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Lime and Saw ash Stabilized WAP Subbase: Performance Assessment for Flexible Pavement

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ABSTRACT

Globally, the generation of Waste Asphalt Pavement (WAP) is increasing rapidly. To address this, the Government of Bangladesh has targeted incorporating 25% WAP in road construction by 2025. This study evaluates the mechanical performance and sustainability potential of WAP blended with Crushed Stone Aggregates (CSA) and stabilized using Hydrated Lime and Sawdust Ash (SDA) for sub base applications in flexible pavements. Eight laboratory mix designs were prepared by varying CSA and WAP contents. Specimens were compacted at optimum moisture using the Modified Proctor method, and performance was assessed through Aggregate Crushing Value (ACV) and California Bearing Ratio (CBR) tests. All blends exhibited strong resistance to crushing, with ACV values ranging between 16% and 17.93%, well below the 25% limit for sub base materials. The CBR results were as follows: 75% CSA + 25% WAP + 3% Lime (9.67%), 75% CSA + 25% WAP + 6% Lime (11.75%), 50% CSA + 50% WAP + 3% Lime (11.40%), 50% CSA + 50% WAP + 6% Lime (17.46%), 75% CSA + 25% WAP + 3% SDA (51.75%), 75% CSA + 25% WAP + 6% SDA (58.75%), 50% CSA + 50% WAP + 3% SDA (38.39%), and 50% CSA + 50% WAP + 6% SDA (29.46%). SDA-stabilized mixes achieved the highest CBR values, confirming superior strength gain, while lime offered improved load-bearing capacity at a lower cost. The study concludes that WAP with proper stabilizers can deliver durable, cost-effective, and sustainable sub base layers for road construction in Bangladesh.

Keywords: Waste Asphalt Pavement (WAP), Crushed Stone Aggregate (CSA), Sawdust Ash (SDA), Hydrated Lime, Pavement Subbase Stabilization

1. INTRODUCTION

Road infrastructure is a key driver of economic development, social integration, and regional connectivity. Globally, the road network exceeds 20 million kilometers, with rapid expansion in Asia and Africa to meet urbanization and industrial growth demands [1]. Roads also account for a substantial proportion of construction material consumption, including aggregates, bitumen, and cement, which contributes to environmental degradation and carbon emissions. The global construction sector is estimated to produce more than 4 billion tons of aggregates annually, and the demand continues to rise due to urbanization and increased vehicular traffic [2]. Bangladesh, with a population exceeding 170 million, has a dense and expanding road network of over 370,000 km, of which only

30% are paved. The Roads and Highways Department (RHD) is responsible for maintenance, rehabilitation, and expansion, and the annual demand for natural aggregates exceeds 70 million tons [3]. At the same time, the frequent maintenance and upgrading of roads generate significant amounts of Waste Asphalt Pavement (WAP), which contains high-quality aggregates coated with aged asphalt binder. Without proper recycling strategies, WAP disposal contributes to environmental pollution, occupies valuable land, and represents a loss of potentially reusable material. The increasing cost of virgin materials, environmental concerns, and the growing volume of WAP present an urgent need for sustainable and economically viable alternatives. Reuse of WAP, particularly in subbase and base layers of flexible pavements, is an emerging solution that addresses both environmental and economic challenges. However, the direct incorporation of WAP often faces technical limitations, including moisture susceptibility, lower strength, and inconsistent performance under tropical climatic conditions. These challenges highlight the need for stabilization techniques to improve the mechanical properties of recycled asphalt aggregates.

2. METHODOLOGY

2.1. Waste Asphalt Pavement (WAP)

Waste Asphalt Pavement (WAP), also known as Reclaimed Asphalt Pavement (RAP), was collected from road rehabilitation works in Fokirhat, Khulna. The reclaimed materials were crushed and sieved (14–25 mm) following ASTM C136 [4]. Due to the presence of aged bitumen binder, WAP aggregates are smoother and less angular than virgin aggregates, leading to slightly reduced inter-particle friction. Laboratory testing showed ACV and AIV values of 17.52% and 20.26%, respectively, both within acceptable limits (<30%) for pavement sub base applications. The performance of WAP is influenced by binder aging, previous traffic loads, and weathering; hence, stabilization with lime or pozzolanic materials such as sawdust ash (SDA) is essential to improve its strength and durability.

The use of WAP minimizes waste disposal and dependence on natural aggregates, promoting environmental sustainability and cost-effective road construction in Bangladesh.

2.2. Crushed Stone Aggregate (CSA)

Crushed Stone Aggregate (CSA) is a fundamental raw material extensively used in construction, agriculture, and other infrastructure sectors. It is typically produced by excavating rock from quarries and crushing it into desired sizes and shapes [5]. In this study, CSA was collected from a local quarry in Rupsha, Khulna. The material was sieved to retain particles passing the 25 mm and retained on the 20 mm sieve, washed to remove dust and deleterious fines.

Laboratory characterization included Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) tests, which recorded 18.67% and 11.45%, respectively—well within the standard limit of 30% for sub-base materials. These results confirm that CSA possesses high crushing resistance and mechanical stability suitable for flexible pavement layers.

2.3. Hydrated Lime

Hydrated lime, chemically denoted as $Ca(OH)_2$, is one of the most effective stabilizing agents used in geotechnical and pavement engineering. In this study, commercial- grade hydrated lime with approximately 95% purity was procured from a local supplier in Khulna.

Lime primarily consists of 65–70% calcium oxide (CaO) and 20–25% calcium hydroxide [$Ca(OH)_2$], along with minor amounts of silica (2–4%), alumina (1–2%), iron oxide (0.5–1%), and magnesium oxide (1–2%). These components actively participate in pozzolanic reactions with silica and alumina present in soil and aggregate fines, forming calcium silicate hydrates (C–S–H) and calcium aluminate hydrates (C–A–H).

2.4. Saw Dust Ash

Saw dust is an organic waste generated as a byproduct during woodworking operations. It is commonly used as a household fuel [6]. The saw dust was gathered from a nearby sawmill at Jamtoli in Khulna. The saw dust ash was obtained by incinerating the saw dust. The most significant components of SDA include calcium, potassium, magnesium, copper, zinc, iron, silicon, and boron [7]. Before being used in the study, the ash had to pass through a sieve No.200 with a 0.075 mm apertur.

Saw Dust Ash (SDA) primarily contains reactive silica and alumina along with calcium, potassium, magnesium, and trace metallic elements. The fine particle size and pozzolanic nature of SDA enhance its reactivity when combined with calcium-rich systems, leading to the formation of cementitious compounds that improve inter-particlee bonding. The ash was sieved through a No. 200 sieve to ensure uniformity and enhance its effectiveness as a stabilizing agent.

2.5. Summary of Material Properties

The key physical and mechanical properties of the materials used in this study were determined through laboratory testing and supplier information. Waste Asphalt Pavement (WAP) exhibited Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) of 17.52% and 20.26%, respectively, indicating acceptable resistance to crushing and impact for pavement sub-base applications. Crushed Stone Aggregate (CSA) showed superior mechanical stability with ACV and AIV values of 18.67% and 11.45%, respectively.

Hydrated lime primarily consisted of calcium oxide and calcium hydroxide, which actively contribute to pozzolanic reactions during stabilization. Saw Dust Ash (SDA), sieved through a No. 200 sieve, contained fine particles rich in reactive silica and alumina along with calcium and alkali elements. These properties enhance particle bonding and strength development in stabilized CSA–WAP mixtures.

2.6. Selection of Stabilizer Content

The stabilizer contents of 3% and 6% were selected based on commonly adopted ranges reported in previous pavement stabilization studies and practical construction considerations. Lower stabilizer contents (around 3%) are generally used to assess initial improvement in strength and particle bonding, while higher contents (around 6%) represent an upper practical limit beyond which strength gain becomes marginal and cost increases significantly. Therefore, the selected percentages allow evaluation of both minimum effective dosage and enhanced stabilization performance while maintaining economic feasibility for field application.

2.7. California Bearing Ratio (CBR) Tests

The California Bearing Ratio (CBR) test is used to determine the strength and bearing capacity of sub-base and base materials for flexible pavements. In this study, the test was conducted on mixtures of Crushed Stone Aggregate (CSA), Waste Asphalt Pavement (WAP), and either Lime or Saw DustAsh (SDA).Photographs of CBR tests are indicated in Figure 1.

Prior to CBR testing, all prepared specimens were compacted at their respective optimum moisture contents. The stabilized samples were then cured for a period of 7 days under controlled laboratory conditions at an average temperature of approximately 27 ± 2 °C. To prevent moisture loss during curing, the specimens were sealed in airtight plastic covers. After curing, soaked CBR tests were conducted in accordance with standard testing procedures to simulate field moisture conditions and evaluate the load-bearing performance of the stabilized mixtures.

Figure 1. California Bearing Ratio (CBR)

3. RESULTS AND DISCUSSION

The results are first presented in tabular form to provide a clear overview of the mechanical performance of Crushed Stone Aggregate (CSA) and Waste Asphalt Pavement (WAP) mixtures under different stabilization conditions. Table 1 presents the Aggregate Crushing Value (ACV) results for lime-stabilized mixes, while the load-bearing performance of stabilized mixtures is evaluated using California Bearing Ratio (CBR) results shown in Table 2 for lime stabilization and Table 3 for Saw Dust Ash (SDA) stabilization. A comparative analysis between lime and SDA is carried out to identify the most suitable stabilizer for pavement sub-base applications.

Table 1. Aggregate Crushing Value (ACV) Test Results using Lime as Stabilizer

CSA (%)	WAP (%)	Lime	CBR (2.5 mm)	CBR (5mm)
75	25	3	5.65	9.67
75	25	6	9.07	11.75
50	50	3	9.08	11.40
50	50	6	10.56	17.46

As shown in Table 1, the Lime-stabilized mixes provide ACV values ranging from 16.17% to 17.93%. The lowest ACV value (16.17%) is obtained with a 50:50 blend of CSA and WAP stabilized with 6% Lime, indicating that this combination provides the best resistance against crushing and therefore better durability.

Table 2. California Bearing Ratio (CBR) Test Results using Lime as Stabilizer

CSA (%)	WAP (%)	Lime	ACV (%)
75	25	3	16.71
75	25	6	17.93
50	50	3	17.37
50	50	6	16.17

As presented in Table 2, the CBR values for Lime stabilized mixes range from 5.65% to 17.46%. The highest strength is achieved with a 50:50 CSA-WAP blend stabilized with 6% Lime, where the CBR at 5 mm penetration reaches 17.46%. This reflects a significant improvement in the load-bearing capacity of the mixture.

Table 3. California Bearing Ratio (CBR) Test Results using Saw Dust Ash (SDA) as Stabilizer

CSA (%)	WAP (%)	SDA	CBR (2.5 mm)	CBR (5mm)
75	25	3	54.61	51.75
75	25	6	50.46	58.75
50	50	3	37.87	38.39
50	50	6	22.76	29.46

Table 3 reveals that SDA-stabilized mixes provide much higher CBR values compared to Lime, ranging from 22.76% to 58.75%. The peak performance is observed for 75% CSA and 25% WAP stabilized with 6% SDA, where the CBR at 5 mm penetration reaches 58.75%. This indicates that SDA is highly effective in enhancing the shear strength and load-bearing capacity of pavement sub base material.

The comparatively high CBR values obtained for SDA-stabilized mixtures can be attributed to improved particle packing and enhanced pozzolanic activity. The fine particle size of SDA fills voids within the aggregate matrix, resulting in a denser structure and reduced deformation under load. In addition, the reactive silica and alumina present in SDA react with available calcium to form cementitious compounds, significantly increasing stiffness and load resistance. Similar strength enhancement trends have been reported in previous studies involving ash-based stabilizers in pavement sub-base materials.

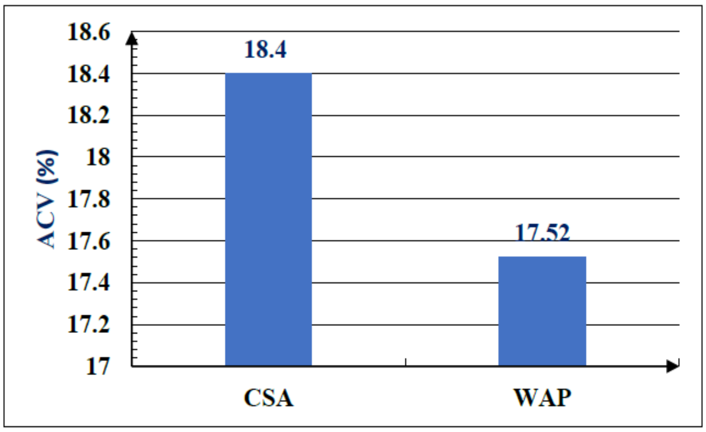

Figure 2. ACV values of CSA and WAP

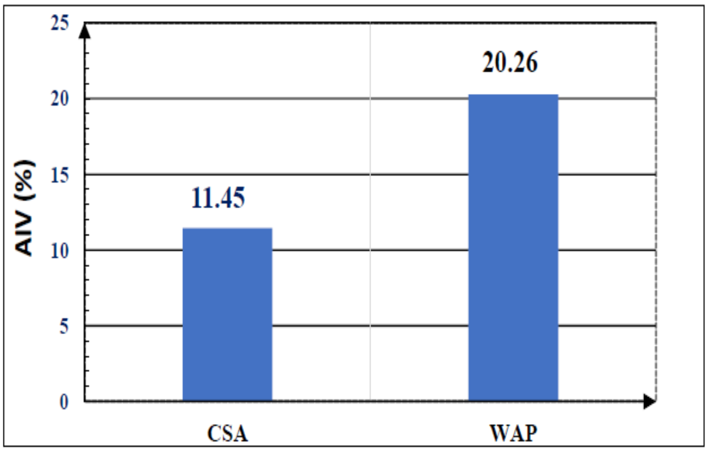

Figure 3. Aggregate Impact Value (AIV) of CSA and WAP

The bar chart in Figure 2 highlights the superior mechanical strength of the WAP material over the CSA. The CSA material exhibits an ACV of 18.4%. This higher value suggests it is comparatively weaker and more susceptible to crushing. The WAP material shows an ACV of 17.52%. Although the difference between the two values may appear small, it is significant in civil engineering practice, showing that WAP would perform better in applications where resistance to compressive stress is essential.

As shown in Figure 3, The CSA has a very low AIV of 11.45%, which indicates that it is extremely tough and highly resistant to sudden impacts. The WAP records a much higher AIV of 20.26%, which highlights its brittleness and poor performance under impact loads.

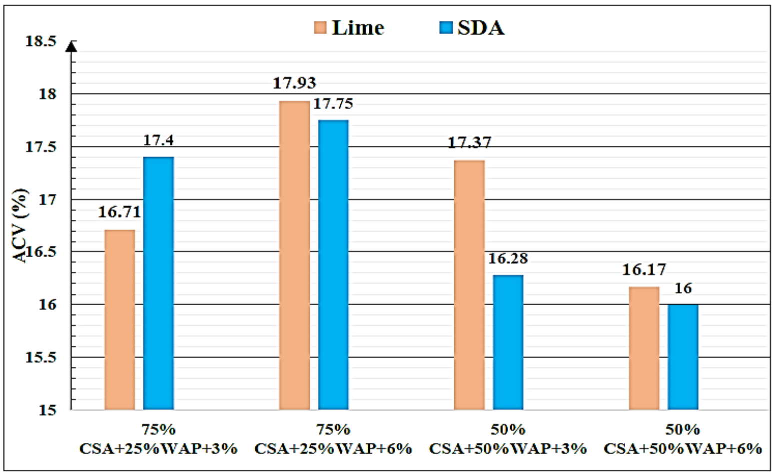

Figure 4. Aggregate Crushing Value (ACV) of Lime and SDA Stabilized Mixes:

The results indicate that SDA is generally a more effective stabilizer than Lime, especially in mixtures with higher WAP content and higher stabilizer dosages. This highlights the potential of SDA as a sustainable alternative to conventional stabilizers for producing durable pavement sub-base materials.

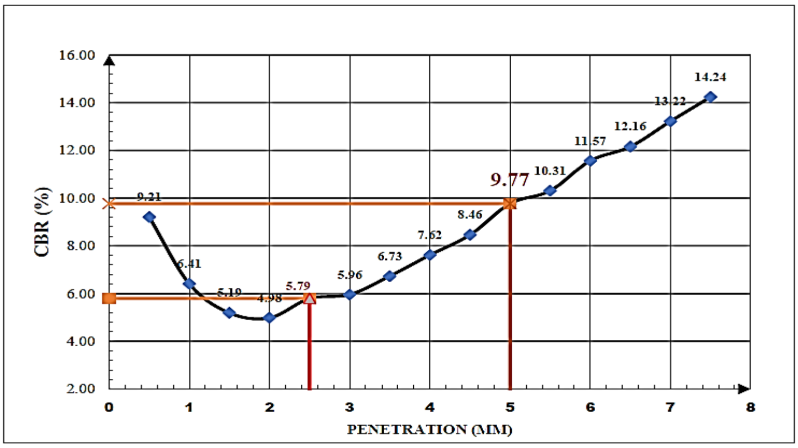

Figure 5. Load-Penetration Curve (CBR) of 75% CSA, 25% WAP stabilized with 3% Lime

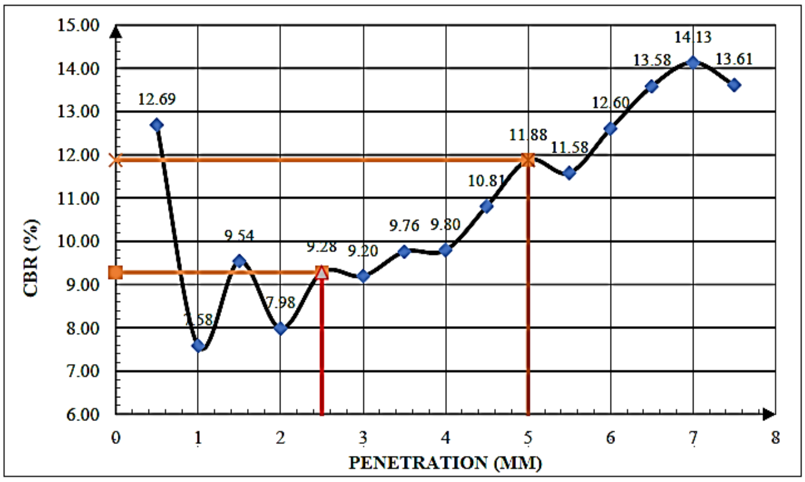

Figure 6. Load-Penetration Curve (CBR) of 75% CSA, 25% WAP stabilized with 6% Lime

Figure 5 illustrates the CBR curve for the tested mixture. - The curve clearly identifies the load at each penetration depth, showing a progressive increase from low values at shallow penetration to the highest at deeper penetration. - The critical points of 2.5 mm and 5.0 mm penetration are prominently marked, corresponding to CBR values of 5.79% and 9.77%, respectively. - This confirms that the mixture exhibits improved strength with increasing penetration, and the final design CBR is taken as the maximum observed value, 9.77%, which will be used in pavement design calculations.

As shown in Figure 6 illustrates, the CBR value at 2.5 mm penetration is 9.28%, while at 5.0 mm penetration it is 11.88%. Since the higher value is adopted as the design CBR, the effective CBR for this mixture is confirmed as 11.88%. This demonstrates that lime stabilization significantly improves the load-bearing performance of the CSA–WAP mixture, making it a promising material for use in sub-base pavement applications.

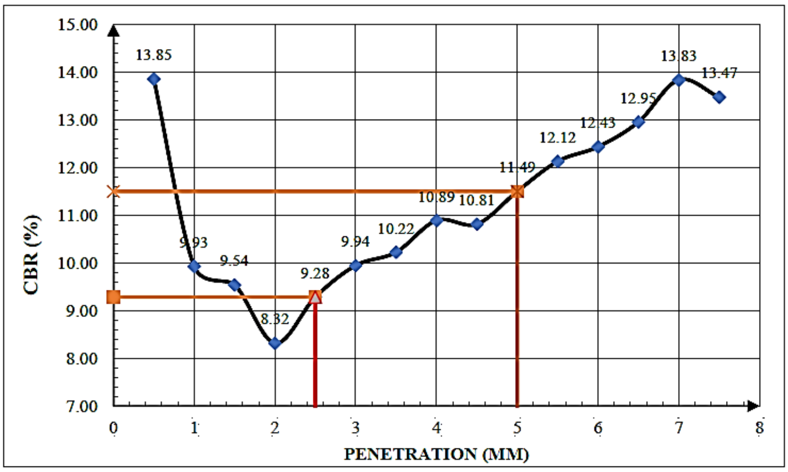

Figure 7. Load–Penetration Curve (CBR) of 50% CSA, 50% WAP stabilized with 3% Lime

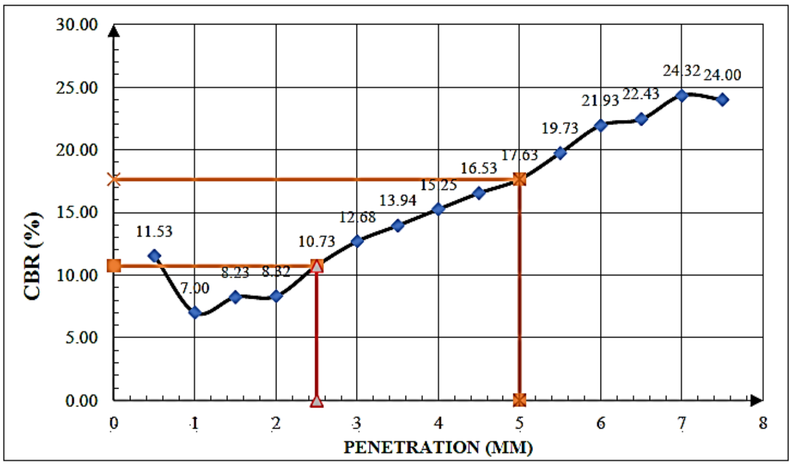

Figure 8. Load-Penetration Curve (CBR) of 50% CSA, 50% WAP stabilized with 6% Lime

Figure 7 shows that the load steadily increases with penetration, reaching its peak near 5.0 mm. Stabilizing the CSA–WAP mixture with 3% lime offers moderate strength improvement, indicating that even a small lime content can enhance inter-particlee cohesion and early stiffness. The CBR values—9.28% at 2.5 mm and 11.49% at 5.0 mm—suggest modest resistance under light loads but adequate strength for sub-base applications.

Figure 8 shows that the CBR values exhibit a steadily rising trend with penetration, reaching a peak of 24.32% at 7.0 mm before showing a slight decline at 7.5 mm. The highlighted points at 2.5 mm and 5.0 mm confirm the substantial strength improvement attributable to lime stabilization. This graphical evidence further validates the tabulated results, reinforcing the conclusion that the 50% CSA – 50% WAP mixture treated with 6% Lime possesses adequate strength and stiffness for use in pavement sub-base construction.

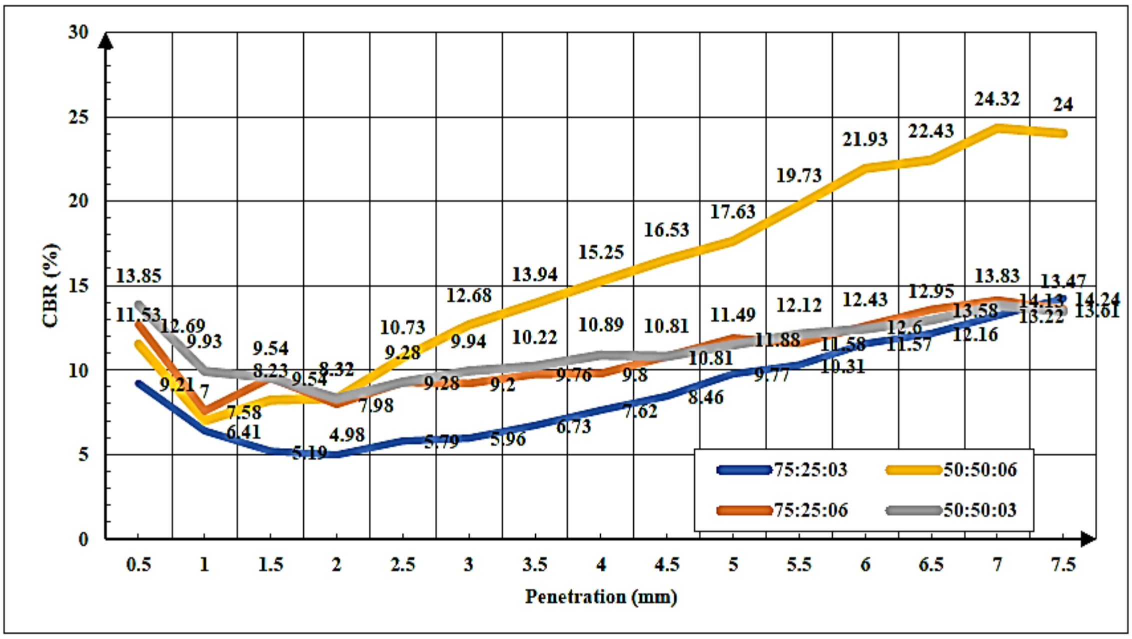

Figure 9. Comparison of CBR Value for Lime-Stabilized CSA-WAP Mixtures

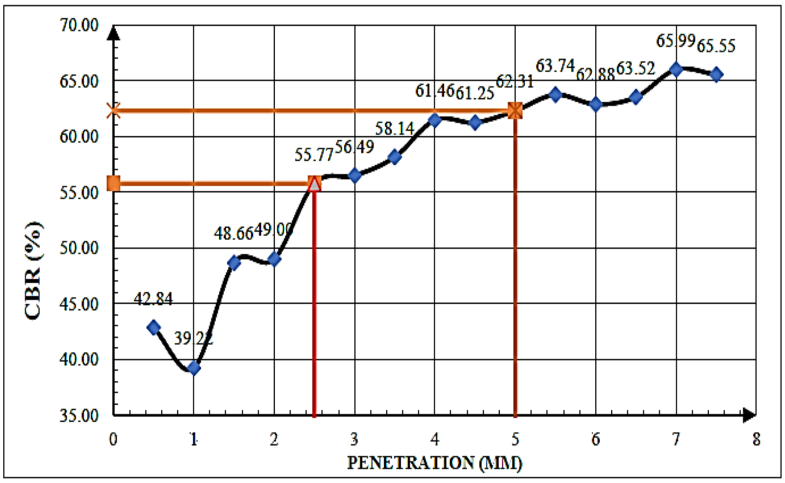

Figure 10. Load-Penetration Curve (CBR) of 75% CSA, 25% WAP stabilized with 3% SDA

Figure 9 shows that the 50% CSA – 50% WAP mixture consistently exhibits higher CBR values compared to the 75% CSA – 25% WAP mixture across all penetration depths. Both mixtures show an increasing trend in CBR with penetration, peaking at 7.0 mm. The 50% CSA – 50% WAP mixture achieves a maximum CBR of 24.32%, whereas the 75% CSA – 25% WAP mixture reaches a peak of 14.13%. This comparison highlights that increasing the proportion of WAP in the mixture, when stabilized with lime, significantly improves the load-bearing capacity of the sub base material.

Figure 10 illustrates the mixture demonstrates the lowest CBR value at 1 mm penetration (39.22%) and the highest at 7.0 mm penetration (65.99%). The highlighted points at 2.5 mm and 5.0 mm confirm the substantial strength improvement achieved through SDA stabilization. The graphical trend reinforces the tabulated data, validating that the 75% CSA – 25% WAP mixture stabilized with 3% SDA possesses high load-bearing capacity, making it highly suitable for Sub Base, Base course.

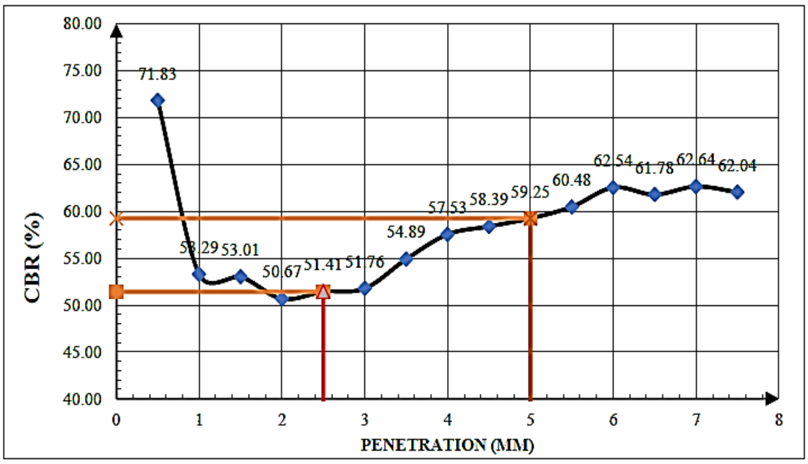

Figure 11. Load-Penetration Curve (CBR) of 75% CSA, 25% WAP stabilized with 6% SDA

Figure 11 indicates that the mixture demonstrates the lowest CBR at 2 mm penetration (50.67%) and the highest at 6 mm penetration (62.54%). The highlighted points at 2.5 mm and 5.0 mm confirm the material's substantial strength gain, emphasizing its suitability for sub-base applications in flexible pavements. The consistently high CBR values indicate that the 6% SDA stabilized CSA- WAP mixture can reliably resist traffic-induced stresses, providing durable and stable sub-base support.

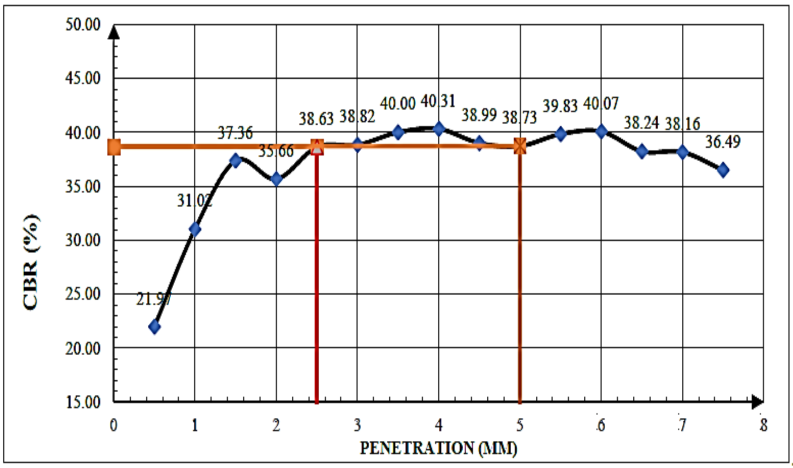

Figure 12. Load-Penetration Curve (CBR) of 50% CSA, 50% WAP stabilized with 3% SDA

As shown in Figure 12, the mixture achieves its key reference CBR values at 2.5 mm (38.63%) and5.0 mm (38.73%), confirming the effectiveness of 3% SDA in improving the sub-base strength for balanced CSA-WAP mixtures. The graphical trend indicates moderate but consistent performance, suggesting suitability for light to medium traffic sub-base applications.

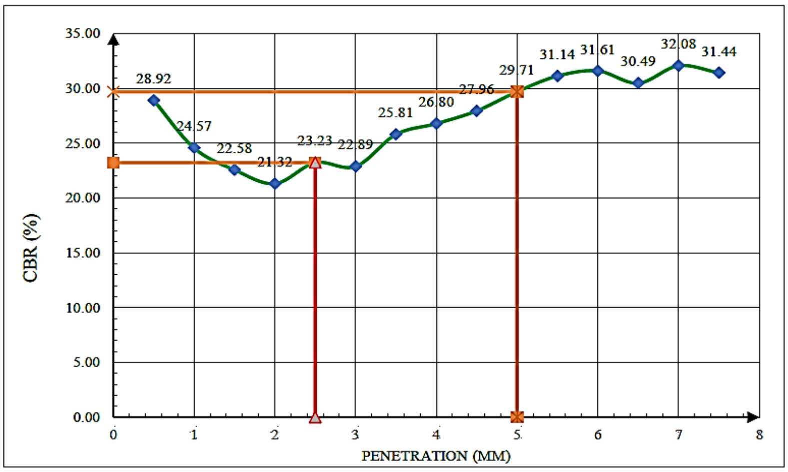

Figure 13. Load-Penetration Curve (CBR) of 50% CSA, 50% WAP stabilized with 6% SDA

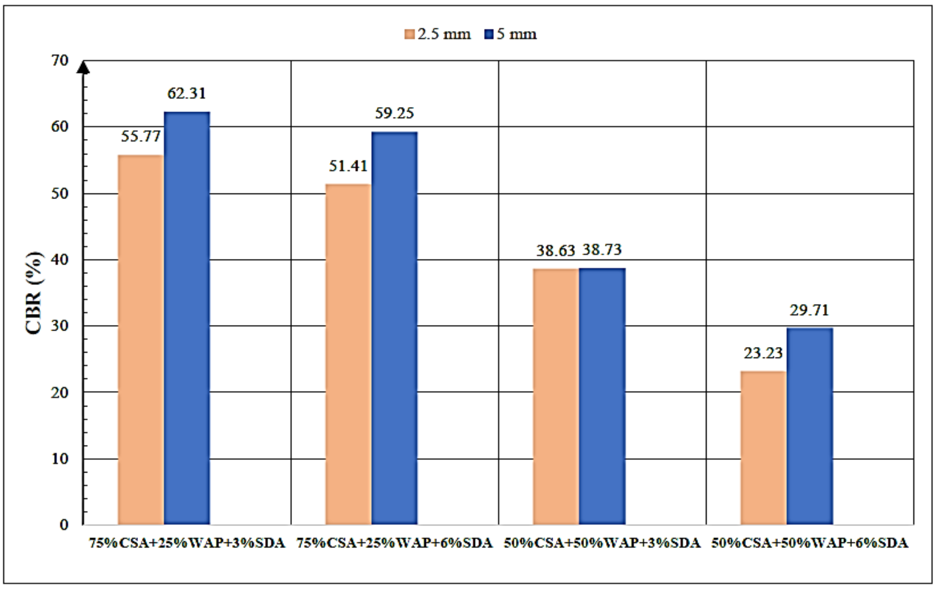

Figure 14. Comparison Of SDA Stabilized CBR Value

Figure 13 illustrates the load–penetration behavior of the 50% CSA–50% WAP mixture stabilized with 6% Saw Dust Ash (SDA). The load increases steadily with penetration, indicating enhanced stiffness and resistance to deformation. The reference CBR values at 2.5 mm and 5.0 mm penetration confirm that increasing SDA content improves the load-bearing capacity of balanced CSA–WAP mixtures, making them suitable for pavement sub-base applications under moderate traffic conditions.

This visual representation reinforces the tabulated results and confirms that Saw Dust Ash (SDA) stabilization significantly enhances the mechanical performance of CSA–WAP mixtures. The comparison clearly shows increasing CBR values with higher SDA content, providing a reliable basis for selecting SDA-stabilized mixtures for pavement sub-base and, in some cases, base course applications.

When compared with the specifications of the Roads and Highways Department (RHD) of Bangladesh, the stabilized mixtures satisfy and, in several cases, exceed the minimum CBR requirements for pavement sub-base layers. Particularly, SDA-stabilized mixes demonstrate CBR values that are also suitable for base course applications under light to medium traffic conditions, indicating strong potential for practical implementation.

4. CONCLUSION

This study was guided by four specific objectives: Firstly, the investigation of mechanical properties of Waste Asphalt Pavement (WAP) blended with Crushed Stone Aggregate (CSA) in different proportions demonstrated that the mixture alone offers moderate performance.

Secondly, the assessment of two stabilizers—hydrated lime and Saw Dust Ash (SDA)—highlighted their effectiveness in enhancing the strength and durability of WAP–CSA blends. Lime provided consistent improvement due to its pozzolanic reaction, while SDA showed promising results as a sustainable alternative, particularly when used at higher dosages. Both stabilizers improved the load-bearing capacity of CSA–WAP mixtures; however, Saw Dust Ash (SDA) demonstrated significantly higher strength improvement in terms of CBR values, while hydrated lime provided moderate but consistent enhancement. In addition, SDA offers added sustainability benefits due to its waste-derived nature.

Thirdly, the evaluation of stabilized and unstabilized mixtures through laboratory tests such as Aggregate Crushing Value (ACV) and California Bearing Ratio (CBR) confirmed the mechanical enhancement achieved through stabilization. CBR values, especially at the standard penetrations of 2.5 mm and 5.0 mm, clearly reflected the improvement in strength, while ACV results supported the increased resistance to crushing. These findings validate the role of stabilization in making recycled mixtures structurally reliable.

The reuse of Waste Asphalt Pavement (WAP) significantly reduces the demand for virgin aggregates and minimizes landfill disposal, leading to lower material extraction and transportation costs. Additionally, the utilization of Saw Dust Ash (SDA), an industrial by-product, contributes to waste reduction and lowers reliance on conventional stabilizers. These combined benefits enhance the environmental sustainability and economic efficiency of pavement construction, particularly in resource-constrained regions such as Bangladesh.

Finally, the determination of the most sustainable and cost effective mix proportion revealed that partial replacement of CSA with WAP, when combined with suitable stabilizers, reduces dependency on virgin aggregates while maintaining compliance with Roads and Highways Department (RHD) specifications. This approach not only ensures technical suitability but also promotes environmentally responsible and economically feasible road construction practices in Bangladesh. In summary, the study successfully fulfilled all four objectives by demonstrating that WAP, when properly blended and stabilized with lime or SDA, can serve as a sustainable, cost-effective, and durable subbase material for flexible pavements.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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