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A Study That Combines Fine Aggregate Replacement with Bottom Ash and Sisal Use in Densified Grade Bitumen Mixes

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Abstract: In this study, dense graded bituminous blend specimens are created using natural aggregate as coarse aggregates, bottom ash as exceptional aggregates, fly ash as filler, and sisal fiber as an additive. The proportion of mixture for dense graded bituminous macadam (DBM) grading has been accounted for in accordance with MORTH having nominal maximum aggregate size (NMAS) of 26.5 mm. To reinforce the mixture, slow-setting emulsion (SS-1)-coated sisal fiber is added in varying percentages of 0%, 0.25%, 0.5%, 0.75%, and 1% by weight of the mixture, with varying lengths of 5 mm, 10 mm, 15 mm, and 20 mm. On the initial stage of the research, specimens were prepared with two types of paving bitumen, VG30 and VG10. VG30 bitumen exhibited superior Marshall Characteristics in the initial trials and was therefore considered for the next phase of testing. Specific tests with Marshall Test outcomes were used to determine the marshal characteristics, most effective binder content, and most effective fiber content as well as the finest fiber length. Marshall balances as high as 15kN were obtained with a bitumen content of 5.57 percent, a fiber content of zero percent, and a fiber length of 10 millimeters. In addition, for the purpose of delivering the performance of the pavement, a number of overall performance evaluations, including a moisture susceptibility test, oblique tensile strength (ITS), creep test, and tensile energy ratio of bitumen mixtures, were conducted. Coal ash as a good mélange and filler, stabilized with natural sisal fiber and SS-1 emulsion in advance, has been discovered to result in engineering properties that are not only high-quality, however also vastly superior. Utilization of non-traditional combinations, such as coal ash and natural fiber, may therefore aid in the discovery of a new method of bituminous pavement construction. By substituting natural sources of sand and stone soil for coal ash, it is possible to find a cost-effective method for its reuse. Coal ash dumping is a major concern for anyone concerned with its disposal and environmental contamination.

Keywords: - Indirect tensile strength Test, Static creep Test, Tensile strength ratio Test, Retained Stability Test, Dense Grade Bitumen Mix (DBM), Bottom ash, Sisal fiber.

Introduction

Pavements, highways, and roads are regarded as a nation's backbone, upon which its growth and development depend. Typically, each nation has a series of programs for building new road infrastructures or enhancing the existing ones. A more durable, performance-oriented, and seamless pavement surface requires a substantial investment in the construction of both flexible and rigid pavement. In India, where highways serve as the primary mode of transportation, the government has made substantial investments in the construction and maintenance of pavement. A thorough engineering study can save a significant amount of capital and paving materials, resulting in a highway with reliable performance. Regarding flexible pavement, there are two crucial considerations: paving design and mixture formulation. This research focuses on the engineering properties of bituminous mixtures made from alternative or non-traditional materials.For the preparation of bituminous mixtures, coarse, fine, and infill aggregates are typically used. In many locations, aggregates of various size fractions are not readily available, necessitating their procurement from great distances and resulting in exorbitant cost increases. Alternatively, a number of coal-based thermal power facilities have been constructed to partially meet the demand for electricity. According to reports, approximately 120 million tons of ash are produced annually by forty main thermal power plants in India. The majority of coal ash is likely to be disposed of either dry or moist in nearby open areas or by grounding into artificial lagoons or dumping yards. In terms of land usage, health risks, and environmental perils, such a vast quantity of these types of waste materials does pose challenging problems. Human life, wildlife, and the environment must be protected with the uttermost care during both the disposal and use of hazardous materials. In order to mitigate the negative impact of these materials, a comprehensive study is required to determine how they can be utilized in a manner that will satisfy the needs of society. Bituminous pavement accommodates of a combination of stone chips, graded from nominal most aggregates length (NMAS), via the exceptional fraction smaller than zero.0.5 mm mixed with suitable quantity of bitumen that can be compacted adequately with smaller air voids and will have good enough dissipative and elastic residences. The purpose of bituminous mix design is to decide the truthful share of bitumen and aggregates fraction to yield a combination that is effective, long lasting, reliable and competitively priced.

II. Objective of the work

This experimental study was conducted to enable the optimal use of coal ash as a nonconventional aggregate in conjunction with natural fiber (Sisal fiber) as an additive, by assuring adequate performance in the areas of fatigue, moisture susceptibility, and creep value. Again, the potential effects of fiber on bitumen mixtures are considered, and a comprehensive study was conducted to determine the optimal fiber content and fiber length for enhancing the engineering properties of bituminous mixture.

1. Our specific objecttoobtainaMarshalltestwithmixofbottomashandflyashpreparewithDBMalso find the stability of flow values.
2. To find out the indirect tensile strength to endure cracking.
3. To find out the role of use of emulsion coated fiber, coal ash or both in DBM mix.

III. Literature Review

Shuler, T. S. (2022) performed a laboratory study on six bottom ash obtained throughout the state of Indiana and tried to physically characterize the materials. Tests included Unit weight, Florida Bearing Test, Hveem Centrifuge Kerosene Equivalent and Oil Ratio Specific Gravity, Dry Sieve Analysis, and a degradation analysis. Performance tests are also done by Florida Bearing Test on fine aggregate-ash mixtures prior to mix with bitumen; Marshall Stability on specimens in the dry as well as the soaked condition, Hveem Stability and Cohesion and Skid Resistance.

R. E. Long and R.W. Floyd (2021) studied that aggregate shortages and increased transportation costs have greatly increased prices of related construction items in areas of Texas which is not blessed with natural aggregates. Some natural aggregates are not performing up to expectations as documented by stripping, rutting and other visual signs of pavement distress noted throughout the Department. Because of these spiralling construction costs and need to field evaluate bottom ash, District 1, supported by the Materials and Tests Division, decided to construct three field test pavements substituting bottom ash for part of the natural aggregates in hot mix asphaltic concrete (HMAC).

David Q. Hunsucker (2020) conducted an experimental bituminous surface overlay, which was placed in October 1987 on State Route 3 in Lawrence County, Kentucky. The experimental section utilized bottom ash aggregate, limestone and natural sand aggregate. He conclude that because of the absorptive characteristics of bottom ash aggregate, nearly fifty percent more bitumen is required in the mixture. The increased asphalt content results in a higher unit bid price for the bituminous concrete material. The combination of bottom ash aggregates with limestone and natural sand aggregate appears to improve the overall performance of a bituminous surface mixture, especially with respect to its skid resistant properties.

Musselman et al. (2018) performed a two year demonstration project has been initiated where bottom ash was used as a 50% substitute aggregate in a asphalt pavement. The demonstration project includes noteworthy testing of possible environmental influences and pavement performance both in the laboratory and at the demonstration roadway. Data was gathered which include analytical data on groundwater and surface water quality impacts, surface run-off and suction lysimeter samples. Physical roadway performance was monitored through remote sensing using strain resistance and temperature probes as well as in situ and destructive pavement analysis.

Khaled Ksaibati and Jason Stephen (2015) studied the possible utilization of incorporating bottom ash in bitumen mixes. For the field evaluation in this research project, a test pavement section was constructed with control bottom ash and bitumen mixes. Laboratory testing was done by using the Georgia Loaded Wheel Tester (GLWT) and Thermal Stress Restrained Specimen Tester (TSRST).

IV. Methodology

1. Experimental Design

The adopted gradation for DBM sample has been considered as specified in MORTH (2013) and is given in Table-1. Throughout the experimental study the aggregate gradation given in Table4wasfollowed, and the following tests were performed. The aggregate gradation curve is shown in figure 1.

Table 1: Gradation of Aggregate.

Sieve size (mm)	Adopted gradation (%Passing)	Specified limit (%Passing)
37.5	100	100
26.5	95	90-100
19	83	71-95
13.2	68	56-80
4.75	46	38-54
2.36	35	28-42
0.3	14	7-21
0.075	5	2-8

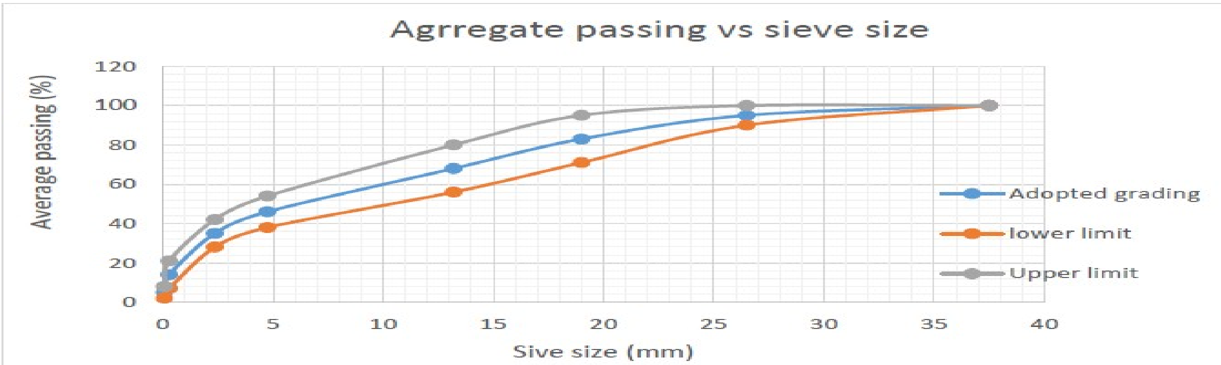


Figure 1: Aggregate Gradation Curve.

2. Design Mix

The DBM mixtures were prepared in accordance with the Marshall procedure specified in ASTM D6927-2015. All ingredients of mixture, such as coarse aggregates, fine aggregates, filler, fiber and VG-30 bitumen were mixed in a specified procedure. Before preparing the samples, fibers were coated with SS-1 emulsion and stored in a hot air oven at 1100C. Coated fiber are stored for 24 hours to ensure proper coating around each fiber and to drain down extra bitumen that may adhere to fiber .Then the fibers were cut into specified lengths of about 5mm, 10mm, 15mm and 20mm. The aggregates and bitumen were heated separately to the mixing temperature of 1550C to 1600C. The temperature of the aggregates was maintained 100C higher than that of the binder. Required quantities of bitumen VG-30 and coated emulsion fiber pieces were added to the pre-heated aggregates and thoroughly mixed.

3. Static Indirect Tensile Test

Static indirect tensile test of bituminous mixes was performed in accordance to ASTM D 6931 (2007) to assess the resistance to thermal cracking for a Marshall cylindrical specimen that is loaded in vertical diametrical plane. This tests were carried out on DBM specimen which were prepared at their optimum binder content, optimum fiber content and optimum fiber length as calculated from Marshall properties analysis. The effect of temperature on the Indirect Tensile Strength (ITS) of mixes with and without fiber was also studied. The load at which tensile crack were develop in the specimen were noted down from the dial gauge of the proving ring and was calculated.

Figure 2: Loading and Failure Pattern Of Indirect Tensile Strength Test.

4. Static Creep Test

This test method is used to determine the resistance to permanent deformation of bituminous mixtures at specific temperatures. For Static Creep test sample were prepared at their optimum binder content, optimum fiber content and fiber length. The test was conducted as per Texas department of transportation (2005) specification. The specimens were placed in a hot air oven maintained at a temperature of 40°C for three to five hours prior to start of the test. Then 125 lb. (556 N) load was applied for one hour followed by 1 min initial loading rest. This allows the loading platens to achieve more uniform contact with the specimen. The deformation was registered in each 5 min intervals starting from 0 min to 60 min by using a dial gauge graduated in units of 0.002 mm. After then the load was removed and its recovery was registered up to next 5 min at 1 min intervals. A graph has been plot between time and deformation.

V. Results and Discussion

This chapter deals with results analysis and discussion for test that are carried out for DBM sample in previous chapter. This chapter is divided into three sections. In first section the parameter and the equation used for Marshall Property's analysis are given below. Second section deals with calculation and comparison of optimum binder content, optimum fiber content and optimum fiber length of DBM mixes with and without coal ash used as fine aggregate and filler. Third section deals with analysis made from the experiment such done in previous chapter static indirect tensile, static creep test at 400C, moisture susceptibility test (Tensile strength ratio), and retained stability test.

1. Stability

It is seen from the figure 3 that using of coal ash in DBM mix is not satisfactory with respect to stability value, when compared with conventional mix. The maximum stability value of 11.83 kN was achieved when 14% of coal ash by weight of the mix was mixed for preparing DBM samples.

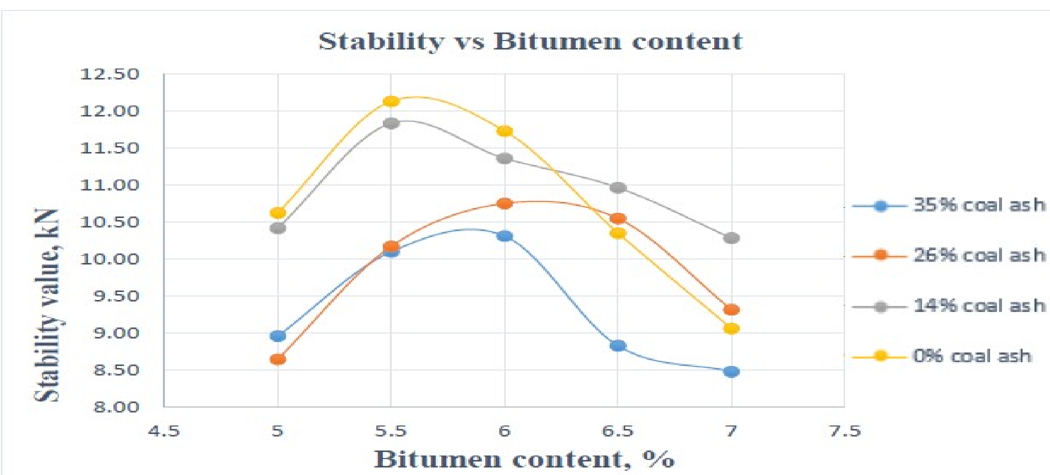
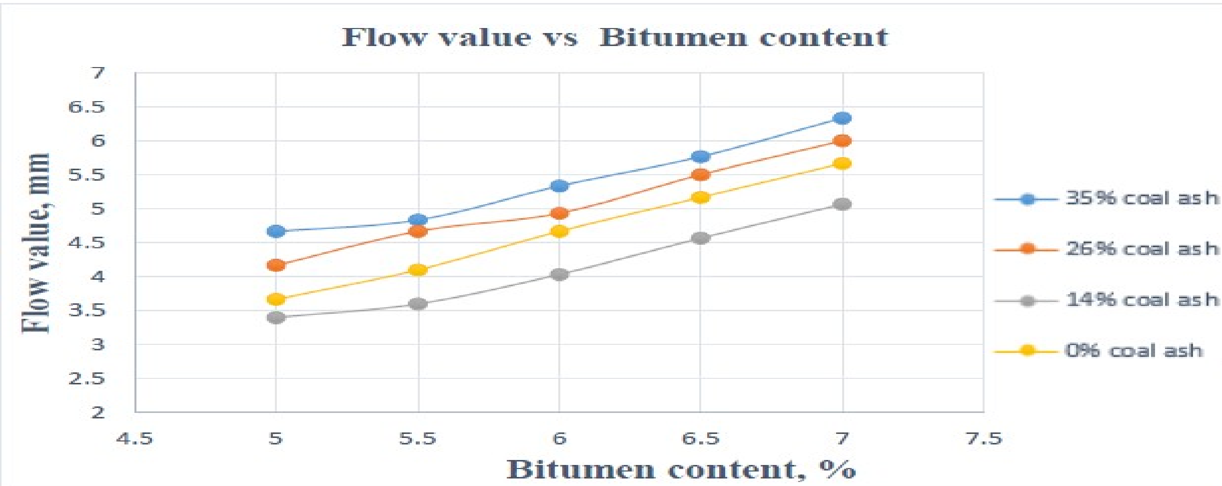


Figure 3: Variation of Stability Value with Bitumen Content at Different Coal Ash Content.

2. Marshall Flow value

It was seen from the flow value vs bitumen content graph shown in figure 4 that with increase in bitumen content



and Coal ash content the flow value increase. But with 14% coal ash content by weight of mix the flow value decrease as compare to the conventional mix.

Figure 4: Variation of Flow Value with Bitumen Content at Different Coal Ash Content.

3. Unit weigh

From the graph shown in figure 5 it is clear that with addition of fiber the unit weight decreases compare to the conventional mix. It was also observed that not only addition of fiber but alsocoalashreducedtheunitweighttoo.Thisisbecauseofbothfiberandcoalasharelightermaterialthan bitumen. The fiber content and fiber length has a significant effect on minimizing the unit weight.

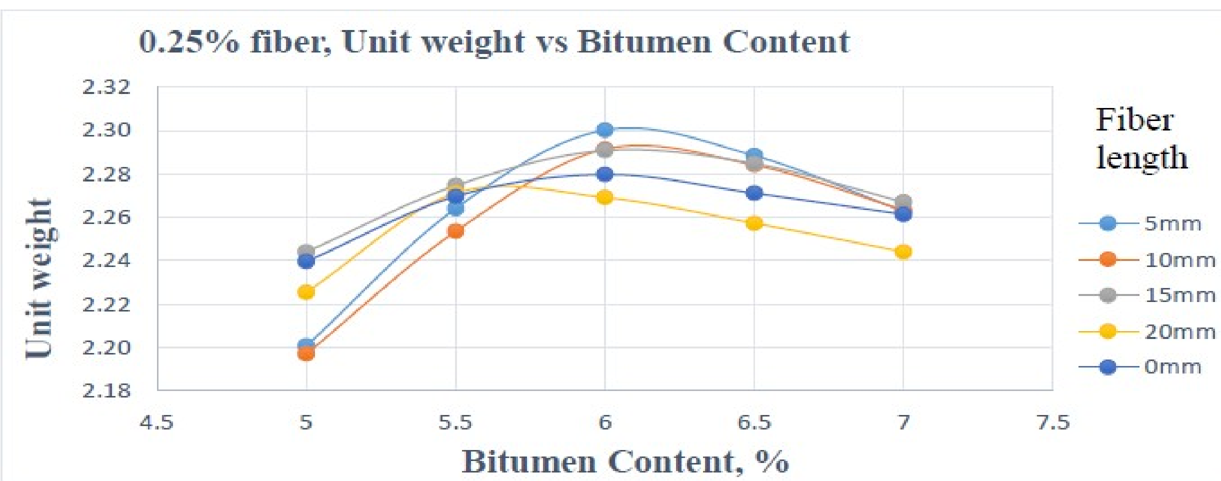


Figure 5: Variation of Unit Weight Value with Bitumen Content In 0.25% fiber Content at Different Fiber Length.

4. Voids

Generally DBM have HMA due to well graded aggregates. But at the initial stage of the study, the DBM sample prepared with coal ash have higher air voids in compare to conventional mix. Due to this reason sisal fiber is added to somewhat minimize the air voids. And as a result from the graphs shown in figure 6 it is clear that with increase in fiber content and fiber length the air void in the mixture decreases as compare to normal DBM mix. It has also observe that the air void was 14% less as compared to conventional DBM mix, when prepare with optimum coal ash content and optimum sisal fiber property.

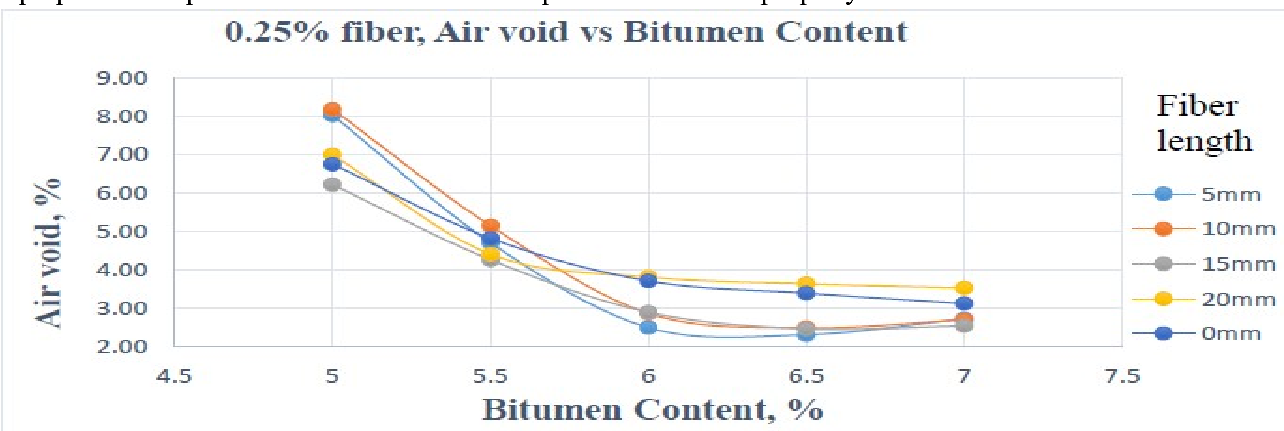


Figure 6: Variation of Air Void Value with Bitumen Content In 0.25% fiber Content At Different fiber Length.

5. Resistance to Moisture Damage (Tensile Strength Ratio (TSR))

The results of tensile strength ratio (TSR) in respect of two different types mixes, one modified and other unmodified are presented in Table 5.2. It was observed that with addition of both fiber and coal ash together, resistance to moisture induced damage was increased as compared to the conventional DBM mixture. This may due to the lesser amount of air voids in modified DBM mixture than unmodified mixture, when prepared with emulsion coated sisal fiber. Similarly from the table 5.1, it is observed that a minimal value of resistance to moisture damage is achieved when the mix was prepared with either fiber or coal ash.

Table 2: TSR of DBM Mixes with and without fiber And Coal Ash.

Tensile strength ratio			**Design requirement**
Type of mixes	DBM With coal ash	DBM Without coal ash	Minimum 80% (as per MORTH specification)
DBM With fiber	84.77%	82.04%	
DBM Without fiber	82.35%	80.26%	

6. Static Creep Test

Static creep test is a measure of permanent deformation due to constant loading for a long period of time. It was observed from the deformation and time graph shown in figure 7 that the deformation value for DBM sample that is prepared with 0.5% fiber content, 10mm fiber length, 14% coal ash (9% bottom ash and 5% fly ash) by weight of the mix and optimum binder content of 5.6% by weight of the mixture decreased when compared with other modified and unmodified DBM mix. It is also seen that with either addition of coal ash or fiber in the mixture, the deformation value decrease when compared to conventional mixture.

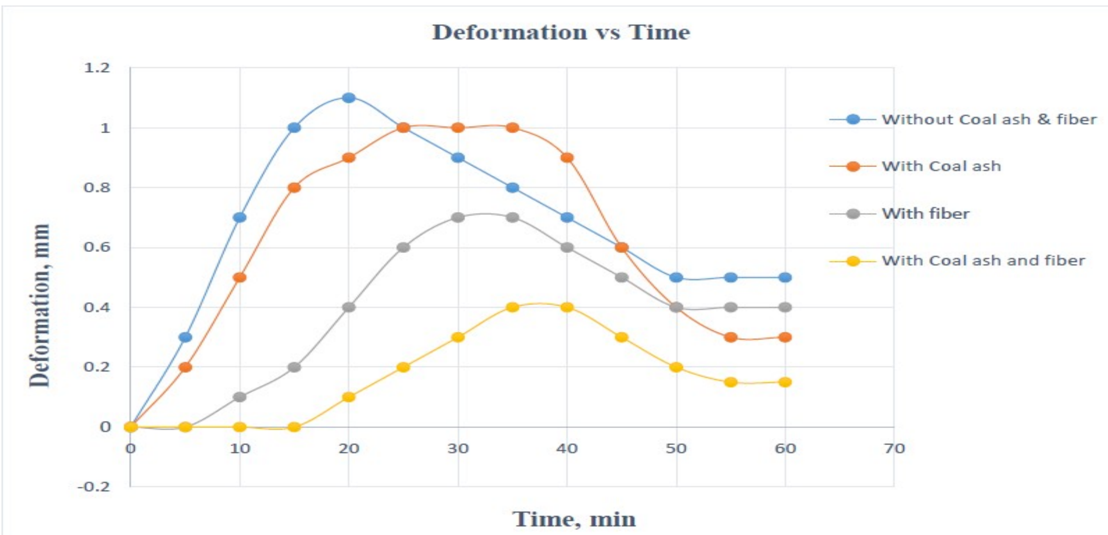


Figure 7: Variation of Deformation Value at 400C for DBM Sample With Respect To Time.

VI. Conclusion

1. Based on the results of the Marshall tests, it was determined that the DBM mixes prepared with bottom ash and fly ash in 300-75 micron sizes and passing 75 micron were the best mixes meeting the Marshall criteria when the bitumen content, fiber content, and fiber length were 5.6%, 0.5%, and 10mm, respectively.
2. It is also observed that Marshall stability and flow values are acceptable when the coal ash content is less than 15%.
3. It is also observed that as fiber content and fiber length increase, air-voids and flow diminish and the Marshall Quotient rises, which is a result of the material's increased stability value.
4. Increasing fiber content and fiber length necessitated a higher optimal bitumen concentration and emulsion for coating the fibers.
5. Based on the indirect tensile strength test, it is concluded that the addition of emulsion-coated fiber and coal ash increased the indirect tensile strength of the sample, which provides an outstanding engineering property for the DBM sample to resist thermal cracking.
6. It is also observed that the addition of emulsion-coated fiber, coal ash, or both to DBM enhances its resistance to moisture-induced damage, as measured by the tensile strength ratio and retained stability values.

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