# Effect of saw dust ash (SDA) and recycled asphalt pavement (RAP) in the bituminous concrete

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**Abstract.** The present study deals with the effect of saw dust ash (SDA) as an alternative filler and recycled asphalt pavement (RAP) material in bituminous concrete (BC). Several physical and chemical experiments were performed to characterize the SDA and RAP material according to the standard specifications. To execute such study, virgin aggregate and RAP were blended as 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 25 :75, 0 :100% and 8% SDA was used as filler to prepare the BC mix. In this study, 2% ordinary Portland cement (OPC-43) was utilized to prepare the control mix. However, to quantify the performance of RAP and 8% SDA in the BC mix, several Marshall properties, and the performances criterion against various distress (rutting, cracking, and moisture susceptibility) were conducted. The experimental results reveal that 60% RAP-8%SDA enriched BC mix shows superior rutting, cracking, and moisture resistance potency with the highest structural integrity of 82.10%. Since the dominant percent of calcium oxide mineral present in that filler reacts with the dipolar carboxylic acid which already exists in an aged binder and thus the adhesive property of the binder in the BC is improved significantly. **Keywords:** Bituminous concrete, Reclaimed asphalt pavement, Saw dust ash (SDA), Rutting, Cracking, Moisture susceptibility.

## 1. Introduction

Filler materials contribute significant performance to improve the servals engineering property in a bituminous mix. It increases the bonding strength between aggregate and bitumen. Various researchers used different types of waste materials, such as fly ash, bottom ash, corn-cab ash, pond ash, rice husk ash, etc., as alternative filler in bituminous mixes for flexible pavement. But SDA was rarely used to prepare the bituminous mix with RAP material. It was reported in 2008, that 2.2 million tonnes of saw dust are produced per year in India from the sawmill and plywood sectors [1]. Utilizing such waste materials in the pavement industry significantly impacts the environment as well as economical.

Few studies used saw dust ash as a mineral filler in the BC mixture for flexible pavements instead of conventional fillers [2,3,4]. Nevertheless, their investigation did not significantly meet the criteria for using SDA in the BC mix. Furthermore, research is needed on a larger scale to quantify the impact and monitor the suitability of SDA in BC mix for bituminous pavements with significant performance.

The current investigation was conducted to observe the effects of various percentages of RAP material with 8% SDA as filler material on the strength properties of BC mixes. This study explored the features and suitability of RAP material and 8% SDA, by performing Marshall strength, parameters, rutting, cracking, and moisture susceptibility. However, the work plan of this investigation is embedded in Figure1, to clearly understand the entire work.

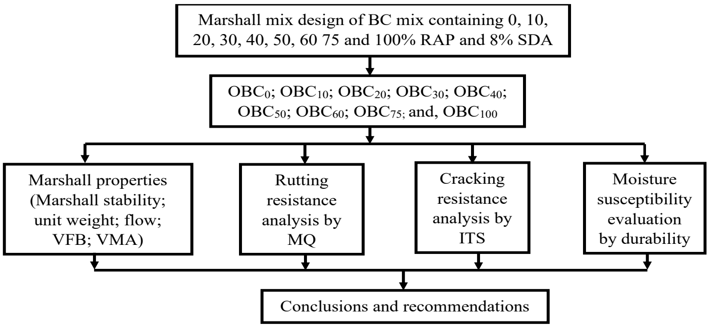



Figure 1. Flow chart of the investigation

## 2. Objectives

In view to evaluate the performance of the RAP and8% SDA as a nonconventional filler material to prepare the BC mix, the primary objectives of the study are drawn as stated below:

- To characterize the study materials such as RAP and SDA by determining physical, and chemical properties with a comparison with the standard specifications.
- To determine the OBC and several Marshall parameters for RAP and 8%SDA enriched BC mix.
- To ascertain resistance against rutting in terms of Marshall quotient (MQ) and cracking in terms of ITS test on the varying percentage of RAP-8%SDA modified BC mix.
- To evaluate the moisture susceptibility of the BC mix containing several proportions of RAP and 8% SDA by performing retained Marshall stability (RMS) test.

## 3. Materials and Methodology

Detailed physical and chemical properties of bituminous mix components such as aggregate, bitumen, SDA, and OPC have been performed to check the eligibility of the materials to be used in the BC.

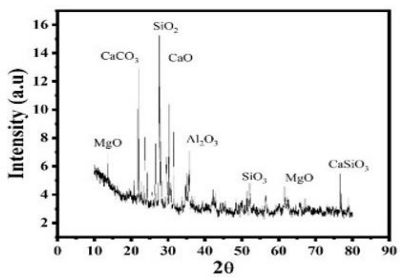
### 3.1 Materials

#### *3.1.1 Aggregate*

Various experiments were performed to characterize the aggregate as per the Indian speciation [5], and collected from the local quarry, in West Bengal, India. These results are specified in Table 1. Further X-RD and X-RF tests were conducted to quantify crystalline nature and chemical compositions and these results are stated in Figure 2, and Table 2.

Table 1. Physical properties of several percentages of RAP

| Property of aggregate | Percentage of RAP added | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 75% | 100 % |
| Specific gravity | 2.83 | 2.75 | 2.73 | 2.74 | 2.72 | 2.71 | 2.73 | 2.74 | 2.72 |
| Water absorption (%) | 1.51 | 1.53 | 1.55 | 1.52 | 1.50 | 1.51 | 1.62 | 1.68 | 1.74 |
| Combined Flakiness and elongation indices (%) | 15.89 | 15.95 | 16.02 | 16.17 | 17.34 | 17.45 | 17.14 | 17.55 | 18.82 |
| Soundness (%) | 7.75 | 8.45 | 8.61 | 8.89 | 8.91 | 9.21 | 9.25 | 9.30 | 9.44 |
| Impact value (%) | 17.95 | 18.10 | 18.60 | 18.76 | 19.27 | 19.78 | 20.15 | 20.88 | 21.24 |
| Los-Angeles abrasion value (%) | 19.45 | 19.67 | 19.89 | 20.01 | 20.54 | 20.79 | 21.41 | 22.20 | 23.12 |



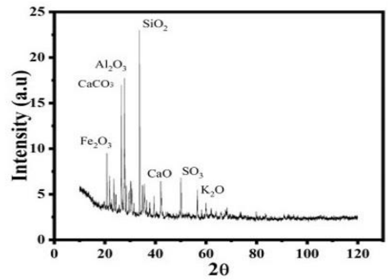




Figure 2. X-RD results of virgin aggregate(a) and RAP(b)

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

| Percentage of components | RAP aggregate | Virgin aggregate | Percentage of components | RAP aggregate |
|---|---|---|---|---|
| $SiO_2$ | 45.19 | 48.80 | SiO2 | 45.19 |
| CaO | 6.23 | 5.98 | CaO | 6.23 |
| $Fe_2O_3$ | 11.20 | 13.40 | Fe2O3 | 11.20 |
| MgO | 3.23 | 4.34 | MgO | 3.23 |
| $Mn_2O$ | 5.51 | 6.11 | Mn2O | 5.51 |
| CaCO3 | 3.32 | 1.12 | CaCO3 | 3.32 |
| $SO_3$ | 2.31 | 2.23 | SO3 | 2.31 |
| $Al_3O_3$ | 14.54 | 15.78 | Al2O3 | 14.54 |
| $K_2O$ | 1.10 | 1.19 | K2O | 1.10 |

### *3.1.2 RAP*

RAP was obtained from the state highway (i.e., SH-1) in the Nadia district of West Bengal state (India). Then, RAP and aged bitumen were extracted by performing the centrifugal apparatus as per the standard guideline [6]. The evaluated physical properties of RAP are tabulated in Table. 1.

### *3.1.3 Bitumen*

In this investigation, VG-30 bitumen was utilized and collected from Indian Oil Corporation Limited (IOCL) Haldia, WB, India. Several tests were tested to ensure the satisfaction of the bitumen as per the Indian standard. The results of virgin and RAP bitumen are depicted in Table.3.

Table 3. Physical properties of bitumen

| Property | Desirable value | Type of bitumen | |
|---|---|---|---|
| | | Virgin bitumen | Virgin bitumen |
| Penetration (100gm, 5s, dmm.) | 45(minimum) | 67.00 | 64.00 |
| Softening point, (°C) | 47(minimum) | 46.00 | 50.00 |
| Specific gravity at 27°C | 0.97-1.04 | 1.00 | 0.98 |
| Ductility at 27°C | 40(minimum) | 80.00 | - |
| Absolute viscosity at 60°C (poise) | 2400-3600 | 2980 | 3100 |

### *3.1.4 Saw Dust Ash (SDA) and OPC*

This research used SDA as a non-conventional filler in the bituminous accumulated collected from Kalyani puffed rice mill in West Bengal, India. Detailed physical and chemical properties were evaluated by satisfying the required criteria as per the Indian specification and stated the results in Table. 4.

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Table 4. Physical properties of saw dust ash and OPC

| Name of Experiment | Estimated results of SDA | Estimated results of OPC-43 |
|---|---|---|
| Specific gravity | 2.22 | 3.14 |
| Water absorption | 1.01 | 1.00 |
| Bulk density | 1436kg/$m^3$ | 1441kg/$m^3$ |
| Plasticity Index | 3.95 | Non-plastic |

## 3.2 Characterization of study filler

### *3.2.1 Specific gravity*

The specific gravity (SG) of the studied filler was calculated by measuring the particle's volume by displacement of water, or other liquids, using Archimedes' principle The experiment results are specified in Table 4.

### *3.2.2 X-RF test and loss on ignition*

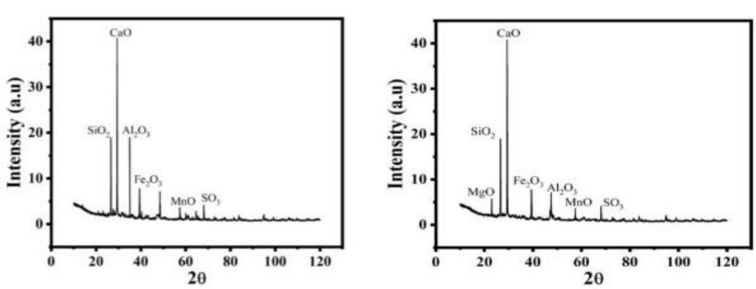
The chemical analysis of the filler is significant since the mechanical bond that occurs in the filler-bitumen system is related to the type and percentages of elements that compose the filler. XRF was utilized to measure the chemical ingredients of the fillers by following the standard guidelines [7] and the results are specified in Table 5. Further, the organic content of the filler was determined using the Loss-On-Ignition (LOI) test.

Table 5. X-RF test result of conventional fillers OC-43 and SDA

| Name of Composition (%) | Ordinary Portland cement (OPC-43) | Saw dust ash (SDA) |
|---|---|---|
| CaO | 64.2 | 58.5 |
| $SiO_2$ | 22.03 | 6.16 |
| $Al_2O_3$ | 7.19 | 5.83 |
| $Fe_2O_3$ | 6.55 | 9.28 |
| MgO | 2.75 | 1.34 |
| MnO | - | 0.04 |
| Alkalies($Na_2O$, $K_2O$) | 0.95 | 0.72 |
| $SO_3$ | 2.17 | 15.68 |
| Loss on Ignition | - | 7.58 |

### *3.2.3 X-RD test*

X-RD analysis was used to characterize the crystallographic structure of filler by using a Rigaku D/Max-IIIC difference with Cuka radiation over the range of 5-40$^0$C (2 theta- 10-120$^0$C) and a rate of 0.2$^0$mm$^{-1}$ at room temperature. The X-RD results of SDA are evaluated in Figure 3.




(a) (b)

Figure 3. X-RD test results of OPC(a) and SDA(b)

### 3.3 Methodology

#### *3.3.1 Marshall mix design*

The Marshall method was performed to estimate the optimum binder content (OBC) and Marshall volumetric properties at a 4% air voids level as per standard guidelines [5, 8]. There the bitumen content of the mix has varied between 5.2 to 6.0 percent, having a 0.2 percent increment. A total of 75 Marshall samples were made for testing purposes. Preparation of Marshall samples has been initiated by heating the aggregates at a temperature of 100 ± 5$^0$C for 24 hours to assure a moisture-free state. After the gradation of aggregate, a total of 1200 g of such dry aggregate has been heated at 170-180$^0$C for 10 minutes to elevate the temperature before bituminous coating in a pan. After that, the 130$^0$C warm bitumen was added and thoroughly mixed with the bitumen-aggregate mixture for 5 minutes at a temperature of 155$^0$C and poured into a preheated mold. Eventually, mechanical energy was applied on either side of the sample for compaction at a temperature of 145$^0$C and left for a day before the test execution.

#### *3.3.2 Rutting resistance of RAP-8%SDA-modified BC mix*

Rutting is a typical parameter for the design of flexible pavement which is highly responsible for the performance of pavement Marshall's quotient (MQ) was used to measure the resistance of the mix against rutting [9]. MQ) is calculated as the ratio of the stability(kN) to flow(mm) has obtained from the Marshall stability test at predetermined OBC. A total of 27 Marshall samples were prepared to determine the MQ for assessing the RAP-8% SDA-modified BC mixer's resistance against rutting action.

#### *3.3.3 Cracking resistance of RAP-8%SDA enriched BC mix*

The cracking resistance of RAP-8% SDA-modified BC mix was quantified following the indirect tensile strength (ITS) test as per the standard specification [10]. The test was performed at 25°C, and a compressive force was applied to a specimen so that the specimens failed due to tensile stresses induced in the specimens. The tensile stress at which failure occurs is the tensile strength of bituminous mixes. A total of 27 samples were fabricated to estimate the ITS. ITS was calculated using equation 1.

$$Indircet\ tensile\ strength = \frac{2000F_{max}}{\pi dt} \quad (1)$$

Where, $F_{max}$ = Failure load (N); d = diameter of the sample(mm); and t = thickness of the sample (mm).

### 3.4 Moisture damage evaluation of SDA enriched BC mix by retained Marshall stability test

To counteract the moisture susceptibility of the bituminous mix retained Marshall stability (RMS) test was adopted as per the standard guideline [11]. A total of 108 Marshall samples were prepared and were divided into two subsets (wet-subset and dry subsets). For dry subsets, the samples were immersed 30-40 minutes in the water bath at 60°C. Assessment of such properties could be performed by laboratory scale by modified Marshall immersion test by immersion of the samples in different periods (0, 1, 4, 7, and 14 days) at 60ºC. The RMS value was calculated using the following equation 2.

$$RMS = \frac{Marshall\ stabilty\ in\ wet\ sample}{Marshall\ stability\ in\ dry\ sample} \times 100 \quad (2)$$

## 4. Results and discussion

### 4.1 Mix Design by Marshall method

In this study, the Marshall mix design method was adopted to achieve the OBCs and Marshall parameters as shown in Figure 4. Variation of OBCs results has been observed in various proportions of RAP-8% SDA modified BC mix. The results indicate that 60%RAP-8%SDA modified BC mix consumes 0.20% lesser OBC compared to the control mix as shown in Figure 4(a).

On the other hand, the Marshall stability value increases from 15.47-18.61kN, while the flow value decreases from 3.96-3.65 mm by increasing the RAP from 0 to 60% as shown in Figure 4(b and c), and then decreases up to 100% RAP. Eventually, a linear relationship is observed between density and voids filled with bitumen (VFB) in the current mix. Both parameters, density, and VFB are ascended from 2.405-2.450g/cm$^3$ and 70.92-74.43% respectively for using 60RAP-8% SDA in the BC mix, after that, both are descended up to 100% RAP-8% SDA modified BC mix as shown in Figure4(d and e). The highest VMA of 17.43% is found for the control mix and the lowest VMA of 15.84% for the 60% RAP-8% SDA modified mix is depicted in Figure4(e).

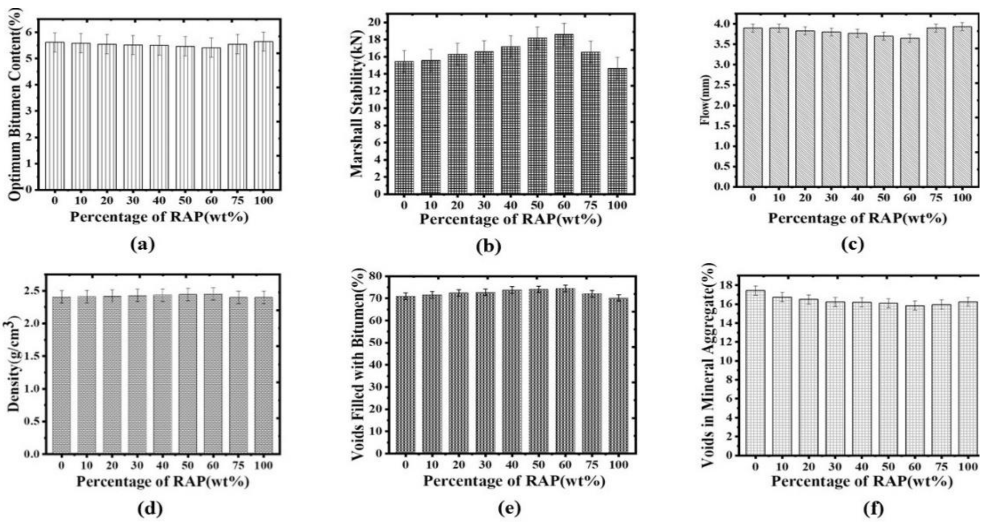



Figure 4. Marshall Parameters of RAP-8% SDA modified BC mix.

## 4.2 Evaluation of the rutting performance of SDA modified BC mix by Marshall Quotient

MQ indicates the resistance to permanent deformation, and shear stress, and hence incorporation with rutting, as reported by Zoorob and Suparma 2000[9]. The results have revealed that the highest MQ of 4.96kN/mm had emanated using 60%RAP- 8% SDA in BC mix as specified in Figure 5, with the lowest OBC of 5.42%. A greater MQ value denotes a superior resistance to permanent distortion and greater resistance against rutting. It was found that CaO, $SO_3$, and loss of ignition of SDA reduce the pavement raveling and enhance the rutting resistance.

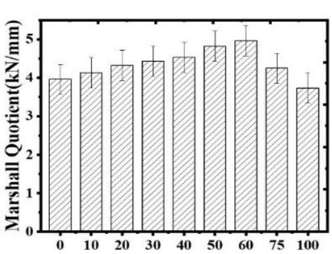



Figure 5. Marshall quotient of RAP-8%SDA modified BC mix

## 4.3 Assessment of cracking resistance of SDA-modified BC mix

ITS results of RAP-8% SDA enriched BC mixes play a vital role in pavement design, incorporating the mixture's resistance against cracking. It is indicated that the 60% RAP- 8% SDA enriched BC mix has perceived the highest ITS value of 1865.37kPa, which is 37.06% higher than the control mix, as specified in Figure 6. Hence 60% RAP- 8%SDA modified BC mixes have produced the highest cracking resistance in terms of ITS value due to higher filler content that may reduce the air voids of the mix.

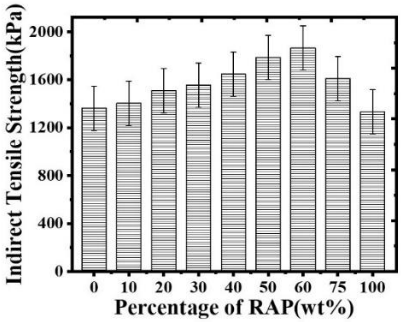



Figure 6. Cracking resistance of RAP-8%SDA modified BC mix in terms of ITS value

## 4.4s Moisture damage evaluation of SDA enriched BC mix by a retained Marshall stability test

A greater RMS value indicates the greater moisture resistance of the mix and these results are depicted in Figure 7**.** RMS value of the control mix gradually decreases to 100, 90.32, 82.82, 65.94, and 58.35% at prolonged immersion periods of 0-, 1-, 4, -7- and 14-days respectively. The RMS value of the control mix has satisfied the standard RMS value of 80% as per the guideline [12] up to a 4-day immersion period.

The RMS results of all RAP-modified mixes are satisfied with the specified value for the 1st and 4th day immersion period. However, 60% RAP - 8% SDA enriched bituminous mix shows the highest RMS value of 99.85 and 89.08% for the 1st and 4th-day immersion period respectively which satisfies the standard RMS value. But, the magnitude of such value has produced unsatisfactory results (*i.e.*,78.13% and 69.48%) for the 7th and 14th -day immersion period as shown in Figure 7. It has been perceived that 60% RAP- 8% SDA enriched BC mix is sustained the more moisture-damaged resistivity significantly may be due to sound adhesion between that aggregate and virgin bitumen in a fourteen-day immersion period.

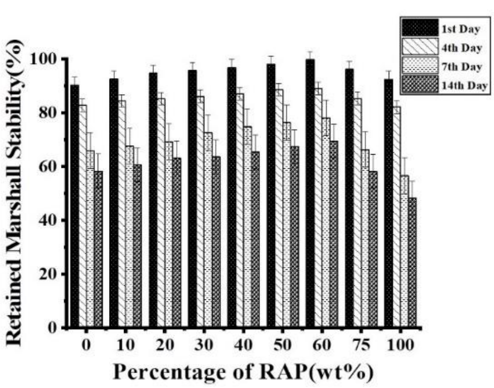



Figure 7. RMS of bituminous mix contains several percentages of RAP-8%SDA

## 5. Conclusions

After analyzing the results, some important conclusions are summarized below :

- Presence of $SiO_2$, and CaO in the SDA, obtained from the X-RF test, indicates the significant enhancement of the performance of the BC mix with RAP by increasing the density of the bituminous mixture.
- The results of the Marshall test reveal that 60% RAP-8% of SDA modified BC mix has the highest Marshall stability of 18.61kN, and density of 2.450g/cm$^3$ with the highest VFB of 74.43%, and the lowest OBC of 5.42% which 0.20% higher compared with the control mix. Hence 60% RAP-8% SDA-modified BC mix perceived maximum durability due to the strong compatibility of RAP with virgin bitumen.
- The MQ results indicate that the 60%RAP-8% SDA enriched BC mix shows superior stiffness and cracking resistance among the other studied mixes due to the presence of CaO, $SiO_{2,}$ and higher loss on ignition of SDA.
- RMS test results indicate that 60% RAP-8% SDA modified BC mix sustains the moisture resistivity significantly up to 4-day immersion with the highest RMS value of 99.85% due to sound adhesion between that aggregate (RAP and virgin aggregate) and virgin bitumen. Since dipole nature of the carbonyl component in the binder seduces either like or alike molecules to connect with it through hydrogen bonding during heating.

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