Determination of Optimum Quantity of Reclaimed Asphalt Pavement in WMA Mixes Using Zycotherm as Additive

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Abstract. Hot Mix Asphalt (HMA), the conventional method adopted for pavement construction is being produced at a higher temperature which would lead to many environmental consequences. With the progress of time the introduction of Warm Mix Asphalt (WMA) helped in the reduction of production temperature and minimizing the environmental impacts. Further improvement in technology lead to the use of reclaimed asphalt pavement (RAP) which would reduce the binder and aggregate required. However, the use of WMA and RAP has many disadvantages. The addition on RAP in WMA mix is an attempt to solve some these problems. This paper examines the performance of various proportion of RAP that could be incorporated in WMA mixes. Marshall mix design was adopted for the preparation of specimen and the additive used for the study is Zycotherm. Specimens with different RAP content were prepared and tested to find the optimum RAP content by analyzing volumetric properties of mixes.

Keywords: Warm Mix Asphalt, Reclaimed Asphalt Pavement, Zycotherm.

1 Introduction

Since the 1900s, Hot Mix Asphalt (HMA) has been the most common and generally accepted technology for asphalt pavement construction in European countries and the USA. HMA, both asphalt binder and aggregates are heated up to high temperatures to about 180 °C (Saride et al., 2016). Later on, with the increasing cost and the availability of raw materials for asphalt pavement and the increasingly strict environmental protection, the sustainable development of the economy and environment has become a hot issue in the asphalt industry. The Kyoto Treaty was developed in 1997, thus setting the objective for European countries to develop policies and technologies to meet Warm Mix Asphalt (WMA) (Hettiarachchi et al., 2019).

WMA was developed to produce asphalt at lower temperatures of about 140 °C due to addition of suitable additives, with performances and characteristics equivalent to or even sometimes better than that of conventional HMA (Guo et al., 2020). WMA technologies mostly focus on the binder (bitumen) by adding different additives to improve its properties. These technologies, which produce asphalt between 120 °C and 140 °C, facilitate proper coating of the aggregates and hence the workability and compatibility of the mix while also reducing production and compaction temperatures by 20–40 °C which addition of additives. The WMA additives can be generally divided into three main types; organic, chemical and foaming. Organic additives like Sasobit and Asphaltan B contain organic wax (Rubio et al., 2012). These additives when added to the binder reduce the mixing and compaction temperatures. Chemical additives like Zycotherm and Evotherm consist of surfactants, emulsifier and anti-stripping agent (Ayazi et al., 2017). These additives chemically modify the binder and improve the active adhesion force. Foaming additives such as Zeolites and Advera increases the volume of binder by injecting steam into it and thus allows the reduction of mixing and compaction temperature (Rubio et al., 2020). With the reduction in mixing and compaction temperature, the energy consumption reduces, minimizing fume and odor emissions. Thus WMA when used as a pavement material is much more environment friendly than the traditional HMA and is much more energy efficient and is the need of the day.

In the recent years the reusing of the pavement material obtained during maintenance and reconstruction is being widely used as a sustainable solution. This has given rise to a new technology known as Reclaimed Asphalt pavement. Reclaimed Asphalt pavement or RAP is the term given to remove pavement materials containing asphalt and aggregates. The RAP is usually procured using a milling machine. The RAP not only reduces the quantity of virgin aggregate but also the binder that needs to be added to the mix. Thus the use of RAP is a great way to utilize waste materials while preserving the environment and saving costs involved in production and construction (Alsalihi et al., 2020, Guo et al., 2020).

In the modern era, the combination of Warm mix Asphalt-Reclaimed Asphalt pavement (WMA-RAP) is widely getting recognized. As mentioned earlier, WMA and RAP technologies have various advantages such as reduction in cost and eco-friendliness however this technology also present some disadvantages (Hettiarachchi et al., 2019). One among the major disadvantage is the low production temperature in WMA will lead to insufficient adhesion between asphalt binder and aggregate, which may affect the rutting resistance and moisture susceptibility of the asphalt mixture. A large amount of aged binder in RAP material can reduce the workability and mixing efficiency of asphalt mixture and result in premature distresses of asphalt pavements, which is something we are trying to find a solution for by our study.

Combining the characteristics of WMA and RAP, WMA-RAP technology can be benefited to solve these problems when they are used together. The WMA-RAP has better rutting resistance due to the aged materials in RAP. And WMA additives can improve the poor workability of RAP because they can reduce the viscosity of aged asphalt binder. And along with WMA additives, the poor workability of RAP was improved because they can reduce the viscosity of aged asphalt binder. The WMA-RAP technology results in the benefits such as lowering mixing temperature which helps to conserve energy and reduce emissions. It also provides better workability and performance and improves the economic performance by reducing the quantity of aggregate and binder.

The objective of this study is to examine the shift in optimum binder content due to the addition of Zycotherm in WMA mix containing various proportion of RAP. The study also aims to perform volumetric analysis of Warm Mix Asphalt incorporated with different quantities of Reclaimed Asphalt Pavement. Finally the optimum quantity of RAP that can be incorporated with WMA is determined.

2 Methodology

The methodology of the study included three stages. The first stage was the material preparation. The materials used were virgin aggregate, VG30 binder and reclaimed asphalt pavement. The properties of the virgin aggregate were determined by various tests which include Sieve Analysis, Impact test, Flakiness Index Test and Specific Gravity. The binder used was VG30 and the WMA additive Zycotherm. The binder properties were determined by various tests like Viscosity Test, Specific Gravity and Penetration test. The next step was to obtain the RAP properties. It was obtained by determining the binder content, grading on extracted aggregates and the specific gravity.

The next stage in methodology was the mix design. The Marshall method of mix design was adopted. Three specimens for each binder content 4.5%, 5%, 5.5%, 6% and 6.5% were prepared. Marshall Stability Test was done on each specimen and the optimum binder content was obtained. The Marshall Mix Design of RAP integrated WMA mixes at three different binder contents was then determined. That is, OBC, OBC+0.5% and OBC-0.5%. This gave the shift in optimum binder content when RAP was added. The specimens are then prepared with 20%, 40%, 60% and 80% RAP.

The final stage in methodology comprises of analysing the volumetric properties. Marshall Stability Test was carried out on the specimens prepared with different proportion of RAP. The results were analyzed and the optimum RAP content that can be incorporated in WMA using Zycotherm was determined.

3 Materials

The materials used for the study were virgin aggregates which were of the sizes: 12mm, 6mm, M-sand and dust, VG-30 binder, RAP and Zycotherm the WMA additive. Preliminary test were conducted to check the suitability of materials used in the study.

3.1 Aggregates

Basalt was used as virgin aggregate and had a nominal size of 12.5mm. The sieve analysis was done to find gradation. Shape test, Impact test and Specific gravity tests were conducted to evaluate the properties were analyzed to check whether they satisfy the required standards.

Gradation of aggregates. Bituminous Concrete Grading II (BC) gradation was selected for the experiment, as per MoRTH specifications. Sieve analysis was performed as per IS 2386 (Part 4) – 1963 on the aggregates to check the gradation. From the results of the sieve analysis it was observed that the aggregates confirmed to BC grade II gradation. The gradation of virgin aggregates is given in table 1.

Table 1: Gradation of virgin aggregates

Sieve Size	Percentage Finer (%)	Standard Values (%)
9.5 mm	75.11	70-88
4.75 mm	54.98	53-71
2.36 mm	45.31	42-58
1.18 mm	34.86	34-48
600 µ	28.43	26-38
300 µ	20.67	18-28
150 µ	14.99	12-20
75 µ	7.89	4-10

Properties of virgin aggregates. The various properties of virgin aggregate and its requirements satisfactory for the study is given in table 2.

Table 2: Properties of virgin aggregates.

Sl. No	Test Conducted	Test Results	Requirements(As Per IS 2386 (Part 4) – 1963)
1)	Flakiness Index Test	18.53%	25%
2)	Impact Test	26.32%	30%
3)	Specific Gravity Test	1) 12mm- 2.67 2) 6mm- 2.74 3) M sand- 2.67 4) Dust- 2.7	2.5-3 2.5-3 2.5-3 2.5-3

3.2 Binder

VG-30 binder was used for the study as it is suitable for the weather condition in Kerala i.e., the moderate temperature and also considering the heavy traffic loads. Zycotherm was used as the additive. The quantity of Zycotherm was fixed as 0.125% of total weight of the bitumen. Based on the average values recommended by the manufacturer, Zydex Industries (0.1%- 0.15%). It was poured and mixed with the bitumen boiling at 140^0 C. The properties were checked for its suitability for the study. The following table 3 represents the properties of the binder. The bitumen properties were found to satisfy the requirements as can be inferred from table 3.

Table 3: Properties of binder

Sl. No	Test Conducted	Test Result	Requirements (IS 2386 (Part 4) – 1963)
1	Penetration Test	54mm	>45mm
2	Specific Gravity	1.04	Nil
3	Viscosity test (test done at135^{0}C)	575.68cSt	Min. 350cSt

3.3 Reclaimed Asphalt Pavement (RAP)

In the present study the RAP was obtained by milling operation from Aroor – Chengannur road (NH-66). Various tests were carried out in RAP materials in order to evaluate its suitability for the further investigation.

Binder Content. The RAP materials were subjected to solvent (tri chloroethylene) extraction method by centrifuge extractor and the average bitumen content was found to be 4.46%.

Gradation of extracted aggregates. The aggregate recovered after bitumen extraction was subjected to sieve analysis to ensure that the RAP followed BC gradation II as per MoRTH specification (referred table MoRTH 500). The result of the sieve analysis is shown in table 4.

Table 4: Gradation of extracted aggregates

Sieve Size	Percentage Finer (%)	Standard Values (%)
9.5 mm	85.43	70-88
4.75 mm	61.54	53-71
2.36 mm	42.49	42-58
1.18 mm	34.8	34-48
600 µ	27.01	26-38
300 µ	19.83	18-28
150 µ	12.43	12-20
75 µ	6.57	4-10

Properties of RAP aggregates. The properties of extracted aggregates from RAP were checked whether adequate in comparison with the requirements of virgin aggregates, as specific requirements of RAP are not mentioned anywhere. The specific gravity of the RAP aggregates was determined using an Asphalt Density Mixer and the flakiness index test was done to assess shape properties of RAP aggregates. The results of properties of RAP aggregates is given in table 5.

Table 5: Properties of RAP aggregates

Sl. No	Test Conducted	Test Result	Requirements for virgin aggregates (As per IS 2386 (Part 4)-1963)
1	Specific Gravity	2.465	2.5-3
2	Flakiness Index	20.78%	< 25%
3	Impact Test	28.57%	< 30%

4 Mix Design

The Marshall method of mix design, as standardized by the American Society for Testing and Materials (ASTM) and by the American Association of State Highway and Transportation Officials (AASHTO) was used to prepare samples of WMA. After performing the required preliminary tests on aggregates and bitumen to evaluate its suitability to be used in the mix, the procedures of Marshall Method were initiated. The procedures, trends and apparatus mentioned below confirms to MS-2.

4.1 Mixing And Compaction Temperature

Viscosity Test was conducted at temperatures of 110^0C, 120^0C, 130^0C and 140^0C on the bitumen modified with Zycotherm to determine the mixing and compaction temperature. According to MS-2, Clause 4.2.1, the mixing temperature is the temperature corresponding to a viscosity of 170 cSt and was obtained as 140^0C. The compaction temperature is the temperature corresponding to a viscosity of 280 cSt and was obtained as 137.5^0C.

4.2 Optimum Binder Content

Mixes were prepared with binder content of 4.5%. 5%, 5.5%, 6% and 6.5%. The maximum theoretical density (Gmm), effective specific gravity (Gse) and bulk specific gravity (Gmb) was determined according to the methods specified in MS-2 clause 5.4. Using this, the volumetric properties were determined and plotted against the binder contents.

The optimum binder content and properties of the pavement mixture was evaluated using various graphs.

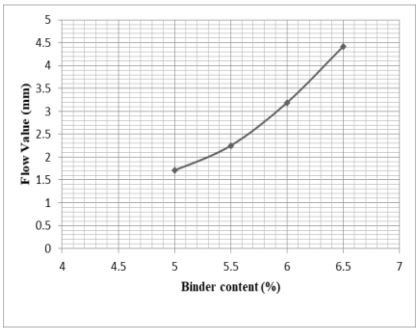

Fig.1 Binder Content versus Stability

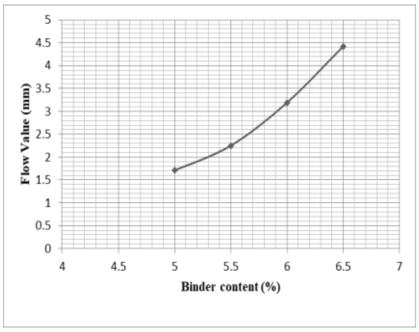

Fig.2 Binder Content versus Flow value

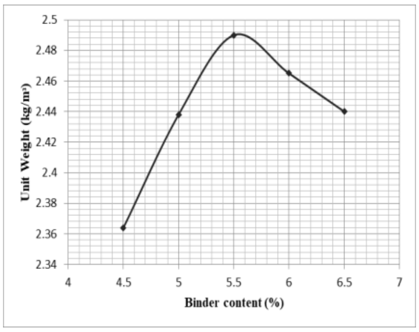

Fig.3 Binder Content versus Unit weight

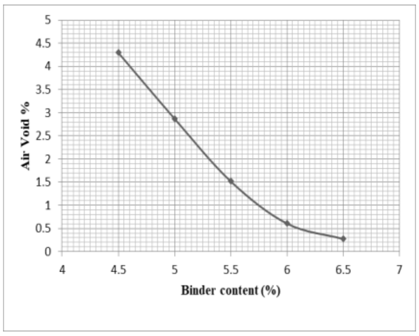

Fig.4 Binder Content versus Air voids

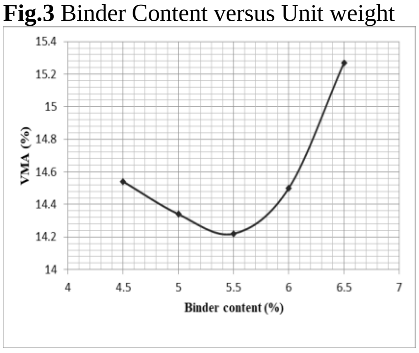

Fig.5 Binder Content versus VMA

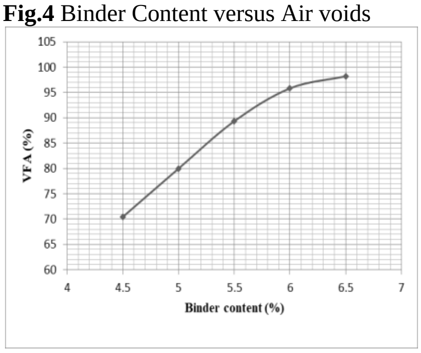

Fig.6 Binder Content versus VFA

From the above graphs (fig.1, fig.2, fig.3, fig.4 fig.5, fig.6), it is clear that the virgin mix satisfies the criteria given in Table 7.2 in MS-2.According to MS-2, Clause 7.4.5, from the binder content versus air voids graph, the OBC is the value corresponding to 4% air voids and was determined as 4.65%

After the determination of OBC of the control mix, specimens were prepared with 20%, 40%, 60% and 80% RAP. The theoretical maximum density (Gmm), effective specific gravity (Gse) and bulk specific gravity (Gmb) was determined to obtain the volumetric properties of the mix incorporated with different proportions of RAP.

5 Results and Discussion

After the completion of Marshall Stability test on WMA incorporated with 20%, 40%, 60% and 80% RAP, the following results were obtained

Binder content versus Stability. According to MS-2, Clause 7.4.2, the stability value increases with an increase in binder content up to a maximum, after which the stability decreases. WMA incorporated with 40% and 60% RAP followed the trend as per the clause mentioned.

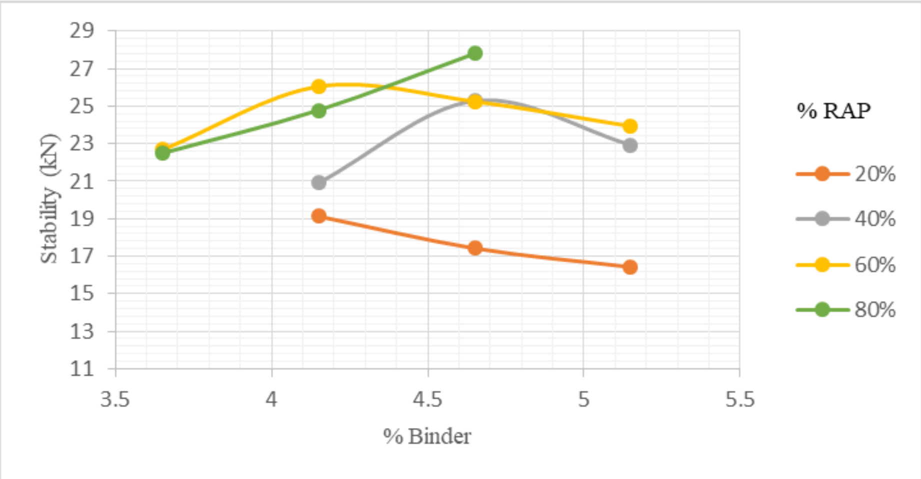

Fig.7. Binder Content versus Stability

As per MS-2 table 7.2, the Marshall Mix design criteria specify a minimum stability of 8006 N for heavy traffic. From the Fig. 7, all the graphs fall within the criteria. For the mix containing 20% and 80% RAP, the curve can be obtained by preparing specimens with variation in binder content by ± 0.5% accordingly as required. The increase in stability value with an increase in RAP content may be due to the increase in stiffness of the mix and the increase in stiffness of the mix could be due to the presence of aged binder present in the RAP.

Binder content versus Flow value. As per MS-2, Clause 7.4.2, the flow value consistently increases with an increase in binder content. As shown in the Fig. 8 all graphs follow this trend.

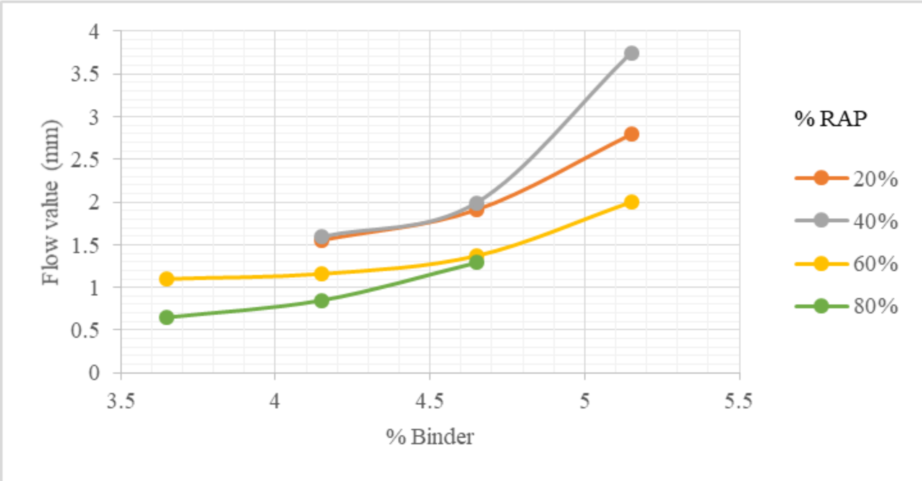

Fig.8. Binder Content versus Flow value

As per MoRTH specifications, the flow value lies between 3 and 5. But from Fig. 8, it can be seen that none of the graphs satisfied the criteria. This may be due to the decrease in effective dosage of Zycotherm in the mix with the increase in RAP content which in turn increased the stiffness of mix.

Binder content versus Unit weight. As per MS-2, Clause 7.4.2, the curve for unit weight of total mix follows the trend similar to the stability curve, that is it increases with an increase in binder content, reaches a maximum and then decreases. All the graphs as shown in the Fig. 9 follow the given trend.

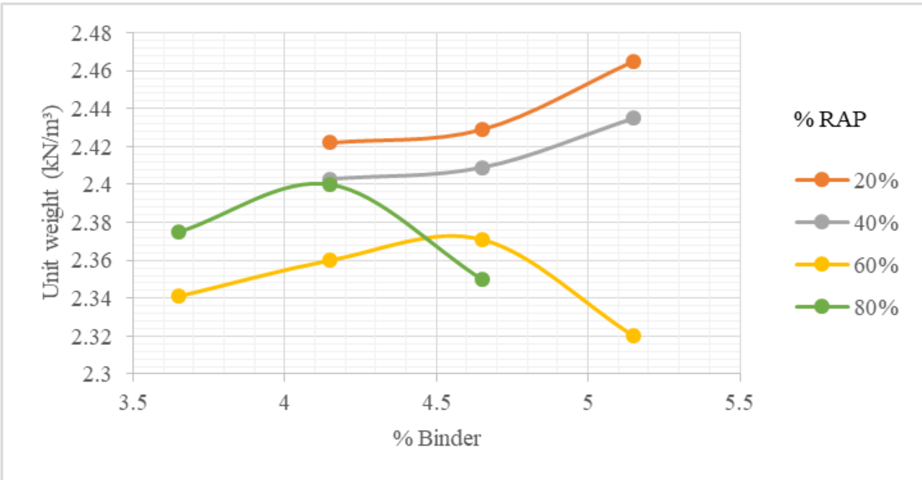

Fig.9. Binder Content versus Unit weight

Binder content versus Air voids. As per MS-2, Clause 7.4.2, the percent of air voids, steadily decreases with increasing binder content, ultimately approaching a minimum void content. From the Fig. 10, it can be seen that all graphs follow the given trend.

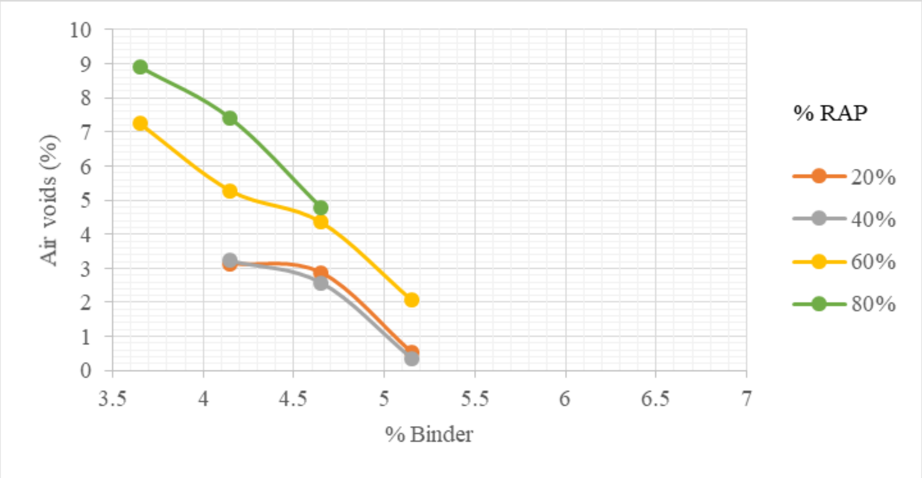

Fig.10. Binder Content versus Air voids

From the graph, it is observed that 20% and 40% RAP requires less binder than the optimum binder content while 60% and 80% RAP requires more binder than optimum binder content. This is related to the content of aged and virgin binders and mixing temperature. More RAP content would decrease the mixing temperature, which would result in insufficient melting of the RAP.

Binder content versus Voids in mineral aggregate (VMA). As per MS-2, Clause 7.4.2, the percent voids in the mineral aggregate, VMA decreases, reaches a minimum value, and then increases with an increase in binder content.

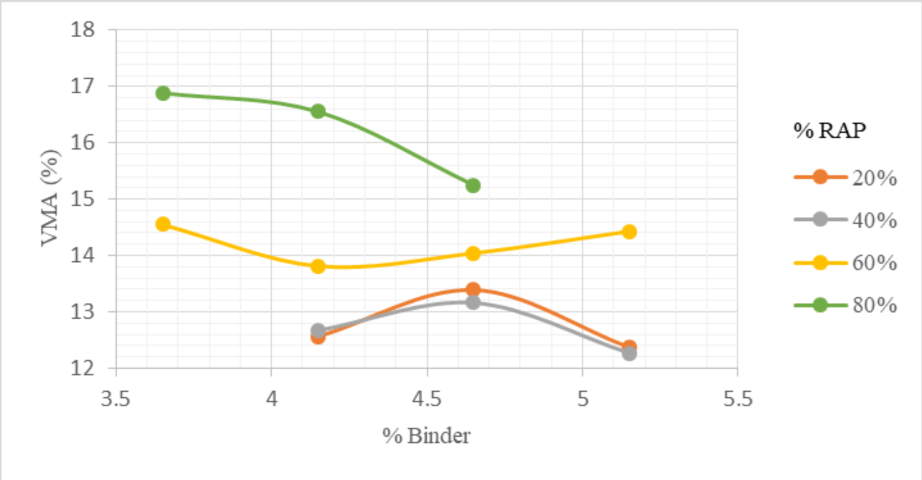

Fig.11. Binder Content versus VMA

From the Fig. 11, the mix containing 20% and 40% RAP doesn't follow the trend as per MS-2 for which further study needs to be performed. Only the mix with 60% RAP incorporated followed the trend. As per MS-2, table 7.3, the minimum percent of voids in mineral aggregate should be 14% and only 60% RAP has satisfied this criteria.

Binder content versus Voids filled with Asphalt (VFA) As per MS-2, Clause 7.4.2, the percent voids filled with asphalt, VFA, steadily increases with an increase in binder content.

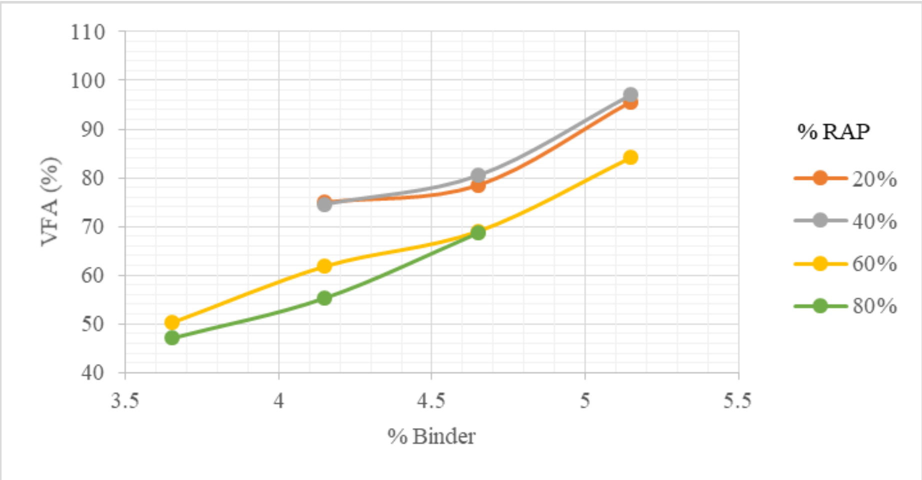

Fig.12. Binder Content versus VFA

From the Fig. 12, it can be noted that a mix containing all proportions of RAP satisfied the trend. From MS-2, table 7.2, the value for the percent voids filled with asphalt should lie between 65% and 75%. The mix containing 60% and 80% RAP satisfied these criteria with VFA values 71% and 67% respectively. The VFA values for 20% and 40% RAP are 78% and 76% respectively. The VFA is showing a decreasing trend with an increase in RAP content. This might be due to the improper melting of bitumen from RAP. Also due to improper melting, the bonding of bitumen with aggregate might not have happened enough and thus causing the compaction not being proper. It shows that compaction of the mixture increases with low RAP content and decreases with high RAP content. After analyzing the above graphs, the mix containing 60% RAP satisfied all the criteria and hence is the optimum RAP content that can be incorporated in the WMA mix. After analyzing the performance of various proportion of RAP in WMA mix the following points are observed:

- From the Binder content versus Stability graph and Binder content versus Flow value graph it is observed that the stability increases while the flow value decreases with an increase in RAP content. This may be due to the increase in stiffness of the mix due to the addition of RAP. To reduce the stiffness of the mix, a possible solution is to increase the effective dose of Zycotherm.
- From the Binder content versus Air voids graph, the mix containing 20% and 40% RAP has binder content less than the optimum binder content while 60% and 80% has binder content greater than the optimum binder content. With the increase in RAP content, increasing the mixing temperature would soften the aged binder in the RAP, thus, reducing the amount of binder content to be added.
- From the Binder content versus Voids filled with Asphalt (VFA) graph, there is a decrease in VFA values with an increase in RAP content. This may be due to the decrease in binder filled in between the aggregate which in turn decreases aggregate-aggregate distance and thus the mix gets more compacted. This can be rectified by increasing the mixing temperature of RAP and effective dose of Zycotherm which ensures the proper binding of aggregate with binder. This in turn increases the aggregate- aggregate distance, thus proper compaction of the mix is ensured.

6 Conclusion

In this paper the property and performance of the WMA mix incorporated with varying proportion of RAP was studied. Marshall Method of mix design was used to prepare the specimens. Specimens with varying quantities of RAP were prepared and tested to evaluate the effect of RAP in WMA mixes. By analyzing the results obtained it is observed that there is a decrease in the binder required for the mix containing 20% and 40% RAP. While the mixes having 60% and 80% RAP required more binder than the optimum binder content. This shift maybe due to the insufficient melting of the binder from the RAP which could be rectified by increasing the mixing temperature of mixes which contain higher quantity of RAP. After analyzing the performance of the mix with varying quantities of RAP, the mix containing 60% satisfied all the criteria and is the optimum quantity of RAP which could be incorporated in WMA mixes. The scope of the work that can be done further are:

- The mixing temperature of RAP needs to be increased in order to ensure the proper melting of the aged binder present. Further studies are needed to find the ageing of RAP to obtain the optimum mixing temperature of the RAP.
- The mix having 60% RAP is stiffer and this might result in the fatigue of the pavement. This problem can be solved by increasing the dose of Zycotherm, a WMA additive. More study needs to be carried out to optimize the quantity of Zycotherm in the mix.

References

1. Guo, M., Liu, H., Jiao, Y., Mo, L., Tan, Y., Wang, D., Liang, M. "Effect of WMA-RAP technology on pavement performance of asphalt mixture: A state-of-the-art review", *Journal of Cleaner Production*, Science direct volume 266 (2020).
2. Hettiarachchi, C., Hou, X., Wang, J., Xiao, F. "A comprehensive review on the utilization of reclaimed asphalt material with warm mix asphalt technology", *Construction and Building Materials*, Science direct volume 227 (2019).
3. Ayazi, M. J., Moniri, A., Barghabany, P. "Moisture susceptibility of warm mixed- reclaimed asphalt pavement containing Sasobit and Zycotherm additives", *Petroleum Science and Technology.* (2017).
4. Saride, S. M., Avirneni, D., Javvadi, S. C. P. "Utilization of Reclaimed Asphalt Pavements in Indian Low-Volume Roads", *Journal of Materials in Civil Engineering,* ASCE Volume 28 issue 2 (2016)
5. Rubio, M. C., Martínez, G., Baena, L., Moreno, F. "Warm mix asphalt: an overview*" Journal of Cleaner Production*, Science direct volume 24, pp 76-84 (2012).
6. Alsalihi M., Faheem A. (Compaction and Performance of Warm-Mix Asphalt with High-Reclaimed Asphalt Pavement J. Mater. Civ. Eng. ASCE (2020)

RESPONE TO THE REVIEWS

REVIEW 1

1. How the Zycotherm is mixed?

   The Zycotherm was poured and mixed with the bitumen boiling at 140^0 C.

2. How much quantity of Zycotherm is added?

   The quantity of Zycotherm was fixed as 0.125% of total weight of the bitumen. This was the average of the values recommended by the manufacturer, Zydex Industries (0.1%- 0.15%).

3. @ Table 3; Mention the test temperature.

   The viscosity test was conducted at 135^0 C as per Indian Standards - IS: 73-2006.

4. Mention the properties of the binder plus additive.

   Penetration test, specific gravity test and viscosity test were done on the binder which was mixed with Zycotherm. The test results are given in the following table.

Sl. No	Test Conducted	Test Result	Requirements (IS 2386 (Part 4) – 1963)
1	Penetration Test	54mm	>45mm
2	Specific Gravity	1.04	Nil
3	Viscosity test (test done at135^0C)	575.68cSt	Min. 350cSt

5. Make a comment/ include the properties of RAP aggregate.

   The properties of extracted aggregates from RAP were checked whether adequate in comparison with the requirements of virgin aggregates, as specific requirements of RAP are not mentioned anywhere. The specific gravity of the RAP aggregates was determined using an Asphalt Density Mixer and the flakiness index test was done to assess shape properties of RAP aggregates. The results of properties of RAP aggregates is given in table below.

Properties of RAP aggregates

Sl. No	Test Conducted	Test Result	Requirements for virgin aggregates (As per IS 2386 (Part 4)-1963)
1	Specific Gravity	2.465	2.5-3
2	Flakiness Index	20.78%	< 25%
3	Impact Test	28.57%	< 30%

6. 20% and 80% curve are not following the trend. Any comments?

   The curve can be obtained by preparing specimens with variation in binder content by ± 0.5% accordingly as required.

7. Please check the value mentioned 8006N

   As per MS-2, table 7.2 (Page no: 87), the minimum value required for heavy traffic flow is 8006N.

8. Curve (20% and 40%) showing increasing trend where as 60% curve presents zigzag trend w.r.t binder content?

   The 20% and 40% RAP curve might follow the trend as per given in MS 2 if specimens are prepared with increment in binder content by 0.5% (i.e., 5.65%, 6.15% etc.).

REVIEW 2

From the binder content v/s flow value graph we it can be seen that the flow value decreases with an increase in RAP content. This may be due to the reduction in the effective dosage of Zycotherm. Therefore, the performance test such as fatigue test, rutting test can only be carried out after the optimization of the dosage of Zycotherm.