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Influence of the Performance of Reclaimed Asphalt Pavement (RAP) Material on Bituminous Mix

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ABSTRACT

The utilization of reclaimed asphalt pavement (RAP) material to prepare a durable bituminous concrete (BC) mixture, used for flexible pavement surface courses is a challenging task in this investigation. RAP material is one of the latest substitutes for virgin aggregate and virgin binder of the bituminous mix. Using RAP material in flexible pavements can improve the engineering properties of bituminous mix and is also beneficial for economic and environmental. To execute such study, virgin aggregate (VA) has been replaced by 0, 10, 20, 30, 40, 50, 60, 75, and 100% of RAP material, respectively, in the cited mix with 2% Ordinary Portland Cement (OPC) as mineral filler. To characterize the RAP material, several laboratory tests such as specific gravity test, water absorption test, shape test, impact test, Los-Angeles abrasion test and, advanced tests as X-RF, X-RD, and GPC test, etc. have been employed. However, to assess the durability and strength of RAP enriched BC mix, Marshall stability test, modified Marshall immersion test, indirect tensile strength (ITS) test and, Cantabro abrasion test has been conducted. Marshall stability test, modified Marshall immersion test, ITS test, and Cantabro abrasion test is explored that 50% RAP modified bituminous mix has the capability to best perform than the other studied mix in terms of durability and strength. Because the molecular bonding of carbonyl compound between aged and virgin binder is suspected in the mix improvement factor that leads to the longer span life of the RAP modified flexible pavement.

Keywords: OBC; RMS; TSR; SDI; Durability.

1. INTRODUCTION

Recycling of RAP material is going to increase tremendously day by day all over the world. But bituminous pavement recycling techniques in India are still prevalent that way. Although, India is the second-largest road network in the world after the United States (about 4.2 million kilometers) [1]. The total length of road network in India as on March 31, 2016, is NH 101,011 km (Ministry of Road Transport and Highways), SH 176,166 km, (State / UT Public Works Department), other PWD roads 561,940 km (State Public Works / UT Division), rural roads 3,935,337 km (Panchayat, JRY, and PMGSY) and 509,730 km of urban roads (local government and municipality). However, developed countries use higher amounts of RAP material in the pavement industry. It has been found that 33 million tons of RAP material are used for recycling purposes each year in the USA, which is about 80% of the total RAP material collected from the old asphalt pavement [2]. And Sweden, about 0.84 million tons, Germany 7.3 million tons, Denmark 0.53 million tons, and the Netherlands about 0.12 million tons of RAP are used each year [3]. Because the utilization of RAP material has multiple advantages such as economic, environmental, technical, conservation of energy, asphalt concrete aggregate and asphalt cement supplement, hot mix asphalt and cold mix asphalt, etc. Besides, RAP material can enhance the performance of the bituminous mix, such as stiffness and rutting resistance [4]. The previous researchers stated that 15% to 70% RAP material was used successfully to construct the flexible pavement in the base course and the sub-base course whether only 15% to 30% RAP material was used in the surface course on the flexible pavement. Furthermore, the investigation is needed to use a higher proportion of RAP material to construct the surface course of flexible pavement. In this study, after extracting the RAP material as per the guidelines [5, 6], it was used to prepare BC mix for flexible pavement. To determine the RAP percentage which produces the most durable bituminous concrete mix by modified Marshall immersion test, at prolonged immersion conditioned (0, 1, 4, 7, and 14th days) to keep the temperature of water bath at 60°C, which is the prime of this investigation. The indirect tensile strength test is a supportive test of modified Marshall Immersion has been performed. Furthermore, a Cantabro abrasion test was performed to evaluate the raveling effect of the pavement due to vehicular movement. However, the flow chart of this investigation is embedded in Figure 1.

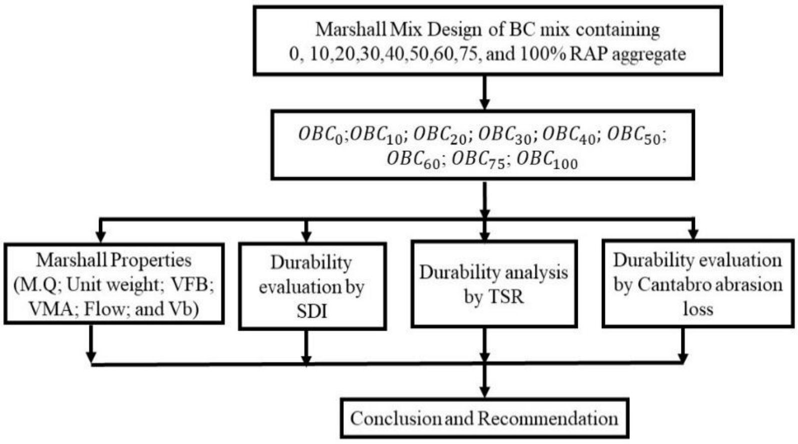

Figure. 1 Flow chart of the work plan

2. MATERIALS AND METHODOLOGY

In the present study, basaltic aggregate as base aggregate, VG-30 bitumen as base bitumen, RAP and, ordinary Portland cement (OPC-43) (as filler material) have been selected to check the suitability of these materials as per Indian specifications used in BC mix for flexible pavement.

2.1. RAP AGGREGATE (OBTAINED FROM RAP MATERIAL) AND VIRGIN AGGREGATE

RAP material is one of the very usable recycled materials that has been very useful in recent times. Nowadays, utilization of RAP material is going to increase rapidly day by day. RAP material was collected from state highway (SH)-1, at Chakdah, West Bengal, India. And the virgin basalt aggregate was utilized as base aggregate was collected from the local PWD office of Kolkata, WB, India. The physical properties, such as specific gravity test, shape test, soundness test, impact test, Los-Angeles abrasion test, water absorption test, X-RD test and, X-RF tests were conducted following the Indian Standards [7, 8] to verify whether the selected materials are satisfied the minimum requirements of the Indian specification [9]. The X-RD (X-Ray diffraction) results of RAP and virgin aggregate are depicted in Figures 2 and 3, respectively. Physical properties of added RAP aggregate and X-RF (X-Ray fluorescence spectroscopy) test results are furnished in Tables 1 and 2, respectively.

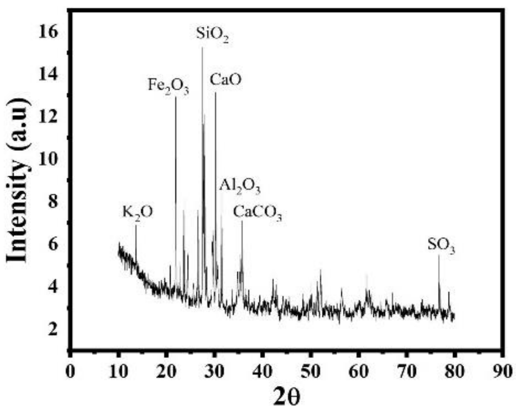

Figure 2. X-RD result of RAP aggregate

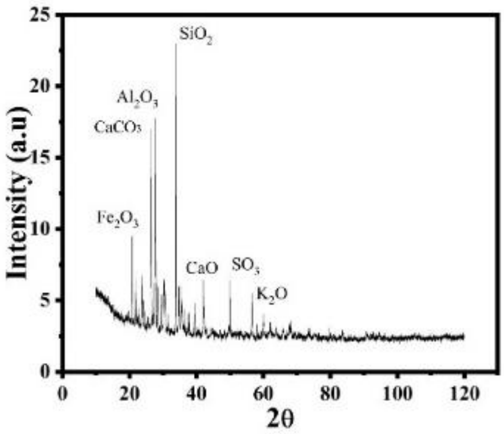

Figure. 3 X-RD result of Virgin aggregate

Table1. Physical properties of percentage of added RAP

Percentage components	RAP	Virgin aggregate
SiO2	**45.19**	**46.80**
CaO	**6.23**	**5.98**
Fe2O3	**11.20**	**9.40**
Mgo	**3.23**	**4.34**
MnO	**5.51**	**6.11**
CaCO3	**3.32**	**1.12**
SO3	**2.31**	**2.23**
Al2O3	**14.54**	**15.78**
K2O	**1.10**	**1.19**
Titanium oxide	**2.10**	**0.95**
K2O	**1.21**	**1.92**
Sodium oxide	**1.11**	**1.32**

Table 2. X-RF test result of RAP and virgin aggregate

Properties	Percentages added RAP material								
	0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**75%**	**100%**
Coarse Aggregate (C.A)									
Specific gravity	**2.8**	**2.82**	**2.84**	**2.85**	**2.87**	**2.88**	**2.9**	**2.91**	**2.92**
Shape test value (%)	**15.89**	**15.95**	**16.02**	**15.87**	**17.34**	**17.45**	**17.14**	**17.55**	**18.82**
Soundness test (%)	**5.23**	**5.45**	**5.61**	**5.89**	**5.91**	**6.21**	**7.22**	**8.10**	**8.19**
Impact test (%)	**17.95**	**18.10**	**18.60**	**18.76**	**19.27**	**19.78**	**20.15**	**20.88**	**21.24**
Los-Angeles's abrasion test (%)	**19.45**	**19.67**	**19.89**	**20.01**	**20.54**	**20.79**	**21.41**	**22.20**	**23.12**
Water absorption (%)	**1.51**	**1.53**	**1.55**	**1.52**	**1.50**	**1.51**	**1.62**	**1.68**	**1.74**
Fine aggregate (F.A)									
Specific gravity	**2.7**	**2.61**	**2.63**	**2.65**	**2.66**	**2.67**	**2.62**	**2.64**	**2.68**
Water absorption test (%)	**1.58**	**1.61**	**1.64**	**1.65**	**1.65**	**1.66**	**1.67**	**1.68**	**1.69**
Filler									
Specific gravity	**3.15**								

2.2. VIRGIN BITUMEN AND AGED BITUMEN (OBTAINED FROM RAP MATERIAL)

In this investigation, 60/70 penetration grade bitumen (VG-30) was selected as the binder material of the BC mix. Bitumen is used in large quantities every year in India and around the world. Thus, it will be very important to preserve the natural source of the bitumen for future purposes. For this study, bitumen was procured from Haldia Refinery Oil Corporation Limited, West Bengal, India. Various tests like specific gravity test, penetration test, softening point test, flexibility test, and viscosity test, etc., were conducted as per Indian standards [10-12]. The physical properties of the aged bitumen and virgin bitumen are presented in Table 3. And the result of the conventional test of the aged bitumen blended with VG-30 bitumen at optimum composition is embedded in Table 4.

Table 3. Physical properties of different types of studied bitumen

Property	Desirable value	Type of bitumen		Standards
		Virgin	**Aged**	
Specific gravity at 27°C	**0.97-1.04**	**1.00**	**0.98**	**IS:1202-1978**
Penetration, (100gm, 5s, dmm.)	**45(min.)**	**67.00**	**64.00**	**IS 73:1203**
Softening point, (°C)	**47(Min.)**	**46.00**	**50.00**	**IS 73: 1205**
Ductility at 25°C	**40(Min.)**	**80.00**	**77.00**	**IS73:1208**
Absolute viscosity at 60^0C(Poise)	**2400-3600**	**2560**	**2780**	**IS73:1206(part 2)**

Table 4. Result of conventional test of aged bitumen blended with VG-30 bitumen at optimum composition

Sample No.	Penetration at 25° C (IS 73:1203)	Softening Point(°C) (IS 73 :1205)	Absolute viscosity at 60°C (IS 73:1206-Part2)
1	**65**	**49**	**2600**
2	**63**	**49**	**2580**
3	**64.6**	**49.5**	**2700**
4	**65.70**	**47**	**2500**
5	**66**	**48**	**2540**
6	**63**	**48**	**2560**
7	**60**	**49**	**2600**
8	**60.4**	**49.5**	**2600**
9	**60.6**	**49.80**	**2500**
10	**65**	**49**	**2500**
Mean	**63.33**	**48.78**	**2568**

2.3. FILLER MATERIAL

In this investigation, OPC - 43 was used as the filler material, was collected from the local PWD office, Kolkata, WB, India. The filler material can increase the stiffness between binder and aggregate, and it is also attributed to decelerating the permanent deformation of the BC mix. Specific gravity was performed as per Indian specifications. The specific gravity of filler material is furnished in Table 1.

2.4. METHODOLOGY

2.4.1. RAP EXTRACTION

The RAP material was extracted by standards guidelines [5, 6]. For this experiment, 500 grams of RAP material was taken and placed in the bowl of a centrifugal machine. Add benzene to the RAP material until it is completely submerged. It was taken not more than one hour before the solvent disintegrated. Initially rotate the centrifuge machine slowly and then gradually increases the speed by 3,600 rpm. Operate the machine until the bitumen and benzene are completely removed through the outlet pipe of the centrifuge machine. Then, add 200ml of benzene and follow the same manner as aforementioned above. Repeat the same procedure a minimum of three times. Collect the benzene bitumen and RAP aggregate and dry in the oven at a temperature of 1050C to 1100C and cool it at ambient temperature.

2.4.2. GEL PERMEATION CHROMATOGRAPHY (GPC) TEST

Gel permeation chromatography (GPC) or size exclusion chromatography is one of the most useful techniques to characterize the polymers in terms of analytical phase, based on the molecular size or weight distribution through a given medium – in this case, bitumen content. Many researchers [13-19] were attempted the GPC test to distinguish the different types of bitumen incorporated with the molecular distribution. This molecular distribution can be distinguished in three different categories, such as large molecular size (LMS), medium molecular size (MMS), and small molecular size (SMS) [15]. But no investigation has found any link between bituminous performance property and MMS and SMS. A solvent is required to dissolve the bitumen into it and prepare a bituminous solution. In this investigation, the most common solvent, tetrahydrofuran (THF), is used based on its excellent reproducibility relative to another one- solvent such as toluene. It should be careful to remove all residual bubbles from the solvent; otherwise, the residual bubble may create a sound effect on the derived GPC profile. Then THF is injected into the vial to dissolve the prepared bituminous sample. Check that the bitumen is completely dissolved to prepare a solution. The mix can be done using a centrifugal machine or stored 24 hours at room temperatures. Storage time should be increased 72hours for rubber asphalt and high viscosity asphalt binder with high polymer. The concentration of the solution may be changed or not, as per the requirement of the test. The test is performed at a temperature from 35°C to 50°C. However, the temperature is not an effective parameter of the test results.

2.4.3. MARSHALL MIX DESIGN

Marshall Mixes design method is a holistic approach to achieve the optimum bitumen content (OBC) and Marshall volumetric parameters of the BC mix with a variable percentages RAP material. The gradation-I of the aggregate of BC mix is chosen as per Indian specification [9], and the gradation curve of BC mix is embedded in Figure 4. Marshall Stability has defined the resistance to plastic flow of cylindrical samples [20]. To prepare RAP enriched bituminous mix, RAP aggregate and virgin aggregate is heated separately at 154°C-160°C and 170°C to 180°C, respectively. Preheated virgin bitumen (135°C) is added with virgin aggregate and mix it properly. Aged bitumen is stirred manually for about 5 min. They are maintaining the temperature of the mix at 150°C-160°C. The RAP aggregate and aged binder were then mixed with this mixture, and a homogeneous mixture was prepared and compacted in a preheated mold with a Marshall hammer by applying specific force as per the standards guideline. [9, 20-23]. Bituminous mixes are usually prepared in the field at a mixing temperature not exceeding 160°C. The bitumen content is selected as 5.2% to 6% in 0.20% increment. A total of 135 samples (i.e., 3 replicates × 5 binder content × 9 different RAP contents) are prepared to find 9 separate optimum bitumen contents (OBC).

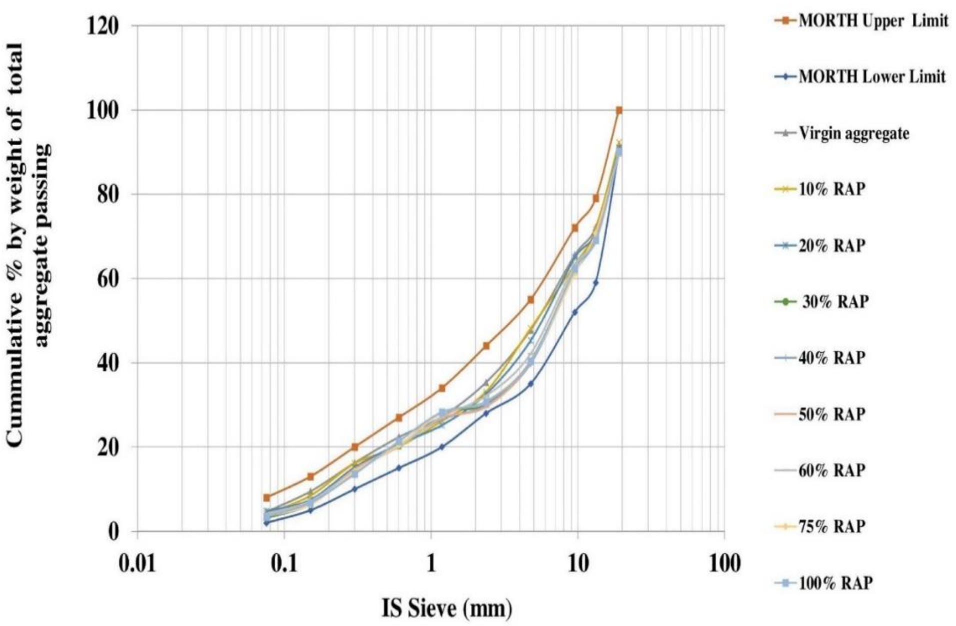

Figure 4. Gradation curve of BC mixes

2.4.4. MODIFIED MARSHALL IMMERSION TEST

To account for the structural integrity of bituminous mix due to the moisture effect, a modified Marshall immersion method has been conducted as per the previous researchers' approach [24]. In this test, the standard Marshall specimens (diameter100.01mm and height 63.5mm) were prepared at predetermined OBC. Retained Marshall stability (RMS) value was estimated for pre-compacted specimens by soaking in the water bath for 0, 1, 4, 7, and 14 days, keeping the temperature of the water bath at 60°C. RMS has defined the stability value of the wet samples to the stability value of the dry samples in percentages. A total of 135 samples (i.e., 3 replicates × 9OBCs×5 different soaking periods) were prepared to estimate the RMS value of RAP modified bituminous mix. RMS value was estimated using equation 1.

$$\mathrm{RMS}=\frac{S_i}{S_0}\times 100 \qquad (1)$$

Where; RMS = retained Marshall stability (%); Si= stability of wet specimen at time t_i; S_0= stability of dry specimen.

Further, analysis of moisture-induced damage of RAP enriched bituminous mix, the durability index has been employed. Out of three durability indices, only a second durability index (SDI) was applied to analyze the moisture effect of RAP modified bituminous mix. However, the second durability index is quite accurate than the other two indices. The SDI is indicated as the wide area of stability loss that lies between the durability curve and S_0 [26-28]. This index is also revealed the stability lost in one day where its value is positive. However, to assess the SDI of RAP enriched bituminous mix the modified Marshall Immersion test was selected. A total of 135 samples (i.e., 3 replicates × 9OBCs × 5 different immersion times) were prepared, and immersion time was considered as 0, 1, 4, 7and 14 days and maintained the temperature of water bath at 60˚C. The following equation was used to estimate the SDI value.

$$SDI = \frac{1}{t_n} = \frac{1}{2t_n}\sum_{i=0}^{n-1}(S_i - S_{i+1})[2t_n - (t_i + t_{i+1})] \quad (2)$$

Where, S_{i+1} = percent retained strength at time t_{i+1}, S_i=percent retained strength at time t_i, t_{i+1}= soaking periods.

2.4.5. INDIRECT TENSILE STRENGTH TEST

To assess the moisture susceptibility of the bituminous mix in terms of tensile strength ratio (TSR), the indirect tensile strength (ITS) test was adopted as per another approach [27]. Several investigators [20, 23, 28] were used the ITS test to quantify the durability of RAP modified bituminous mix due to moisture-induced damage. A total of 27(*i.e.*, 3replicates×9OBCs) Marshall samples were prepared at predetermined OBC to estimate the TSR. To estimate the TSR (%), the samples were submerged in a water bath at 60˚C for 24 hours for conditioned, then placed in the water bath at 25˚C for 1 hour. For the dry subset, the samples were soaked in the water bath at 25˚C for 25minutes. TSR was calculated by the following equation, 3

$$TSR = \frac{S_w}{S_d} \times 100 \quad (3)$$

Where, S_w = average indirect tensile strength of wet specimen (kPa); estimated by Eq. 4; and; Sd = average indirect tensile strength of dry specimen (kPa), estimated by Eq. 5;

$$S_w = 2000 \times \frac{P}{\pi t d} \quad (4)$$

$$S_d = 2000 \times \frac{P}{\pi t d} \quad (5)$$

Where, P = maximum load(N); t =height of specimen immediate before the test(mm); and d= diameter(mm) of the specimen.

2.4.6. CANTABRO ABRASION TEST

Cantabro abrasion test was tested to indirectly measure the abrasion resistance of bituminous pavements due to wear according to the Chinese specification [29]. Samples were prepared at OBC to determine the abrasion mass loss of compacted hot-mix bituminous specimen, having a standard diameter 6.35cm and height of 10.01cm. Few investigators [30-36] were approached the Cantabro abrasions test to evaluate the durability and raveling of the bituminous mix. Even for the perforated asphalt concrete mix design method in China, the minimum asphalt content was determined by the Cantabro friction test [33]. In this study, for conditioning purposes, the samples were soaked in water at 20°C for 20 hours. To execute this test, the Los-Angeles abrasion testing machine has been utilized without any iron balls by account of the percentage of weight loss of Marshall sample after the experiment completion. Before placing the specimen into the abrasion machine, the sample was weighed. The Los Angeles abrasion machine is operated at a speed of 30-33 revolutions per minute and a total of 300 rotations are required to complete the test. After certain revolutions were completed, remove the broken loose material from the test sample and weigh the sample. Cantabro mass loss was estimated by the following equation 6.

$$m = \frac{m1 - m2}{m1} \times 100 \quad (6)$$

Where; m= Cantabro mass loss in percentage; m1= weight of the sample before the experiment; m2= weight of specimen after the experiment.

3. RESULTS AND DISCUSSION

3.1. EVALUATION OF THE PERFORMANCE OF BITUMEN BY GPC TEST

In this research work, Figure 5, is depicted the size distribution of LSM and SMS value of different types of bitumen, such as aged bitumen, the blend of aged and virgin bitumen and, virgin bitumen. Primarily, LSM and SMS values of all studied bitumen are linearly increased. After a certain time, LSM and MMS values drastically increased and then suddenly fell. Finally, again a linear increment has been observed for all studied bitumen. However, the peak value of LSM (90%) value has been observed for aged bitumen whereas, the lowest peak value of LSM (50%) is found for virgin bitumen. But combined bitumen is showed a moderate LSM and MMS value. On the other hand, Figure 6, is depicted the percent of the area of LMS and SMS value of the bitumen, whereas the maximum area of LMS and MMS was occupied by the aged bitumen and the minimum for the virgin bitumen. However, the aged bitumen contains 5.44% higher area than the virgin bitumen. The aged bitumen can occupy the highest percentage of the area than the other studied bitumen. Because the aging effect is occurred in the aged bitumen content due to the oxidation effect and for this, the aged bitumen contains the highest area than other studied bitumen. It can be said that the aged bitumen can enhance the performance of the bituminous mix incorporated with a durable than the virgin bitumen.

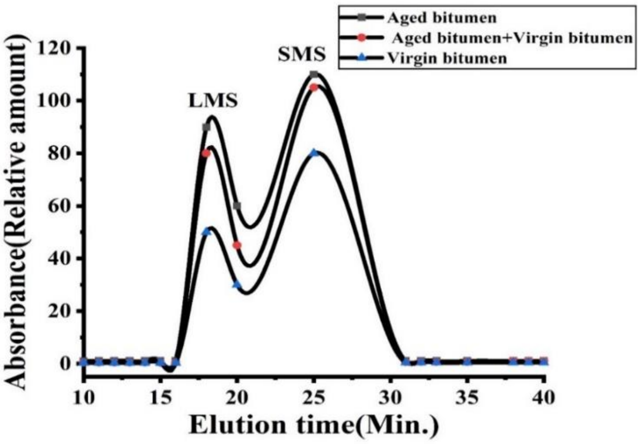

Figure 5. GPC test result of size distribution of bitumen

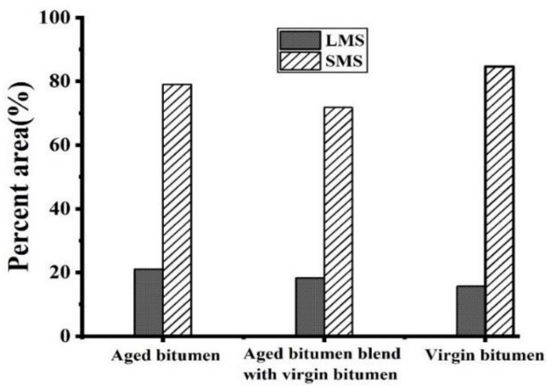

Figure 6. GPC test result of bitumen area under the peak

3.2. EVALUATION OF THE PERFORMANCE OF RAP ENRICHED BITUMINOUS MIX BY MARSHALL STABILITY TEST

Marshall stability test was conducted to address the design parameters and optimum bitumen content (OBC) of bituminous concrete (BC) mix. Table 5 contains the Marshall stability test result, and it is revealed that the value of OBC fell from 5.620-5.615% for 0-100% RAP. The minimum OBC (5.590%) is found in corresponds to the highest Marshall stability (18.49 kN), and unit weight (2.435 g/cm3) for 50% RAP enriched bituminous mix. Not all OBC values are acceptable; only OBC values will be accepted for those who have a corresponding Marshall quotient lies between 2.5-5 as per Indian specifications [9]. However, 5.62% OBC is the mode value for the RAP modified BC mix. And it is already said that 50% RAP modified bituminous mix contains the minimum percentage of OBC, which consumed 0.28% less bitumen than the control mix. Flow is another important parameter of the Marshall stability test. It is defined as the vertical deformation when the maximum load has been applied to the sample at a time of the Marshall stability test. In this study, as per Table 5, the flow value is consistently reduced from 3.95 to 3.75 mm. for 50% RAP modified bituminous mix. And then raised by 5.50mm for 100% RAP enriched bituminous mix. Another important parameter of the Marshall quotient (stability/flow, kN/mm) is related to the stiffness of the bituminous mix. Maximum Marshall quotient has been observed for 50% RAP enriched bituminous mix, which is 25.76% higher than the control mix. And there a vice-versa relationship is found between the percentage of air voids (Vv%)) and percentages of voids filled with bitumen (VFB%), and a linear relationship has been observed with voids of mineral aggregate (VMA%) of the bituminous mix. The higher percentage of RAP material reduces the voids and increases the adhesiveness of bituminous mix due to the oxidation effect of aged bitumen of RAP. Because up to 50% RAP, the aged bitumen compatibility mix with virgin bitumen and virgin aggregate, after that, the compatibility disappears for other percentages of RAP modified bituminous mix. In Table 5, VFB is increased using 50% RAP from 70.92-74.94% and then dropped by 70.00% for 100% RAP. It can be said that 50% RAP enriched bituminous mix leads to better service life for flexible pavement because molecular bonding of carbonyl compound between aged and virgin bitumen is suspected in the mix improvement factor after that physical aging is prominently activated on the other studied mixes.

Table 5. Variation of Marshall Parameters containing the variable percentage of RAP in corresponding OBC

Percentage of RAP	OBC (%)	Unit weight (gm/cc)	Marshall Stability (kN)	Flow (mm)	Vv (%)	VMA (%)	VFB (%)	M.Q (kN/mm)
0	**5.620**	**2.405**	**15.47**	**3.95**	**4.64**	**17.43**	**70.92**	**3.92**
10	**5.610**	**2.412**	**15.95**	**3.89**	**4.70**	**17.20**	**71.78**	**4.10**
20	**5.597**	**2.416**	**16.58**	**3.85**	**4.59**	**17.05**	**72.89**	**4.31**
30	**5.594**	**2.419**	**16.95**	**3.80**	**4.97**	**16.95**	**73.96**	**4.46**
40	**5.592**	**2.423**	**17.38**	**3.78**	**4.39**	**16.50**	**74.34**	**4.60**
50	**5.590**	**2.428**	**18.49**	**3.75**	**3.25**	**16.16**	**74.94**	**4.93**
60	**5.630**	**2.409**	**16.91**	**4.12**	**3.70**	**17.25**	**72.65**	**4.10**
75	**5.640**	**2.400**	**13.42**	**4.79**	**4.95**	**18.45**	**71.62**	**2.80**
100	**5.651**	**2.397**	**11.35**	**5.50**	**5.02**	**19.41**	**70.04**	**2.06**

3.3. ANALYSIS OF THE MOISTURE EFFECT OF RAP ENRICHED BITUMINOUS MIX BY DURABILITY INDEX

A modified Marshall immersion test was attempted to evaluate the moisture effect analysis of bituminous concrete mix by durability index. In Table 6, fluctuation retained Marshall stability (RMS) has been observed. The results explore that the RMS value consistently increases from 90.32-98.56% for 50% RAP enriched bituminous mix and then the descent it from 95.65-90.13 % for 100% RAP modified bituminous mix for 1-day immersion. All RMS value in these studied mixes is higher than 80%. Subsequently, the RMS value is linearly decreased with increasing the immersion period. Because increasing immersion period increases the pores of the bituminous mix and adhesion and cohesion failure has occurred of the binder of the mix. 50% RAP enriched bituminous mix contains 76.49% RMS value beyond the 7th day's immersion period, which is lower than 80%. A higher RMS value indicates the higher moisture resistivity potency. In this test, it is suggested that 50% RAP is produced the highest moisture restive bituminous mix than the other studied mixes. As per Figure 7, fluctuation of the second durability index (SDI) value is found for the RAP modified bituminous mix. Initially, SDI is gradually decreased from 24.15 to 16.29% up to 50%RAP modified bituminous mix. Then SDI value is increased from 19.47 to 26.03% up to 100 RAP enriched modified mix. Eventually, 100% RAP enriched bituminous mix contains 1.88% higher durability index than the control mix. However, 50% RAP enriched bituminous mix is more efficient in resisting moisture-induced damage than the other studied mixes. The structural integrity was estimated using the SDI value, which is shown in Figure 7. There is no doubt that the relationship between SDI and structural integrity is inversely proportional to each other. The maximum structural integrity is observed corresponding to the minimum SDI value for the 50% RAP modified bituminous mix. Similarly, the minimum structural integrity is found corresponding to the maximum SDI value for the 100% RAP modified bituminous mix. This is because aged bitumen helps to increase the adhesion of bituminous mix up to 50% RAP enriched bituminous mix due to physical hardening, which is prone after 50% RAP.

Table 6. Retained Marshall Stability (%) of different percentages of RAP enriched bituminous mix In several immersion periods

Percentages of RAP	RMS in different immersion time series (Days)			
	1st Day	**4th Days**	**7th Days**	**14th Days**
0	**90.32**	**82.82**	**65.94**	**58.35**
10	**92.45**	**83.76**	**67.16**	**60.71**
20	**94.58**	**85.38**	**71.19**	**62.27**
30	**97.02**	**86.60**	**73.36**	**63.18**
40	**97.78**	**87.74**	**75.70**	**65.735**
50	**98.56**	**89.34**	**76.49**	**67.215**
60	**95.65**	**87.13**	**73.92**	**57.155**
75	**92.08**	**84.34**	**64.29**	**48.56**
100	**90.13**	**81.19**	**57.78**	**39.98**

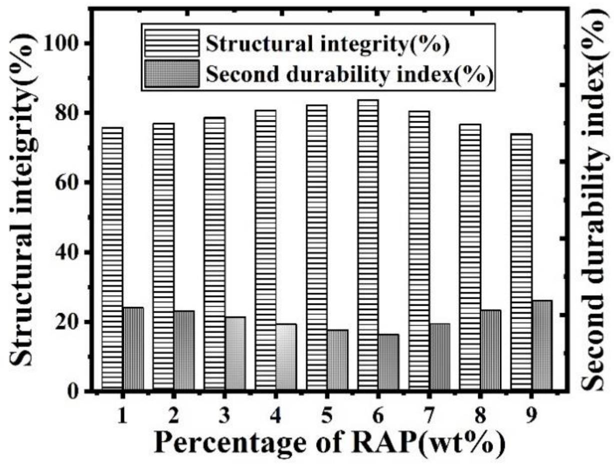

Figure 7. Durability index and structural interiority of RAP modified bituminous concrete mix.

3.4.5. ASSESSMENT OF MOISTURE SUSCEPTIBILITY OF RAP ENRICHED BITUMINOUS MIX BY INDIRECT TENSILE STRENGTH TEST (ITS)

To quantify the short-term durability of BC mix, tensile strength ratio (TSR) has been conducted. To find out the TSR, an indirect tensile strength test was attempted on a wet subset to a dry subset for 24-hour immersion in the water bath at a temperature of 60°C. Figure 8, is described the dry and the wet subset of ITS value consistently increases up to 50% RAP enriched bituminous mix from 1553.67-1936.62kP and 1360.92-1912.65 kPa, respectively. Subsequently, the ITS value fell from 1690.32-1155.035 kPa for dry samples and 1575.33-916.49 kPa for wet samples. But the ITS value of the 50% RAP modified bituminous mix for the dry subset is 23.9 kPa greater than wet conditioned subsets. As per Indian specification [9], 80% should be the minimum value of the indirect tensile strength ratio. All measured results are satisfied the minimum TSR value. Table 7, contains the increasing trend of TSR value for 50% RAP enriched bituminous mix, and then gradually reduces the TSR value for 100% RAP enriched mix from 98.77-80.05%. It indicates that 50% RAP enriched bituminous mix has the highest moisture resistance potency than other studied mixes. Because the aged bitumen compatibility mixed with virgin aggregate and virgin bitumen up to 50% due to oxidation effect of RAP material. Then the degree of compatibility was decreased or disappeared. Eventually, it was found that RAP material can enhance the TSR property of the bituminous mix [37].

Table 7. Fluctuation of TSR ratio of bituminous concrete containing different percentages of RAP

Percentages of RAP	Tensile strength ratio
0	**87.59**
10	**89.91**
20	**91.67**
30	**94.42**
40	**96.53**
50	**98.77**
60	**93.20**
75	**85.63**
100	**80.05**

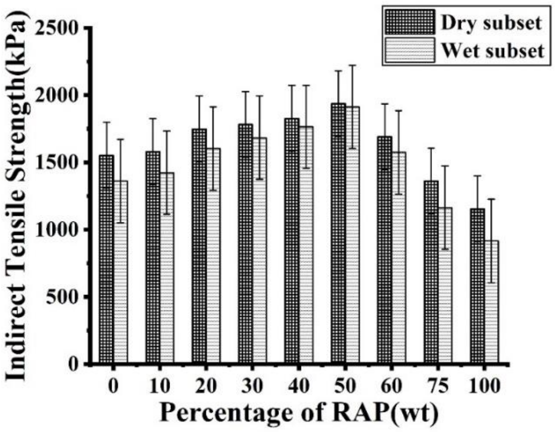

Figure 8. Indirect tensile strength of RAP modified bituminous concrete mix

3.4.6. QUANTIFICATION OF DURABILITY, AS WELL AS BONDING STRENGTH OF RAP MODIFIED BITUMINOUS MIX BY CANTABRO ABRASION TEST

Cantabro abrasion test was conducted to estimate the wear and tear by abrasive force caused by vehicular movement [38]. And hence, evaluation of Cantabro abrasion loss is very important to design flexible Pavement. Other hand, Cantabro abrasion loss suggests the bonding strength between aggregate and bitumen. As per Figure 9, primarily Cantabro abrasion loss is linearly decreased from 12.55 - 8.71% up to 0 - 50% RAP modified bituminous mix and thereafter gradually increased from 10.35- 12.90 for 60-100% RAP. However, maximum Cantabro abrasion loss is found for 100% RAP enriched bituminous mix, which is 0.35% higher than the control mix. And minimum Cantabro abrasion loss is observed for 50% RAP modified bituminous mix, which is 3.4% lower than the control mix. It can be said that a 50 % RAP can enhance the property of the bituminous mix in terms of durability as well as strength of the mix. Hence, 50% RAP has the highest resistance potency due to moisture induce damage to accompany wear and tear caused by the traffic movement.

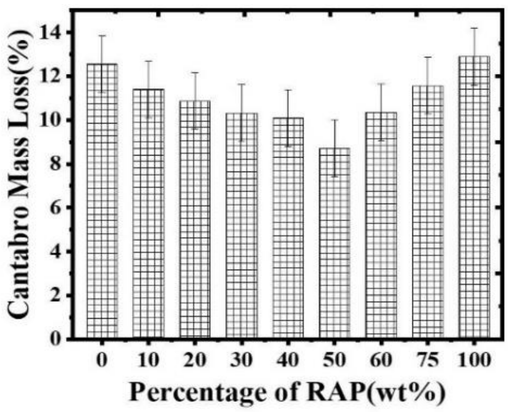

Figure 9. Cantabro test of RAP enriched bituminous mix concrete

4. CONCLUSION

In this study, RAP is a very influential substitute material of virgin aggregate as well as virgin bitumen in terms of the economic and environmental prospectus in the bituminous concrete (BC) mix. Several tests are performed, and the test results are satisfied the required criteria and determine the RAP percentage, which is produced the most durable bituminous mix for flexible pavement. However, based on the experimental results, the following conclusion can be drawn-After estimating the physical and chemical properties of RAP and aged bitumen and comparing the results with Indian standards, it can be said that RAP material can be used as the substitute for virgin aggregate and virgin bitumen in a bituminous mix. And RAP material can enhance the engineering properties significantly and lead to a longer span of life of the bituminous concrete mix. Based on the Marshall stability test, it can be concluded that 50% RAP material prominently improves the Marshall volumetric parameters. Because, up to 50% RAP modified bituminous mix, the aged bitumen and RAP aggregate compatibility mixes with virgin bitumen and virgin aggregate and prepares a homogeneous mix. Eventually, physical aging is prominently activated due to the oxidation effect for aged material. Hence, 50% RAP material can perform best than the other studied mixes. The modified Marshall immersion test (long-term durability test) is explored that 50% RAP enriched bituminous mix has the lowest durability index (16.29%) with the highest structural integrity (84.71%). It indicates that 50%RAP enriched bituminous mix has a higher moisture-resistance capacity than other studied mixes. Lower carboxylic acid is suspected in 50% RAP material, which enhances the structural integrity of the bituminous concrete mix due to moisture-induced damage. The tensile strength test is a short-term durability test as well as a supportive test of the modified Marshall immersion test. 50% RAP is showed the highest tensile strength ratio (98.77%), which is 11.18% higher than the control mix. And, hence, 50% RAP enriched bituminous mix has the highest moisture resistivity potency with less Cantabro abrasion loss value (8.71%) than the other studied mixes. Less abrasion loss ratio indicates the highest abrasion resistance potency of RAP modified bituminous mix due to the wear and tear of pavement by vehicular movement. However, it can be said that 50% RAP may perform better than other studied mixes in terms of strength and durability. Because aged bitumen has been filled, the voids of the mix due to the physical hardening effect, which is occurred tremendously, after 50% RAP. Eventually, short-term aging, losses of the engineering properties of bitumen. Hence, it can be said that 50% RAP can improve the performance of bituminous mix positively and significantly to produce the most durable mix. In this study, only one source of RAP was investigated. Collecting the RAP from several sources and investigating it, in the same manner will be the future work of this study. Besides rutting and fatigue study of the RAP enriched bituminous mix will be another future work.

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CONFLICT OF INTEREST

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