INFLUENCE OF REDISET-WMX (ADDITIVE) ON MIXING TEMPERATURE OF ASPHALT CONCRETE

Supported by tetfund

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Received: September 08, 2020 **Accepted:** January 14, 2021

Abstract: The high energy consumption and emission of air pollutants to the environment during the asphalt concrete production process, contribute to global warming. This effect leads to the development of warm mix asphalt technology, in which asphalt concrete is produced at a lower temperature without compromising its in-service performance. This has been achieved through the use of organic and inorganic additives. Because of this, this study investigated the suitability of Rediset-WMX as an additive in lowering the mixing temperature in asphalt production. Marshall Design method was adopted for specimen preparation and testing. Fifteen (15) samples were prepared and compacted for strength and volumetric properties assessments at varying bitumen contents of 4.5, 5.0, 5.5, 6.0, and 6.5%, in accordance with the Asphalt Institute and Indian Ministry of Road Transport and Highways (MoRTH) standards.Optimum Bitumen Content (OBC) of 5.5% was obtained. The OBC with varying proportions of Rediset-WMX (1.0, 1.5, and 2.5%) was used for the asphalt concrete mixes in the study to determine the optimum temperature and dosage of Rediset-WMX. Results showed that the optimum temperature and optimum dosage of Rediset-WMX are 120^0C and 2.0%, respectively; samples prepared with these parameters satisfied most of the requirements as perthe Indian Ministry of Road Transport and Highways (MoRTH). Hence, a 25% reduction in mixing temperature was achieved through warm mix asphalt technology with Rediset-WMX as an additive, compared to conventional hot mix asphalt technology. Therefore, Rediset-WMX is suitable for use as an additive in warm mix asphalt production for the construction of roads with heavy traffic.

Keywords: Bituminous concrete, hot mix asphalt, rediset-WMX, warm mix asphalt

Introduction

Traditional hot-mix asphalt (HMA) has been the essential material in bituminous paving over the past decades. Sadly, the production of HMA is associated with high energy consumption that leads to the release of air pollutants into the environment. Hot mixed asphalt has been the traditional material for road pavement, parking lots, and airport runways. The production of hot mixes involves heating the aggregates and the bitumen at temperatures ranges between 150 - 160^0C (Capitão *et al.*, 2012). In an attempt to reduce the effect of greenhouse gases (GHG) emission as a result of fossil fuel consumption globally, efforts have been made by researchers to develop techniques that could reduce the high consumption of energy and the release of air pollutants in asphalt production without compromising its workability and mechanical performance. As long as a remarkable temperature decrease could be achieved in asphalt mix production, at the same time maintaining the workability and mechanical properties of the material the same as or even better than that of HMA, the benefit to the society would be paramount (Capitão *et al.*, 2012). Therefore, scientific researchers and technicians evolved new technologies for asphalt production, commonly known as warm mix asphalt (WMA) (D`Angelo *et al*., 2008; Capitão *et al.*, 2012).

WMA is an asphalt mix that is mixed at temperatures lower than conventional hot mix asphalt. Typically, the mixing temperatures of warm mix asphalt mixtures range from 100 to 140^0C compared to the mixing temperatures of 150–160^0C for hot mix asphalt (Capitão *et al.*, 2012). Decreasing the temperature in the production of WMA will lower fuel usage, thus, reducing the cost of production and emissions of air pollutants that are directly connected to fuel usage; this reduces the emissions of greenhouse gases and other Gaseous pollutantslike carbon dioxide (CO_2); carbon monoxide (CO); nitrogen dioxide (NO_2), etc., (Abdullah *et al.*, 2014; Xiao *et al.*, 2012). There are different categories of technologies that are used for the production of warm mix asphalt (WMA); the addition of additives (organic additives and chemical additives) andfoaming processes (sub-divided into water-containing and water-based processes) (Rubio *et al.*, 2012; Kumar and Suresha, 2019). The organic additives are paraffinic hydrocarbons which are combined with asphalt mixture to lower the mixing temperature by reducing the viscosity of bitumen,while the chemical additives are a combination of emulsification agents, surfactants, and polymers which improve coating, mixture workability, and compaction as well as reducing the mixing and paving temperature (Shaleha *et al.*, 2017). These chemicals include Sasobit, Rediset-WMX, Cecabase, and Evotherm (Kumar and Suresha, 2019). The use of foaming process technology involves the injection of cold water into the hot binder or by adding synthetic zeolite directly into the asphalt mixing chamber. As evaporation occurs rapidly, water is encapsulated into the binder forming a large volume of foam; with this, the volume of binder expands and thereby increasing the workability and compatibility of the mixture at lower temperatures (Kumar and Suresha, 2019; Xiao *et al.*, 2012). These technologies reduce the viscosity of the asphalt binder and allow the aggregate to be fully coated at a given temperature that is lower than the normal mixing temperatures. The application of WMA can have a significant impact on the whole pavement construction projects. Reports revealed that manufacturers and materials suppliers have achieved energy savings on the order of 30%, with a corresponding reduction in CO_2 emissions of about 30% (Wei Goh *et al.*, 2007). The mixture production and placement temperature could bring several benefits in terms of costs, environmental, and performance (Jones, 2004). The use of additive blended asphalt technology for the production of warm mix asphalt (WMA) has become popular for more than a decade over the use of traditional hot mix asphalt (HMA). However, quite a severalkinds of research have been conducted to study the benefit of using additives in producing warm mix asphalt (WMA). Smiljanic *et al.* (2011) reported that Rediset-WMX is a poly-functional additive based on fatty amine surfactants and polyethylene. It dissolves easily and blends completely in hot asphalt binder (Arega and Bhasin, 2012). Rediset-WMX shows great performance in reducing the rotational viscosity of asphalt binders (Abdullah *et al.*, 2014; Sengoz and Oylumluoglu, 2013). A rediset-WMX dose of 1 to 2% enables the production of the warm mix at 30°C to 40°C lower temperature than hot mix and this could reduce fuel consumption by at least 20% and significantly lower emissions not only at the hot mix plant but also at the paving site (Jones *et al.*, 2010). Jones *et al.* (2010) conducted a study to investigate the influence of Rediset-WMX additive in producing and compacting temperature of warm mix asphalt. They reported that specimens with Rediset-WMX additive were produced and compacted at an approximate temperature of 35°C (63°F) lower than the specimens produced and compacted at conventional hot-mix asphalt method and possess similar stability andair-void contents.Behl and Chandra, (2017) in their study, evaluated the effects of three different WMA additives on its aging characteristics; Sasobit, Rediset-WMX, and Evotherm. The results revealed that Rediset-WMX warm-mix binders showed higher creep stiffness values and also improved the aging index at lower mixing temperatures, which indicates their improved resistance to low temperature cracking. Munshi (2013) Conducted a study on a warm mixed design on asphalt using modified binders (PMB 40 and CRMB 60) and added 2% Rediset-WMX as an additive to the modified binders. He reported that a reduction of 40°C in mixing and compaction temperature of asphalt mixes by adding 2% additive by weight of the binder was achieved and the mixture fulfilled all volumetric requirements of asphalt mixes.

Although the use of organic additives and industrial by-products in asphalt production has gained attention from many research studies. However, there are limited investigations on the use of Rediset-WMX (a chemical additive) in asphalt mix production through warm mix technology. This study was conducted to explore the suitability of using Rediset-WMX as an additive in asphaltic concrete and focuses on lowering the mixing temperature of a bituminous mix by warm mix asphalt technology with VG-30 bituminous binder. The objectives of the research work are to check the suitability of bitumen binder (VG-30) in the warm mix design of Bituminous Concrete (BC); improve the cohesive strength of the mix by addition of Rediset-WMX, and to reduce mixing and compaction temperature of BC mixture. For this purpose, the Marshal Mix design method was adopted to determine the engineering properties of asphalt concrete.

The incorporation of Rediset-WMX in warm mix asphalt technology could reduce the energy consumption in bituminous concrete production, and thus, the environmental degradation by the emission of toxic air pollutants could be reduced.

Materials and Methods

Materials

Materials used in this study include; coarse aggregates, fine aggregate, bitumen, mineral filler (lime), and bituminous additive (Rediset-WMX). All the materials were obtained from the appropriate supplies within Jodhpur, India. The bitumen used for the study was of viscosity grade – 30 (VG-30), it is primarily used to construct an extra heavy-duty Bitumen pavement that needs to endure substantial traffic loads. It can be used instead of a 60/70 Penetration grade bitumen binder.

Methods

The method employed in this study for the experimental tests was in accordance with the requirements of the MoRTH (Indian Ministry of Road Transport and Highways) specification that includes IS codes and relevant ASTM codes. Various tests were carried out to determine the physical properties of coarse and fine aggregate, bitumen (conventional and modified), and mineral filler. Subsequently, determinations of optimum binder content, optimum temperature, as well as the optimum dosage of additive were carried out as highlighted in the following Sub Section.

Tests on bitumen

Bitumen testing contains different tests on plain bitumen and bitumen with additives (Rediset). All tests satisfied the requirements for the physical properties of binders as per MoRTH standards. The tests conducted on bitumen and their results are presented in Table 1.

Test on coarse and fine aggregate

Aggregates used in this study were tested as per procedures given in relevant IS codes. All tests satisfied the requirements given in MoRTH section 500 clauses 509, table 500-17. The tests conducted on coarse aggregates and fine aggregates are presented in Table 2.

Marshall test and specimen preparation

The specimens were prepared in accordance with the Asphalt Institute (Institute, 1997) recommendations. A total of twenty-four (24) specimens were prepared and each specimen weighs 1200 g, 101.5 mm in diameter, and 63.5 mm in height; and heavy traffic situation was simulated by compacting each specimen with 75 hammer blows on each side. The sample bulk specific gravity was determined in accordance with ASTM D1559 (2004). The specimens were tested for Marshall Stability and flow using the Marshall test method in accordancewith ASTM D1559 (2004) (Standard, 2004). The volumetric test carried out are; Bulk Specific Gravity(G_{mb}), void in mineral aggregate (VMA), void in the mix (VIM), and voids filled with bitumen (VFB). Theoretical Maximum Specific Gravity of the Mix (G_{mm}) was determined using ASTM D 2041-95 and G_{mb} using ASTM D1188-96 (Papagiannakis and Masad, 2017). ASTM D3203-94 was used to estimate VIM.

The optimum bitumen content was determined using the relationships between binder content and the properties of the mixtures such as stability, flow, bulk density, VFB, VMA, andVIM. Three (3) specimens each were made for five bitumen content (4.5, 5.0, 5.5, 6.0 and 6.5%), making a total of fifteen (15) samples. The optimum binder content was selected as the average binder content for maximum density, maximum stability, and specified percent air voids in the total mix.

The same procedure was followed to prepare the other samples for the determination of Optimum temperature and Optimum Dosage of Rediset-WMX using the optimum binder.

Results and Discussion

Preliminary tests on bitumen

The preliminary test conducted on bitumen shows that the bitumen (Viscosity Grade – 30) is of 60/70 penetration grade. It satisfies various code requirements (IS: 73-2013) and MoRTH specifications (Highways (MoRTH), 2005) for ductility, softening point, specific gravity, solubility viscosity, and flash and fire point tests. Hence the bitumen was found suitable for this study. The test results conducted on the bitumen are as presented in Table 1.

Preliminary tests on aggregates

Aggregate properties influence mechanical properties as well as weather resistance of bituminous pavement. The results for the preliminary test on the physical properties of aggregates are presented in Table 2. The strength tests carried out on aggregates satisfied the requirements of MoRTH, (2005). Thus, the test results revealed that the aggregate materials are suitable for asphalt mix production, and can provide required serviceability and durability requirements of asphalt mixtures within the designed life.

Table 1: Preliminary test results and code limits on the bitumen

Test conducted	Code Used	Test Result	Code Limit (IS:73, 2013)
Penetration at 25°C, 0.1 mm	ASTM D5-97	65	Min. 45
Softening point (°C)	ASTM D36-95	56	Min. 47
Flashpoint (Cleveland open cup) °C	ASTM D92-02	310	Min. 220
Ductility at 25°C, cm	ASTM D113	85	Min. 40
Specific gravity at 25°C, (g/cc)	ASTM D70	1.02	0.97 – 1.02
Solubility in trichloroethylene, %	ASTM D2042	99	Min. 99
Viscosity test,	IS: 1206- Part 2	2585	2400 - 3600

Table 2: Test results on the aggregates materials

Test Conducted	Code Used	Test Result	Code Limit(MoRTH, 2005)
Aggregate Crushing Value (%)	BS 812 Part 112	19.36	Max. 30
Aggregate Impact Value (%)	BS 812 Part 111	15.35	Max. 27
Specific Gravity of Coarse Aggregate	ASTM C127	2.70	2.55 – 2.9
Specific Gravity of Fine Aggregates	ASTM C128	2.63	2.50 – 3.0
The density of Coarse Aggregate	ASTM C127	1460	>1200
Bulk Density of Fine Aggregates (kg/m^3)	ASTM C127	1602	>1500
Water Absorption for Coarse Aggregate (%)	BS 812 Part 2	0.53	< 2
Water Absorption of Fine Aggregate (%)	BS 812 Part 3	1.83	< 2
Sieve analysis (passing 0.075 mm) (%)	IS:2386 PART I	2.23	Max. 5.0

Particle size distribution of aggregates and blending proportion

Figure 1 represents the blended particle size gradation of aggregates. The blend curve of the aggregates lies within the MoRTH (Ministry of Road Transport and Highways) standards and requirements. Hence, the gradation of aggregates is suitable for use in asphalt concrete mix design. The combined aggregate distribution and blending of the materials fall between the MoRTH (2005) upper and lower limits. This implies compliance with the relevant specifications; hence, it is considered good for the production of asphalt concrete that can meet strength and durability requirements in service. Similar findings were also reported in related research conducted by Shuaibu *et al.* (2019).

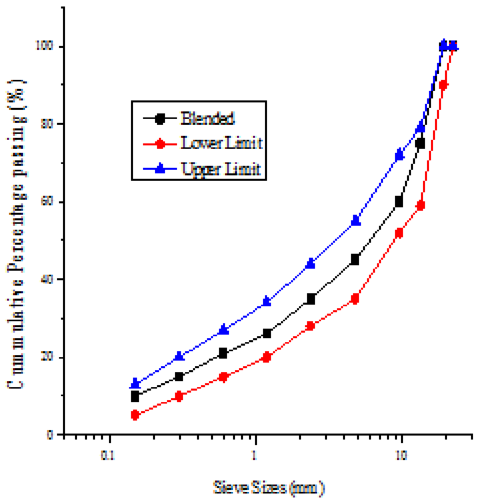

Fig. 1: Blended gradation of aggregate

Optimum binder content

To determine the optimum binder content (OBC) required for the asphalt concrete mixture that will satisfy the code requirement, Marshall Test was performed on the samples prepared at varying binder content. Relationships between binder content and the properties of asphalt mixtures such as stability, flow, Bulk density, VFB, VMA, and VIM were established as presented in Table 3 and Figs. 2 – 7. The optimum binder content was calculated based on the average of bitumen contents obtained at maximum stability, maximum bulk density, and median percentage of air void in the mix as specified by Asphalt Institute (1997).

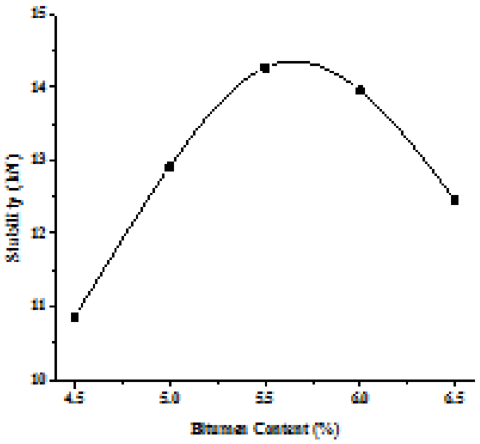

Fig. 2: Stability against bitumen content

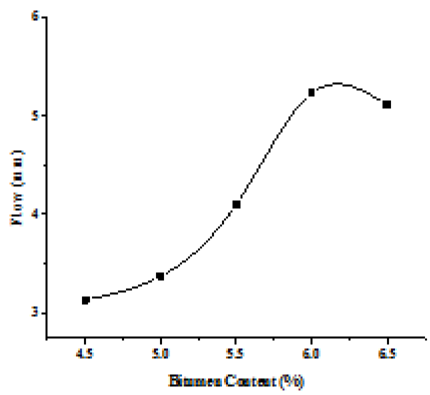

Fig. 3: Flowagainst bitumen content

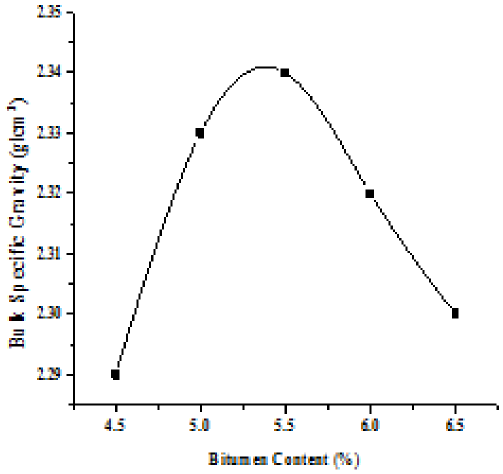

Fig. 4: Bulk density against bitumen content

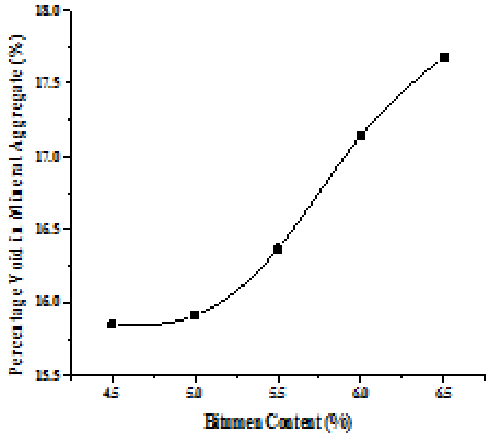

Fig. 6: VMA against bitumen content

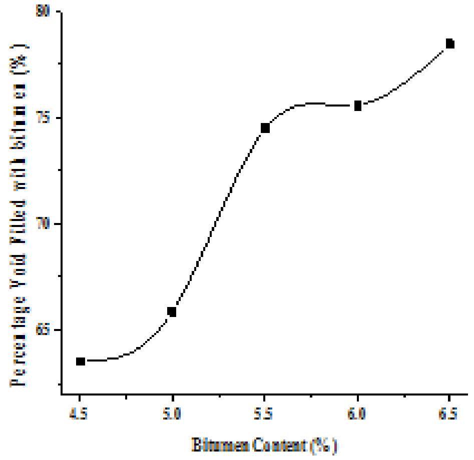

Fig. 5: VFB against bitumen content

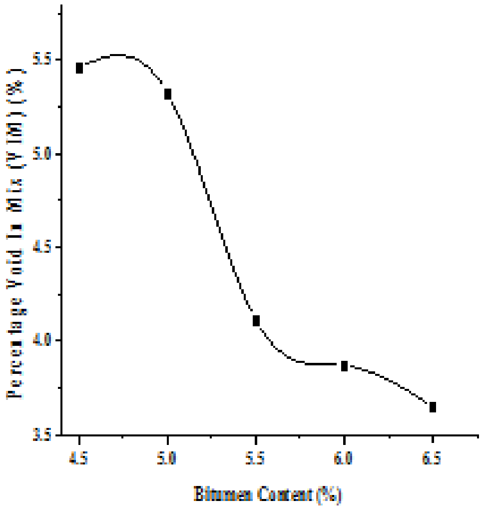

Fig. 7: VIM against bitumen content

Table 3: Averages of Marshall test results for control

S/N	Bitumen (%)	Stability (kN)	Flow value (mm)	Bulk S.G (g/cm^3)	VIM (%)	VFB (%)	VMA (%)
1	4.5	10.86	3.13	2.30	5.46	63.54	15.85
2	5.0	12.91	3.37	2.33	5.32	65.87	15.91
3	5.5	14.26	4.11	2.34	4.11	74.48	16.37
4	6.0	13.95	5.23	2.32	3.87	75.58	17.14
5	6.5	12.45	5.13	2.31	3.65	78.46	17.68

The optimum bitumen content was obtained to be 5.5% which was calculated as follows;
Bitumen content at the maximum stability = 5.6 %
Bitumen content at the maximum value of bulk density = 5.3%
Bitumen content at the median percent of air voids = 5.58%
Optimum Bitumen Content (OBC) = 5.49 (5.5 approximately).

Table 4: Test results for modified bitumen and code limits

Test conducted	0% Rediset-WMX	1.5% Rediset-WMX	2.0% Rediset-WMX	2.5% Rediset-WMX	Code Limit (IS:73, 2013)
Penetration at 25°C, 0.1 mm	65	66	67	69	60 - 70
Softening point (°C)	56	53	51	50	Min. 47
Ductility at 25°C, cm	85	82	78	80	Min. 40
Viscosity test, (poise)	2586	2568	2544	2521	2400 - 3600
Specific gravity at 25°C, (g/cc)	1.026	1.01	0.99	0.98	0.97 – 1.02

Tests on modified bitumen

The results for the tests conducted on the modified bitumen are presented in Table 4. The Bitumen was modified with three proportions of Rediset-WMX additive; 1.5, 2.0, and 2.5% by weight of the bitumen. The results revealed that all three samples satisfied all requirements as per IS: 73-2013. Although there are some little changes in the properties when rediset-WMX was added; for example, when 2.5% of Rediset-WMX was added to the plain bitumen, its values for penetration at 25ºC changes from 65 to 69 mm; softening point changes from 56 to 50ºC; ductility from 85 to 80 cm, etc., but the changes are within the requirements provided by the relevant standards. This behavior of material agrees with the work of Jones *et al*. (2010). Therefore, the modified bitumen is suitable for the production of asphalt concrete.

Marshall test results for Asphalt with modified bitumen at Optimum binder content of 5.5%

The results of stability-flow and volumetric analysis (VIM, VMA, and VFB) with bitumen modified by adding 1.5, 2.0, and 2.5% dosage of Rediset-WMX at temperatures 110, 120, and 130°C, are as shown in Figs. 8 to 13.

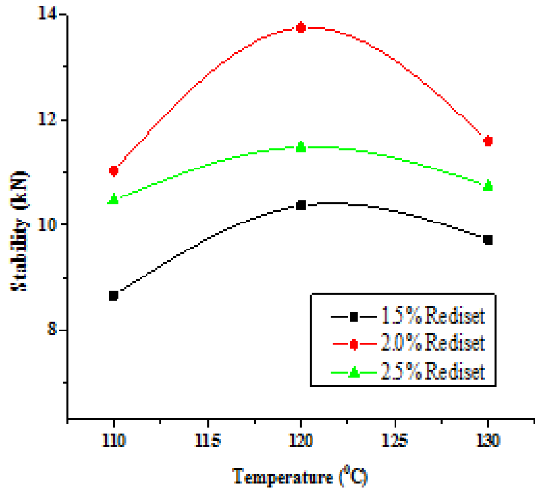

Fig. 8: Stability against temperature

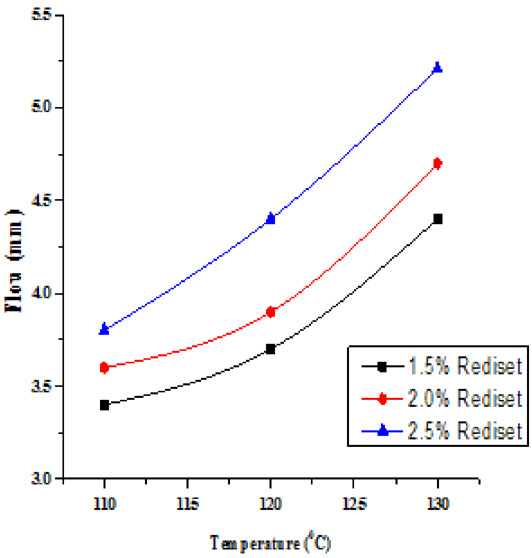

Fig. 9: Flow against temperature

Figure 8 presents the results of the Marshall Stability test on the asphalt mix against temperature. Marshall Stability is the maximum load a compacted specimen can carry at a standard temperature of 60°C (Shuaibu *et al.*, 2019). The results revealed that the maximum stability was attained at 120^{0}C for all the three proportions of Rediset-WMX additive. The optimum dosage of the additive was found to be 2.0% which corresponds to a stability value of 13.75 kN. The stability values satisfy the requirements as specified in the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements of a minimum of 9 kN except for 1.5% additive bitumen modifier at 110ºC. The reduction in mixing temperature could be attributed to the ability of the Rediset-WMX additive in reducing the viscosity of the binder, enhance the adhesion between asphalt and aggregates, and provide an effect for easier compaction.

Figure 9 presents the Marshall Flow test results at varying temperatures. Flow is the Measure of Flexibility of Asphalt mix that indicates the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. The figure shows that the flow increases with an increase in both temperature and percentage of Rediset-WMX additive. Two of the flow values obtained; 3.7 and 3.9 mm corresponding to 1.5 and 2.0% Rediset additive, respectively at a temperature of 120ºC, falls within the limit (2 – 4 mm) specified by the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements.

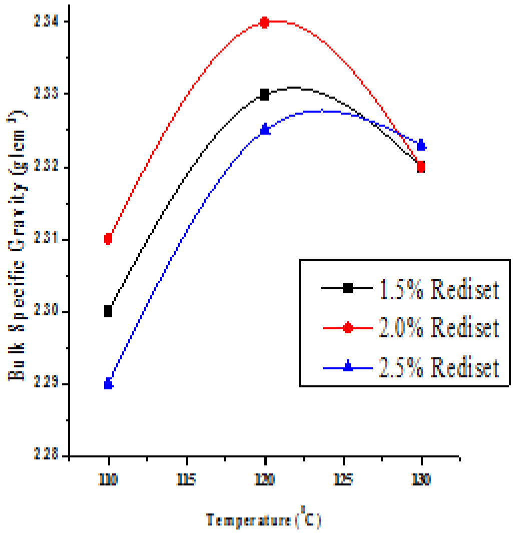

Fig. 10: Bulk density against temperature

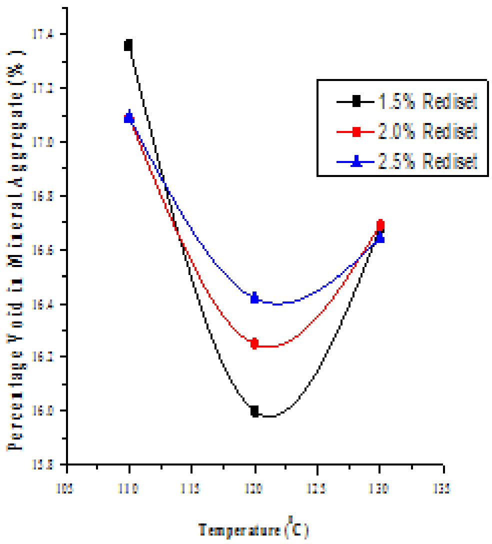

Fig. 11: VMA against temperature

The result for the bulk specific gravity is as presented in Fig. 10. The results revealed that there was no significant difference in bulk specific gravity of asphalt mix with modified bitumen and that of the plain bitumen (control) specimens. The maximum bulk specific gravity of 2.34 was obtained at a temperature of 120^0C corresponding to 2.0% of the additive.

Figure 11 presents the void in mineral aggregate at a different dosage of additives and mixing temperature. It is observed from the figure that the VMA decreased as the mixing temperature increased from 110 to 120^0C and increased as the mixing temperature further increased to 130^0C. This implies that the optimum mixing temperature for asphalt with bitumen modified by Rediset additive is 120^0C by the fact that minimum VMA for all the proportions of the additive were attained at 120^0C. The void in mineral aggregate obtained with 2.0% additive satisfied the minimum requirement of 16% as specified in the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements.

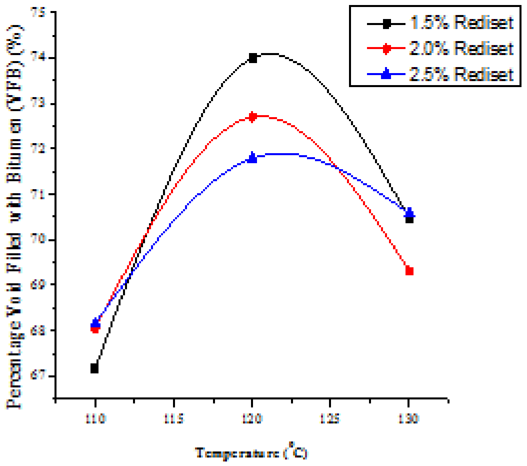

Fig. 12: VFB against temperature

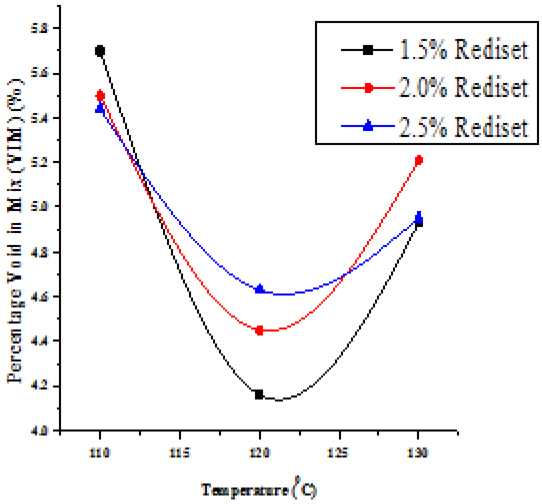

Fig. 13: VIM against temperature

Figure 12 presents results for Void filled with bitumen VFB at varying mixing temperatures. VFB is the portion of the total volume of void space between the aggregates particles that is occupied by bitumen. The void filled with bitumen increased as the mixing temperature increased from 110 to 120°C and decreased as the mixing temperature further increased to $\mathbf{130^0}$C. The results obtained at various mixing temperature and percentage of Rediset-WMX additivespecified the requirements of the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements of 65 – 75%.

The results obtained for the void in the mix (VIM) is as presented in Fig. 13. The results revealed that VIM decreased as the mixing temperature increased form $\mathbf{110}$ to $\mathbf{120^0}$C and increased as the mixing temperature further increased to $\mathbf{130^0}$C. The results obtained for the void in the mix at mixing temperature of $\mathbf{120^0}$C satisfied the requirements of 3 – 5% as specified in the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements.

In general, the results obtained revealed that the properties of mixtures with modified bitumen such as stability, flow, bulk density, VFB, VMA, and VIM satisfies the requirements as specified by the relevant codes at a mixing temperature of 120^0C for all the proportions (1.5, 2.0 and 2.5%) of Rediset-WMX additive. The mix with 2.0% additive produces asphalt with the highest stability and its bulk specific gravity is equal to that of the control. Therefore the optimum mixing temperature was found to be 120^0C and the optimum percentage additive was also found to be 2.0%.

Conclusions

The Experimental testresults and observations obtained in this study led to the following conclusions;

The test results for the physical and mechanical properties of coarse and fine aggregates satisfied the requirements for use in asphalt concrete production.

The results for the tests conducted on plain bitumen and modified bitumen with additive satisfied the requirement for use in asphalt production as per the Indian Ministry of Road Transport and Highways (MoRTH, 2005) standards and requirements. Hence, bitumen binder (VG-30) is suitable for use in the warm mix design of Bituminous Concrete (BC)

The bitumen penetration and viscosity test results showed that bitumen with Rediset is less viscous than plain bitumen. Thus, it provides a better coating to the aggregate surface and also gives better bonding through its viscous property. Hence, the adhesion is improved.

The Marshall Test results obtained for asphalt mix with Rediset-WMX additive revealed that the optimum temperature (mixing temperature) was $120^0C$with 5.5% bitumen content and Rediset-WMX additive of 2.0%. Hence, a reduction in asphalt mixing temperature of 40^0C was achieved by adding a 2% additive.

Conflict of Interest

Authors declare that there is no conflict of interest reported in this work.

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