) conducted the Marshall test, immersion compression test, water sensitivity test in his study and concluded that the temperature production and compaction of the mixtures influences the final results. In addition the best result were obtained for the mixtures compacted at 90°C and the mixtures compacted at 60°C, in most cases were excluded for failing to meet specified requirements.

2. EXPERIMENTAL PROGRAM

An experimental program was developed to investigate the effect of amine based modifiers addition on the rheological properties of recycled asphalt materials. Three different percentages of RAS modified mixtures were mixed with three different amine based modifiers separately. An empirical formula was proposed to identify the blending behaviors of the designed modified mixtures.

2.1. Materials

2.1.1. Virgin Binder

Un-modified binder which was classified as PG 64-22 according to the Superpave specification was selected for this study. It was used in an attempt to offset the potential mixture stiffening due to the use of high percentage of RAS in the mixture. Based on the viscosity of the binder, the mixing temperature was 180°C. **Table 1** shows properties of the virgin binder.

2.1.2. Roofing Asphalt Shingles (RAS)

The tear-off shingles used for this experiment was obtained from a local roofing company in Greensboro, North Carolina. Shingle was processed by grinding followed by sieving. An industrial Hamilton Beach grinder was used to create particles with 85% passing of sieve #200.

To conduct the experiment the virgin asphalt binder (PG 64-22) was blended with different percentages of RAS ranging from 20 to 40%. Mixing was performed utilizing a laterally attached oscillating mixer. Shearing was conducted at 400 rpm at 180°C. Mixing duration was 60 min.

2.1.3. Bio-Binder

Bio-binder is derived from non-petroleum based renewable resources like wood and corn. Recently, research efforts have suggested using a bio-binder along with the petroleum based asphalt to produce a bio-modified binder (Fini *et al*., 2011b; 2012). So the bio-binder could be an alternative to petroleum based asphalts. In this study bio-binder used was produced by thermochemical liquefaction processing of swine manure under relatively high Temperature (T = 340°C) and Pressure (P = 10.3 MPa) for specific Residence Times (RT = 80 min) is used to produce bio-oil and utilizes the heavy residue remaining in this process as an asphalt modifier. **Table 2** shows chemical composition of bio-binder and asphalt.

2.1.4. Rediset

The modifier Rediset can also treated as warm mix asphalt which lower compaction temperature needs lower optimum binder content to conform to the mix design criteria, it's stability and quotient is lower than mixture fabrication at high temperatures. The lower temperature leads to less energy consumption and lower emissions production at the asphalt mixing plants. Study showed that Optimum Binder Content (OBC) of Warm Mix Asphalt (WMA) is slightly lower than the OBC for HMA without warm additive rediset and furthermore the higher rediset content slightly decreases the asphalt mixture stability but increase the VFA. It implies that higher rediset content has a softening role in the asphalt mixtures (Hamzaha *et al*., 2013) which enhance the homogeneity of the binder. **Table 3** shows the recommended doses.

Table 1. Properties of base binder PG 64-22

Specific gravity @15.6°C	Flash point, cleveland open Cup, °C	Change in mass RTFO	Absolute viscosity at 60°C, Pa.s
1.039	335	-0.0129	202

Table 2. Comparison of chemical composition of bio-binder and asphalt (Fini *et al*., 2011b; 2012)

Component (%wt)	Bio binder	AAD-1
Carbon (C)	72.58	81.60
Hydrogen (H)	9.76	10.80
Nitrogen (N)	4.47	0.77
Oxygen (O)	13.19	0.90
Water content	2.37	
Ash content	0.13	

Table 3. Recommended doses of liquid rediset by wt. of mixture (AkzoNobel Surface Chemistry)

Application	Doses (%)
Warm-mix (Standard paving and PG grades)	0.4-0.6
Compaction Aid	0.3-0.5
High-RAP, PMB and higher PG binders	0.5-0.75
Foam warm-mixes	0.3-0.5

2.1.5. Evotherm

Evotherm technology is important to using it successfully in asphalt pavement construction projects. Evotherm WMA is a comprehensive chemical additive system designed to allow the production and compaction of high quality asphalt pavements at temperatures as much as 100°F lower than conventional HMA. The benefit is the reduction in the consumption of energy when manufacturing the asphalt mixes, as the job materials need to be heated less than when manufacturing the conventional hot mix. Various job sites have shown a savings of around 40% in energy (Maze *et al*., 2003), with measured gains from 35 to 55% depending on the moisture content of the aggregate materials and the ambient weather conditions. In addition the reduction temperature is a significant drop in the emission rates of stack gases and particulates at the mix plant. One study showed the 48% reduction in greenhouse gases, 58% reduction in nitrogen oxides and 41% reduction in Sulpher dioxide, which is responsible for acid rain (Maze *et al*., 2003).

2.2. Specimen Preparation

As described **Table 4**, to conduct the study, three different percentages of RAS and three different modifiers were designed. All together 24 specimen were made; three sample were made only RAS with virgin binder no modifier here called control, three were control and Rediset, three were control and Evotherm and three were control and Bio- binder for spindle SC4-27 and same amount of specimen were made for V73 spindle. Here the doses of modifiers were chosen 1.5% for Rediset, 0.5% for Evotherm and 5% for Bio-binder by weight of mixture. To make homogeneous mixture RAS and virgin asphalt was blended at 400 rpm at 180°C during 60 min for each percentage of RAS; similarly each type of modifiers were then blended at 400 rpm and at 130°C during 20 min separately for each RAS percentages. Mixing was performed utilizing a laterally attached oscillating mixer, then from each blended mixture 10.5 gm specimen was poured in aluminum chamber. The chamber/tube was then placed into a preheated thermosel during 20 min. To measure the viscosity a Brookfield viscometer was chosen.

3. TEST PROCEDURES

3.1. Viscosity Measurement

Study was conducted to measure viscosity of the all prepared specimen at different temperatures and shear rates using a Brookfield viscometer (RV-DVIII Ultra) following ASTM D4402 test procedure. To prepare specimens, the authors poured 10.5 g of each material into different aluminum chambers to gain a better sampling of the entire blend. They then placed the tubes into a 30-min preheated thermosel to reach thermal equilibrium. To investigate properties of the modified binders, they run the test at 105, 120, 135 7 150°C at speeds of 5, 10, 20, 25, 50 and 100 rpm. Then the authors preheated the sample and thermosel at its designed temperature for an additional 20 min to ensure the achievement of thermal equilibrium. They used two spindle SC4-27D and Vane Spindle V73 separately (Brookfield Engineering, Middleboro, MA) for testing and conducted the first viscosity reading after 15 min of shearing. Then, they recorded three more results in 3 min intervals to ensure consistency of viscosity measurement. **Table 5** showed the measured viscosity data from both spindles.

3.2. Blending Index

Blending index is an indication of degree of blending achieved between the oxidized binder in RAS and virgin binder.

Table 4. Description of the Test Materials and it's proportions

Base binder	Shingles content (%)	Source of materials	Description: Control	Rediser modified	Evotherm modified	Bio-binder modified
PG 64-22	20	Tear-Off	PG 64-22+ 20%RAS	PG 64-22+20% RAS+1.5% Rediset	PG 64-22+20% RAS+0.5% Evotherm	PG 64-22+20% RAS+5%Bio-binder
PG 64-22	30	Tear-Off	PG 64-22 +30% RAS	PG 64-22+30% RAS+1.5% Rediset	PG 64-22+30% RAS+0.5% Evotherm	PG 64-22+30% RAS+5% Bio-binder
PG 64-22	40	Tear-Off	PG 64-22 +20% RAS	PG 64-22+40% RAS+1.5%Rediset	PG 64-22+40% RAS+0.5%Evotherm	PG 64-22+40% RAS+5%Biobinder

Table 5. Measured viscosity of all mixture at 20 rpm

Blend	Tem. (C)	Control Spindle (SC27)	Control Spindle (V73)	Rediset modified Spindle (SC27)	Rediset modified Spindle (V73)	Evotherm modified Spindle (SC27)	Evotherm modified Spindle (V73)	Bio-binder modified Spindle (SC27)	Bio-binder modified Spindle (V73)
20% RAS	105	5554.33	12553.00	4045.60	8346.60	4600.00	6902.33	3593.00	4866.00
	120	1867.00	4208.00	1358.60	2720.00	1650.00	2434.00	1263.00	1647.00
	135	737.50	1398.00	645.00	1132.67	650.00	998.86	516.66	727.37
	150	350.00	715.30	304.00	553.00	350.00	463.70	280.66	345.87
30% RAS	105	6715.00	13559.00	5621.00	9669.00	5888.00	10165.00	4117.00	6000.00
	120	2183.00	4359.00	1862.60	3272.33	1972.00	3466.33	1429.00	2297.00
	135	837.50	1676.00	720.80	1302.00	808.33	1373.00	600.00	898.89
	150	391.66	731.47	337.50	633.10	395.80	642.50	287.50	397.75
40% RAS	105	7275.00	17985.00	5971.00	14278.00	7188.00	13063.00	5979.00	7067.00
	120	2393.00	4744.00	1971.00	3932.00	2387.60	4209.00	2000.00	2856.00
	135	945.83	1864.00	820.60	1507.00	904.00	1560.00	775.00	1163.00
	150	437.50	820.36	366.60	567.70	425.00	695.50	363.00	419.00

The blending index of the RAS-modified binder was evaluated using a viscosity variation versus temperature. Using the difference between the two measurements at the same temperature and speed rate, a blending index was defined as follow:

$$Bx = \frac{\log\log(\eta_{SC27})}{\log\log(\eta_{V73})} * \log\log(T) * 100\% \quad (1)$$

To applying the above formula, the blending indices were calculated for all designed mixture and all temperature at 20 rotational speeds (rpm). And valued were shown in **Table 6**.

Where:

- T is the temperature of the binder at known point in Celsius unit (°C)
- η_{SC27} and η_{V73} are the viscosities of the binder at the known points(cP)

3.3. Temperature Susceptibility

Temperature susceptibility is a measure of how fast the binder properties changes with temperature changes (Claudy *et al*., 1998). The temperature susceptibility of the RAS-modified asphalt blends were evaluated by developing Temperature-viscosity plots for the prepared specimens. If an asphalt binder has a high susceptibility to temperature, its viscosity changes rapidly as the temperature changes. Asphalts with high temperature susceptibility are not desirable as they are more prone to thermal and U.V. oxidation (Firoozifar and Foroutan, 2011). Therefore it is important to numerically quantify the temperature susceptibility of the binder. Following equation has been commonly used to calculate the Temperature Susceptibility (VTS) (Rasmussen *et al*., 2002):

$$VTS = \frac{\log\log(\eta_2) - \log\log(\eta_1)}{\log(T_2) - \log(T_1)} \quad (2)$$

Where:

T_1 and T_2 = The temperature of the binder at known point in Rankin unit (R)

η_1 and η_2 = The viscosities of the binder at the known points (cp)

The magnitude of the VTS is directly proportional to the temperature susceptibility of the binder.

Table 6. Temperature effects on various modifier modified binder in presence of 20% RAS

Shear rate		Rotational speed (RPM)/log viscosity (cP)				
		1.7	3.4	6.8	8.5	
	T (°C)	5	10	20	25	Average
Blend	105	1.21	2.42	4.88	6.13	3.66
	120	1.37	2.74	5.52	6.92	4.14
Control	135	1.57	3.16	6.36	7.98	4.77
	150	1.73	3.48	7.01	8.89	5.27
VTS		-3.35	-3.31	-3.36	-3.21	-3.31
Rediset modified	105	1.26	2.53	5.10	6.38	3.82
	120	1.44	2.91	5.82	7.28	4.36
	135	1.59	3.25	6.55	8.20	4.90
	150	1.78	3.63	7.29	9.18	5.47
VTS		-3.06	-3.05	-3.02	-3.08	-3.05
Evotherm modified	105	1.29	3.85	5.21	6.52	4.22
	120	1.46	2.94	5.91	7.39	4.42
	135	1.60	3.22	6.67	8.39	4.97
	150	1.74	3.56	7.50	9.57	5.59
VTS		-2.64	-2.67	-3.10	-3.27	-2.92
Bio- binder modified	105	1.30	2.62	5.26	3.80	3.25
	120	1.48	2.98	5.97	7.47	4.48
	135	1.68	3.37	6.74	8.44	5.06
	150	1.84	3.73	7.55	9.45	5.64
VTS		-3.07	-2.99	-3.08	-3.09	-3.06

Note: Every nnumber is shown as 103 (1cP* 103 PaS)

4. RESULTS

Analysis of the data showed that the all modified binder has similar properties in terms of temperature susceptibility. **Table 6** presents the all modified binder results for Temperature Susceptibility (VTS) at 20% RAS content and viscosity measurement at various speeds (5, 10, 20, 25, 50 and 100), RAS percentages (20, 30 and 40%) and temperature (105, 120, 135 and 150°C). The viscosity measurements at 105°C of percentage of RAS at 50 and 100 rpm were too high to be measured; therefore, the VTS and blending index values could not be calculated at that rotational speed.

5. DISCUSSION

The author founds that the introduction of the amine based modifiers to the RAS mixed asphalt binder was beneficial because of the amine based modifiers influence on reducing the blend's overall viscosity; therefore one can accommodate higher percentages of RAS without depleting the engineering properties. The lower viscosity modified mixture also allows for the mixing and compaction temperature which decrease energy consumption and after all construction cost. A simultaneous comparison of viscosity results from three different amine based modifier binders with control (RAS modified with PG 64-22) showed that modification with the bio-binder led to significant lowering in the asphalt binder's viscosity.

The authors also found that the difference between the viscosity values of the mixtures become less significant at high temperature.

To study the temperature susceptibility of each binder, the authors calculated the VTS values by using Equation 2 and shown in tabular form in **Table 6**. The result values was plotted in **Fig. 2** and the plots showed that all modifiers (Rediset, Evotherm and Bio-binder) modified mixtures have lower slopes than that of the control binder, which indicating that the temperature susceptibility of the binder was reduced because of the modification with amine based modifiers.

In this figure the temperature susceptibility curves of all binders are above the control binder curve; therefore it can be conclude that binders have less slope and less susceptible than control.

Investigating the blending index of each mixtures, the authors calculated the Bx values by using Equation 1. They plotted the results for each modified binder at 20, 30 and 40% of RAS and at 20 rpm in **Fig. 3** through 5.

From **Fig. 3**, it can be seen that all three modifiers showed comparative increment in Bx with increasing the temperature. Among them Bio-modified binder showed higher Bx values than Evotherm and Rediset modified binder. The blending index value was increased from 29.7 to 32.5 which is 2.8% increment from 105 to 150°C.

In **Fig. 4**, the blending index at 150°C is higher than the other temperatures in all binders. The increment in Bx from 105 to 150°C for Rediset modified binder is 1.18. However, the Bx increase for Evotherm modified binder found to be around 2.0 and for Bio-binder modified binder to be 2.3%. Therefore, the increment in bio-binder found to be higher than the other two. Same trend can be seen at 40% RAS content binder shown in **Fig. 5**.

Furthermore, the blending indexes of all binders at 135oC were determined to study which percentage of RAS can lead to improved blending results. It was found that 20% RAS content binders in all case showed higher value than 40% RAS content followed by 30% RAS content. The values were plotted in **Fig. 6**.

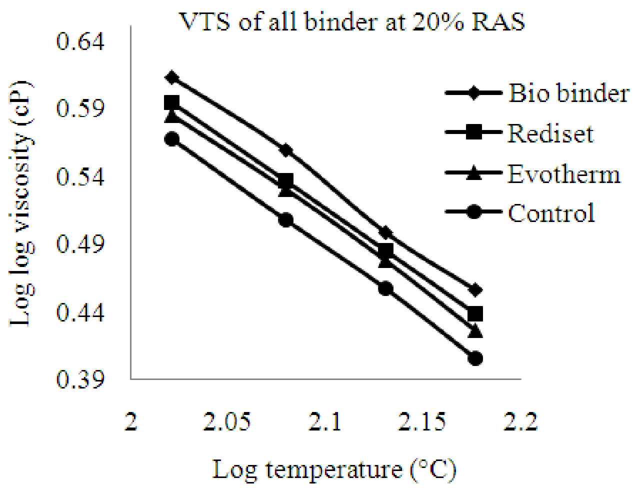
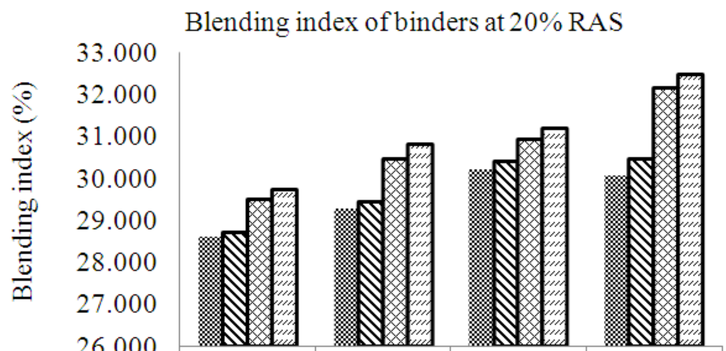
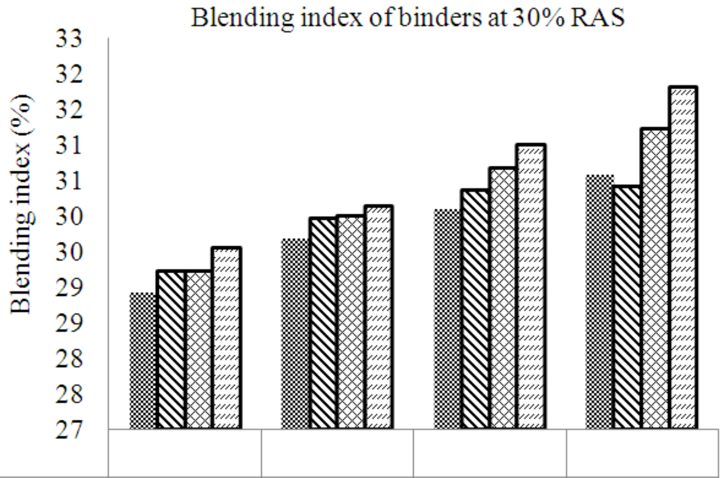


Fig. 2. VTS for all samples at 20% RAS for V73 spindle values



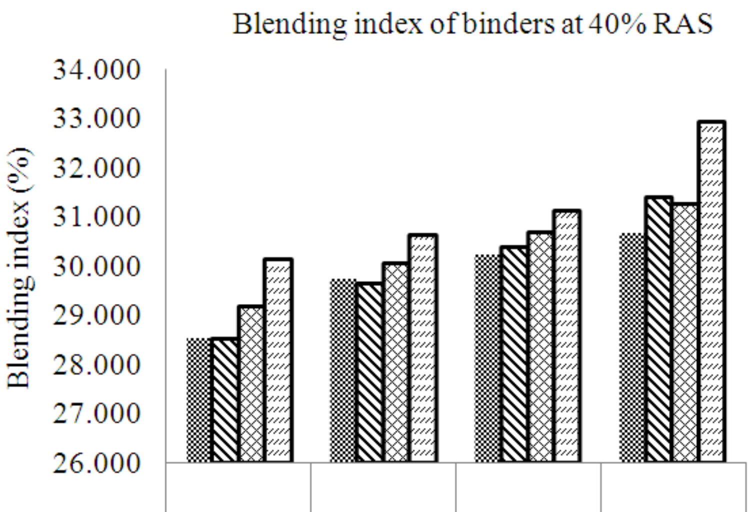
Control	28.603	29.260	30.195	30.061
Rediset modified	28.694	29.422	30.390	30.436
Evotherm modified	29.493	30.456	30.924	32.153
Bio-binder modified	29.709	30.796	31.180	32.449

Fig. 3. Bx for all modified binders at 20% RAS and 105, 120, 135 and 150°C temperature



Control	28.908	29.670	30.092	30.575
Rediset modified	29.214	29.964	30.357	30.404
Evotherm modified	29.218	29.986	30.657	31.220
Bio-binder modified	29.543	30.130	30.987	31.797

Fig. 4. Bx for all modified binders at 30% RAS and 105, 120, 135 and 150°C temperature



Control	28.515	29.731	30.228	30.662
Rediset modified	28.510	29.624	30.382	31.386
Evotherm modified	29.154	30.052	30.663	31.239
Bio-binder modified	30.129	30.615	31.108	32.925

Fig. 5. Bx for all modified binders at 40% RAS and 105, 120, 135 and 150°C temperature

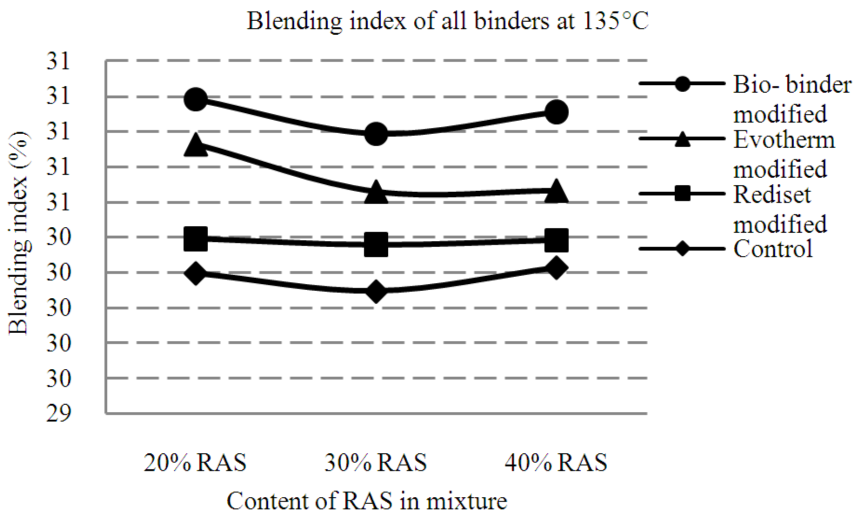


Fig. 6. Change of Bx of all modified binders at 135°C temperature

6. CONCLUSION

The viscosities measured from different modified mixture were analyzed through coefficient of variation. Viscosity results showed that the vane spindle consistently shows higher viscosity than smooth spindle. The coefficients of variation were decreased as temperature and rotational speed increased. It was also shown that the coefficient of variation was lower in bio-binder modified mixture than those of Rediset and Evotherm modified mixture.

To study the blending status and effectiveness of each modified binder, in this study an empirical index (Bx) was introduced Calculating Bx for three different modifiers in this study, it was shown that all modifiers effectively increased the blending index of RAS mixtures. It was further found out that bio-binder could be more effective in enhancing blending index than Rediset and Evotherm.

In addition, the study of the temperature susceptibility showed all three modifiers can improve temperature susceptibility compared to control binder. Among the three modified binder, bio modified binder showed less temperature susceptibility than other two modified binder.

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