

Experimental Investigation on Stability and Flow Characteristics of Sustainable Bituminous Concrete Using Cement as Filler and Waste Plastic as Binder

Ambika C J^{1*}, K Mamatha¹, M Vishwanath¹, P Jyothi¹

¹Department of Civil Engineering, Ballari Institute of Technology & Management, Ballari – 583101, Karnataka, India

*Corresponding Author: praveen.madalageri@gmail.com

Abstract - Flexible pavements rely on bitumen as the primary binder, and rising bitumen consumption has motivated research into partial binder replacement using waste and admixture materials. This study investigates a sustainable bituminous concrete mix in which cement is used as an additional filler and waste low-density polyethylene (LDPE) plastic partially replaces bitumen as binder. Marshall specimens were prepared with cement at 4%, 8%, and 12% by weight of bitumen, each combined with waste plastic at 10%, 20%, and 30% by weight of bitumen, and tested for Marshall stability and flow per ASTM D1559, alongside ultrasonic pulse velocity (UPV) testing to assess mix density and quality. The combination of 12% cement and 10% plastic produced the highest Marshall stability of 1208 kg, satisfying MORTH requirements for heavy traffic roads, while flow values remained within the 2–4 mm MORTH range at lower plastic contents and increased at higher plastic contents. The highest UPV, indicating the densest mix, was obtained for 8% cement with 10% plastic. The results demonstrate that cement-modified, plastic-bound bituminous concrete can meet MORTH stability and flow requirements for heavy traffic pavements while beneficially reusing waste plastic, offering a sustainable alternative to conventional bitumen-only mixes.

Key Words: Bituminous concrete, waste plastic, cement filler, Marshall stability, flow value, ultrasonic pulse velocity.

1. INTRODUCTION

Pavements are central to a country's transport infrastructure, and flexible pavements bound with bitumen have been the dominant construction practice for decades. Steadily increasing traffic intensity, together with wide daily and seasonal temperature variation, places growing demands on the strength and durability of bituminous mixes, and has driven extensive research into binder modification using polymers, rubber, and other admixtures to improve stiffness, rutting resistance, and low-temperature performance.

Rapid growth in transportation infrastructure has increased bitumen consumption and, with it, road construction cost. At the same time, the rising volume of waste plastic — particularly single-use low-density polyethylene (LDPE) — has become a significant environmental concern. This study addresses both issues by developing a bituminous concrete mix in which waste LDPE plastic partially replaces bitumen as binder, while cement is introduced as an additional filler to reduce stripping of aggregate from bitumen and improve mix

cohesion. The resulting mix is evaluated through Marshall stability and flow testing and ultrasonic pulse velocity (UPV) measurement, with the aim of identifying a cement-plastic combination that meets MORTH specifications for heavy traffic roads while reducing both bitumen demand and plastic waste.

2. LITERATURE REVIEW

Bastidas-Martinez et al. [1] reviewed the use of Recycled Concrete Aggregates (RCA) in hot-mix asphalt manufacturing, reporting that mixtures incorporating RCA can meet construction quality requirements, particularly for low-volume roads, despite the large quantities of natural aggregate otherwise required.

Amoussou et al. [2] used pulsed power technology to extract asphalt binder from asphalt concrete specimens and evaluate the quality of the recovered aggregate and residues, finding that extracting modified asphalt binder is more difficult and energy-intensive than extracting straight asphalt binder.

Feng et al. [3] reviewed asphalt-aggregate separation methods for reclaimed asphalt pavement (RAP) materials, noting their significant recycling value given the non-renewable resources — asphalt and aggregate — that RAP contains, and their relevance to upgrading solid-waste recycling technology for asphalt pavements.

Vora and Desai et al. [4] reported that Crumb Rubber Modified Bitumen (CRMB) improved the engineering properties of bituminous mixes, including higher Marshall stability and longer surface life for 40 mm bituminous concrete layers compared with conventional 60/70 paving grade bitumen, along with lower long-term pavement maintenance costs.

Padma Rao et al. [5] found that a 15% tyre-shred concentration was an optimum modifier level for bitumen at a mixing temperature of 165°C, beyond which further improvement in binder properties was not significant, and reported that the modified binder showed higher resistance to oxidative hardening than neat bitumen.

Sivakumar et al. [6] explored the use of waste plastics, including polyethylene and polypropylene, in bituminous concrete, finding that incorporating plastic waste improved the stability and strength of the mix while reducing its sensitivity to water.

Sharma and Rathi [7] investigated cement-modified bitumen, replacing a small proportion of bitumen with cement, and found that the combination enhanced mechanical properties, though workability and flexibility of the mix were somewhat compromised — laying groundwork for subsequent research combining cement with plastic waste.

Arvind and Praveen [8] analysed plastic-modified bitumen combined with cement, showing that cement improved compressive strength while plastic enhanced water resistance and durability, and demonstrated synergistic benefits of the combined binder system for load-bearing capacity and crack resistance.

Gopala Krishnan et al. [9] examined the joint use of plastic and cement in modifying bituminous concrete, finding increased mix stability, improved resistance to moisture damage, and enhanced overall durability, with cement acting as a hardening agent and plastic improving flexibility and waterproofing.

Mohd and Latha [10] studied the long-term performance of bituminous mixes containing both cement and plastic binder, reporting reduced pavement distress — rutting, cracking, and fatigue failure — particularly under extreme weather conditions, and highlighted the sustainability benefits of this binder combination.

Collectively, this literature establishes that both cement and waste plastic can independently improve bituminous mix properties, and that their combined use offers synergistic benefits. However, limited work has systematically evaluated Marshall stability and flow across a full factorial range of cement and plastic proportions, which the present study addresses.

3. MATERIALS AND METHODOLOGY

3.1 Materials

Coarse aggregate (12.5 mm and 6.3 mm fractions) and fine aggregate (4.75 mm and 2.36 mm fractions) were sourced from an existing bituminous pavement. M-sand was used as filler material, sourced from local quarries. Cutback bitumen, used as the base binding agent, was procured from a local dealer. Ordinary Portland cement was introduced as an additional filler/admixture at 4%, 8%, and 12% by weight of bitumen, sourced from a local dealer. Waste low-density polyethylene (LDPE) plastic was used as a partial binder replacement at 10%, 20%, and 30% by weight of bitumen. The materials used are shown in Fig. 1.



Fig -1: Materials used in the study — (a) coarse aggregate; (b) fine aggregate; (c) filler material (M-sand); (d) cutback; (e) cement; (f) waste plastic

3.2 Aggregate Properties and Gradation

Basic properties of the coarse aggregate were determined and are summarised in Table 1. Aggregate proportioning for the mix was carried out using Rothfutch's graphical method as per IRC 29-1988 (Fig. 2), which blends multiple coarse and fine aggregate fractions to achieve the target gradation for bituminous concrete surface course. Table 2 gives the specified gradation limits for a 13 mm nominal aggregate size (Grade 2) as per IRC 29-1988, against which the blended aggregate gradation was checked, and Table 3 gives the resulting weight of each aggregate fraction used per batch.

Table -1: Properties of coarse aggregate

Property	Value
Aggregate crushing value	19%
Aggregate impact value	19%
Los Angeles abrasion value	24%
Specific gravity	2.77
Angularity number	15%
Elongation index	17%
Flakiness index	22%

Table -2: Specified aggregate and binder grading for bituminous concrete, Grade 2 (13 mm nominal size, 30–45 mm layer thickness), per IRC 29-1988

Sieve size (mm)	% passing by weight
19	100
13.2	79–100
9.5	70–88
4.75	53–71
2.36	42–58
1.18	34–48
0.6	26–38
0.3	18–28
0.15	12–20
0.075	4–10
Bitumen content (% by wt.)	5.0–7.0
Bitumen grade	VG 30 (pen. 65)



Fig -2: Aggregate gradation blending by Rothfutch's graphical method (IRC 29-1988)

Table -3: Weight of each aggregate fraction used per batch

Aggregate fraction	Proportion (%)	Weight (g)
Coarse agg.-2 (12.5 mm)	6.25	72
Coarse agg.-1 (6.3 mm)	27.0	312
Fine agg.-1 (4.75 mm)	7.29	84
Fine agg.-2 (2.36 mm)	17.7	204
Filler (M-sand)	41.66	480
Total	100	1150

Note: aggregate fraction labels and proportions are reproduced as recorded in the source project report.

3.3 Mix Preparation and Specimen Casting

The optimum bitumen content was first established as 7% by weight of the aggregate-filler blend (80 g per specimen batch), following the general approach for bituminous mix design set out in IRC guidelines: selection of aggregate and grading, determination of specific gravities, proportioning of aggregates, preparation of test specimens, determination of compacted specimen density and void parameters, and final selection of bitumen content. Cylindrical Marshall specimens of 101.6 mm diameter and 63.5 mm thickness were then prepared for each of the nine cement-plastic combinations (4%, 8%, and 12% cement, each with 10%, 20%, and 30% plastic, by weight of bitumen), plus a bitumen-only control at the optimum bitumen content. For each mix, the aggregate blend was heated to 175–190°C, and the bitumen-cement-plastic binder was heated to 120–165°C before being combined and mixed until the aggregate surfaces were fully and uniformly coated. The mix was compacted in a pre-heated mould using a standard Marshall rammer, applying 75 blows on each face at a drop height of 457 mm, after which the specimen was cooled, extruded, and prepared for testing (Fig. 3). At least three specimens were prepared for each mix combination.



Fig -3: Experimental procedure — (a) collection of raw materials; (b) heating and mixing of the aggregate-binder blend; (c) cast Marshall specimens; (d) processing of waste plastic prior to blending

3.4 Testing Methods

Marshall stability and flow were determined in accordance with ASTM D1559. Each cured specimen was placed in the Marshall testing head and loaded perpendicular to its cylindrical axis at a constant deformation rate of 51 mm/min at a standard test temperature of 60°C (Fig. 4). The maximum load carried by the specimen, expressed in kilograms, was recorded as the Marshall stability, and the corresponding vertical deformation at maximum load, expressed in millimetres, was recorded as the flow value. Where the compacted specimen thickness deviated from the standard 63.5 mm, an appropriate correction factor was applied to the measured stability value. In addition to Marshall testing, ultrasonic pulse velocity (UPV) was measured on each mix to provide an approximate, non-destructive indication of mix density and internal homogeneity, for comparison against typical concrete quality grading.

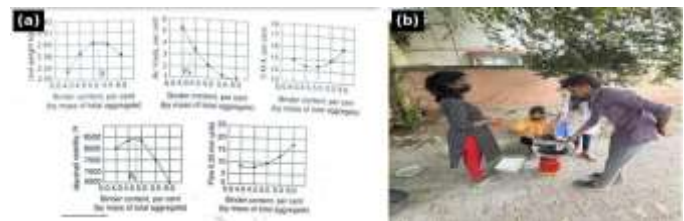


Fig -4: Marshall stability testing — (a) Marshall stability testing machine; (b) test in progress

4. RESULTS AND DISCUSSION

4.1 Marshall Stability and Flow

Table 4 presents the highest Marshall stability and flow value recorded for each cement-plastic combination, taken from three replicate specimens per mix. The bitumen-only control mix (7% optimum bitumen content) achieved a stability of 960 kg with a flow of 4 mm. Among the cement-plastic combinations, 12% cement with 10% plastic produced the highest Marshall stability of 1208 kg, exceeding the control by about 26% and comfortably satisfying MORTH stability requirements for heavy traffic roads. Stability generally decreased as plastic content increased from 10% to 20–30% within each cement level, while flow values increased correspondingly, indicating a trade-off between stiffness and deformability as more plastic is incorporated.

Table -4: Marshall stability and flow values for different cement-plastic combinations (highest of three specimens)

Mix	Stability (kg)	Flow (mm)
Control (OBC 7%)	960	4
4% cem + 10% plas.	956	6
4% cem + 20% plas.	990	4
4% cem + 30% plas.	988	4
8% cem + 10% plas.	980	3
8% cem + 20% plas.	840	7.8
8% cem + 30% plas.	824	8.4
12% cem + 10% plas.	1208	6.9
12% cem + 20% plas.	915	8
12% cem + 30% plas.	930	9.4
4% cem + 10% plas. (repeat)	983	8.8
8% cement only	1008	8.8
12% cement only	1100	9

Note: the last three rows are reproduced as labelled in the source project report; the labelling suggests these represent a repeat trial and cement-only (no added plastic) mixes, but this could not be independently verified against the raw data.

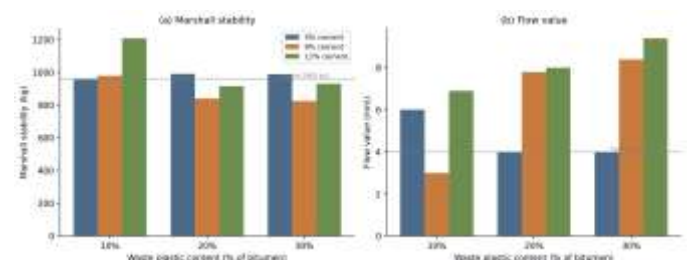


Fig -5: (a) Marshall stability and (b) flow value across cement and waste plastic proportions (dashed line: bitumen-only control)

4.2 Ultrasonic Pulse Velocity

Table 5 presents the highest ultrasonic pulse velocity (UPV) recorded for each cement-plastic combination. The highest UPV value, 5000 m/s, was obtained for 8% cement with 10% plastic, indicating the densest and most homogeneous mix among those tested, though this combination did not correspond to the highest Marshall stability — consistent with the observation that a dense mix is not necessarily a high-strength mix. Referenced against typical concrete quality grading (Table 6), all tested combinations fall in the

“excellent” category (UPV above 4.5 km/s), suggesting good internal compaction and low void content across the mix range studied.

Table -5: Ultrasonic pulse velocity for different cement-plastic combinations (highest of three specimens)

Mix	UPV (m/s)
4% cem + 10% plas.	4739
4% cem + 20% plas.	4929
4% cem + 30% plas.	4685
8% cem + 10% plas.	5000
8% cem + 20% plas.	4658
8% cem + 30% plas.	4890
12% cem + 10% plas.	4856
12% cem + 20% plas.	4980
12% cem + 30% plas.	4917
4% cem + 8% cem (combined)	4886
8% cem + 12% cem (combined)	4864

Note: the last two rows are reproduced as labelled in the source project report; the combined cement-level labelling could not be independently verified against the raw data.

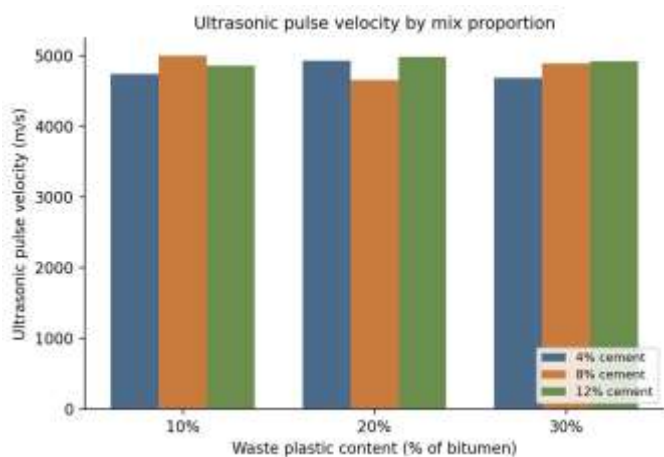


Fig -6: Ultrasonic pulse velocity across cement and waste plastic proportions

Table -6: Concrete quality grading by ultrasonic pulse velocity

Pulse velocity (km/s)	Concrete quality
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

4.3 Discussion

The combination of 12% cement and 10% plastic gave the best overall Marshall performance, with the highest stability (1208 kg) and a flow value (6.9 mm) within an acceptable range for heavy traffic roads as per MORTH. At the same cement level, increasing plastic content to 20–30% reduced stability and increased flow, suggesting that excess plastic softens the mix and reduces its resistance to deformation once an optimum plastic dosage is exceeded. At lower cement content (4%), stability remained relatively stable across plastic dosages, while at 8% cement, stability dropped markedly beyond 10% plastic, indicating that the effect of plastic content on mix stiffness is sensitive to the cement dosage present.

The divergence between the stability-optimal mix (12% cement + 10% plastic) and the UPV-optimal mix (8% cement + 10% plastic) illustrates that the densest mix, as indicated by UPV, is not necessarily the mix with the highest load-bearing capacity — density and strength are related but distinct properties, and both should be considered when selecting a

design mix. Overall, the results support the use of cement as a filler admixture alongside waste plastic binder as a viable, MORTH-compliant approach to sustainable bituminous concrete, with 10% plastic content combined with a cement dosage of 8–12% offering the best balance of stability, flow, and density for heavy traffic pavement applications.

5. CONCLUSIONS

This study evaluated the Marshall stability, flow, and ultrasonic pulse velocity of bituminous concrete incorporating cement as a filler admixture (4%, 8%, 12% by weight of bitumen) and waste LDPE plastic as a partial binder replacement (10%, 20%, 30% by weight of bitumen). The following conclusions are drawn:

- Use of waste plastic as a partial bitumen replacement produces an eco-friendly bituminous concrete without compromising the mix's ability to meet MORTH specifications, offering a practical route to reducing both bitumen demand and plastic waste.
- The combination of 12% cement and 10% plastic gave the highest Marshall stability (1208 kg), satisfying MORTH requirements for heavy traffic roads.
- Cement alone (without added plastic) at higher dosages also produced high stability values, with flow values that satisfied MORTH requirements for heavy traffic roads.
- The highest ultrasonic pulse velocity was obtained for 8% cement with 10% plastic, indicating the densest mix, though this combination did not coincide with the highest-strength mix — underscoring that density and Marshall stability should be assessed together rather than density alone being used as a proxy for strength.
- Overall, the combination of cement filler and waste plastic binder in bituminous concrete can achieve stability and flow values that satisfy MORTH specifications for heavy traffic roads, supporting its use as a sustainable alternative to conventional bitumen-only mixes.

REFERENCES

- [1] J. G. Bastidas-Martinez, F. A. Reyes-Lizcano, and H. A. Rondon-Quintana, “Use of recycled concrete aggregates in asphalt mixtures for pavement,” 2022.
- [2] R. I. H. D. T. Amoussou, K. Ishimatsu, N. Oyama, and M. Shigeishi, “Separation of aggregates from asphalt concrete using pulsed power technology,” vol. 9, no. 1, pp. 1403–1410, 2015.
- [3] D. Feng, J. Cao, L. Gao, and J. Yi, “Recent developments in asphalt-aggregates separation technology for reclaimed asphalt pavement,” 2022.
- [4] N. Vora, R. Desai, et al., “Use of crumb rubber modified bitumen in bituminous concrete layers,” n.d.
- [5] P. Padma Rao, G. Sambasiva Rao, et al., “Effect of tyre-shred concentration on bitumen binder properties,” n.d.
- [6] Sivakumar et al., “Use of waste plastics in bituminous concrete,” 2010.
- [7] Sharma and Rathi, “Use of cement-modified bitumen in road construction,” 2014.
- [8] Arvind and Praveen, “Plastic-modified bitumen combined with cement for road construction,” 2015.
- [9] Gopala Krishnan et al., “Use of plastic and cement in modifying bituminous concrete,” 2017.
- [10] Mohd and Latha, “Long-term performance of bituminous concrete mixes containing cement and plastic binder,” 2021.

- [11] Gopala Krishnan et al., "A study on the performance of crumb rubber modified bitumen by varying the sizes of crumb rubber," *International Journal of Engineering Trends and Technology (IJETT)*, vol. 14, no. 2, 2014.
- [12] N. Kumar K. and H. N. Rajakumara, "Study of using waste rubber tyres in construction of bituminous road," *International Journal of Scientific & Engineering Research*, vol. 7, no. 5, 2016.
- [13] B. Shubham, M. Anil Kumar, and B. Purnima, "Evaluation of modified bituminous concrete mix developed using rubber and plastic waste materials," *International Journal of Sustainable Built Environment*, pp. 442–448, 2017.
- [14] Z. Jiang, J. Ponniah, and G. Cascante, "Improved ultrasonic pulse velocity technique for bituminous material characterization," 2006.
- [15] J. L. McQuillen, H. B. Takallou, R. G. Hicks, and D. Esch, "Economic analysis of rubber-modified asphalt mixes," *Journal of Transportation Engineering*, vol. 114, no. 3, pp. 259–277, 1988.
- [16] W. C. Vonk and A. L. Bull, "Phase phenomena and concentration effects in blends of bitumen and Cariflex TR," in *Proc. 7th Int. Roofing Congress*, Munich, Germany, 1989.
- [17] J. L. Goodrich, "Bitumen and polymer modified bitumen properties related to the performance of bitumen concrete mixes," *Journal of the Association of Asphalt Paving Technologists*, vol. 57, pp. 116–160, 1998.
- [18] A. H. Ali, N. S. Mashaan, and M. R. Karim, "Investigations of physical and rheological properties of aged rubberised bitumen," *Advances in Materials Science and Engineering*, vol. 2013, Article ID 239036, 2013.
- [19] J. Peralta, H. M. R. D. Silva, A. V. Machado, J. Pais, P. A. A. Pereira, and J. B. Sousa, "Changes in rubber due to its interaction with bitumen when producing asphalt rubber," *Road Materials and Pavement Design*, vol. 11, no. 4, pp. 1009–1031, 2010.
- [20] IRC 29-1988 (Reprinted 2004), *Guidelines for the Design of Flexible Pavements*, Indian Roads Congress, New Delhi.
- [21] ASTM D1559, *Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*, ASTM International.
- [22] S. K. Khanna, C. E. G. Justo, and A. Veeraragavan, *Highway Engineering*, Nem Chand & Bros Publications, p. 370.