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Evaluation of Adhesion and Moisture Susceptibility of Cotton Stalk Modified Bitumen

Adeel Iqbal[1*], Sajjad Ahmad[1], Hafiz Ammar Zahid[2], Abid Latif[1] and Muhammad Zahid[1]

[1]Department of Civil Engineering, Bahauddin Zakariya University, Multan, Pakistan
[2]Department of Civil Engineering, University of Engineering and Technology, Taxila, Pakistan

Email: chadeel6657@gmail.com; Başlıca yazarın mail adresi

***Abstract* –** Worldwide, the improper disposal of agricultural waste poses a major threat to the environment. One of the primary topics of modern research in pavement engineering is the environmentally sustainable disposal of waste by utilizing it as a modifier in bitumen. It has been discovered that biochar, which is made from a variety of agricultural wastes, can be used to alter or partially replace the traditional bitumen. Using Cotton Stalk (CS) waste to create biochar for utilization in bitumen can enhance the characteristics of the binder while helping to mitigate the environmental issues. In this study, CS biochar modified binder at weight percentages of 2%, 4%, 6%, and 8% has been investigated to evaluate the effects on the characteristics of the control binder. In addition to the standard binder tests, the bitumen bond strength test and the rolling bottle test are performed to determine the modified binder adhesion and moisture susceptibility. Based on the findings of this research, a biochar-modified binder with a weight percentage of 8% of the total binder content exhibited the best adhesion and moisture susceptibility. There was a noticeable performance increase when biochar and bitumen were mixed together in an optimal manner. Biochar's potential to reduce environmental effects and improve bitumen's performance makes it an attractive option for binder modification in the pavement sector in subtropical and tropical areas.

Keywords – Bitumen, Agriculture Waste, Cotton Stalk, Biochar, Bitumen Bond Strength

I. INTRODUCTION

Using hot mix asphalt for flexible pavement has been a long-standing practise in many countries. Traditional job mix formulas (hot mix asphalt) lead to a variety of stress-related issues, including rutting, fatigue cracking, and moisture damage. Extremes of low and high temperatures, as well as overloading, contribute to these issues [1], [2]. Binder modification is the most effective method for resolving all stress-related issues [3]. Binders are modified in various ways to reduce rutting, fatigue, and water damage. The pressing issue of waste disposal in the modern world has been worsened by a lack of available space and environmental pollution. As the population grows, waste disposal in landfills and the associated health issues also increasing [4], [5].

Cotton Stalk (CS) is a valuable agricultural by-product across the world. Cotton is grown on more than 12 million acres of land in around 80 countries [6]. Approximately, 40 million ton of CS is produced annually only in China [7]. Agricultural waste is often disposed in landfills, where it contributes to pollution in the surrounding area. During the rainy months, this garbage mixes with the groundwater and ruins its quality for human consumption. Additionally, there is now a severe lack of land, which further intensifies the issue of CS waste disposal. Effective usage of CS waste has the potential to lessen these environmental issues [8].

Eventually, as time goes on, the amount of asphalt binder available will reduce due to the limited supplies of petroleum asphalt. Another factor reducing the amount of asphalt binder is the introduction of environmental rules on digging for new resources. Because of all of these issues, asphalt binders are becoming more difficult to produce, which has caused their price to climb. Scientists have been working on a new substance that may partially replace traditional asphalt. Materials that meet these criteria of being sustainable, inexpensive, and good for the environment are the focus of current research [9].

Animal manure [10], urban garden waste [11], grass [12], [13], tea residues [14], and waste coffee [15] are some of the sources that may be used to create bio asphalt, which has the potential for the replacement for traditional asphalt binder. By using extraction or thermal chemical liquefaction, biomass may be converted into bio-asphalt, a sustainable substance with a low impact on the environment [16]. Consequently, bio asphalt is a viable replacement for conventional asphalt binder [17].

Researchers have developed a variety of cutting-edge methods to extract biochar from biomass. Most often, pyrolysis is used because it allows biomass to be converted into solids, liquids, and gases by thermal breakdown in the absence of oxygen. While different pyrolysis methods such as quick, slow, catalytic, and flash pyrolysis exist, slow pyrolysis has shown to be the most effective and popular for producing biochar [18]–[20]. In the slow pyrolysis process, the biomass is first heated to remove excess water, and then heated to temperatures of around 400 degrees Celsius in the absence of oxygen. biochar is the solid product of this process [21].

In recent years, bio-asphalt, made from biodegradable materials, has emerged as a viable replacement for asphalt made from petroleum. Bio-binders have been developed to partially replace asphalt binders in roads and airport pavement. We were able to greatly reduce the temperatures required for mixing and compacting asphalt by combining the original binder with a bio-adhesive generated from the thermochemical conversion of pig manure to form a bio-modified binder (BMB). It was also shown that using leftover vegetable oil in the binder can extend its fatigue life and reduce fatigue cracking [22]. Petroleum asphalt and bio-asphalt made from biomass heavy oil have their individual functional groups identified by means of Fourier transform infrared spectroscopy (FTIR) and a technique known as spectral analysis of resonant absorption near-infrared spectra (SARA). Resins, also known as polar aromatics, and asphaltenes make up the bulk of bio-asphalt [23]. Asphalt binders susceptibility to heat and shear is mitigated when 10% by weight of biochar made from pig dung is added [24]. Both bio-asphalt and petroleum-based asphalt have comparable elemental distributions and typical compositions, and there are only minor differences between the two in terms of functional groups [25].

In this research, CS biochar was extracted and utilized as an asphalt binder modification, and its characteristics were studied to determine the impact of biochar on traditional binder. Standard techniques, such as conventional binder tests, bitumen bond strength test and the rolling bottle test, were used to determine the effect of CS biochar on asphalt binder characteristics.

II. MATERIALS AND METHOD

A. *Materials*

The Pak Arab Oil Refinery is the source for bitumen 60/70. Margalla Hills aggregates were used in this research. After being obtained from local distributors, CS agricultural by-products were subjected to a slow pyrolysis process to produce biochar. The pyrolysis-produced biochar was crushed and sieved through a 0.075mm mesh to standardise its particle size and filter out any remaining impurities.

B. *Mixing Proportion*

In order to make the modified binder, CS biochar was mixed with a control binder at 2%, 4%, 6%, and 8% concentrations for 60 minutes at a shear mixer speed of 1500 rpm at a temperature of 180 degrees centigrade. After the preparation phase, the created specimens were put through a number of tests designed to evaluate the behaviour of control binders and biochar-modified binders.

Table 1. Test dose of CSBC

Sr. No	Dosage
1	Control Binder + 2% CSBC
2	Control Binder + 4% CSBC
3	Control Binder + 6 % CSBC
4	Control Binder + 8% CSBC

C. *Sample Preparation and Analysis Method*

The effect of the CSBC on binder was evaluated by conducting penetration and softening point tests in accordance with ASTM D5 [28] and ASTM D36 [29], were used to evaluate the effect of the CSBC modified binder. The BBS test was carried out in accordance with ASTM D 4541 to examine the adhesion of bitumen to aggregate in both dry and wet conditions using the PATTI (Pneumatic Adhesion Tensile Testing Instrument) [30]. Dry and wet curing tests were performed on all samples (24, 48, and 72 hours).

The bitumen and aggregate binding strength were evaluated for all CSBC modified binders. The Pull Off Tensile Strength (POTS) is calculated by inserting the PATTI value into equation 1 to get the bursting pressure at which the stud breaks away from the aggregate sample.

$$POTS = \frac{(BP \times A_g) - C}{A_{ps}} \tag{1}$$

Where, POTS = “Pull-off Tensile Strength”,
BP = “Burst Pressure”
Ag = “Contact area having a value of 2620 mm^2”
C = 0.286 = Piston constant
Aps = 127 mm^2 = Area of pull-stub
For this study F-4, stub type was used.

RBT was conducted in accordance with EN 12697-11 [31] to investigate the CSBC modified binder's resistance to moisture. One hundred seventy grammes of aggregate and eight grammes of bitumen were combined to make the sample. Bitumen samples were obtained after 6-hrs, 24-hrs, 48-hrs, and 72-hrs of rolling time.

III. RESULTS AND DISCUSSION

A. *Conventional Testing*

The impact of these additives on bitumen was investigated via the use of traditional testing methods. Penetration and softening point tests were carried out to determine whether or not modified bitumen was softened or hardened, respectively. This is important since bitumen's adhesion and resistance to moisture damage are directly affected by its softening and hardening [32]. Fig. 1 demonstrates the standard testing research findings.

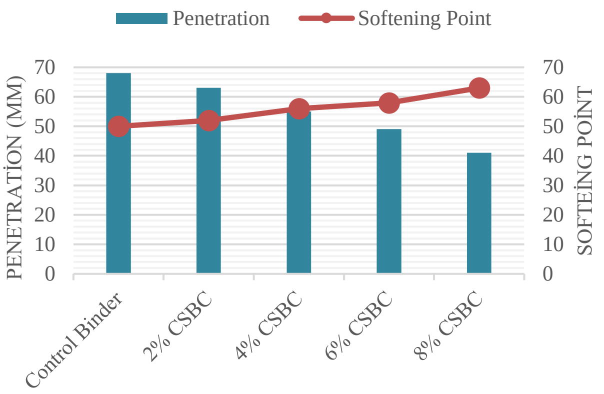

Fig. 1 Penetration and Softening point values of control binder and modified binders

As CSBC was added to the control binder at a rate of 8% by weight of binder, the penetration value dropped by 39.7%, but the softening point raised by 26.1% compared to the control binder. In the 6% CSBC modified control binder, the penetration value was found to be 27.1% lower and the softening point value was found to be 16.1% higher than the control binder.

Therefore, the binder becomes stiffer as the CSBC dose is increased; this is because of the penetration values drop, and the softening point rises as CSBC is added to bitumen. Therefore, the stiffening effect was given as dominant by each CSBC at lower penetration values, in contrast to the control binder. Positive softening point readings at high temperatures suggest that resistance to irreversible deformation increases with temperature [33].

B. *Analysis of Adhesion*

Pneumatic Adhesion Tensile Testing Instrument (PATTI) was used in the experimental assessment of CSBC’s effects on adhesion. The major benefit of this kind of test is the ease with which adhesion between bitumen and aggregate may be identified by the application of force. By incorporating 8% CSBC in the binder weight of 60-70 pen bitumen, an increase in dry-condition POTS levels of 42% against the control binder was observed. The error bar in Fig. 2 depicts the average positive deviations from the control binder.

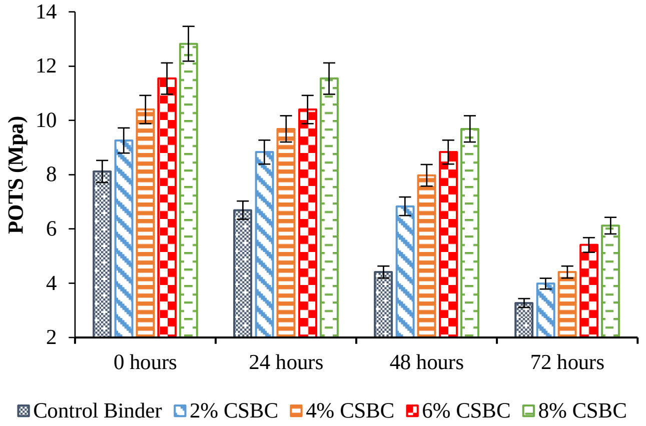

Fig. 1 Dry and wet POTS values for virgin and CSBC modified binders

Although the POTS values of the CSBC reduce after 24, 48, and 72 hours of wet conditioning, they are still greater than those of the control binder. This is because water enters the bitumen-bitumen interface and the bitumen-aggregate contact, therefore weakening the binding [32].

In dry circumstances, the POTS values of the CSBC-modified bitumen were greater than those of the control binder. However, after being conditioned in water, the modified bitumen's values were lower than they had been in dry circumstances.

C. *Analysing the surface for potential failure*

There are two kinds of failures that occur when a stub separates from an aggregate surface: adhesive failure and cohesive failure. The failure mode is established by visually identifying bitumen residues on the aggregate sample. When more than half of the aggregate surface area is still coated with bitumen after failure, we refer to it as a "cohesive" (C) failure; otherwise, we refer to it as an "adhesive" (A) failure. Cohesive adhesive (CA) failure occurs if there is still 50% bitumen on the aggregate..

Table 2: Coverage percentage of Bitumen

CT	**0% CS**	**2% CS**	**4% CS**	**6% CS**	**8% CS**
0 hr	72C	76C	72C	70C	68C
24 hr	61C	71C	63C	65C	67C
48 hr	50C/A	60.5C	48.9A	47A	46A
72 hr	32A	45A	40A	38A	35A

CT = Curing time; A = Adhesive failure; C = Cohesive failure; C/A = 50% adhesive 50% cohesive failure

Samples were conditioned both in a dry and wet condition, and the results are shown in Table 2 along with the percentage of bitumen covering and the failure type. After 24 hours of water conditioning, the CSBC-modified binder bond strength was increased, and its failure mode shifted from cohesive to adhesive. Adhesive failure in all CSBC modified binders was shown after 48 hours of water conditioning.

D. *Analysis of Water Damage with RBT*

The interaction of bitumen and aggregate was tested using the rolling bottle method. Figure 3 demonstrates that as rolling time increases, bitumen coverage decreases. When compared to the control binder, the improved adhesion provided by CSBC-modified bitumen was noticeable. After 72 hours of rolling, the modified binder containing 8% CSBC achieves 35% more coverage than the control binder. Adhesion was improved significantly in the CSBC modified binder over the control binder.

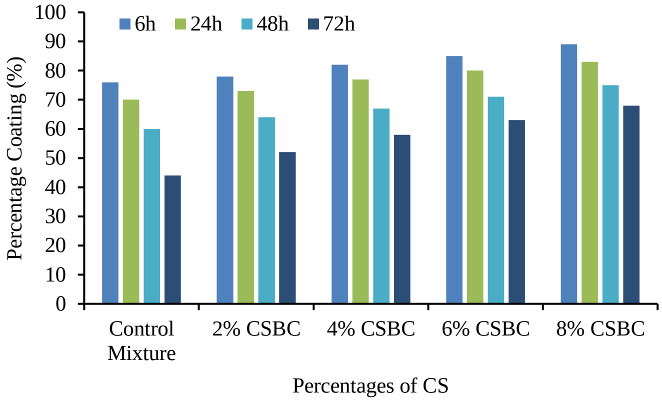

Fig. 3 Coverage percentages of CSBC modified and untreated bitumen over time of varying durations

IV. CONCLUSION

The study's findings led to the following conclusions.

- The penetration value drops by 39.7% points when 8% CSBC is added to bitumen, leading to a 26% point rise in the softening point compared to the control binder. Adding CSBC to the control binder makes it harder, which lowers the penetration values and raises the softening point.
- When compared to the control binder in the dry state, the POTS values for the control binder rise by 42% when 8% CSBC is added. The POTS values for control binder and CSBC modified binder are lower after 72 hours of water conditioning compared to the dry state. As a result, the modified CSBC

binder exhibits greater POTS values than the control binder.

- When compared to the control binder, CSBC's modified binder coverage increases by 35% when 8% CSBC is added. The CSBC modified binder has greater bitumen coverage than the control binder after 72 hours of rolling.

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