THE EFFECT OF DIFFERENT AGENTS ON WARM MIX ASPHALT PAVEMENTS

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ABSTRACT

In this study, the effects of four different modifiers on Warm Mix Asphalt were investigated. The Standard tests were applied to the binder, aggregate and the modified bitumen to define their properties and to compare their test results. The conventional binder was modified by adding different amounts of different agents to the B50/70 bitumen. The Penetration, Softening point, Bending Beam Rheometer, Dynamic Shear Rheometer,Rolling Thin Film Oven Test and Kinematic viscosity tests were applied to the binder to determine its physical properties, and the same tests were carried on the extracted binder samples. Three different WMA production techniques were implemented. The first one was Foam technique, and two different zeolite based agents were used for production of WMA samples. The second one was chemical modifier technique, and a liquid agent was mixed to the binder for producing WMA samples. The last one was Wax technique, and a Sasobit based modifier mixed with the binder was used to produce the samples. Lime stone of aggregate were used for WMA mix. Stripping, Absorption and Magnesium sulfate tests were applied to the aggregate. Determination of the water sensitivity, Rutting, Bulk density and Stability tests were carried out on the samples for analyzing of different WMA mix types. The last test was on the recovery binder, after recovering of the binder from HMA.
Comparisons were made between the three types of WMA mixes. The laboratory tests results of WMA samples, conventional and recovered binder samples are presented in the "Conclusions" section of the study.

Keywords: Warm Mix Asphalt, modifiers, emission, wax, foam

1. INTRODUCTION

Current regulations on emissions and energy conservation are making attractive the reductions in asphalt mix production temperature. It allows a reduction in the temperatures at which asphalt mixes are produced and placed. The main benefit of producing and placing asphalt mixes at a lower temperature is the reduction in energy consumption, greenhouse gas emissions, fumes, and odors generated at the plant and the paving site. Also, the technical benefits are substantial including reduction of short term binder hardening, reduction of mixture tenderness, and possible extension of the construction season. With WMA systems, the temperature of bituminous material at the end of compaction is lower than the temperature with HMA, and also closer to service temperature. Accordingly, the usage of WMA allows quick return to traffic. For the same reasons, multiple lifts of WMA may be place on top of one another within a short period of time.

There are primarily three technologies that have been observed to produce WMA. The three methods of WMA are; Warm Asphalt Mix-Foam, Chemical and Wax. All three methods reduce the viscosity of the binder at a certain temperature range, allowing the aggregate to be fully coated at lower temperatures than in conventional hot mix (HMA) production.

The primary objective of this research was to find out how the agents effect on WMA. In the process of answering that question, different agents were added to the warm mix asphalt and compared with each other and also compared to traditional hot mix asphalt (HMA).

The conventional binder was modified by adding different amounts of different agents to the B50/70 bitumen. The Penetration, Softening point, Bending Beam Rheometer (BBR), Dynamic Shear Rheometer (DSR), Rolling Thin Film Oven Test (RTFOT) and Kinematic viscosity tests were applied to the binder to determine its physical properties, and the same tests were carried on the extracted binder samples. Three different WMA production techniques were implemented. The first one was Foam technique, and two different zeolite based agents were used for production of WMA samples. The second one was chemical modifier technique, and a liquid agent was mixed to the binder for producing WMA samples. The last one was Wax technique, and a modifier mixed with the binder was used to produce the samples. Lime stone of aggregate were used for WMA mix. Stripping resistance, Flakiness index, Specific gravity, Absorption and Magnesium sulfate tests were applied to the aggregate. Determination of the water sensitivity, Rutting, Bulk density and Stability tests were carried out on the samples for analyzing of different WMA mix types. The last test of the study was on the recovery binder samples, after recovering of the binder from HMA in accordance to the related procedures.

To evaluate fundamental properties and characteristics of laboratory WMA and HMA specimens, analysis and results of all types of laboratory tests are discussed in the Conclusion section.

2. MATERIALS

Laboratory testing was performed to determine if there were significant differences between Hot Mix Asphalt (HMA) and Warm Mix Asphalt (WMA) produced using different agents with the same mix designs. HMA and WMA specimen samples were prepared with limestone as aggregate, B50/70 bitumen as binder, and Wax, Zeolite and other chemicals as additives to modify the mix.

2.1. Aggregate

The aggregates used for this Project were chosen from the quarry in Kocaeli-Gebze region. To determine the physical properties of the aggregates some standard tests were applied. These tests include Sieve analysis, Specific gravity for coarse-fine aggregate and mineral filler, Absorption, Stripping resistance, Magnesium sulfate tests, Flakiness index, and Aggregate abrasion value tests. The objective of the tests carried on the aggregates was to determine the properties of limestone (both coarse and fine materials) aggregate and to decide their availability of the mix. The test results for both the coarse and fine of aggregates, are shown in Table 1. The density of the filler, evaluated as 2.745 g/cm^3.The gradation chosen for this project was the wearing course Type1 gradation of Turkish Road Authority specification. Table 2 summarizes the properties for such kind of aggregate distribution and specification. The graph for the HMA and WMA gradation and the specification range is shown in Figure 1.

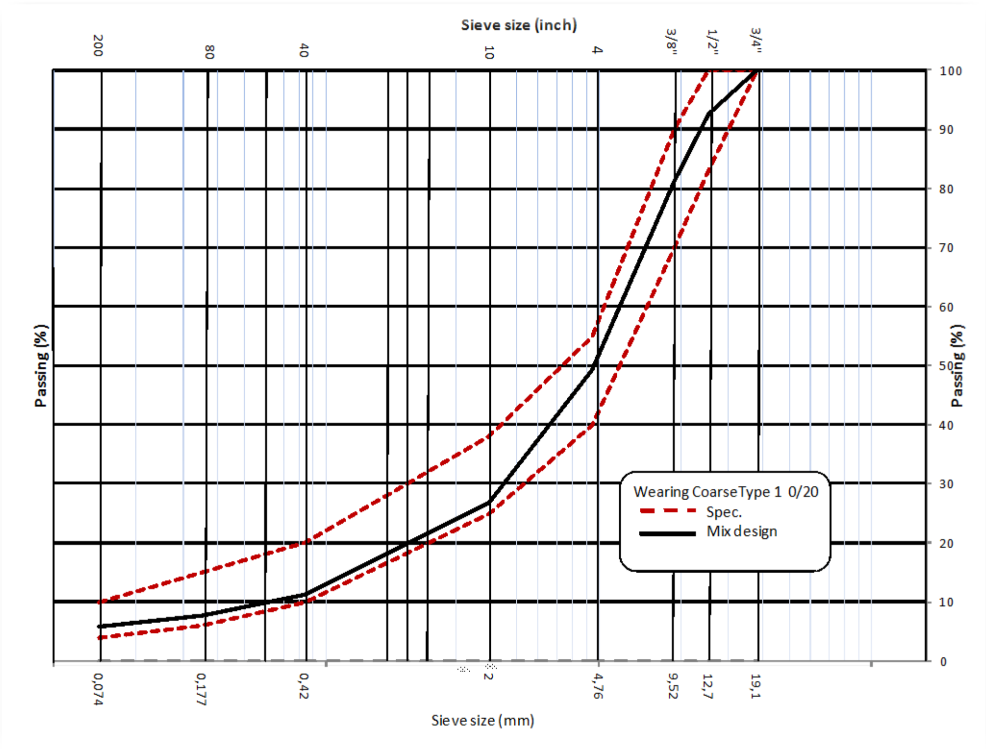

Figure 1: Aggregate gradation for HMA and WMA

Table 1: Coarse aggregate test results

Properties	Unit	Test Method	Spec.	Test Results
Flakiness index	%	TS EN 933-3	-	17
Los Angeles	%	TS EN 1097-2	Max. 30	22
Absorption	%	TS EN 1097-6	Max. 2,0	0,62
Magnesium sulfate test	%	TS EN 1367-2	Max. 16	8,8
Stripping resistance	%	Nicholson	Min. 50	60-70
Coarse aggregate density	g/cm^3	TS EN 1097-6	-	2,71
Fine aggregate density	g/cm^3	TS EN 1097-6	-	2,68
Filler density	g/cm^3	TS EN 1097-7	-	2,745

It can be clearly seen from the tables above that, the limestone aggregate is available to be used for the mixtures HMA and WMA. Since test results are stated inside the range limits of the specification.

Table 2: Size distribution and specification HMA and WMA

Sieve Size No	Sieve Size mm	Specification Type1 (%)	Passing Percent (%)
3/4″	19,0	100	100
1/2″	12,7	83-100	89,6
3/8″	9,52	70-90	78,6
No. 4	4,76	40-55	52,7
No. 10	2,0	25-38	31,0
No. 40	0,42	10-20	12,5
No. 80	0,177	6-15	8,2
No. 200	0,074	4-10	5,9

2.2. Bitumen (B 50/70)

The binder (B50/70 Bitumen) used for this study was from Turkish Petroleum Refineries. In the binder testing system, samples of the binders qualified as 50–70 pen (B50/70). The standard bitumen tests were carried out on the conventional and modified binder samples. In the first group, B 50/70 bitumen samples were tested as control specimens. In the second set of tests, modified bitumen samples prepared with liquid chemical additive and Wax were tested. The liquid chemical additive named as Cheml in this project. The standard conventional and modified bitumen tests were performed including Penetration, Softening point, Fraass breaking point, Flash point, Density, Kinematic viscosity, Loss on heating, DSR, BBR and RTFOT test. Test results of the both conventional and modified bitumen samples are shown in Table 3.

Table 3: Binder test results

Properties	Unit	Test Method	B 50/70 Control	B 50/70 +Cheml	B 50/70 +Wax
Penetration grade	0.1mm	TS EN 1426	61.6	62.2	38.1
Softening point	ºC	TS EN 1427	49.2	48.5	75.9
Fraass Breaking point	ºC	TS EN 12593	-12	-11	-9
Flash point	ºC	TS EN 2592	326	294	284
Density	g/cm^3	TS EN 15326	1.029	1.036	1.027
Kinematic viscosity	mm^2/s	TS EN 12595	467.5	470.2	419.6
Loss on heating	%	TS EN 12607-2	0.4	0.4	0.3
DSR (Pass fail Temp.)	ºC	TS EN 14770	64	64	76
BBR (Slope 60 s, 12 ºC)	MPa	TS EN 14771	90	84	88
RTFOT	%	TS EN 12607-1	0.6	0.6	0.4

As seen from the Table 3, the binder used for this project is available for production of WMA and HMA mixes. The test results are included inside the range of specifications.

2.3. Additives

Many different polymers are used to modify asphalts and each has their own associated physical properties. On the basis of the demand of the available WMA additives in the industry, widely used three different Warm Mix Asphalt additives were selected; Foaming additives, liquid chemical and Wax additives. To evaluate the mixture samples, a dozen of tests were performed in the laboratory. All results were compared with each other also compared against traditional Hot Mix Asphalt.

2.3.1 Foaming Additives

Zeolites have been used to enhance coating of aggregates by asphalt at a lower production temperature. Zeolite includes approximately 20% of water trapped in its porous structure. Upon heating to approximately 85°C, the water is released, and then foamed asphalt is produced. In the more useful zeolites, the spaces are interconnected and form long wide channels of varying sizes depending on the mineral. These channels allow the easy movement of the resident ions and molecules into and out of the zeolite structure. Zeolites are characterized by their ability to lose and absorb water without damage to their crystal structures. They can have the water in their structures driven off by heat and other solutions pushed through the structure. They can then act as a delivery system for the new fluid.

Two types of zeolite base additives were used as modifiers for the study, which named as Zeo1 and Zeo2 in this project. The zeolite powder samples Zeo1 and Zeo2 are shown in Figure 2.

Figure 2: Zeo1 and Zeo2 powder samples

Zeo2 is available in a very fine white powdered form in 25 or 50 kg bags or in bulk for silos. It is a manufactured synthetic zeolite (Sodium Aluminum Silicate), which has been hydro thermally crystallized. By adding zeolite to the mix at the same time as the binder, a very fine water spray is created. This release of water creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperatures. According to the Manufacturer, the first type of zeolite was added at a rate of 0.25% percent, and the second was added at a rate of 0.40 by mass of the mix.

2.3.2 Chemical Additive (Cheml)

Chemical additive (Cheml) is an organic additive, a product of France which is liquid at 25°C used as an additive in the production of the WMA. The chemical additive acts at the interface between mineral aggregate and asphalt, in a similar way that a surfactant acts at an interface between water and asphalt that does not significantly change the rheological properties of asphalt. The chemical additive enables to reduce the asphalt mix production and lay down temperature by 20 to 40°C and keeps the same mechanical properties as a standard HMA. Cheml was added to the binder (B50/70) for preparing binder samples, at a rate of 0.4% percent by mass of the binder. Cheml is stable under the temperature of the bitumen. The mixture was at temperature of 125ºC, a mix velocity of 600 rpm and a mixing duration of 10 minutes. The liquid chemical additive (Cheml) is shown in the Figure 3.

2.3.3 Wax Additives

Wax is a product of Germany which is a mixture of long chain hydrocarbons produced from coal gasification using the Fischer-Tropsch synthesis and is also known as a FT paraffin wax. The wax's melting point is at about 100°C and it is completely soluble in bitumen at temperatures above 120°C, and it does not separate out on storage. This type of wax reduces viscosity at working temperatures which makes the asphalt easier to process, provides the option of reducing working and mixing temperatures and thereby reducing fume emissions, saving energy and reducing production cycle times. According to Wax manufacturers, the optimum addition of wax has been found to be 3% by weight of the bitumen. Granule wax sample is shown in Figure 3.

Liquid chemical

Granule Wax

Figure 3: Liquid chemical (Cheml) and granule wax samples

The mixture was at temperature of 125ºC, a mix velocity of 600 rpm, and a mixing duration of approximately 120 minutes.

3. EXPERIMENTAL PROGRAM

A laboratory study carried on with conventional hot mixtures (HMA) samples, and warm mix asphalt (WMA) samples, for comparison of the mixtures (typical dense graded mixtures; Turkish Road Authority, Wearing Course Type1 0/20), to determine their properties.

WMA specimens were produced as per the recommendations made by the additive manufacturer. The dosage rate and type of method for different additives are explained in the related instructions by manufacturers. Basically, two types of the processes are used with four different additives. In the wet process, the additive is to be added with binder prior to mixing process. While in the dry process, the additive is to be added along with bitumen into the aggregate during mixing process. The specimens were prepared by wet process for wax and Cheml additive, and by a dry process for zeolite (powder). Analysis was also performed on extracted binder from the mixture samples to determine if aging had a significant effect on WMA as compared to HMA.

Comparisons were made between the test results of different samples, for all types of mixes and materials. The laboratory tests results carried on the mix samples are presented in the "Conclusions" section of the study.

3.1. WMA and HMA Sample Tests

Basic characteristics of laboratory HMA and WMA specimens were measured that include Bulk Density, Marshall stability, Flow, Water sensitivity for conditioning and non-conditioning specimens, Rutting and Stripping resistance.

The temperatures of aggregate, mixture, and compacted specimen were measured throughout the sample preparation process of each specimen. WMA mixtures were produced at temperatures between 130°C and 135°C whereas the control HMA mixture at around 160°C. WMA mixtures were compacted at temperatures around 120°C whereas the control HMA mixtures were compacted at temperatures around 135°C. The result of Bulk density and Stripping resistance tests performed in the laboratory for all type of mixes are presented in Table 4.

Table 4: Characteristics of WMA and HMA samples

Properties	Unit	Test Method	Type of Mix				
			HMA Control	WMA Cheml	WMA Wax	WMA Zeo1	WMA Zeo2
Bulk Density	g/cm^3	TS EN 12697-6	2.37	2.29	2.36	2.34	2.34
Stripping Resistance	%	Nicholson	60-70	75-85	75-85	-	-

Marshall Stability:

Marshall Stability testing of compacted HMA and WMA were performed, using compacted specimens to determine the stability and flow values of the samples. Laboratory test results were evaluated, using Stability correlation ratio values if the specimen's thickness is not exactly 63.5 mm. Table 5 and Figure 4 shows Marshall Stability values of HMA and WMA specimens.

Water Sensitivity Test:

Five different asphalt specimen sets (one of them was control mix), approved by related Standard (TS EN 12697-12 Bituminous mixtures - Test methods for hot mix asphalt - Part 12: Determination of the water sensitivity of bituminous specimens) were conditioned and the related tests were carried on. The indirect tensile strength of cylindrical specimens of bituminous mixtures test was applied to the samples. Test results of all types of mixes are shown in Table 5. The same values are shown graphically in Figure 5.

Table 5: Characteristics of HMA and WMA samples

Properties	Unit	Test Method	Type of Mix				
			HMA Control	WMA Cheml	WMA Wax	WMA Zeo1	WMA Zeo2
Stability	Kg	TS EN 12697-34	1430	915	1229	1111	921
Flow	mm	TS EN 12697-34	3.01	4.89	4.35	5.60	3.70
Water Sensitivity (Non-cond.)	kPa	TS EN 12697-12	698	647	891	598	591
Water Sensitivity (Cond.)	kPa	TS EN 12697-12	434	400	464	397	432
Rutting (PRD air %)	%	TS EN 12697-22	4.83	7.45	4.56	8.61	5.79

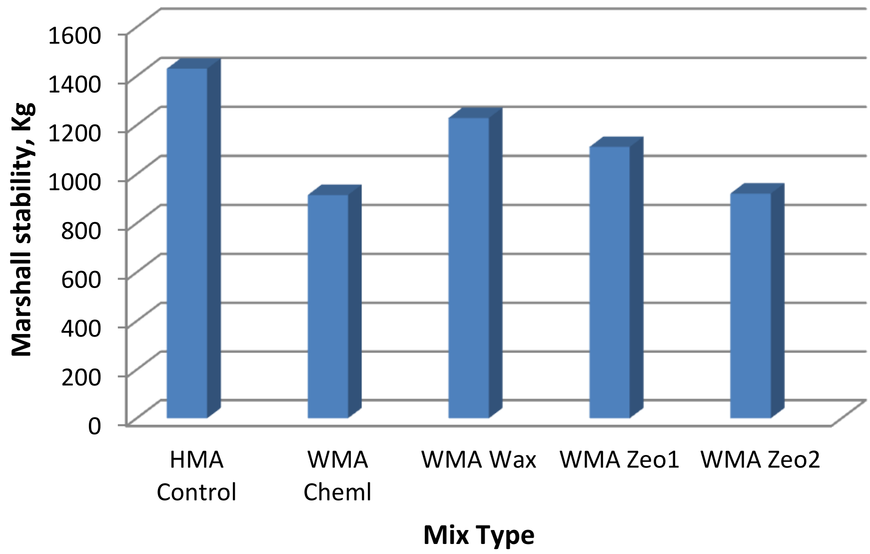

Figure 4: Marshall stability values of HMA and WMA specimens

The measured stability of the specimen sets for both HMA and WMA at a temperature of 60°C. For all types of WMA mix samples the stability values were less than those of HMA, control specimens'. On the other hand, WMA samples of Wax mixtures have the best stability values followed by HMA mixes.

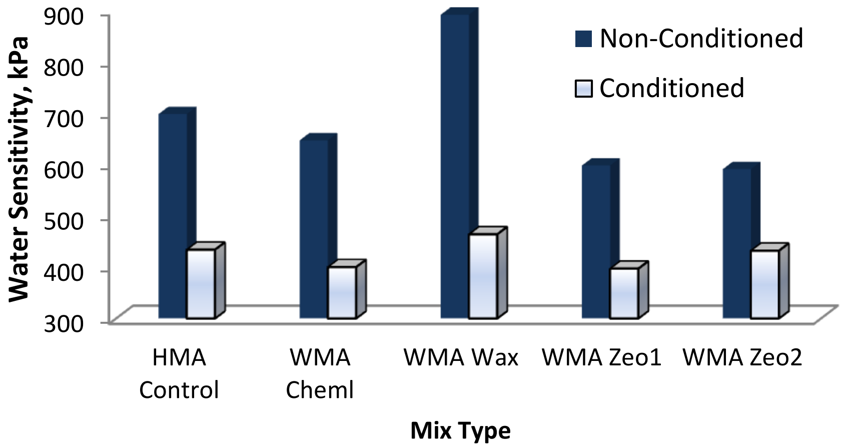

Figure 5: Water sensitivity values of HMA and WMA specimens

The figure above states expressly that water sensitivity values of conditioned specimens were less than those of Non-conditioned specimens for all types of HMA and WMA mix samples. On the other hand, WMA samples of Wax mixtures have the highest values of water sensitivity.

Hamburg Wheel-Track Test:

The Hamburg Wheel-Tracking Device measures the combined effects of rutting and moisture damage by rolling a wheel across the surface of an asphalt concrete slab. The device is composed of three main parts; Mixer, Compactor and Testing unit. The Hamburg Wheel-Track Testing of Compacted HMA and WMA were performed, using compactor unit of the same device. Measurements were taken as a graph for all points along the passes through 20000 cycles, to provide a specimen measurement; samples were composed of three graph lines sets (at the left, center, and right locations shown in Figure 5). Samples were tested at 60°C for a conditioning duration of 240 minutes, while a 700 N load was applied. The test was considered to be complete at 20,000 passes. Figure 5 illustrates the development of rutting in the samples for HMA and WMA specimens.

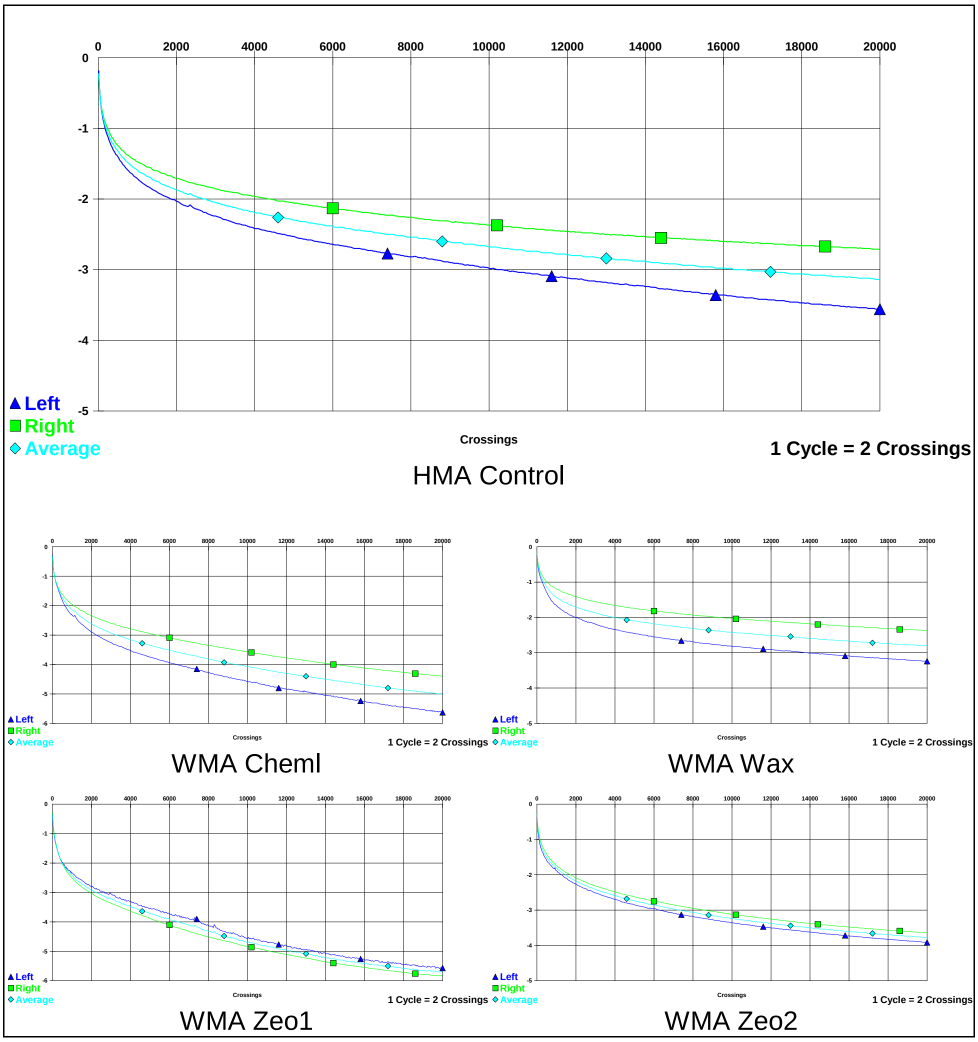

Figure 5: Rutting values of HMA and WMA specimens, Depth in mm

The measured rut depths of the specimen sets for both HMA and WMA at 20,000 cycles are less than 6mm. Based on the depth of rutting after 20,000 passes, it can be seen clearly that the specimens prepared with Wax have the least depth of rutting. On the other hand, all other mixture specimens have more depth of rutting than control samples. For Wax agent, WMA specimen set was shown to have an average of more than 0.2 mm less rutting than the control mixture at all passes. From these observations, it can be concluded that WMA with Wax is better resistance to permanent deformations than the conventional mixtures. The rutting test results of HMA control and WMA mix types are shown in Figure 5.

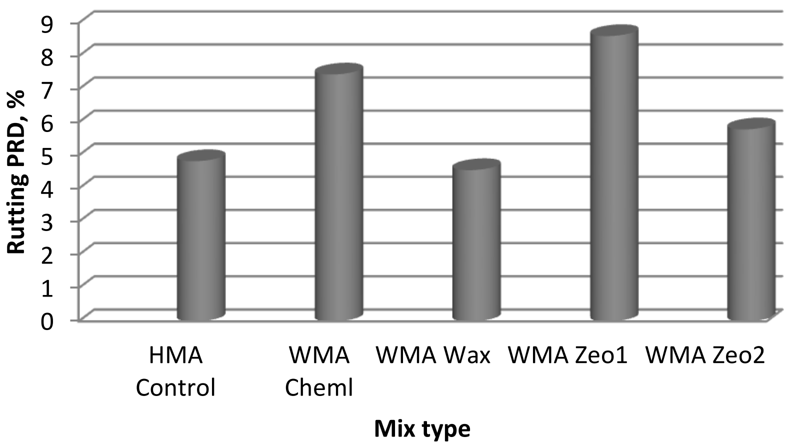

Figure 6: Rutting values of HMA and WMA specimens, PRD %

3.2. Recovery Binder Tests

The last step of the study was on the recovery binder samples, after extracting of the binder from HMA and WMA mixtures. Laboratory tests were carried out on five mixture samples; Conventional mixtures, WMA modified with Foaming additives, Cheml and Wax in order to obtain extracted bitumen characteristics. The asphalt content of the specimen samples was obtained using the standard tests (TS EN 12697-3 Bituminous mixtures - Test methods for hot mix asphalt - Part 3: Bitumen recovery: Rotary evaporator) of extraction of bitumen from bituminous paving mixtures.

Some standard tests were applied to the extracted binder for determination of comparing the behavior of the extracted bitumen types with each other and also with the conventional bitumen and determine their properties. These tests include Penetration, Softening point, Fraass breaking point, Flash point, Density, Kinematic viscosity, Loss on heating, DSR and BBR test. Comparisons were made between the HMA and WMA binders, for all types of mixes. Results of the tests for all type of mixture specimens are shown in Table 5 below.

Table 5: Recovery binder test results

Properties	Unit	Test Method	Recovery B 50/70	Recovery +Cheml	Recovery +Wax	Recovery +Zeo1	Recovery +Zeo2
Penetration grade	0,1mm	TS EN 1426	29.0	25.8	24.4	28.8	34.5
Softening point	ºC	TS EN 1427	60.5	64	77.4	66.8	57.4
Fraass Breaking point	ºC	TS EN 12593	-7	-9	-8	-9	-8
Flash point	ºC	TS EN 2592	284	302	244	290	308
Specific gravity	g/cm^3	TS EN 15326	1,027	1.034	1.040	1.032	1.032
Kinematic viscosity	mm^2/s	TS EN 12595	992	1240	837	1146	817
Loss on heating	%	TS EN 12607-2	0.09	0.4	0.6	0.5	0.4
DSR (Pass fail Temp.)	ºC	TS EN 14770	76	76	82	76	76
BBR (Slope 60s, 12ºC)	MPa	TS EN 14771	97	98	99	73	58
RTFOT	%	TS EN 12607-1	0.2	0.6	0.7	0.7	0.7

The results in Table 5 above suggested that Loss on heating and RTFOT values of WMA are higher than those of HMA. Again, the WMA produced with Cheml and Zeo1 appeared to perform slightly higher viscosity values than HMA while that of Wax and Zeo2 perform lover values. There were no significant differences between HMA and WMA mixture values of DSR and BBR test results. Analysis using the Wax, Cheml and Zeo1 modifiers to perform WMA showed that Penetration values of recovery binders are lower than those of HMA while Zeo2 mixture is higher. The results showed very little difference in the Fraass breaking point values of WMA mixtures compared with the hot mixtures.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the research of the tests carried out in the laboratory and data presented in this paper, the following conclusions and recommendations can be drawn;

- The research results show that in laboratory conditions warm mix asphalt stability, compare to hot mix asphalt, decreases in (15-35) %.
- There were no significant differences in DSR and BBR test results between the HMA and WMA. The laboratory-produced mixtures had similar properties. WMA with Wax agent, were slightly higher than other samples.
- It is therefore concluded that the wax is most likely of the three methods to be used.
- Generally, WMA appeared to be compact more easily than HMA
- The Water Sensitivity values of conditioned specimens were less than those of Non-conditioned specimens. Test results showed that both the HMA and WMA were resistant to moisture susceptibility. The results indicated certain difference between the performance of Wax mixes.
- The laboratory-produced WMA with Wax agent, rutted slightly less than HMA samples.
- Fraass Breaking Point results indicated that the WMA performed slightly better at lower temperature than HMA.
- For the proper definition of warm mix asphalt mechanical characteristics the experimental research should be prolonged by increasing in number of tests and using several methods for the definition mechanical characteristics.
- The Researches should be continued to investigate additional WMA technologies, stone mastic asphalt produced using WMA technology, and WMA produced with high percentages of RAP.
- The research is needed to validate the research findings for mixtures with different binders and aggregate structures and also with different WMA technologies.

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