

Experimental Investigation on Stability and Flow Characteristics of Sustainable Bituminous Concrete Using Recycled Aggregates and Admixtures

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Abstract - The growing demand for road infrastructure and depletion of natural aggregate resources have driven interest in sustainable alternatives for bituminous pavement construction. This study investigates the stability and flow characteristics of bituminous concrete (BC) prepared using recycled asphaltic pavement (RAP) aggregates as partial replacement for virgin aggregates, with cement and jaggery powder as admixtures. Recycled coarse and fine aggregates were separated from existing bituminous pavement using a combined physical and chemical (diesel solvent) method. Marshall Stability tests were conducted on cylindrical specimens compacted at optimum bitumen content (5%) for thirteen admixture combinations of cement and jaggery (5–15% each) by weight of bitumen. Ultrasonic Pulse Velocity (UPV) tests assessed the internal quality of the compacted specimens. The 11% cement-only combination yielded the highest Marshall Stability of 1070 kg with a flow value of 6 mm, satisfying MoRTH specifications for heavy traffic roads, while 11% cement with 8% jaggery achieved 1010 kg. UPV values ranged from 4054 to 5000 m/s across all mixes, indicating good to excellent matrix quality. The study demonstrates that sustainable bituminous concrete meeting heavy-traffic specifications can be produced from recycled aggregates with appropriate admixtures, reducing natural resource consumption and construction waste.

Key Words: Recycled asphaltic pavement, bituminous concrete, Marshall stability, flow value, cement admixture, jaggery powder.

1. INTRODUCTION

Socio-economic development of a country is closely linked to the quality and extent of its transportation infrastructure. Pavements play a critical role in the efficient movement of goods and people, and the steady rise in commercial traffic intensity combined with significant daily and seasonal temperature variation demands improved road performance characteristics [1].

The rapid expansion of road networks has led to enormous consumption of natural coarse aggregates for bituminous concrete construction. Continued extraction at current rates is unsustainable, and shortages of quality natural aggregate are projected in the near future. At the same time, existing bituminous pavements generate large quantities of reclaimed asphalt pavement (RAP) material during rehabilitation and

reconstruction, which is typically discarded or under-utilised. Recycling RAP as aggregate in new bituminous mixes presents an opportunity to simultaneously address resource depletion and construction waste [2], [3].

Increased mix stiffness through the use of recycled aggregates and admixtures improves rutting resistance in hot climates while permitting the use of relatively softer base bitumen, which in turn provides better low-temperature performance. Admixtures such as cement and jaggery powder have been investigated individually in bituminous systems: cement reduces aggregate stripping from the bitumen film through its binding action, while jaggery contains carboxyl groups that promote hydration-related bonding and enhance initial strength [4], [5].

This study systematically investigates thirteen combinations of cement and jaggery as admixtures in a RAP-based bituminous concrete mix, evaluating Marshall Stability, flow values, and Ultrasonic Pulse Velocity (UPV) to identify the optimum admixture proportion for heavy-traffic pavement applications.

2. STUDY AREA

All experimental work was conducted at the Department of Civil Engineering, Ballari Institute of Technology and Management (BITM), Ballari, Karnataka, India. Recycled coarse and fine aggregates were sourced from existing bituminous pavements in the Ballari region. Quarry dust used as filler material was obtained from local stone quarries. Bitumen (VG-30 grade), cement (OPC 53 grade), and jaggery powder were procured from local dealers in Ballari. Diesel used as a chemical solvent for separation of bitumen from recycled aggregate was obtained from a local fuel outlet. All material testing and specimen preparation were carried out at the Civil Engineering laboratory, BITM, Ballari.

3. LITERATURE REVIEW

Bastidas-Martínez et al. [1] conducted a comprehensive state-of-knowledge review on the use of Recycled Concrete Aggregates (RCA) in asphalt mixtures, primarily hot-mix asphalt (HMA). The study concluded that mixes incorporating RCA comply with quality requirements in construction specifications, particularly for low-volume roads, demonstrating the technical viability of recycled aggregates in bituminous pavement construction.

Amoussou et al. [2] investigated the extraction of asphalt binder from both straight-grade and polymer-modified asphalt concrete specimens using pulsed power technology. The study found that extraction of modified asphalt binder requires more energy than straight asphalt binder, providing important insights into the separation processes applicable to RAP processing.

Feng et al. [3] reviewed the application prospects of various asphalt-aggregate separation methods for RAP materials, highlighting the significant recycling value of RAP due to its content of non-renewable resources including asphalt binder and mineral aggregate. The review provided a reference framework for upgrading solid waste recycling technology in asphalt pavement applications.

Vora et al. [4] demonstrated that Crumb Rubber Modified Bitumen (CRMB) in bituminous concrete layers produces higher Marshall Stability values than conventional 60/70 paving grade bitumen. The study showed that 40 mm BC surface courses with CRMB exhibited improved pavement life and lower maintenance costs due to enhanced durability and performance.

Rao et al. [5] identified 15% tyre shred concentration as the optimum modifier content for bitumen modification at a mixing temperature of 165°C, with a blending protocol of 15 minutes mixing, 1 hour reaction, and 30 minutes final mixing. Improvements in flash point and specific gravity were observed over neat bitumen, though marginal, indicating acceptable rheological compatibility.

4. MATERIALS AND METHODOLOGY

4.1 Materials

Recycled Coarse Aggregate (RCA): Recycled coarse aggregates were obtained by processing existing bituminous pavement using a combined physical and chemical separation method. The aggregates exhibit irregular, broken morphology, as is characteristic of RAP-derived coarse aggregate. Physical properties are given in Table 1.

Recycled Fine Aggregate: Recycled fine aggregate passing the 2.36 mm sieve was also recovered from the existing pavement. The quality and density of the fine aggregate strongly influence the hardened properties of the bituminous mix.

Filler Material (Quarry Dust): Quarry dust obtained from local stone quarries was used as filler material. Filler fills inter-aggregate voids and increases the bulk density of the bituminous mix.

Bitumen: Bitumen acts as the binding agent in the mix, filling inter-aggregate voids and bonding adjacent aggregate particles across layers. The bitumen properties are summarised in Table 2.

Cement (Admixture): OPC 53 grade cement was used as an admixture to reduce stripping of aggregates from the bitumen film and to enhance the cohesion of the mix.

Jaggery Powder (Admixture): Jaggery powder was blended with bitumen at proportions of 5%, 8%, 11%, and 14% by

weight of bitumen. The carboxyl groups in jaggery are reported to promote hydration-related bonding reactions, enhancing initial strength and adhesion in the bituminous matrix.

Diesel (Separation Solvent): Petroleum diesel was used as a chemical solvent to break the bond between the bitumen coating and the aggregate surface during RAP processing. It acts as a releasing agent that enables separation of recycled aggregates from the bituminous matrix.



Fig -1: Materials used in the study — (a) recycled coarse aggregate, (b) recycled fine aggregate, (c) bitumen (VG-30), (d) cement, (e) jaggery powder, (f) diesel solvent

Table -1: Physical Properties of Recycled Aggregates

Test	Result
Aggregate Crushing Value	19%
Aggregate Impact Value	19%
Specific Gravity	2.77
Elongation Index	17%
Flakiness Index	22%

Table -2: Properties of Bitumen (VG-30)

Test	Result
Penetration Test	144 mm
Ductility Test	82 cm
Softening Point Test	34°C
Specific Gravity	0.99

4.2 Separation of Bitumen from Recycled Aggregates

A combination of physical and chemical methods was adopted for separating bitumen from the RAP material. The procedure involved the following steps:

- Collection of bituminous concrete from the existing pavement.
- Determination of the quantity of diesel required for the separation process.
- Breaking down the bituminous concrete to the required size to limit diesel consumption.
- Soaking the bituminous concrete in diesel for an estimated period to dissolve the bitumen coating.
- Brushing the soaked aggregate to remove residual bituminous coating, yielding clean recycled aggregate.

4.3 Mix Design

The Marshall method was adopted for bituminous mix design. The aggregate gradation and constituent quantities used for specimen preparation are given in Table 3. The optimum bitumen content (OBC) was determined as 5% by weight of total mix through standard Marshall mix design procedure.

Table -3: Aggregate Gradation and Weight of Constituents per Specimen

Sieve Size	Weight Retained (g)
20 mm retained	204
12.5 mm retained	72
6.3 mm retained	312
4.75 mm retained	84
Filler (Quarry Dust)	480

4.4 Specimen Preparation — Marshall Method

Marshall Stability testing was conducted on compacted cylindrical specimens of 101.6 mm diameter and 63.5 mm thickness. The load was applied perpendicular to the axis of the cylindrical specimen through curved loading heads at a constant deformation rate of 51 mm per minute, at a standard test temperature of 60°C. Marshall Stability is defined as the maximum load (kg) carried at this temperature, and Flow Value as the total deformation (mm) at maximum load.

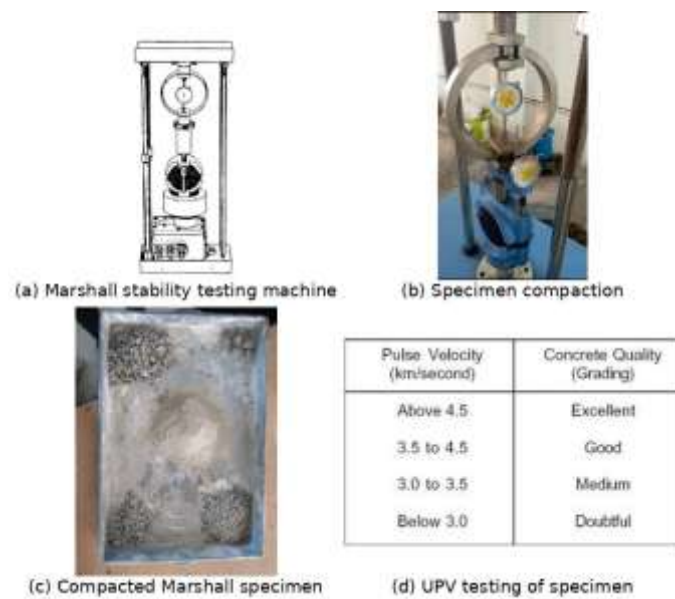


Fig -2: Marshall specimen preparation and testing — (a) Marshall stability testing machine, (b) specimen compaction, (c) compacted specimen, (d) UPV testing of specimen

Thirteen admixture combinations were tested at OBC (5% bitumen content), covering cement at 5%, 8%, 11%, and 14% by weight of bitumen crossed with jaggery powder at 5%, 8%, 11%, and 14%, plus cement-only mixes at 11% and 15%. A minimum of three specimens were prepared per combination and the highest stability value reported.

4.5 Ultrasonic Pulse Velocity (UPV) Test

The UPV test was conducted on all compacted Marshall specimens to assess the internal quality and uniformity of the bituminous matrix. The pulse velocity is measured by recording the transit time of an ultrasonic pulse through the specimen and is used here for comparative quality assessment, analogous to its established use in evaluating cement concrete quality per IS 13311.

5. RESULTS AND DISCUSSION

5.1 Marshall Stability and Flow Values

Tables 4 and 5 present the Marshall Stability and Flow values for all admixture combinations tested. The highest stability and flow values from three specimens per combination are reported. The control mix at OBC (5% bitumen, no

admixture) achieved a stability of 960 kg with a flow of 4 mm.

Table -4: Marshall Stability and Flow Values — Cement–Jaggery Combinations (Part I)

Mix	S1 (kg)	S1 Flow	S2 (kg)	S2 Flow	S3 (kg)	S3 Flow	Peak (kg)	Peak Flow
Control (OBC 5%)	960	4	—	—	—	—	960	4
5% cem + 5% jag	906	6	711	6	752	6	906	6
15% cem + 15% jag	901	3	942	4	886	4	942	4
8% cem + 8% jag	927	3	680	3.2	906	3.5	927	3
8% cem + 11% jag	690	6.5	778	6.7	788	7.8	788	6.7
8% cem + 14% jag	783	8.4	710	6.8	695	7	783	8.4

Table -5: Marshall Stability and Flow Values — Cement–Jaggery Combinations (Part II)

Mix	S1 (kg)	S1 Flow	S2 (kg)	S2 Flow	S3 (kg)	S3 Flow	Peak (kg)	Peak Flow
11% cem + 8% jag	1010	6.9	855	7.5	900	7.7	1010	6.9
11% cem + 11% jag	757	7	819	8	875	8	875	8
11% cem + 14% jag	880	9.4	710	10	880	9.5	880	9.4
14% cem + 8% jag	906	7.8	973	8.8	875	9.2	973	8.8
14% cem + 11% jag	875	8.9	865	7.8	950	8.8	950	8.8
14% cem + 14% jag	789	9	990	9	910	9.8	990	9
11% cement only	1070	6	875	5.5	950	5.8	1070	6
15% cement only	865	5	876	5	855	5.5	876	5

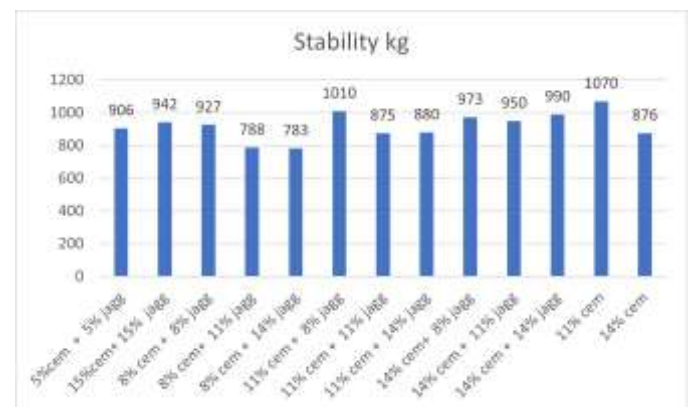


Fig -3: Marshall stability values for all cement–jaggery admixture combinations

The results reveal a clear influence of admixture type and proportion on stability and flow. The 11% cement-only mix achieved the highest Marshall Stability of 1070 kg with a flow value of 6 mm, satisfying MoRTH specifications for heavy traffic roads (minimum stability ≥ 900 kg, flow 2–4 mm for BC surface course). The combination of 11% cement and 8% jaggery achieved 1010 kg stability, also meeting heavy traffic requirements.

The addition of jaggery beyond 8% with 11% cement progressively reduced stability, attributed to the excess organic material disrupting the cement–bitumen–aggregate bond. At higher jaggery proportions (14%), flow values increased substantially (up to 10 mm), indicating reduced stiffness and susceptibility to deformation under loading. The 8% cement combinations with varying jaggery showed intermediate stability values (783–927 kg) but elevated flow (6.5–8.4 mm), limiting their suitability for heavy traffic applications.

The 14% cement combinations showed stability values of 950–990 kg but with higher flow (7.8–9.8 mm), suggesting that excessive cement content introduces brittleness without proportionate stability gain. The 5% cement + 5% jaggery combination achieved 906 kg stability with a flow of 6 mm, acceptable for medium traffic but marginally below the heavy traffic threshold.

5.2 Ultrasonic Pulse Velocity Results

UPV measurements for all mixes are presented in Tables 6 and 7. Higher UPV indicates a denser, more homogeneous internal structure with fewer voids.

Table -6: Ultrasonic Pulse Velocity (UPV) Results — Part I (m/s)

Mix	Sample 1	Sample 2	Sample 3	Peak
5% cem + 5% jag	4829	4786	4522	4829
15% cem + 15% jag	4839	4777	4688	4839
8% cem + 8% jag	4839	4658	4412	4839
8% cem + 11% jag	4934	5000	4717	5000
8% cem + 14% jag	4688	4213	4261	4688

Table -7: Ultrasonic Pulse Velocity (UPV) Results — Part II (m/s)

Mix	Sample 1	Sample 2	Sample 3	Peak
11% cem + 8% jag	4870	4464	4237	4870
11% cem + 11% jag	4491	4054	4658	4658
11% cem + 14% jag	4360	4545	4286	4545
14% cem + 8% jag	4717	4808	4386	4808
14% cem + 11% jag	4688	4360	4386	4688
14% cem + 14% jag	4545	4601	4934	4934

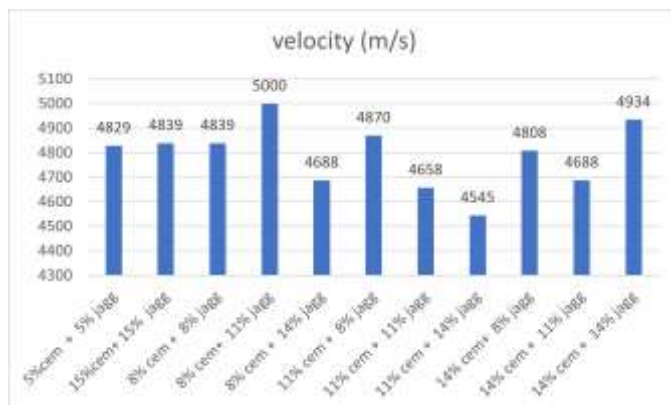


Fig -4: UPV values for all cement-jaggery admixture combinations

UPV values across all mixes ranged from 4054 to 5000 m/s, indicating good to excellent quality of the compacted bituminous matrix. The highest UPV of 5000 m/s was recorded for the 8% cement + 11% jaggery combination, suggesting superior internal density for that mix despite its lower Marshall Stability (788 kg). This indicates that jaggery at moderate proportions contributes to void filling and improved matrix homogeneity, even when the overall mechanical stability is not maximised.

The 11% cement-only mix, which exhibited the highest stability (1070 kg), recorded high UPV values consistent with a dense, well-bonded internal structure. The 11% cement + 8% jaggery combination (1010 kg stability) also showed UPV values exceeding 4800 m/s in the best sample, confirming the quality of the matrix. Lower UPV values (4054–4237 m/s) in the 11% cement + 11% jaggery and 11% cement + 14% jaggery mixes are consistent with the reduced stability

observed in those combinations, as excess jaggery creates localised weak zones in the matrix.

6. CONCLUSIONS

Based on the experimental investigation on Marshall Stability, flow characteristics, and Ultrasonic Pulse Velocity of sustainable bituminous concrete prepared from recycled asphaltic pavement aggregates with cement and jaggery admixtures, the following conclusions are drawn:

- The use of recycled aggregates separated from existing bituminous pavement by a combined physical and chemical method is technically feasible for producing sustainable bituminous concrete, reducing dependence on natural aggregate and diverting pavement waste from disposal.
- The 11% cement-only admixture combination achieved the highest Marshall Stability of 1070 kg with a flow value of 6 mm, satisfying MoRTH specifications for heavy traffic roads.
- The combination of 11% cement and 8% jaggery achieved a Marshall Stability of 1010 kg with a flow of 6.9 mm, also meeting MoRTH heavy traffic requirements while partially replacing cement with an agricultural by-product.
- Stability decreases and flow increases with jaggery content beyond 8% at any cement level, indicating that excessive jaggery addition is detrimental to mix stiffness and deformation resistance.
- UPV values ranging from 4054 to 5000 m/s across all mixes indicate good to excellent internal quality of the compacted bituminous matrix. The highest UPV (5000 m/s) was recorded for 8% cement + 11% jaggery, suggesting optimal void filling by jaggery at moderate proportions.
- The study confirms that sustainable bituminous concrete meeting heavy-traffic pavement specifications can be produced using recycled aggregates with proper admixture selection, offering both economic and environmental benefits through waste valorisation and resource conservation.

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