

# Evaluation of Sustainable SMA Mix Prepared Using Recycled Concrete Aggregates



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**Abstract** The disposal of Construction and Demolition (C&D) waste generated in the cities has become a serious environmental problem nowadays. The use of Recycled Concrete Aggregates (RCA) obtained from this C&D waste can reduce the amount of virgin aggregates for pavement construction. In this study, the recycled concrete aggregates are used in the manufacture of Stone Matrix Asphalt (SMA) mix. The fine and coarse aggregates in SMA mixes are partially replaced by RCA. The Marshall and volumetric properties of the SMA mixes containing RCA are evaluated and compared with the conventional SMA mix. The use of these SMA mixes prepared with RCA reduces the volume of natural resources consumed and solves the disposal problem of the C&D waste. This study thus actually paves a sustainable way for the asphalt pavement industry.

**Keywords** Construction and demolition (c&d) waste · Stone matrix asphalt (SMA) · Sustainability · Recycled concrete aggregates (RCA)

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## 1 Introduction

Road networks play a crucial role in the economic and social development of a country. The spurt in the growth of traffic and overloading of vehicles decreases the life span of roads laid with conventional bituminous mixes. This also leads to the reduction in the riding quality due to premature failure of the flexible pavements. It is observed that Stone Matrix Asphalt mixture (SMA) is an ideal mixture for long lasting highways. SMA is a gap graded aggregate-asphalt hot mixture with 70–80% coarse aggregate, 8–12% filler, 6.0–7.0% binder and normally 0.3% fibre. SMA provides excellent resistance to rutting due to slow, heavy and high volume traffic, and resistance to deformation at high pavement temperatures. Environmental, economic and technical problems have led to increasing attention being paid to the subject of recycling solid waste materials in the construction of road infrastructure.

Studies were carried by Giri et al. [1] on the use waste materials such as recycled concrete aggregates (RCA) and waste polyethylene from milk packaging (WPMP) in bituminous mixes. RCA was pre-treated with bituminous emulsion (PRCA) to reduce its water absorption. The performance of the different bituminous mixes was found out in terms of Marshall test parameters. Bituminous mixes containing PRCA and WPMP produce good results compared with conventional aggregate mixes. El-Badawy et al. [2] reviewed the current status of using recycled materials in pavement construction worldwide and the gained benefits in terms of economic savings, environmental impact, and sustainability. A study was conducted by Dalhat et al. [3] on the effect of using combined form of recycled plastic waste (RPW) as a mineral aggregate supplement in a dense-graded hot mix asphalt (HMA). The results showed that combined RPW as an aggregate supplement has advantages over the use of normal aggregates.

This study aims to partially replace the natural aggregates in SMA mixtures through laboratory studies, and compares the test results with mixtures containing natural aggregate. For this purpose, Marshall Stability test were conducted on samples with and without RCA in SMA mix. Using of the RCA decrease areas required for disposal by removing the increase of waste concrete. It results in decreasing of the consumption of energy from aggregate production and transportation.

## 2 Materials

### 2.1 Aggregates

Aggregates were collected from a local supplier. Coarse aggregates of 20 mm down (Aggregate 1) and 10 mm down (Aggregate 2) and quarry dust were used. The physical properties of the aggregates such as the Aggregate Impact Value, Aggregate Crushing value, Water Absorption, Flakiness Index, Elongation Index and Specific Gravity were determined and they satisfied all the physical requirements specified

**Fig. 1** Coir fiber used during experimentation process



by IRC: SP: 79-2008. The aggregates were sieved to meet the physical requirements specified by IRC: SP: 79-2008 [4].

## **2.2 Bitumen**

VG-30 bitumen was collected from a local supplier. Tests such as Softening Point, Ductility, Penetration and Specific Gravity were conducted and its physical properties were satisfied as per the requirements specified by IS 73: 2013 [5].

## **2.3 Stabilizer Used-Coir Fibre**

As coconut fibre contains certain amount of cellulose, this will result in better interlock between the aggregates and thereby improving the strength and reducing the possibility of drain down during transport and paving. Panda et al. [6] has suggested a 0.3% coconut fibre addition in the SMA mixes which brings significant improvement in the engineering properties of SMA mixes (Fig. 1).

## **2.4 Recycled Concrete Aggregates (RCA)**

Construction and Demolition (C&D) waste were collected from Maradu flat demolition site. Steel reinforcement were removed. The RCA used in this investigation for SMA mixes satisfied all the physical requirements specified by IRC: SP: 79-2008. Rondon-Quintana et al. [7] studied the use of blast furnace slag aggregate in hot-mix asphalt. Here, virgin aggregates are partially replaced with RCA. C&D waste

**Fig. 2** C&D Waste in Maradu Site



**Fig. 3** RCA



collected from the demolition site is shown in Fig. 2 and the prepared RCA is shown in Fig. 3.

### **3 Methodology**

#### ***3.1 Aggregate Proportioning by Rothfutch Method***

Two types of mixtures were prepared in this study. Mix I consisted of virgin aggregates (CSA) and it was used as a control mix. Mix II was prepared with a combination of RCA and CSA. The sieve analysis of Mix I and Mix II were conducted and the

grain size distribution curves for both the mixes were plotted. The obtained gradations of Mix I and II should be within the desired limits set by IRC: SP: 79-2008. The mixes were then prepared in the obtained aggregate proportions.

### **3.2 Marshall Method of Mix Design**

The aggregates and quarry dust (total weight equal to 1200 gm) and coir fibre (0.3% of total weight of aggregates) were proportioned and mixed for Mix I. The cylindrical specimens were prepared in the laboratory following the Marshall mix design procedure. First sieving is done for coarse and fine aggregates. Sampling of coarse and fine aggregates is carried out for 13 mm SMA composition as specified by IRC: SP: 79-2008. Total sample weight is 1200 gm including filler and binder. Aggregates were heated to a temperature of 120–140 °C and bitumen was heated to a temperature of 130 °C. The bitumen was added in required quantities i.e., 5, 5.5, 6, 6.5 and 7%. It is then mixed with bitumen and is compacted with a hammer with a falling weight of 4.54 kg falling from a height of 40 cm, by giving 50 blows on each side for compaction. The sample is allowed to dry for the next 24 h and then it is taken out of the mould with the help of sample ejector. Its weight in air, water, radii, thickness and height is calculated. Before conducting the Marshall test, each of the samples was kept in hot water bath for 30 min at 60 °C. Two samples each of 5.5, 6, 6.5 and 7% bitumen were prepared respectively for bituminous course and Marshall Test was carried out to calculate their stability.

Similarly, the aggregates, quarry dust and RCA (total weight equal to 1200 gm) and coir fibre (0.3% of total weight of aggregates) were proportioned and mixed. Two samples each of 5.5, 6, 6.5 and 7% bitumen were prepared respectively for Mix II and Marshall Test was carried out (Fig. 4).

#### **3.2.1 Marshall Test**

The samples are removed from the hot water bath and supposed to undergo Marshall Test. It is kept under testing machine and loaded at constant rate of deformation of 5 mm per minute till failure. The test head with the specimen is placed in position in the loading machine and the base-plate of the loading machine is raised until the top of the test head is in contact with the bottom of the proving ring or load cell. The deformation measuring dial gauge or flow meter is now placed in position and adjusted to read zero. The load is applied through the Marshall test setup maintaining a constant deformation rate of 51 mm per minute. The load and deformation readings are closely observed. The maximum load at failure (in kN) and the corresponding deformation (or flow) readings (in mm) are noted. The Marshall test apparatus is shown in Fig. 5. The samples are placed in the hot water bath 30 minutes before the test (Fig. 6).

The Marshall Stability value is computed using the calibrated equation as:



**Fig. 4** Sampling, Mixing, Pouring and Compaction of Mix II

**Marshall Stability (kN) = (0.0249x-0.5549)**, where x is the number of divisions in proving ring.

The corrected Marshall Stability value of each specimen is determined by applying the appropriate correction factor.

**3.2.2 Calculations**

Theoretical Specific gravity, Bulk density, Volumetric properties (% of air voids ( $V_v$ ), % volume of bitumen ( $V_b$ ), % of voids in mineral aggregate (VMA) and % of voids filled with bitumen (VFB)) and Optimum Bitumen Content (OBC) were determined. Based on the Marshall tests performed above, and the values computed, the following graphs were plotted:

- Corrected Marshall Stability versus Bitumen Content
- Flow versus Bitumen Content
- Unit Weight or Bulk Density ( $G_m$ ) versus Bitumen Content
- Percent Air Voids in the total mix ( $V_v$ ) versus Bitumen Content



**Fig. 5** Marshall test apparatus



**Fig. 6** Placing of the samples in the water bath



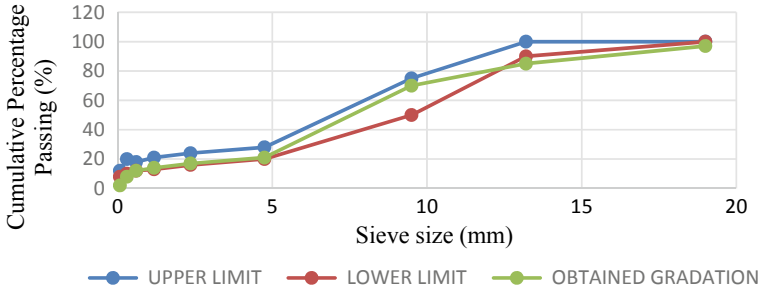


Fig. 7 Conventional SMA gradation curve

The optimum bitumen content (OBC) for the mix design is taken as the bitumen content corresponding to the median of the design limits of Percent Air Voids in the total mix (4%).

## 4 Results and Discussions

### 4.1 Aggregate Mix Proportioning

#### 4.1.1 Conventional SMA Mix

From the sieve analysis performed on Aggregates 1(A), Aggregate 2(B) and quarry dust(C), the grain size distribution curve was plotted and the mix proportions were determined by Rothfutch method. The percentage of aggregates A, B and C in total mix were obtained as given below:

$$A = 20\%, \quad B = 64\% \quad \text{and} \quad C = 16\%.$$

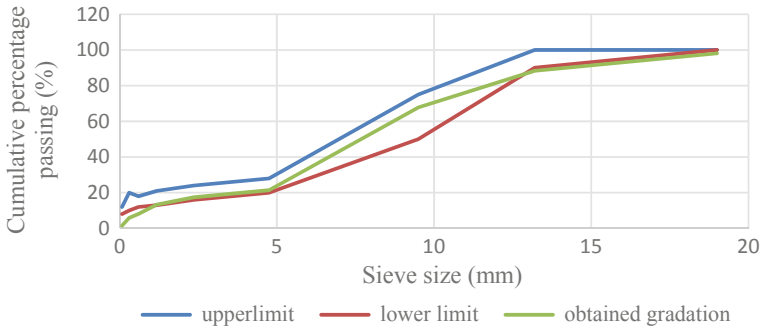
The gradation curve for Mix I is within the limits specified in IRC: SP: 79-2008 and is shown in Fig. 7.

#### 4.1.2 Modified SMA Mix

From the sieve analysis performed on 20 mm down CA(A), 20 mm down RCA(B), 10 mm down FA(C) and quarry dust(D), the grain size distribution curve was plotted and the mix proportions were determined by Rothfutch method. The percentage of aggregates A, B, C and D in total mix were obtained as given below:

$$A = 8\%, \quad B = 13\%, \quad C = 61.5\% \quad \text{and} \quad D = 17.5\%.$$





**Fig. 8** Modified SMA gradation curve

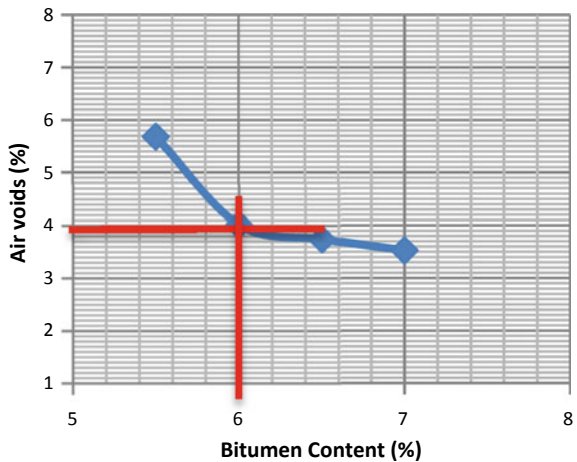
The gradation curve for Mix II is within the limits specified in IRC: SP: 79-2008 and is shown in Fig. 8.

## 4.2 Determination of Optimum Bitumen Content (OBC)

### 4.2.1 Conventional SMA Mix

By plotting Air Voids versus Bitumen content (Fig. 9) graph, the optimum bitumen content for conventional SMA mix was determined. The bitumen content corresponding to 4% air voids is taken as optimum bitumen content and the OBC is 6%. By plotting Stability versus Bitumen content, Flow versus Bitumen content and

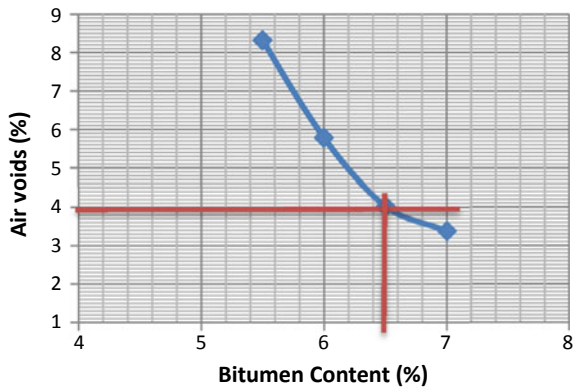
**Fig. 9** Air voids versus bitumen content graph for Mix I



**Table 1** Marshall and volumetric properties of conventional mix

Bitumen content (%)	Marshall stability (kN)	Flow (mm)	Density (g/cc)	V <sub>v</sub> (%)	VMA (%)	Marshall quotient (kN/mm)
5.5	10.166	3.22	2.399	5.683	18.026	3.158
6	12.361	3.45	2.425	4.018	17.565	3.583
6.5	11.956	3.575	2.416	3.745	18.301	3.346
7	10.03	4.35	2.406	3.529	19.067	2.306

**Fig. 10** Air voids versus bitumen content graph for Mix II



Density versus Bitumen content graphs, the Marshall and other volumetric properties were found for the evaluating the performance of the mix. The data presented in Table 1 is based on an average value of two specimens.

**4.2.2 Modified SMA Mix**

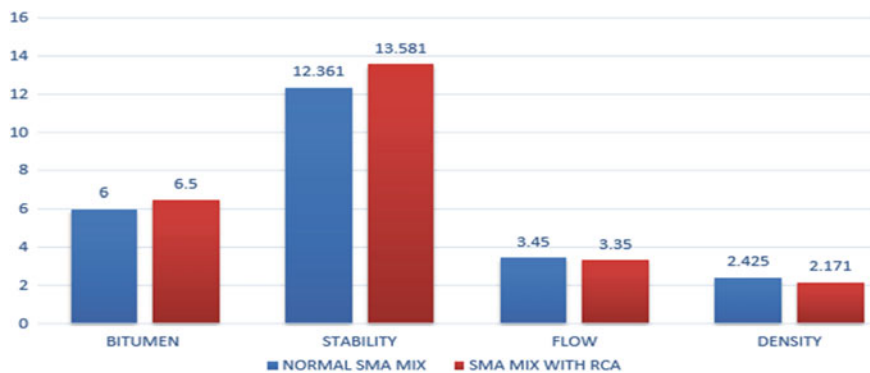
By plotting Air Voids versus Bitumen content (Fig. 10) graph, the optimum bitumen content for modified SMA mix was determined. The obtained OBC is 6.5%. Stability versus Bitumen content, Flow versus Bitumen content and Density versus Bitumen content graphs were plotted to find the Marshall and other volumetric properties. The data presented in Table 2 is based on an average value of two specimens.

**4.3 Comparison of Conventional and Modified SMA Mix**

The comparison of the prepared Conventional and Modified SMA mixes are shown in Fig. 11.

**Table 2** Marshall and volumetric properties of modified mix

Bitumen content (%)	Marshall stability (kN)	Flow (mm)	Density (g/cc)	V <sub>v</sub> (%)	VMA (%)	Marshall quotient (kN/mm)
5.5	11.095	3	2.094	8.39	19.095	3.699
6	13.284	3.175	2.14	5.788	17.748	4.184
6.5	13.581	3.35	2.171	4.027	17.018	4.055
7	11.771	4.225	2.168	3.382	17.407	2.786

**Fig. 11** Comparison of conventional and modified SMA mix

Following conclusions were obtained after the comparison of the conventional and modified SMA mixes:

- **Marshall Stability**

SMA mix with RCA shows better stability value when compared with the reference mix. Due to the interlock of aggregates, the stability has increased by 9.87%.

- **Flow value**

Flow value increases with increase in bitumen content. Generally increase is slow, but later with increase in bitumen content flow value increases. The flow value of SMA mix with RCA has decreased by 2.9%.

- **Air voids**

Since recycled aggregates are porous they absorb more asphalt compared to virgin aggregates leaving less quantity of asphalt binder to fill up the volume of voids. As a result, air voids increase with the level of RA addition in the mix.

- **Voids in mineral aggregate**

VMA in mixes made of RCA is higher than the reference mixes which are made of the natural aggregates. As the recycled aggregates are more porous than natural aggregates, they require more asphalt binder to fill in the pores.

- **Density**

The density of the reference mix is higher than the RCA mix as it require more asphalt to achieve density similar to a mix made with natural aggregates. The density value has decreased by 10.47%.

- **Optimum Binder Content**

The presence of the residual cement mortar on the RCA particles results in the formation of a more porous surface texture of RCA, when compared with virgin aggregates. This explains the reason of the higher bitumen absorption of RCA.

## 5 Conclusion

The primary objective of the study is to evaluate the use of recycled concrete aggregates (RCA) in SMA mixes. Thus the incorporation of RCA in SMA mixes resulted in its increased stability and bitumen content and decreased flow and density.

RCA is a sustainable alternative to natural aggregates. In this study, around 60% of natural aggregates were replaced by RCA. This reduced the cost of production by around 17%. Thus the incorporation of RCA in pavement mixes preserves the natural resources and reduces the C&D waste disposal problems. However, the use of RCA increased the OBC. This is due to the higher bitumen absorption by the porous cement mortar present on RCA. Hence further studies should be carried out on methods to reduce the bitumen consumption and produce sustainable pavement mixes with improved performance.

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