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Performance Evaluation of Flexible Pavements using Recycled Brick Tile Concrete Waste

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ABSTRACT: The rapid increase in the global population has led to significant expansion in the construction industry. Consequently, a substantial amount of construction and demolition waste is generated, which has a severe impact on both the environment and the economies of developing nations. Unfortunately, there are very few treatment facilities or disposal sites available for civil engineering waste, and these disposal sites require a considerable amount of space. The accumulation of Brick-Tile-Concrete (BTC) waste, including recycled aggregates, is a direct result of the ongoing population growth and the subsequent rise in construction and demolition activities. This study conducts an experimental analysis of the effects of substituting BTC waste recycled aggregates for natural coarse aggregates in flexible pavement applications. The findings indicate that the modified mix using BTC waste aggregate achieves higher Marshal Stability compared to the conventional mix. Notably, a maximum Marshal Stability of 12.93 KN was reached at a 35% replacement rate of natural aggregates with BTC waste recycled aggregate. Additionally, the brick and tile materials used have a lower density than conventional aggregates, leading to a decrease in bulk specific gravity.Keywords: Construction industry, waste, Recycled aggregates, Flexible pavement. Brick-Tile-Concrete waste

I. INTRODUCTION

Rapid urbanization, expanding infrastructure requirements, and worries about environmental degradation have made the need for sustainable materials and construction methods a top priority. A large amount of the world's solid waste is produced by the construction sector, with construction and demolition (C&D) waste accounting for the majority of this waste. In India today, there are major issues with the widespread production of construction and deconstruction waste as well as its unlawful deposition.

Construction is a major source of solid waste production. Building construction accounts for roughly 40% of all energy consumption and 50% of all resources used. Every year, roughly 3.7% of all buildings worldwide are demolished. Nearly 80% of concrete and asphalt mixtures used in road construction are composed of aggregates, such as sand, gravel, and crushed stone (Leite et al., 2011).

The Recycled aggregates market records an active increase of 6.8% a year together with more developments in the countries' trends. C&D waste generation in India is likely to reach 530 million tonnes by 2025 (Bhatia & Khandekar, 2021). Recycled aggregates (RA) are materials such as bricks, tiles, and concrete (BTC) recovered from the demolition of structures like roads and buildings. Such materials may be sorted, cleaned, and repaired for use in different construction needs, such as in flexible pavement, a common way of paving the road where asphalt is placed over layers of aggregates.

The effectiveness of recycled concrete aggregate in base & sub-base applications was examined by Bennert et al. [2000]. According to the authors, a blended mixture consisting of 75% natural aggregate and 25% recycled concrete aggregate would have the same resilient response and long-term deformation characteristics as a dense-graded aggregate base coarse, which is currently utilized in base and sub-base layers. According to a 2019 report by the Central Pollution Control Board (CPCB). Nonetheless, pilot projects have shown that these materials can be successfully incorporated into flexible pavements with satisfactory performance and cost results, such as the Delhi-Meerut Expressway, which was constructed using recycled aggregates (Bhatia, 2021). Saveral other studies also carried out on utilization of such waste for flexible pavements (Nagahama et al 2020; Alam, 2021 Zhao et al., 2019;

Jain & Chawla, 2022). Additionally, using recycled materials minimizes disposal and environmental effects by reintegrating waste materials into the construction cycle, which is in line with the principles of a circular economy (Molenaar et al., 2017; Patil and Desai, 2020)

The purpose of this study is to assess how well recycled BTC aggregates perform in flexible pavements and offer information about their possible advantages from an economic and environmental standpoint. Utilizing recycled aggregate is crucial from an environmental and sustainable development standpoint. Concrete, bricks, tiles, glass, and other materials may contain BTC waste aggregate. A number of tests, including Marshall, stability, and tensile strength, are conducted to see if this material can be used in construction and to find the ideal amount of waste that produces satisfactory results. By using these waste materials, natural aggregates will be preserved for use by future generations. Utilizing BTC waste recycled aggregates in the semi-dense bitumen macadam can also help with the disposal issue.

II. LITERATURE REVIEW

There are several studies has been carried out by various researchers to evaluate the performance of flexible pavement from utilization of waste obtained from construction industries. According to research by Kumar & Malik (2022), the tolerance limit was found for the fundamental tests of penetration point, ductility, and softening point. This indicates that PMB (polymer mixed bitumen) exhibits reduced cracking deformation and increased temperature susceptibility. Rao & Mohammed (2020) studied the utilization of waste polymers for low volume rural roads. The stated that better binding property as observed in extraction of binder test and the Marshall stability value of the Semi Dense Bituminous Concrete (SDBC) has increased by about 30 percentage on using PCA.

Purchase et al. (2021) outlined the advantages of material recycling. Their results show that using recycled materials has a great potential to reduce waste, conserve natural resources, and lower carbon emissions related to the production of asphalt. Rahman et al. (2020) highlighted the importance of recycling waste materials in bitumen and asphalt concrete, suggesting that adding recycled aggregates could have a significant positive impact on the environment.

An experimental study on the impact of substituting recycled concrete aggregate (RCA) or recycled clay brick aggregate (RBA) for natural coarse aggregate (NCA) on the compressive strengths of the hardened concrete is presented by Zheng et al. (2018). Compressive strength reductions of up to 13% and 23% were documented by Marinez-Lage et al. [2022] in recycled concrete when 50% and 100% of the mixed recycled aggregates were substituted. Mas et al. [2023] found that 40% substitution reduced compressive strength by 13% to 39%. According to Medina et al. [2022], at 7 and 28 days of curing, the recycled concrete with 25% and 50% replacement ratios had compressive strengths that were 8.7%–15.9% and 15.1%–18.4% lower, respectively, than the controlled concrete without recycled aggregate.

III. MATERIALS AND METHODOLOGY

The purpose of this study is to determine whether using recycled brick, tile, and concrete (BTC) aggregates in the creation of flexible pavements is feasible. Bricks, concrete, tiles, and other materials are utilized. They are used as aggregates after being mixed. In bituminous mixtures, the performance attributes of recycled BTC aggregates and natural aggregates will be contrasted. Aggregates are created from the BTC waste. By crushing them, the aggregates derived from BTC waste are reduced to the necessary size. 25%, 30%, and 35% of the aggregate weight was made up of BTC waste aggregates. Brick, tile, and concrete made up 60:30:10 of the demolition waste, respectively. Prior to their use in the study, a variety of tests were carried out, including impact, crushing, and abrasion tests. Aggregate grading was carried out for semi-dense bitumen macadam. For every percentage of waste recycled aggregates, three samples were made. The different tests conducted on the recycled aggregates from BTC waste in this study

To assess aggregates resistance to impact, the aggregate Impact test [IS:2386Part –4(1963)] is used. Crushing under compressive stress is one way that pavement materials can fail. IS:2386 part-IV standardizes a test for figuring out aggregate crushing strength. A relative indicator of resistance to crushing under a gradually applied crushing load is the aggregate crushing value. A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates. The purpose of the abrasion test is to determine the aggregates hardness and suitability for various pavement construction projects. The Los Angeles abrasion test, which has been standardized in India (IS:2386 part-IV), is the recommended method for determining the hardness property. Finding the percentage of wear caused by the relative rubbing action between the aggregate and steel balls used as an abrasive charge is the basic

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idea behind the Los Angeles abrasion test. Under Indian conditions, a maximum of 40 percent is permitted for the WBM base course. There is a maximum value of 35 for bituminous concrete.

3.1 Marshall Mix Design

The Marshall Stability Test and Flow Test are widely used methods for evaluating the quality and performance of asphalt mixtures, especially in flexible pavements. These tests help engineers understand the load-bearing capacity, stiffness, and deformation characteristics of the asphalt mix, which are essential for ensuring durability under traffic conditions.

The Marshall Stability Test calculates the highest load an asphalt sample can withstand before failing or deforming under pressure. This method is employed to evaluate the asphalt mix's ability to withstand plastic deformation brought on by traffic loads. The sample Marshall Stability is the highest load it can sustain, measured in kN.

The Marshall Stability Test measures the compressive vertical displacement of the asphalt specimen under the load as well as the Flow test. In the Marshall Stability Test, ‘stability’ refers to the value of asphalt that the arrested deformation of the sample can be sustained under additional loading. This value is represented as the total amount of deformation that occurs from the commencement of load application up to the point of load failure, which is defined as the stage at which the specimen can no longer bare the applied load and starts deforms or loses shape. A flow value that is too high, though, may cause issues. Conversely, a flow value that is too low indicates that the mix may be too stiff, which could cause cracking when under load.

IV. RESULTS & DISCUSSION

In order to determine whether Brick-Tile-Concrete (BTC) recycled aggregates are suitable for flexible pavement applications, a number of tests are conducted to evaluate their mechanical properties.

4.1 Impact Test

The Impact Test assesses how resilient the aggregates are to unexpected shocks or impacts. The impact value at 0% BTC is 9.875, according to the results, indicating high resistance to impact loads. The impact values increase to 11.59, 12.56, and 13.11, respectively, as the percentage of BTC rises to 25%, 30%, and finally 35% (Table 4.1).

Table 4.1: Impact test results for different % of BTC recycled Aggregates

Test	BTC % Aggregate	Results (KN)
Impact test	0	9.87
	25	11.59
	30	12.56
	35	13.11

The impact value at 0% BTC is 9.875, which indicates a relatively high degree of toughness and resistance to unexpected loads. The impact value increases to 11.59 when the percentage of BTC reaches 25%. As more BTC aggregates are added, the values continue to rise, reaching 12.56 at 30% and 13.11 at 35%.

4.2 Crushing Test

A crucial factor in determining the aggregate's capacity to tolerate load-bearing conditions in pavements is its compressive strength, which is measured by the Crushing Test. The results indicate that the 0% BTC sample has a reasonable compressive strength with a crushing value of 15.69 (Table 4.2). However, as the BTC content increases, the crushing value also increases, reaching 20.15 at 25%, 22.51 at 30%, and 23.63 at 35%.

Table 4.2: Crushing test results for different % of BTC recycled Aggregates

Test	BTC Aggregate, %	Results
Crushing test	0	15.69
	25	20.15
	30	22.51
	35	23.63

4.3 Abrasion Test

In order to forecast how well aggregates will perform under traffic loads, the Abrasion Test assesses their resistance to wear. The Los Angeles Abrasion Test is a widely used method for this evaluation, which involves placing the aggregates in a rotating drum full of steel balls to replicate the conditions they would face in actual use. The abrasion value for 0% BTC is 14.93, according to the test results (Table 4.3). The abrasion values increase to 17.85, 18.93, and 20.51, respectively, as the BTC content rises to 25%, 30%, and 35%.

Table 4.3: Abrasion test results for different % of BTC recycled Aggregates

Test	BTC % Aggregate	Results
Abrasion test	0	14.93
	25	17.85
	30	18.93
	35	20.51

4.4 Bitumen tests results for VG 30 grade

Table 4.4 presents the findings of several tests conducted on VG 30 grade bitumen, a crucial substance frequently utilized in pavement applications and road construction.

Table 4.4: Tests on bituminous mix modified with BTC waste Aggregates

Test	Value
Penetration test	65.58 mm
Softening point test	48.67 C
Ductility test	50.29 mm
Specific Gravity	1.061

With a penetration value of 65.58 mm, the VG 30 bitumen is comparatively soft, which helps to give pavement layers flexibility. The softening point test establishes the temperature at which bitumen transitions from a solid to a more fluid state. A moderate degree of thermal resistance is indicated by this bitumen grade's softening point of 48.67 °C, which is essential for preventing rutting and deformation in hot weather. A value of 50.29 mm indicates good ductility, or the bitumen's capacity to stretch without breaking. Bitumen's specific gravity is a key indicator of its density concerning water. With a specific gravity of 1.061, bitumen is denser than a lot of other materials used to build roads.

4.5 Marshall Stability test

At the same bitumen content, the modified mix of BTC aggregates was found to have higher Marshall Stability than the conventional mix.

Table 4.5: Marshall Stability at different 0-35% BTC waste Aggregates

Sample No	BTC Waste Aggregates (0%)	BTC Waste Aggregates (25%)	BTC Waste Aggregates (30%)	BTC Waste Aggregates (35%)
A	11.24	12.28	12.61	12.87
B	11.28	12.21	12.65	12.94
C	11.18	12.32	12.58	12.98
Average Value	11.23	12.27	12.61	12.93

The Stability Value (KN) for three samples (A, B, and C) of an asphalt mixture with 0-35% BTS (Brick Tile Concrete) waste aggregate is shown in Table 4.5. At 0%, the sample. Figure 4.1 shows the average stability value for each sample at various percentages of recycled aggregates made from BTC waste. The average stability values for various percentages of BTC waste in an asphalt mix, ranging from 0% to 35%, are shown in Table 4.5. The stability value is 11.23 KN at 0% BTC and rises gradually as the BTC content increases. A stability value of 12.27 KN is achieved at 25% BTC, and it rises to 12.61 KN at 30% BTC. At 35% BTC, the stability is highest, measuring 12.93 KN. The trend line indicates that stability increases as the percentage of BTC recycled aggregates rises.

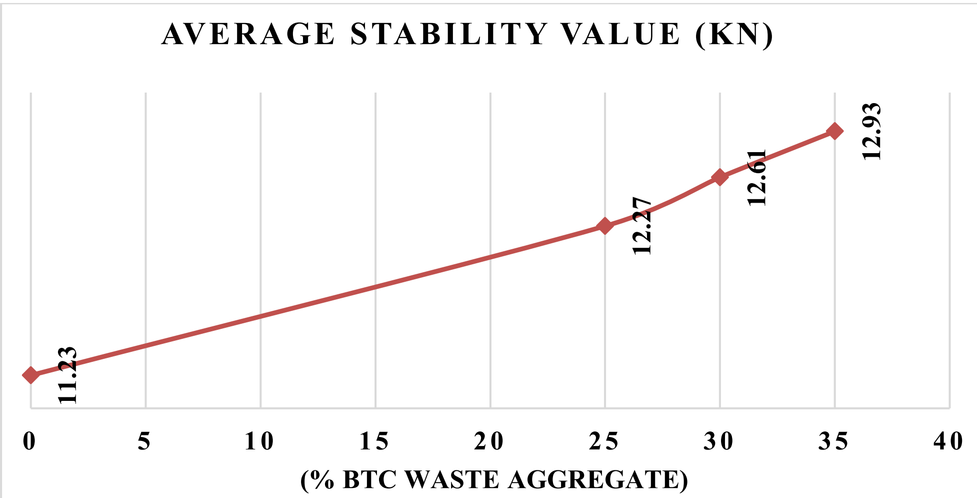

Figure 4.1: Average Marshall Stability at different % of BTC waste Aggregates

The upward trend indicates that stability values improve in tandem with an increase in the percentage of BTC waste aggregates.

4.6 Flow Test

The flow values analyzed at various percentages of BTC waste recycled aggregate are provided by the flow test.

Table 4.6: Flow Test results at 0-35% BTC waste Aggregates

Sample No	BTC Waste Aggregates (0%)	BTC Waste Aggregates (25%)	BTC Waste Aggregates (30%)	BTC Waste Aggregates (35%)
A	3.23	3.12	2.97	2.76
B	3.29	3.1	2.94	2.73
C	3.22	3.09	2.89	2.67
Average Value	3.24	3.1	2.93	2.72

Table 4.6 shows the average flow values for asphalt mixtures made with different amounts of BTC waste aggregates. The flow value indicates how flexible the asphalt mix is and how it deforms under load. To find the average flow value for each sample, we looked at the results for recycled aggregate use ranging from 0% to 35%.

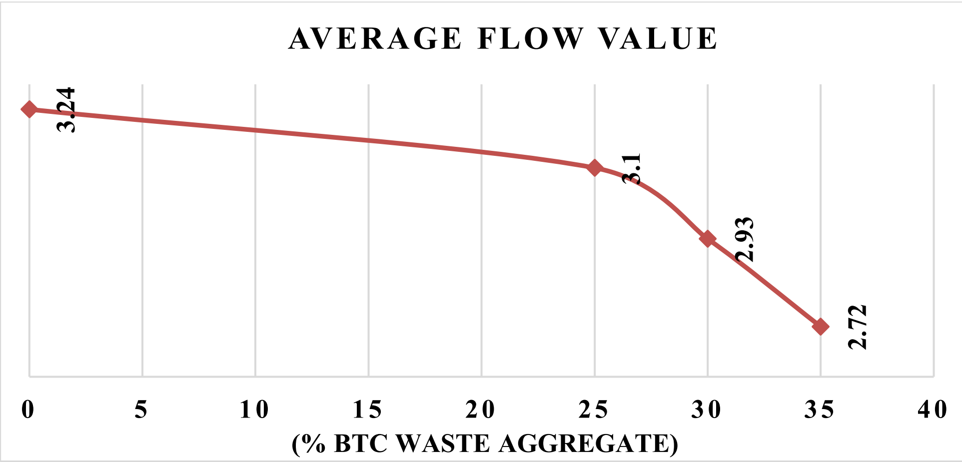

Figure 4.2: Average Flow Test outputs at different % BTC waste Aggregates

As seen in this trend (Fig. 4.2), adding BTC waste aggregate to the asphalt mix decreases its flexibility and stiffens the mixture.

4.7 Bulk Specific Gravity

The Bulk Specific Gravity values of asphalt mixtures with different amounts of BTC (Brick Tile Concrete) waste aggregates, ranging from 0% to 35%, are shown in Table 4.7.

For samples with 0% BTC waste aggregates, the average bulk specific gravity is 2.36. This means the asphalt mixture is relatively dense. As we increase the BTC waste aggregate to 25%, the average bulk specific gravity decreases to 2.30. This shows a slight drop in the mixture's compactness (see Fig. 4.3).

We also measured how the asphalt mix behaves under load by finding the average flow value for each sample using recycled aggregate from 0% to 35%.

Table 4.7: Bulk specific gravity at 0- 35% BTC waste Aggregates

Sample No	BTC Waste Aggregates (0%)	BTC Waste Aggregates (25%)	BTC Waste Aggregates (30%)	BTC Waste Aggregates (35%)
A	2.35	2.3	2.27	2.25
B	2.36	2.3	2.27	2.24
C	2.39	2.31	2.28	2.25
Average Value	2.36	2.3	2.27	2.24

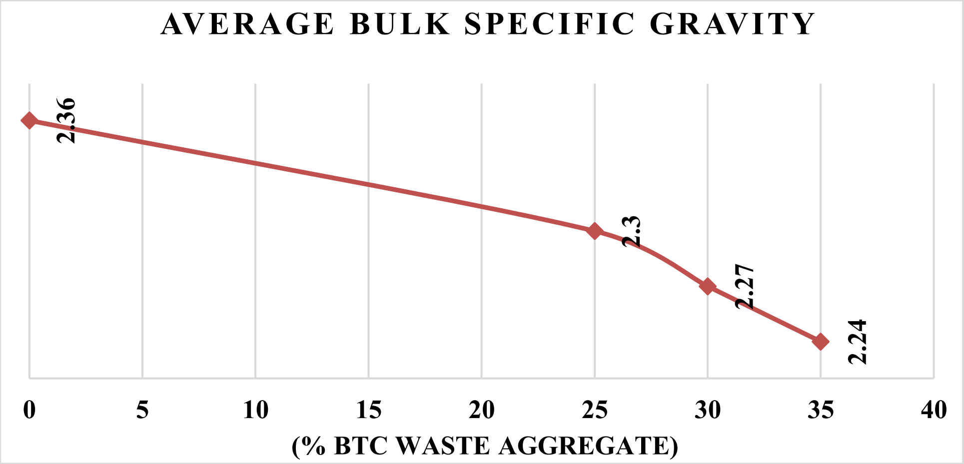

Figure 4.3: Average Bulk specific gravity at different % BTC waste Aggregates

The average bulk specific gravity decreases even more to 2.27 when the percentage of BTC waste aggregate is raised to 30%, and it reaches its lowest at 2.24 when the percentage of BTC waste aggregate is 35%. This pattern demonstrates a steady decline in bulk specific gravity as the amount of BTC waste increases.

4.8 Analysis of Volume of Voids

The study on the percentage of air voids in samples with 0, 25,30 & 35%% BTC waste aggregate show that the distribution of air voids in all samples is comparatively constant. According to Table 4.8, Sample A had 3.23% air voids, Sample B had 3.18%, and Sample C had 3.17% at no BTC waste aggregates.

Table 4.8: Air voids (%) at different 0-35% BTC waste Aggregates

Sample No	BTC Waste Aggregates (0%)	BTC Waste Aggregates (25%)	BTC Waste Aggregates (30%)	BTC Waste Aggregates (35%)
A	3.23	4.293	5.47	5.67
B	3.18	4.29	5.45	5.67
C	3.17	4.288	5.41	5.67
Average Value	3.19	4.29	5.44	5.67

At 25% BTS waste aggregate reveals the percentage of air voids in Sample A was 4.293%, whereas Samples B and C had values of 4.29% and 4.288%, respectively. The percentage of air voids increased even more when the BTS waste aggregate content was raised to 30%. Samples A, B, and C had air void measurements of 5.47%, 5.45%, and 5.41%,

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respectively. For these samples, the average percentage of air voids was 5.44% overall. At BTC Waste Aggregates (35%) the Sample A, Sample B, and Sample C all had the same percentage of air voids (5.67%) when the BTS waste aggregate content was raised to 35%. As a result, the average percentage of air voids for these samples was 5.67%, which was the highest amount of air voids ever found in the study. The percentage of air voids increases with the BTC waste aggregate content. This trend suggests that the increased air voids brought on by a higher BTC waste aggregate content may have an effect on the pavement's density, strength, and durability.

4.9 Analysis of Volume of bitumen %

The purpose of this analysis is to determine how much bitumen is present in various mix samples that contain 0%, 25%, 30%, and 35% recycled aggregates made from BTC waste. The average volume of voids at various percentages of recycled aggregates is shown in figures 4.8. For every mix (0%, 25%, 30%, and 35% of BTC recycled waste), three samples were examined and results are sown in table 4.9.

Table 4.9: % Volume of bitumen at 0% BTC waste Aggregates for sample A, B, C

Sample No	**BTC Waste Aggregates (0%)**	**BTC Waste Aggregates (25%)**	**BTC Waste Aggregates (30%)**	**BTC Waste Aggregates (35%)**
A	11.504	11.249	11.088	11.00
B	11.521	11.244	11.080	10.99
C	11.554	11.24	11.079	10.98
Average Value	11.526	11.297	11.082	10.99

The bitumen volume of Sample A, which contains 0% BTC, is 11.52%; Sample B, which contains 25% BTC, is 11.29%; Sample C, which contains 30% BTC, is 11.08%; and the average for 35% BTC is 10.98%. According to this pattern, bitumen volume decreases as the BTC waste aggregate content rises, which may have an impact on the mixture's binding and overall stability.

4.11 Indirect tensile strength test

The indirect tensile strength increases from 0.59 to 0.73 N/mm2 in a linear fashion. However, the addition of BTC aggregates waste resulted in a decrease in the indirect tensile strength ratio. The ITS ratio is 0.773 for 0% BTC waste recycled aggregate and 0.737 for 35% BTC waste recycled aggregate replacement.

Table 4.11: Indirect Tensile Strength at different % BTC waste Aggregates

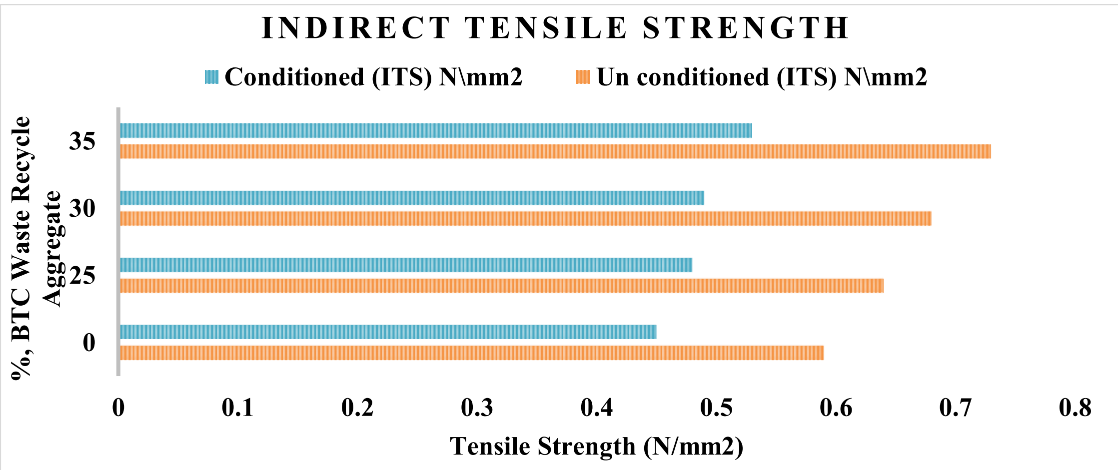

Figure 4.4: Tensile strength test at different % BTC waste Aggregates

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The Indirect Tensile Strength (ITS) values for asphalt mixtures with different proportions of BTC waste aggregates in both conditioned and unconditioned states are shown in figure 4.4. While the conditioned ITS values show strength after exposing the samples to environmental factors like moisture, the unconditioned ITS values show the material's tensile strength before exposure to unfavorable conditions. The ITS ratio for 0% BTC waste aggregate is 0.773 because the unconditioned ITS is 0.59 N/mm² and the conditioned ITS is 0.45 N/mm². The conditioned ITS increases to 0.53 N/mm² at 35% BTC, while the unconditioned ITS values increase to 0.73 N/mm² as the BTC waste percentage rises. As the BTC content rises, the ITS ratio somewhat falls, suggesting a slight decline in strength retention following conditioning.

V. CONCLUSIONS

This paper presents an experimental study examining the effects of utilizing recycled aggregates derived from Building and Construction (BTC) waste as substitutes for natural coarse aggregates in flexible pavement applications. The study employed three types of recycled aggregates: concrete, tile, and brick waste. The following conclusions emerge from the laboratory analysis of BTC waste aggregates:

BTC waste recycled aggregates sourced from buildings were incorporated in proportions of 25%, 30%, and 35% by weight of the total aggregate. The aggregate testing conducted on the demolition waste adhered to the standards set forth in the relevant IS codes.

The modified mix containing BTC waste aggregates exhibited higher Marshall Stability compared to the conventional mix. At a replacement level of 35% with BTC waste recycled aggregates, a maximum Marshall Stability of 12.93 kN was recorded. This increase is attributed to the lower density of the brick and tile materials, which consequently reduced the bulk specific gravity of the mix.

Tests on indirect tensile strength also reflected positive outcomes. The indirect tensile strength values were 0.59 N/mm² at 0% BTC waste recycled aggregate, increasing to 0.73 N/mm² at the 35% replacement level. However, it is noted that the ratio has decreased, indicating a heightened vulnerability to moisture.

The adoption of BTC waste recycled aggregates promotes sustainable development by mitigating waste disposal concerns and conserving natural aggregates for future generations.

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