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# Use of Carbonized Rice Husk and Bio-char as Binder Modifiers in Hot Mix Asphalt

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**Abstract:** Carbonized rice husk (CRH) and biochar (BC) were investigated as partial asphalt binder replacements. TCR and BC modified asphalt binders were initially evaluated with reference to their penetration index and then by volumetric properties, Marshall properties, indirect tensile strength, and moisture damage resistance of HMA made using a modified asphalt binder. Both BC and CRH modifications improved the high-temperature performance of the asphalt binder while reducing the actual asphalt binder required for the optimum HMA. A maximum of 13.75% reduction in actual binder requirement was observed. Although both modifications decreased the Marshall stability and Indirect tensile strength, at most of the modification levels the reductions were small. Marshall stability and Indirect tensile strength values were above the Asphalt institute specifications stipulated for heavy traffic (ESAL>$10^6$ for 20 years) highways. All modifications retained more than 80% of their Marshall stability and Indirect tensile strength when subjected to moisture conditioning.

**Keywords:** Biochar, Hot Mix Asphalt, Marshall Stability, Moisture Susceptibility, Indirect Tensile Test, Retained Marshall Stability

## 1. Introduction

Flexible pavement construction with hot mix asphalt (HMA) as the main construction material has gained popularity over its competitor, rigid pavements, due to its desirable field performance. HMA is a mix of asphalt binder and different sizes of mineral aggregates. Aggregates form a matrix while the asphalt binder binds the matrix of mineral aggregates together in the flexible pavement.

The properties of the asphalt binder can be engineered using modifiers and, in turn, the performance of HMA made with such asphalt binder can be improved. Asphalt binder modifiers such as fibres, plastics, polymers, reclaimed rubber, extenders, antistripping agents, and filler [1,2,3] have been previously studied. A filler modifier would toughen and thicken the binder compared to asphalt alone, in turn, enhancing the adhesion and cohesion of the asphalt binder substantially and providing greater film thickness over the aggregates [4,5]. In addition, the filler modifier in the HMA performs the asphalt binder's role of filling the voids in the mix which is shown to improve the rutting, fatigue, and resistance to the moisture damage of HMA pavement [4,6].

Virgin stone dust is generally used as filler in HMA production. The global shortage of construction materials caused by increased consumption of virgin materials and utilization of waste or by-products as supplementary construction materials has been promoted in many countries. Adding a filler as a modifier is expected to lower the amount of asphalt binder used in the production of HMA.

Carbonaceous materials have long been utilized in HMA as modifiers [7]. Biomass, a type of carbon-based material, has also received attention in the HMA industry. Rice husk ash (RHA), when used as a mineral filler additive in HMA, resulted in higher Marshall stability and lower Marshall flow value compared to those of

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control HMA [8]. Dynamic shear rheological characteristics of asphalt binder with RHA and sawdust ash (SDA) as binder additives were studied, and the findings showed that both modifications increased the complex modulus, rutting behaviour, viscosity, and resistance to deformation at high temperatures [9]. The combined effect of cement dust and RHA as HMA mineral filler additives was experimented with and found that the modification decreased the optimum binder content, and increased the Marshall stability [10]. HMA modified with RHA as a mineral filler is durable compared to control HMA while other volumetric properties of the modification met the specification [11].

Modification of the asphalt binder with RHA as an additive showed an increased viscosity and reduced thermal susceptibility in the asphalt binder [5]. Thami et al. used RHA and date seed ash in HMA as mineral filler and observed an increase in Marshall stability, rutting resistance, and adhesion behaviours with both ashes [5]. The suitability of RHA as a binder modifier with partially replaced fine aggregate with coal bottom ash was investigated, and the optimum rate of replacement was found as 6% of coal bottom ash by the weight of fine aggregate and 11% of RHA by the weight of binder [12].

The suitability of processed wood sawdust was studied as a mineral filler, fine aggregate, and binder additive in the HMA [13,14,15]. The incorporation of fine SDA passing through 0.075 mm sieve (No. 200 sieve, ASTM E11) [16] as a binder additive exhibited improvement in softening point, rutting resistance, penetration, high-temperature performance, and oxidation resistance. However, the shelf-life of the SDA-modified asphalt binder decreased with increased SDA content [9]. The SDA as a mineral filler improved the Marshall and volumetric properties compared to those of control HMA [15], and the resistance to moisture damage and low-temperature cracks [13]. Properties of modified HMA with burned saw dust as fine aggregate replacement met the specification limit defined for the medium traffic highway despite the decrease in the indirect tensile strength and Marshall stability observed [14].

Carbonaceous materials as a mineral filler additive improved the Marshall stability, the Marshall flow, and durability of HMA. However, comparatively limited studies have experimented with the application of biomass as an asphalt modifier required to replace the base binder. Moreover, the annual sawdust generation from the sawmill process has exceeded 112,000 Mt in Sri Lanka [17]. On the other hand, around 8 million metric tons of rice husk per year are produced as a by-product of rice processing in Sri Lanka. Therefore, thinking in terms of the sustainability of HMA in construction, bio waste products availability in Sri Lanka, and limited use of carbonaceous materials as an asphalt modifier, this study aimed to examine the use of biochar (BC) produced from wood sawdust and carbonized rice husk (CRH) as asphalt binder modifiers by considering properties of asphalt binder alone and properties of HMA when used as a binder. Moisture-induced damage in HMA is a very important aspect [18,19] especially so in the case of adding water-absorbent material such as BC and CRH. Therefore, moisture-induced changes in the properties of HMA with modified bitumen will also be investigated in the second part of this study.

## 2. Methods and Materials

### 2.1 Materials

Gneiss rock aggregates of three nominal sizes, coarse (20 mm), medium (14 mm) and filler, were used as conventional material. 60/70 pen-grade bitumen was used as the asphalt binder of HMA. Biochar (BC) and carbonized rice husk (CRH), the two binder modifiers produced from biomass, were used to partially replace the petroleum-based asphalt binder. First, biochar (BC) produced from wood sawdust heated to 400-550 ºC in an airtight container, was used. The second was carbonized rice husk (CRH) which was generated by heating raw rice husk to 400 ºC in an incineration vessel. BC and CRH were dry-sieved and the portion passing through a 0.6 mm sieve (No. 30, ASTM E11) [16] was used in this study [12,20]. The observed properties of aggregates and asphalt modifiers are shown in Table 1.

### 2.2 HMA Sample Preparation

HMA specimens for this study were made utilizing the Marshall mix design procedure. Figure 1 graphically shows the methodology used. First, the proportions of different sizes of aggregates in the mix were determined and made sure the final mix of aggregates met the D-4 mix designation of ASTM D3515 [21]. In the first modification, BC and CRH were used to replace 5,10, and 15 percent of the asphalt

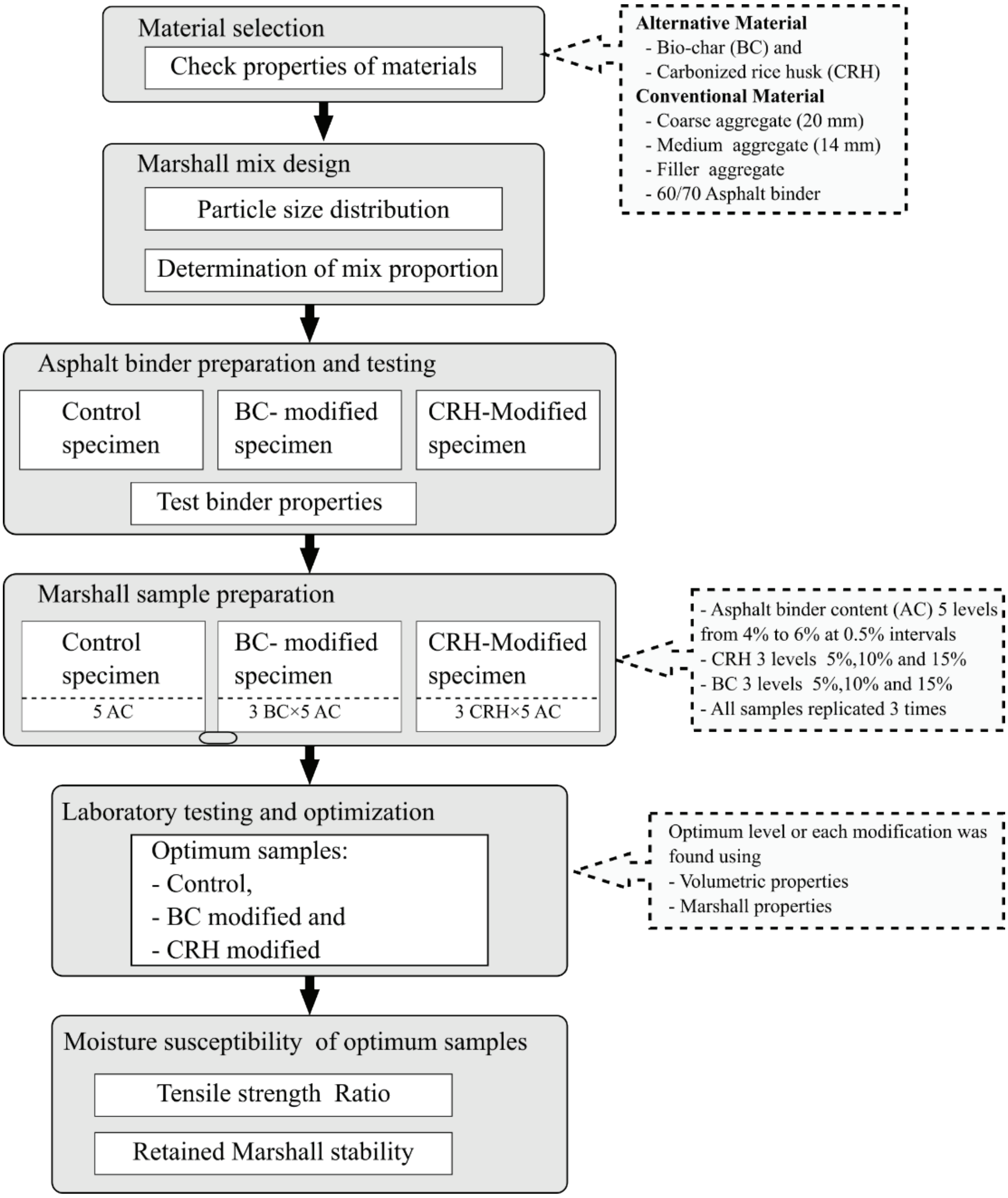

**Figure 1 - Methodology used**

binder weight separately in each modification. Amount of the asphalt binder used in modified and control HMA samples varied from 4 to 6 percent at 0.5 percent intervals. Accordingly, there were 15 combinations (3 BC contents × 5 asphalt contents) in BC-modification and 15 combinations (3 CRH contents × 5 asphalt contents) in CRH-modification. Each combination was replicated three times.

The Marshall test consists of the preparation of cylindrical specimens using the Marshall standard compaction hammer. Marshall specimens were prepared according to ASTM D6926 standard [22]. All ingredients were preheated for two hours in an oven before the sample preparation. Preheated modifiers and asphalt binders were mixed at a rotational speed of 136 rpm for 30 minutes to form CRH and BC-modified asphalt binders. The control HMA specimens were prepared using an unmodified asphalt binder. A heavy traffic (ESAL>$10^6$ for 20-year design life) highway was considered in the compaction of the HMA specimens as stated in the specifications of asphalt institute [23,24], i.e., 75 blows were given to each side of the specimen.

### 2.3 Evaluation of Performance

### 2.3.1 Evaluation of Asphalt Binder

The modified asphalt binders were evaluated considering their penetration values (ASTMD5) [25], specific gravity (ASTMD70) [26], softening point (ASTM D36) [27], and penetration index (PI). When 'SP' is the

**Table 1 - Properties of Aggregates and Asphalt Modifiers**

| Property | | Aggregate | | | Asphalt Binder Modifier | |
|---|---|---|---|---|---|---|
| | | Coarse | Chip | Fine | BC | CRH |
| Specific gravity | Bulk | 2.66 | 2.65 | 2.54 | 1.53 | 1.65 |
| | Apparent | 2.71 | 2.7 | 2.68 | 1.92 | 2.05 |
| Absorption (%) | | 0.52 | 0.76 | 2.27 | 11.97 | 11.84 |
| Nominal size (mm) | | 20 | 14 | 4.75 | <0.075 | <0.075 |

softening point of the asphalt binder measured in degree Celsius, $P_{25}$ is the penetration value of the binder at a standard temperature of $25^{\circ}\mathrm{C}$, the unitless quantity of $PI$ of an asphalt binder can be calculated as in Equation (1) [23,24].

$$PI = \frac{1952 - 500\log_{10}(P_{25}) - 20SP}{50\log_{10}(P_{25}) - SP - 120} \qquad \ldots(1)$$

### 2.3.2 Evaluation of HMA

Before undergoing the Marshall testing procedure, cast Marshall specimens were used to determine the bulk specific gravity (ASTM D2726) [28], VIM, VMA, and VFB values of the mix. Marshall stability and Marshall flow values are used to calculate the Marshall quotient. The optimum sample for each modification was determined considering maximum bulk specific gravity, 4% air voids in the mix, and maximum Marshall stability.

### 2.3.3 Moisture Susceptibility of HMA

Moisture susceptibility in HMA pavements was considered a major cause of HMA pavement failure [29]. The presence of moisture tends to weaken the adhesive bond at the binder-aggregate boundary and the cohesive forces within the asphalt binder or between the asphalt binder and filler [18,30].

To simulate damages caused by wet field conditions, HMA specimens generally are conditioned in water and then subjected to a test. The moisture damage is calculated as the ratio between water-conditioned test results and the corresponding unconditioned test results [31]. The optimum HMA specimens in each modification were prepared again and subjected to a moisture susceptibility testing. The indirect tensile strength (ITS) (ASTM D6931) [32] and the Marshall stability (ASTM D6927) [33] were used in this study to assess moisture damage of HMA specimens. Moisture-conditioned HMA specimens were prepared by soaking them in water at 60 $^{o}$C for 24 hours. ITS in the units of MPa can be computed using Equation (2a) and the tensile strength ratio (TSR) was then computed as shown in Equation (2b).

$$ITS = \frac{2P_{max}}{\pi t d} \qquad \ldots(2a)$$

$$TSR = \frac{ITS_M}{ITS_U} \qquad \ldots(2b)$$

where, $d$ and $t$ are, respectively, the diameter and height of the HMA specimens measured in millimetres, and $P_{max}$ is the peak load (N) attained during the ITS test. $ITS_M$ and $ITS_U$ are respectively the mean values of the ITS of HMA samples which are moisture-conditioned and unconditioned.

Retained Marshall stability ($RMS$) is calculated as the fraction between the mean Marshall stability values of moisture-conditioned ($MS_M$) and unconditioned ($MS_U$) samples as shown in Equation (3).

$$RMS = \frac{MS_M}{MS_U} \qquad \ldots(3)$$

## 3. Results and Discussions

### 3.1 Asphalt Modification

The specific gravity increased continually with CRH and BC contents up to the extent tested and they are higher than that of unmodified control samples. When modifications are compared, CRH-modified asphalt binder showed higher specific gravity compared to that of BC-modified binder. This is to be expected as CRH has a higher specific gravity compared to that of BC (see Table 1). Increased specific gravity would not lead to an increase in the weight of the HMA samples since asphalt is replaced weight to weight basis, however, this would lead to a decreased volume. This has to be considered when volume-based batching is employed.

An observed increasing trend in $SP$ and a decreasing trend in $P_{25}$ with the increase of both

**Table 2 - Properties of Modified Asphalt Binder**

| Specimen type | Modifier content (%) | Specific gravity ASTM D70 | Penetration grade ASTMD5 ($P_{25}$) | Softening point (°C) ASTM D36 (SP) | Penetration index (PI) |
|---|---|---|---|---|---|
| Control | 0 | 1.02 | 66 | 51 | -0.28 |
| BC-modification | 5 | 1.08 | 62 | 56 | 0.52 |
| | 10 | 1.1 | 56 | 59 | 0.86 |
| | 15 | 1.13 | 53 | 63 | 0.92 |
| CRH-modification | 5 | 1.16 | 64 | 52 | -0.11 |
| | 10 | 1.18 | 55 | 54 | -0.02 |
| | 15 | 1.19 | 53 | 57 | 0.55 |

binder modifiers resulted in an increasing trend in the *PI* values of the asphalt binder. Both BC and CRH modifications have shown this increasing trend in the *PI* of the asphalt binder compared to that of unmodified control samples. Since *PI* is used frequently as a proxy for the temperature susceptibility of asphalt binder, it can be stated that while BC and CRH modifications performed better than the control when only considering the modifications, it can be further stated that the BC-modified asphalt can have higher resistance to temperature susceptibility compared to that of CRH-modified asphalt. The properties of the asphalt binder modifications are shown in Table 2.

### 3.2 Marshall Properties of HMAs

Marshall test results with varying asphalt content and modifications are shown in Table 3. For a given level of modification, the Marshall stability increased initially, reached the highest value, and decreased gradually with increasing AC. When the peak Marshall stability values obtained for certain BC and CRH are compared the peak values obtained for the modifications are less than that of the control. However, the observed values are well above the asphalt institute specifications for heavy-traffic (ESAL>$10^6$) highways [23,24]. The peak values of the BC modifications increased initially and then decreased. This variation could be due to reduced effective contact between aggregates with increasing BC particles in compacted HMA. The peak values obtained in the case of CRH modifications remained roughly equal to the increased CRH content. When both modifications are compared, higher Marshall stability can be seen in CRH-modification. This can be postulated to the fact that CRH contains a comparatively higher percentage of fine components compared to BC (See Table 1) [34, 35]. Moreover, a higher percentage of fine components in the CRH modifier may improve the bonding ability of the asphalt binder, which consequently strengthens the adhesion ability among aggregates in HMA. As the result, CRH-modified HMA gained higher Marshall stability compared to BC-modified HMA.

Increasing asphalt content allows the aggregates to float within the mix under loading. Therefore, the Marshall flow of HMAs generally increases with increasing asphalt content [36] this can be observed in the results too (see Table 3). Similarly, the incorporation of binder modifiers in HMA increased the Marshall flow. Increasing CRH and BC content decreased the lubrication capability of the HMA, leading to an increased Marshall flow value. This points to the increased flexibility of the modified HMA. Despite the observed increase in the Marshall flow values, which might indicate poor performance, the observed values were able to meet the asphalt institute specifications for heavy-traffic highways (ESAL>$10^6$) [23,24].

Marshall quotient is a proxy to the empirical stiffness.; stiff HMA would have a high Marshall quotient. The observed decrease in the Marshall stability and increased Marshall flow would result in decreased Marshall quotient compared to the control. Table 3 shows the steady decline of the Marshall quotient with increasing binder modifiers. When the modifications are compared alone the Marshall quotient of BC modification is higher than BC-modified HMA. Therefore, when considering the empirical stiffness and in turn the ability of the pavement against permanent deformation BC-modified HMA had better resistance compared to that of the CRH-modified HMA.

**Table 3 - Marshall Properties of HMA**

| Specimen Type | Modifier content (%) | Binder content (%) | Marshall stability (kN) | Marshall flow (0.25 mm) | Marshall quotient (kN/mm) |
|---|---|---|---|---|---|
| Control | 0 | 4 | 8.4 | 8.2 | 4.1 |
| | 0 | 4.5 | 9.2 | 8.6 | 4.28 |
| | 0 | 5 | 9.3 | 9.2 | 4.04 |
| | 0 | 5.5 | 8.9 | 9.9 | 3.6 |
| | 0 | 6 | 8.2 | 11.2 | 2.93 |
| BC-modification | 5 | 4 | 8.3 | 8.3 | 4 |
| | 5 | 4.5 | 9.1 | 8.6 | 4.23 |
| | 5 | 5 | 9.3 | 9.3 | 4 |
| | 5 | 5.5 | 8.8 | 10 | 3.52 |
| | 5 | 6 | 8.1 | 11.3 | 2.87 |
| | 10 | 4 | 8.3 | 8.4 | 3.95 |
| | 10 | 4.5 | 9.2 | 8.9 | 4.13 |
| | 10 | 5 | 9.1 | 9.3 | 3.91 |
| | 10 | 5.5 | 8.8 | 10.1 | 3.49 |
| | 10 | 6 | 8.1 | 11.4 | 2.84 |
| | 15 | 4 | 8 | 8.5 | 3.76 |
| | 15 | 4.5 | 8.7 | 8.9 | 3.91 |
| | 15 | 5 | 9.1 | 9.4 | 3.87 |
| | 15 | 5.5 | 8.8 | 10.2 | 3.45 |
| | 15 | 6 | 8.1 | 11.5 | 2.82 |
| CRH-modification | 5 | 4 | 8.8 | 9.1 | 3.87 |
| | 5 | 4.5 | 9 | 9.6 | 3.75 |
| | 5 | 5 | 9.1 | 9.9 | 3.68 |
| | 5 | 5.5 | 9 | 10.3 | 3.5 |
| | 5 | 6 | 7.3 | 11.2 | 2.61 |
| | 10 | 4 | 8.6 | 9.6 | 3.58 |
| | 10 | 4.5 | 8.9 | 9.9 | 3.6 |
| | 10 | 5 | 9.2 | 10.4 | 3.54 |
| | 10 | 5.5 | 9 | 10.6 | 3.4 |
| | 10 | 6 | 7.2 | 11.2 | 2.57 |
| | 15 | 4 | 8.4 | 9.5 | 3.54 |
| | 15 | 4.5 | 8.7 | 10 | 3.48 |
| | 15 | 5.0 | 9 | 10.6 | 3.4 |
| | 15 | 5.5 | 9.1 | 11.2 | 3.25 |
| | 15 | 6.0 | 7 | 12 | 2.33 |

### 3.2.1 Optimum Binder Content of HMA

The optimum binder contents, the average binder content of samples with maximum bulk specific gravity, 4% air voids in the mix, and maximum Marshall stability are shown in Figure 2. Except for the first two CRH modifications, the total asphalt binder content of the BC-modified samples was equal to or higher than the control sample. However, as the asphalt binder was partially replaced with a binder modifier, the actual bitumen content required for all optimum samples is less than that of the control HMA. CRH modification was observed to have reduced the actual bitumen content. The availability of the larger percentage of fine particles in CRH can be postulated to the decreased optimum binder content with CRH compared to that of BC-modification. Both modifications observed the lowest optimum binder content at 10% asphalt binder replacement.

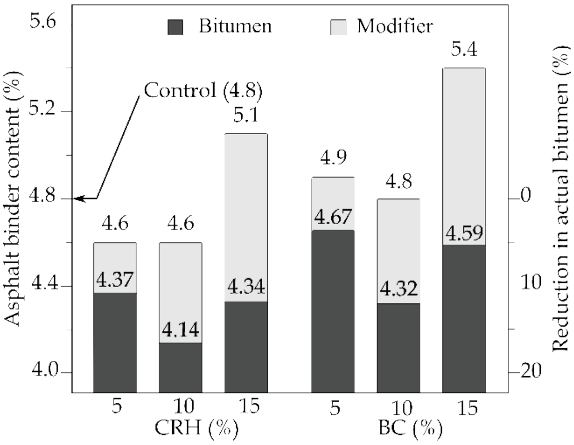

**Figure 2 - Optimum Asphalt Binder Contents of HMAs**

### 3.2.2 Statistical Analysis Marshall Properties

Marshall properties of HMA with and without binder modifiers were compared statistically using a two-factor ANOVA with a significance level ($\alpha$) of 0.05. Table 4 shows the F-values and F-critical values obtained. All obtained F-values are greater than the F-critical, indicating that the properties of modifications are significantly different from the control sample.

## 3.3 Moisture Susceptibility of HMA

### 3.3.1 Indirect Tensile Strength (ITS) and Indirect Tensile Strength Ratio (TSR)

One of the uses of ITS is the evaluation of the potential for fatigue failure, rutting, and thermal cracks [13]. Increasing CRH content in HMA showed an increase of up to 10% replacement of asphalt. This might be postulated to the bonding between CRH particles and asphalt, and the consequent stronger and homogeneous packing formed in CRH-modified HMA. This results in the highest observed ITS at 10% of CRH. Increasing CRH beyond 10%, however, decreased the contact and friction between aggregates, which led to decreased ITS values. The ITS values of BC modifications showed a decrease when the dosages increased from 5 to 10, however, remained constant when increased up to 15%. When the two modifications are compared with <10% replacement, the CRH modification would show a better performance against rutting and cracking resistance as CRH modifications have higher ITS values, the CRH modifications at <10% replacement outperformed the control samples too.

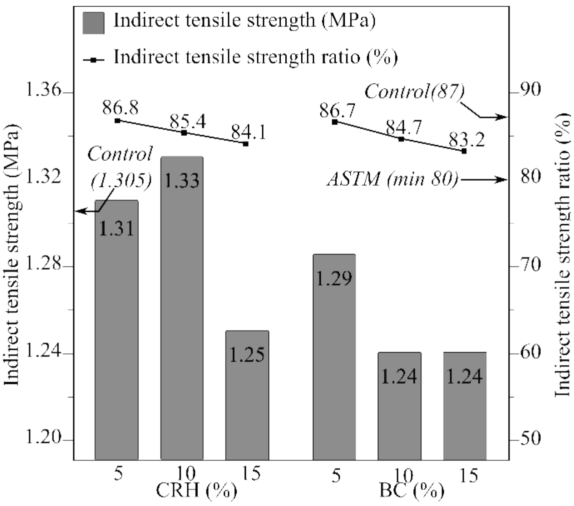

**Figure 3 - Indirect Tensile Strength and Tensile Strength Ratio of Optimum HMA Samples**

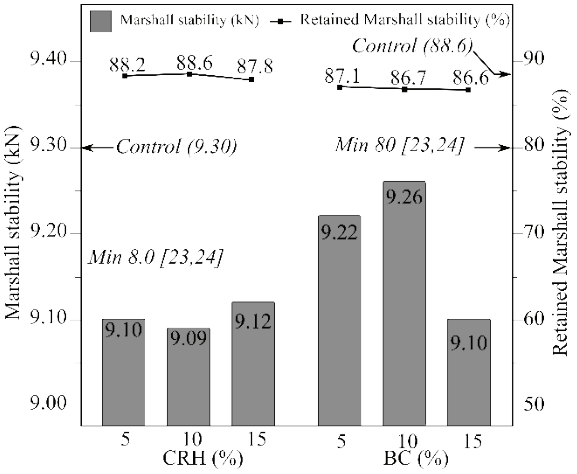

**Figure 4 - Marshall Stability and Retained Marshall Stability of Optimum HMA Samples**

TSR values show a monotonic decreasing trend with increasing dosage of both modifications; however, for the dosages tested for both modifications, the TSR values remained above 80% which is the asphalt institute's specification [23,24]. The decrease in the TSR values with increasing modifier content could be ascribed to the high water-absorbent nature of modifiers compared to conventional aggregate (See Table 1). However, modification with both CRH and BC modifications satisfied the asphalt institute's specification limit of 80% [23,24]. Other studies have also verified that although there is decrease in the strength values, modifications can satisfy 80% requirement [6,7]. Variations in ITS and TSR of optimum HMAs with CRH and BC modifications are shown in Figure 3.

### 3.3.2 Retained Marshall Stability (RMS)

The variation of the Marshall stability and RMS values of optimum HMA samples are shown in Figure 4. All Marshall stability values with modified asphalt binders were below the control value (9.3 kN), however, above the minimum value stipulated for the heavy-traffic highways in asphalt institute's specifications [23,24]. AllCRH modifications showed the highest RMS value among modifications which were also similar to the RMS value of the control sample (88.6%).

**Table 4 - Statistical Analysis Marshall Properties**

| Type of HMA | Property (Dependent) | Content (Independent) | F-value | | p-value |
|---|---|---|---|---|---|
| | | | Observed | Critical | |
| CRH - modification | Marshall stability | Asphalt | 9.0 | | 0.00 |
| | | CRH | 1.4 | | 0.30 |
| | Marshall flow | Asphalt | 43.0 | | 0.00 |
| | | CRH | 19.5 | | 0.00 |
| | Marshall quotient | Asphalt | 31.9 | | 0.00 |
| | | CRH | 2.5 | | 0.10 |
| BC-modification | Marshall stability | Asphalt | 85.2 | | 0.00 |
| | | BC | 4.4 | | 0.00 |
| | Marshall flow | Asphalt | 4357.3 | | 0.00 |
| | | BC | 63.7 | | 0.00 |
| | Marshall quotient | Asphalt | 287.9 | | 0.00 |
| | | BC | 11.8 | | 0.00 |

There was no noticeable change in the RMS with dosage. The RMS value of BC-modified HMA showed a decreasing trend, however, the decrease is also not noticeable. CRH and BC particles are prone to water damage as they readily absorb water. When the modifications are added to the bitumen and mixed well, they become coated with bitumen. This makes them less susceptible to water absorption. As far as moisture damage is concerned there is no clear difference between the two modifications, however, the raw Marshall stability values are high for the BC modifications. Therefore, BC -modified HMA is better performing compared to CRH -modified HMA.

## 4. Conclusions

The feasibility of BC and CRH as asphalt binder modifiers were investigated through the properties of the asphalt binder, and Marshall samples.

When compared with the control, both BC and CRH modifications showed increased resistance to high-temperature susceptibility. Compared to CRH-modified asphalt, BC-modified asphalt was observed to have higher resistance to high-temperature susceptibility at all modification levels.

When compared with the control, both BC and CRH modifications showed a reduced ability to withstand permanent deformation, compared the modifications. However, BC-modified HMA had better resistance to permanent deformation compared to that of the CRH-modified HMA.

Actual bitumen requirements of the optimum modified samples were less than that of the control sample although the total asphalt binder requirement was higher than the control at most of the modification levels. CRH at a 10% replacement level showed the minimum bitumen requirement followed by BC at a 10% replacement level.

In terms of ITS, the CRH modifications outperformed the BC modifications at all levels of modification. Further, up to 10% of CRH, ITS values are higher than the control. Even though both modifiers decreased the tensile strength ratio, they satisfied the asphalt institute's specifications, i.e., the ratio is more than 80% [1,2].

With the introduction of modifications, Marshall stability decreased at all modification levels, however, the maximum decrease is within 5% of the controls. BC modification showed higher Marshall stability values. All modifications retained more than 85% of their stability when subjected to moisture. Though a decreasing trend was observed in the retained Marshall stability of BC-modified HMA, still they satisfied the specification requirement.

It can be concluded that CRH and BC could be used as asphalt binder modifications with tolerable loss in the desired Marshall and ITS properties. BC modification proved to be superior in (i) resistance to high-temperature susceptibility (ii) resistance to permanent deformation and (iii) Marshall stability, while the CRH modifications were found to be superior in (i) bitumen requirement and (ii) ITS. Both CRH and BC modifications equally performed well in the case of moisture susceptibility.

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