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Research Article

Effect of Marble Waste and Coir Fibre Content on the Indirect Tensile Strength of Bituminous Concrete Mixtures

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Abstract

A bituminous concrete mix is a mixture of coarse aggregate, fine aggregate, filler and binder. The mechanical properties of properly compacted pavements are dependent on the interlocking of the aggregate and the consistency of the binder. For the present study, the effect of marble dust and coir fibre on the indirect tensile strength of bituminous concrete mixtures is taken as the topic. Bituminous concrete grade I as per MoRTH and S90 grade bitumen were used. Aggregates and binder were tested for their basic properties to ascertain their suitability for further tests. Modification was done using marble dust and coir fibre. Marshall stability test was conducted to determine the optimum bitumen content for neat bituminous concrete mixes. Then indirect tensile strength (IDT) tests were performed on both neat and modified mixes. IDT test was conducted on BC mix with varying marble content to determine the optimum marble content. Then IDT test was conducted on BC mix prepared with optimum marble content and varying coir fibre content to determine the optimum fibre content. BC mix with 8% marble and 0.5% coir fibre showed maximum strength.

Keywords: *Bituminous Concrete Mix, Marshall Stability Test, Indirect Tensile Strength Test, Optimum Bitumen Content, Optimum Marble Content, Optimum Fibre Content.*

1. Introduction

The use of good quality conventional materials in road construction is becoming increasingly expensive in India due to the increasing demand as well as its scarcity in nature. Further the development and use of new modified paving materials in road construction results in high performance pavement to meet the communities. So, attempts should be made to utilize industrial and agricultural wastes effectively in construction to address environmental and economic concerns.

In India, about 6 million tonnes of waste from marble industries is being released from marble cutting, polishing, processing and grinding. The marble dust is usually dumped on the riverbeds and possesses a major environmental concern. The marble dust deposited in riverbed and around the production facilities causes reduction in porosity permeability of top soil and results in water logging. Attempts are being made to utilize marble dust in different applications like road construction, concrete and bituminous concrete aggregates, cement and other building materials. It is evident from such studies that there is a great potential for recycling of wastes released from different industrial processes. Work carried out by earlier researchers has shown that marble process residues could be used in road construction since they help to reduce permeability and improve settlement and consolidation properties.
Fibres are stabilizing additives that are used in the mixture to prevent mortar drain down and to provide better binding. Fibres commonly used now-a days are polypropylene, polyester, mineral and cellulose.

The main stabilizing additives used in mixes can be classified in to different groups such as fibres, Polymer Powder and flour like materials, Plastics etc. Variety of fibres is added now-a-days to increase the strength of bituminous mixtures. The tensile characteristics of the bituminous mixtures can be increased by adding fibres which gives a number of applications on the surface layer design of pavements.

Generally, roads are classified into flexible and rigid pavements. For rigid roads, concrete is used as the binder and for flexible roads bitumen is used. The different surface layers used for flexible pavements are bituminous concrete mixes, Semi dense bituminous concrete mixes, mastic asphalts etc. Bituminous concrete (BC) mix generally consists of coarse aggregate, fine aggregate, filler and binder. The layers in a flexible pavement structure are subjected to continuous flexing as a result of the traffic loads that they carry, resulting in tensile stresses and strains at the bottom of the bituminous layers of the pavement.

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The tensile properties of these bituminous mixtures are of interest to pavement engineers because of the problems associated with cracking. Indirect tensile strength test is an indicator of strength and adherence against fatigue, temperature cracking and rutting.

In this project, BC mix was prepared with marble waste as filler and coir fibre as an additive. Indirect tensile strength tests were carried out on both neat and modified bituminous concrete mixes and the results were compared.

Scope

- There is a great potential for recycling of marble wastes released from different industrial processes.
- As compared to synthetic fiber, natural fibers are less costly and biodegradable. Coir fiber used in this study is a low cost material.
- Other synthetic and natural fibers and other type of binder can also be tried in mixes and compared.

Objectives

- To prepare BC mixes and determine the optimum bitumen content (OBC) by Marshall Mix design.
- To determine the indirect tensile strength of neat bituminous concrete mix.
- To determine the indirect tensile strength of BC mix modified with marble waste and coir fibre.
- To compare the indirect tensile strength of neat and modified BC mix.

2. Materials

In the present study, BC mixes were prepared using locally available aggregates and S90 grade bitumen, as per the specifications in Ministry of Road Transport and Highways (MoRTH).

Coarse and Fine Aggregates

Coarse aggregates consisted of stone chips collected from a local source, up to 4.75 mm IS sieve size. Offer compressive and shear strength and show good interlocking properties. 20mm down and 10 mm down aggregates were selected.

Table 2.1: Tests on Aggregate

Sl.No.	Test	Result	Specifications as per MoRTH
1	Aggregate Crushing Value Test	26%	Max 30%
2	Aggregate Impact Value Test	25%	Max 27%
3	Aggregate abrasion value test	30%	Max 35%
4	Specific Gravity-Coarse Aggregate	2.71	2.5-3.0
5	Specific Gravity-Fine Aggregate	2.64	2.5-3.0
6	Water Absorption	0.1%	Max 2%

Fine aggregate fills the voids in the coarse aggregate and stiffens the binder. Quarry dust was selected as the fine aggregate.

The aggregates for the study were obtained from a local quarry. They were subjected to various standard tests and the results are tabulated in Table2.1.

Filler

Fills the voids between the fine aggregates, stiffens the binder and reduces permeability. Marble dust was chosen as the filler.

Binder

Fills the voids and also causes particle adhesion. S90 grade bitumen is used. The properties of bitumen were tested and are given in Table 2.2.

Table 2.2: Tests on Bitumen

Sl. No.	Test	Result	Requirement as per IS:73-2002
1	Penetration value	8mm	8-10
2	Ductility	82cm	75cm(minimum)
3	Specific Gravity	1.01	0.99(minimum)
4	Softening Point	45^0C	40-55
5	Viscosity	42S	14-45

Fibre

Fibres are stabilizing additives that are used in the mixture to prevent mortar draindown and to provide better binding. Fibres commonly used now-a days are polypropylene, polyester, mineral and cellulose. The fibre used in this project is coir fibre.

Figure 2.1: Coir Fibre

A. Aggregate Proportioning

Grading of aggregate has been carried out before mix design. For this purpose sieve analysis of aggregate has been done having size 20 mm down, 10 mm down and quarry dust. The final blend of aggregate was obtained by trial and error method. In this method the proportions of the materials are varied until the required gradation is obtained. The solution is obtained by constructing a set of equations considering the lower and upper limits of the required gradation as well as the percentage passing of each type of aggregate.

B. Preparation of Mixes

The aggregates were proportioned and mixed as given in Table 4.1. Approximately 1200g of the mixed aggregates and quarry dust was taken and heated to a temperature of 175 to 190^{0}C. The bitumen was heated to a temperature of 121-145^{0}C and the required quantity of first trial percent of bitumen say, 5, 5.5, 6, 6.5, and 7 percent by weight of material aggregates was added to the heated aggregate and thoroughly mixed at the desired temperature of 154 to 160^{0}C. The mix was placed in a pre-heated mould and compacted by a rammer with 50 blows on either side at 138 to149^{0}C. The weight of the mixed aggregate taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5±3.0 mm. Three specimens were prepared using each trial percentage of bitumen content.

The bulk density, percent air voids and theoretical specific gravity were calculated using the following relationships.

Bulk Density or Mass Density of the specimen,

$$G_m = \frac{Wa}{Wa - Ww}$$

Where,
W_a = weight of the sample in air, kg
W_w= weight of the sample in water, kg

Percent air voids,

$$V_v = \frac{G_t - G_m}{G_t} \times 100$$

Where,
G_m=bulk density or mass density of the specimen
G_t=theoretical specific gravity of mixture

$$G_t = \frac{W}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3}}$$

Where,
W = total weight of the BC mix
W_1=percent by weight of coarse aggregate in total mix
W_2=percent by weight of fine aggregate in total mix
W_3=percent by weight of bitumen in total mix
G_1=Apparent specific gravity of coarse aggregate
G_2=Apparent specific gravity of fine aggregate
G_3=Apparent specific gravity of bitumen

C. Marshall Stability Test

The specimens to be tested are kept immersed under water in a thermostatically controlled water-bath maintained at 60˚C for 30 to 40 minutes. One specimen is taken out from the water bath and is placed in the Marshall test-head. 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 Marshal 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 and the corresponding deformation readings are noted. Stability value is the maximum load in kg before failure.

D. Determination of Optimum Bitumen Content

The average values of each of the above properties were found for each mix with the different bitumen contents. Graphs were plotted with the bitumen content on the X-axis and the following values on the Y-axis.

1) Marshall stability value
2) Unit weight
3) Percent voids in total mix

The optimum bitumen content is the amount of bitumen to be added in a BC mix so that the aggregates are completely coated with bitumen and the voids are minimum. The OBC for the mix design was found by taking the average value of the following three bitumen contents found from the graphs of the test results.

1) Bitumen content corresponding to maximum stability.
2) Bitumen content corresponding to maximum unit weight.
3) Bitumen content corresponding to the median of designed limits of percent air voids in total mix (4%).

E. Indirect Tensile Strength Test

The tensile characteristics of bituminous mixtures were evaluated by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through to opposite loading strip. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametrical plane, ultimately causing the specimen to fail by splitting along the vertical diameter. A 13 mm (1/2″) wide strip loading was used for 101 mm diameter specimen to provide a uniform loading with which produces a nearly uniform stress distribution. A loading rate of 51mm/minute was adopted. Tensile failure occurs in the sample rather than the compressive failure. Metal strips were used so that the load is applied uniformly along the length of the cylinder. The compressive load created a tensile load indirectly in the horizontal direction of the sample. The peak load was recorded and it was divided by appropriate geometrical factors to obtain the split tensile strength using the following equation:

$S_t = \frac{2000P}{\pi D t}$, where

S_t=IDT strength, (kPa)
P=maximum load, (N)
t=specimen height immediately before test, (mm)
D=specimen diameter, (mm)

F. Indirect Tensile strength Test on Neat BC mix

The optimum bitumen content got from the Marshall stability test was used as the bitumen content for all the specimens in which the IDT is to be tested. Three neat samples were prepared and IDT tests were performed on these samples.

G. Indirect Tensile Strength Test on BC Mix with Marble Dust

Using the optimum bitumen content, the test mix was prepared by adding marble dust in the order 6%, 7%, 8%, 9% and 10% of the total weight of the mix. Three samples were prepared for each percentage of marble dust. IDT test was conducted on these prepared specimens and the marble content at which the maximum indirect tensile strength obtained was selected as the optimum marble content.

H. Indirect Tensile Strength Test on BC Mix with Marble Dust and Coir Fibre

By fixing OBC and optimum marble content, BC mixes were prepared by adding coir fibre in the order 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of the total weight of the sample. Three samples were prepared for each percentage of coir fibre content. Indirect tensile strength tests were conducted for these specimens. The maximum tensile strength was obtained at 0.5% fibre content.

Figure 3.1: Heating of Aggregates

Figure 3.2: Heating of Bitumen

Figure 3.3: Preparation of BC Mix

Figure 3.2: Compaction of Specimen

Figure 3.3: Specimen Extraction

Figure 3.4: Waterbath at 60^{0}C

Figure 3.5: Marshall Stability Test

Figure 3.6: Preparation of BC Mix by Adding Coir Fibre

Figure 3.7: Indirect Tensile Strength Test

Figure 3.8: Failure of Specimen after IDT Test

4. Results

Aggregate Proportioning

The aggregates were proportioned and mixed as given in Table 4.1.The proportions of 20mm down,10mm down and quarry dust obtained from trial and error method are shown in Table 4.2.

Table 4.1: Aggregate Gradation

Sieve Size(mm)	Percentage Finer			Desired Gradation for 25mm thick course as per IRC 29:1988
	20 mm down	10 mm down	Quarry dust	
26.5	100	100	100	-
22.4	100	50.5	100	-
13.2	15.4	20.9	100	100
10	3.6	0	100	90-100
5.6	0	0	100	60-80
2.36	0	0	99	40-55
0.6	0	0	65.4	20-30
0.3	0	0	41.1	15-25
0.15	0	0	15.8	10-20
0.075	0	0	4.5	06-09

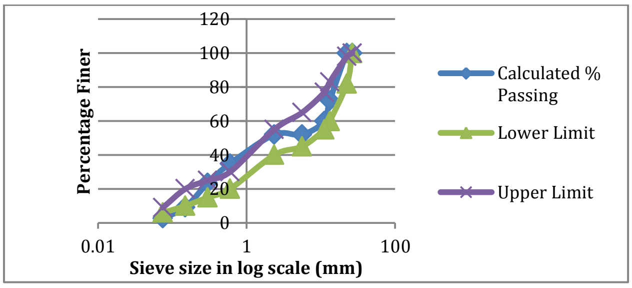

Figure 4.1: Aggregate Gradation curve

Table 4.2: Aggregate Proportion

Sl. No.	Type of Aggregates	% of Aggregates
1	20 mm down	12
2	10 mm down	36
3	Quarry Dust	52

Table 4.3: Marshall Stability Test Results

SI.No	Bitumen content (%)	W_a (kg)	W_w+ W_{basket} (kg)	W_w (kg)	H (cm)	Volume (cm³)	Gm	Gt	V_v (%)	No: of divisions	Stability value (kN)
1	5	1.25	2.10	0.71	6.7	526.21	2.32	2.47	6.34	475	10.31
2	5	1.25	2.10	0.71	6.6	518.36	2.31	2.47	6.64	472	10.25
3	5	1.26	2.11	0.72	6.8	534.07	2.32	2.47	6.05	478	10.38
4	5.5	1.26	2.11	0.72	6.9	541.92	2.33	2.46	5.15	545	11.82
5	5.5	1.26	2.11	0.72	6.8	534.07	2.33	2.46	5.00	541	11.73
6	5.5	1.26	2.11	0.72	7	549.77	2.33	2.46	5.30	549	11.90
7	6	1.26	2.11	072	6.8	534.07	2.33	2.44	4.38	565	12.25
8	6	1.26	2.11	0.72	6.9	541.92	2.33	2.44	4.61	559	12.12
9	6	1.27	2.11	0.72	6.7	526.21	2.34	2.44	4.15	571	12.38
10	6.5	1.27	2.12	0.73	6.7	526.21	2.34	2.42	3.39	568	12.31
11	6.5	1.27	2.11	0.72	6.8	534.07	2.33	2.42	3.69	572	12.40
12	6.5	1.27	2.12	0.73	6.6	518.36	2.35	2.42	3.09	564	12.23
13	7	1.28	2.12	0.73	6.8	534.07	2.33	2.41	3.21	520	11.28
14	7	1.27	2.12	0.73	6.9	541.92	2.32	2.41	3.44	514	11.15
15	7	1.28	2.12	0.73	6.7	526.21	2.34	2.41	2.99	526	11.41

Marshall Stability Test

Marshall stability test was conducted on neat BC mix to determine the optimum bitumen content (OBC). Samples were prepared with bitumen content varying in the order 5%, 5.5%, 6%, 6.5% and 7%. Three samples were prepared using each percentage of bitumen content. Then properties such as unit weight, Marshall stability and percentage voids filled with bitumen were calculated for each BC mix. The results obtained are shown in table 4.3.

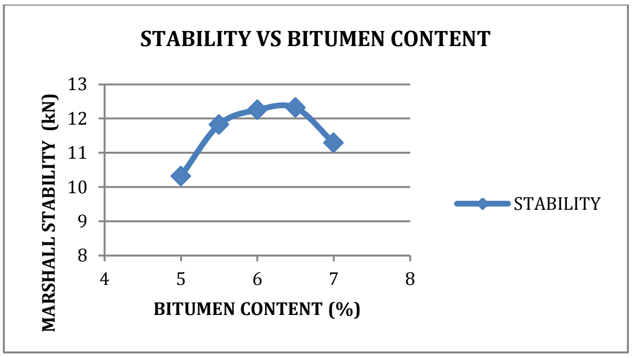

Figure 4.2: Marshall Stability Vs % Bitumen Graph

It is observed that stability value increases with increase in binder content. After a particular percentage of bitumen content, the stability value decreases.

Unit Weight

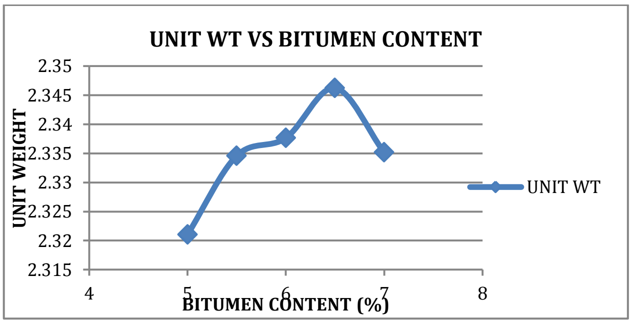

Figure 4.3: Unit Weight Vs % Bitumen Graph

It is observed that unit weight increases with increase in binder content. After a particular percentage of bitumen content, the unit weight decreases.

Air Void

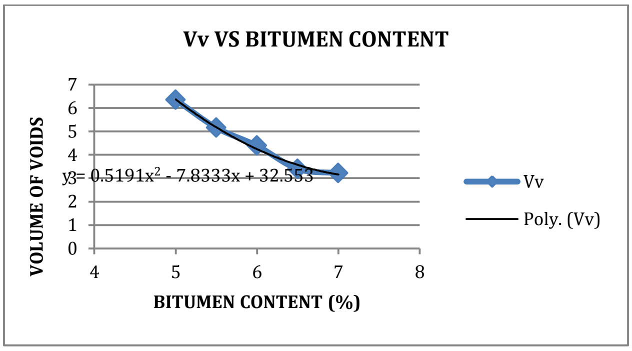

Figure 4.4: Volume of Voids Vs % Bitumen Graph

It is observed that with increase in binder content, the air void decreases. The bitumen content corresponding to 4 % V_v is required for the calculation of the optimum bitumen content.

Determination of Optimum Bitumen Content

The optimum bitumen content for the mix design is found by taking the average value of the following three bitumen contents found from the graphs of the test results. Thus from graphs,

1) Bitumen content corresponding to maximum stability = 6.5%
2) Bitumen content corresponding to maximum unit weight = 6.5%
3) Bitumen content corresponding to the median of designed limits of per cent air voids in total mix(4%)=6.15%

Thus,

OBC= (6.5+6.5+6.15)/3 = 6.4%

Indirect Tensile Strength Test on Neat BC Mix

IDT tests were performed on neat BC with 6.4% OBC and results are shown in table 4.4.

Table 4.4: Indirect Tensile Strength Test Results on Neat BC Mix

Indirect Tensile Strength Test on Neat BC				
Sl.No.	No. of Divisions on Proving Ring	Load in kN	IDT (MPa)	Average IDT(MPa)
1	40	0.9645	0.090	0.09
2	46	1.0935	0.102	
3	34	0.8355	0.078	

Indirect Tensile Strength Test - BC Mix Modified with Marble

IDT tests were performed on BC mix with 6.4 % OBC and by varying the marble dust in the order 6%, 8%, 9% and 10%. Three specimens were prepared for each trial marble content. The results obtained are shown in table 4.5.

Table 4.5: IDT Test Results on BC Mix Modified with Marble

Sl.No.	% of Marble Used	No: of Proving Ring Divisions	Load(kN)	Indirect Tensile Strength (MPa)	Average IDT(MPa)
1	6	57	1.33	0.124	0.13
2	6	63	1.459	0.136	
3	6	60	1.394	0.13	
4	7	70	1.609	0.15	0.15
5	7	68	1.566	0.146	
6	7	72	1.652	0.154	
7	**8**	**92**	**2.082**	**0.195**	**0.201**
8	**8**	**98**	**2.211**	**0.207**	
9	**8**	**95**	**2.147**	**0.201**	
10	9	70	1.609	0.15	0.158
11	9	78	1.781	0.166	
12	9	74	1.695	0.158	
13	10	67	1.545	0.144	0.15
14	10	73	1.674	0.156	
15	10	70	1.609	0.15	

The variation of indirect tensile strength of BC mix with different marble content is shown in figure 4.4.

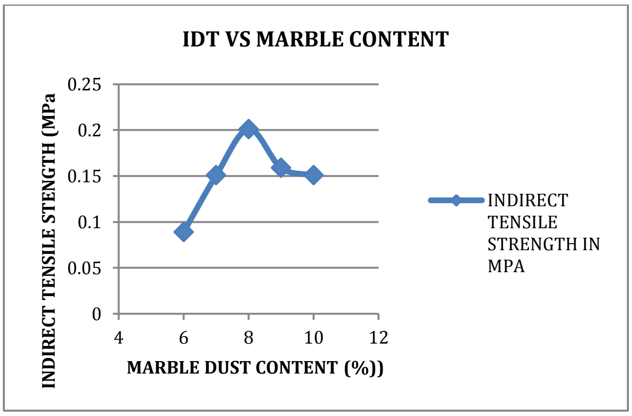

Figure 4.5: % of Marble Content Vs Indirect Tensile Strength

Percentage of marble content at which indirect tensile strength is maximum = 8%

From the above graph, it was observed that, up to 8% marble content, there was an increase in tensile strength. After that the tensile strength is reduced. Presence of marble provides good adhesion between bitumen and aggregate. Thus there will be reduction in stripping of aggregate. Also, due to the presence of fine materials, the voids will be filled by these fine particles resulting in a low void ratio. Thus the density increases and as a result, the tensile strength is increased. When the marble content is increased above a particular level, due to the increase in the fine particles, the surface area increases and the fixed amount of bitumen content added will be insufficient to bind all the materials. This may result in poor tensile strength of the specimen.

Indirect Tensile Strength Test -BC Mix Modified with Coir Fibre

IDT tests were performed on BC mix with 6.4 % OBC, 8% marble dust and by varying the coir fibre in the order 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6%. Three specimens were prepared for each trial percentage of coir fibre content. The results obtained are shown in table 4.7.

Table 4.6: IDT Test Results on BC Mix Modified With Coir Fibre

Sl.No.	% Of Fibre Used	No: Of Proving Ring Divisions	Load (kN)	Indirect Tensile Strength (MPa)	Average IDT (Mpa)
1	0.1	69	1.588	0.148	0.148
2	0.1	71	1.631	0.152	
3	0.1	67	1.545	0.144	
4	0.2	70	1.609	0.15	0.15
5	0.2	67	1.545	0.144	
6	0.2	73	1.674	0.156	
7	0.3	82	1.867	0.174	0.174
8	0.3	80	1.824	0.17	
9	0.3	84	1.91	0.178	
10	0.4	85	1.932	0.18	0.18
11	0.4	83	1.889	0.176	
12	0.4	87	1.975	0.184	
13	**0.5**	**129**	**2.878**	**0.269**	**0.269**
14	**0.5**	**125**	**2.792**	**0.261**	
15	**0.5**	**133**	**2.964**	**0.277**	
16	0.6	76	1.738	0.162	0.162
17	0.6	80	1.824	0.17	
18	0.6	72	1.652	0.154	

The variation of indirect tensile strength of BC mix modified with marble and coir fibre at different fibre contents are given in figure 4.5.

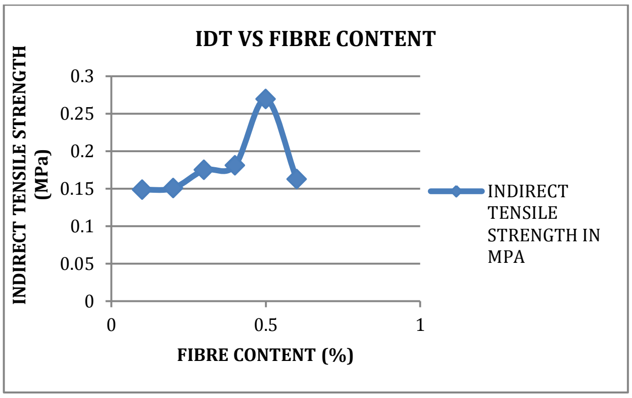

Figure 4.6:% of Fibre Content Vs Indirect Tensile Strength

Percentage of coir fibre content at which indirect tensile strength is maximum = 0.5%

From the graph, it was observed that for BC mix modified with marble and coir fibre, up to 0.5% fibre content there is an increase in tensile strength and after that the value decreases. The improvement in indirect tensile strength would be due to fibre's absorption and adhesion of bitumen which improves the interface adhesion strength and fibre's networking and bridging cracking effects. The addition of fibre beyond a certain level can increase the viscosity of binder, which results from the effects of increase in volume of fibre particles due to the absorption of binder. Therefore, this increase in viscosity inhibits the ability of the binder to coat adequately on the surface of aggregates, thereby leading to the potential loss of bonds between the fibre, binder and the aggregate.

Table 4.7: Percentage Increase in Tensile Strength

Type of Specimen	IDT(MPa)	% Increase in IDT Compared to Neat BC Mix
BC mix modified with marble	0.201	123
Marble and coir fibre added mix	0.269	199

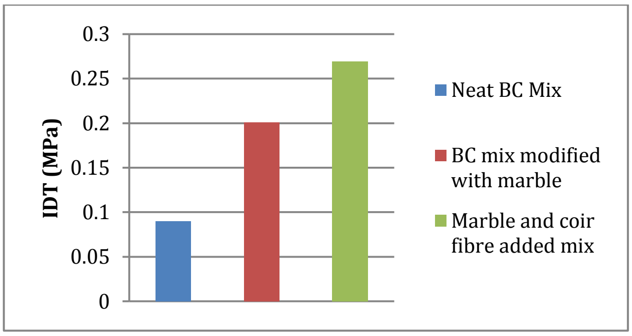

Figure 4.7: Comparison of Indirect Tensile Strength

The tensile strength of BC mixture modified with marble dust increased by 123% compared to the neat mix. The tensile strength of BC mix modified with marble and coir fibre increased by 199 % compared to the neat mix.Table 4.7 shows the percentage increase in tensile strength. Figure 4.6 shows the percentage increase in tensile strength graphically.

Conclusion

- Optimum bitumen content, optimum marble content and optimum fibre content were obtained as 6.4%, 8% and 0.5% respectively.
- By addition of marble dust up to 8%, the indirect tensile strength increases and on further addition, the strength decreases.
- By addition of various percentages of fiber content, the strength goes on increasing up to 0.5% and then decreases.
- The tensile strength of BC mixture modified with marble dust increased by 123% compared to the neat mix.
- The tensile strength of BC mix modified with marble and coir fibre increased by 199 % compared to the neat mix.
- The improvement in indirect tensile strength would be due to good adhesion between bitumen and aggregate.
- By improving the tensile properties, the cracking resistance of BC mix can be improved.
- Indirect tensile strength test is an indicator of strength and adherence against fatigue, temperature cracking and rutting.

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