Enhancement of Cold Mixes by the Utilization of Recycled Asphalt Pavement (RAP) and Plastic-Coated Aggregates

Akshaya Anil[1], Akhil R[2], Ruksana B[3], Varsha Franklin[4], Ammu B Crusho[5]

[1]Student, Dept. of Civil Engineering, Bishop Jerome Institute, Kerala, India
[2]Student, Dept. of Civil Engineering, Bishop Jerome Institute, Kerala, India
[3]Student, Dept. of Civil Engineering, Bishop Jerome Institute, Kerala, India
[4]Student, Dept. of Civil Engineering, Bishop Jerome Institute, Kerala, India
[5]Assistant Professor, Dept. of Civil Engineering, Bishop Jerome Institute, Kerala, India

---***---

Abstract - *Pavements, being the most cost-effective mode of transportation, are currently experiencing degradation primarily due to the emergence of potholes. Potholes present a significant threat in the current scenario, causing discomfort for both drivers and passengers and posing a substantial danger to human life as a whole. It is crucial to address this issue, and several factors contribute to its occurrence, including the use of poor-quality materials, increasing traffic loads, and flooding conditions on roads. Traditionally, hot mix technology has been widely used for road pavement construction. However, this method has its limitations. To overcome these challenges, cold mix technology has been introduced, offering the advantage of not requiring the heating of aggregates and bitumen, thereby reducing overall pollution levels. Despite this progress, limitations still exist, as pothole regeneration is observed even after implementing these advanced technologies. Therefore, there is an urgent need to explore innovative approaches to effectively repair potholes. This discussion focuses on the utilization of Reclaimed Asphalt Pavement (RAP) methods and PET-modified aggregates for preparing cold mixes. Extensive testing has been conducted on aggregates and emulsions, yielding satisfactory results. The findings indicate that these materials are suitable for conventional cold mix design. Subsequently, samples were prepared for the Marshall Test, which allowed for the determination of stability and flow values. Based on these results, the optimal binder content was established. It was observed that the cold mixes with plastic coated aggregate were performing better and we suggest that this mix could be used for pothole-patching and enhancing the overall durability and sustainability of road infrastructure.*

Key Words: Cold mixes, Recycled Asphalt Pavement, PET-modified aggregates, Pothole repair, Sustainability.

1.INTRODUCTION

Potholes are depressions in road surfaces that pose significant challenges for drivers. These roadway imperfections can lead to substantial vehicle damage and present dangers to motorists attempting to navigate around them. Despite roads being the most cost-effective mode of transportation, premature deterioration often occurs, primarily due to the formation of potholes. Potholes vary in size, depth, and location, necessitating tailored repair methods to address the specific characteristics of each pothole effectively.

The prevalence of potholes is increasing, particularly in the context of road construction in Kerala, where the commonly used hot mix asphalt method has proven insufficient in preventing pothole formation. The introduction of cold mix asphalt has extended the life of roads, but further enhancements are required for more satisfactory results. To achieve this, the incorporation of new additives into conventional cold mixtures becomes essential. Cold mix asphalt, when appropriately modified, demonstrates the potential to significantly outperform hot mix asphalt, indicating the necessity for advancements in the conventional cold mix approaches.

In the realm of highway infrastructure, a concerted effort is underway to mitigate the carbon footprint associated with traditional construction methods. Among these efforts, Cold Mix Asphalt technology stands out as a promising solution. Unlike its counterparts, Cold Mix Asphalt (CMA) eliminates the need for material heating by employing asphalt emulsion and cutback as binding agents. These substances, liquid at room temperature, facilitate mixing and compaction without the energy-intensive heating process required by Hot Mix Asphalt and Warm Mix Asphalt.

CMA, boasting superiority in cost-effectiveness, energy efficiency, and environmental friendliness, operates within a manufacturing temperature range of 0–40 °C. Its key advantages include cost-effectiveness, environmental friendliness, reduced emissions, and ready availability. This sets the stage for a promising future in eco-friendly road construction. To further enhance the performance of CMA and address the prevailing challenges, this research explores the incorporation of Recycled Asphalt Pavement (RAP) and plastic-coated aggregates into the mix design.

As reported in previous studies, the utilization of RAP and plastic-coated aggregates in CMA has the potential to improve its durability, resistance to rutting, and overall sustainability (Oreto et al., 2021) (Puccini et al., 2019)

(Sangiorgi et al., 2017) (Yang, 2014). These modifications aim to contribute to the efficient and long-term repair of potholes, ultimately enhancing the safety and reliability of road infrastructure.

1.1 CMA Types and Developments

Studies led by Hayder Kamil Shanbara et al. have explored the various types of Cold Mix Asphalt (CMA), with a particular focus on Cold Bitumen Emulsion Mixture (CBEM). CBEM, a prominent CMA mixture, involves blending bitumen emulsion and mineral aggregates to create a versatile, bituminous mix. However, the absence of a widely accepted design method poses challenges, prompting investigations into various procedures.

CBEM's independence from environmental conditions, its on-site or off-site applicability, and its eco-friendly nature make it an appealing choice for road construction. Despite these advantages, issues persist, such as varied mixing materials, climatic effects on mix curing, and the lack of a unified curing protocol.

1.2 Innovative Approaches to Pothole Repairs

Li et al.'s investigation centres on repairing asphalt pavement potholes using inclined interface joints, emphasizing the impact of joint interface shape on service life. The study reveals that a thirty-degree inclination interface joint significantly enhances fatigue life compared to a vertical joint. The use of highly viscous modified emulsified asphalt in tack coats further improves performance.

1.3 Stabilizing Granular Materials with Nano-Modified Emulsions

Jordan et al. explore the stabilization of granular materials using New-Age Modified Emulsions. The study highlights the construction-friendly nature of NME, offering cost-effective solutions to common construction-related problems. Recommendations include maintaining equipment, using specified quality construction water, and providing adequate supervision.

1.4 Optimizing Fiber-Reinforced Asphalt Mixtures

Ferotti G et al. investigate high-performance fiber-reinforced asphalt mixtures, emphasizing the impact of fiber type and content on mixture performance. Testing evaluates stability, tensile strength, and abrasion resistance, revealing that CEL fiber-reinforced mixtures outperform others primarily in the context of maintenance activities in bituminous pavement surfaces.

1.5 Assessing the Quality of Cold Mix Asphalt

Boateng et al.'s study in Ghana assesses the quality of CMA as a pothole repair material, evaluating factors such as moisture sensitivity, stiffness, and rutting resistance. The findings suggest that CMA can effectively address potholes, provided adequate quality control measures are implemented during production and placement.

2. METHODOLOGY

The proposed research aimed to enhance the performance of Cold Mix Asphalt (CMA) by incorporating Recycled Asphalt Pavement (RAP) and plastic-coated aggregates. Initially, the necessary materials were carefully selected, including emulsified bitumen, coarse and fine aggregates, cement as a filler, PET bottles, and RAP. To ensure the materials met the required standards and were suitable for construction, a series of tests were planned for the aggregates, emulsified bitumen, PET-modified aggregates, and RAP. After conducting these tests, conventional cold mixes were created based on the principles of the Marshall Mix design method. The optimal binder content was identified by determining the Marshall Stability and flow values. The mixes were further improved by incorporating PET bottles to modify the coarse aggregates. Additional tests were performed on the modified aggregates, and modified cold mixes with varying PET content were prepared to establish the maximum stability value. The next step was to characterize the RAP, and cold mixes incorporating RAP were designed and tested using the Marshall Test to determine the optimal RAP content for the highest stability value. The results from the modified mixes and the conventional mix were compared. Once the maximum stability values for PET and RAP content were identified, and the optimal binder content was fixed, the mixes were prepared and subjected to moisture-induced susceptibility tests to evaluate their tensile strength. The thorough analysis aimed to determine the mix that demonstrated superior stability and indirect strength values.

3. RESULTS AND DISCUSSION

This section presents and discusses the findings of the conducted tests and analyses.

3.1 Test on Aggregate

Physical and mechanical properties of the aggregates were evaluated through a series of tests, including impact value, specific gravity, water absorption, crushing value and Los Angeles abrasion as per the Indian Standard procedure and the results are shown in Table 1.

Table -1: Test on Aggregate

Tests	Observed Value	Permissible Limits	Inference
Impact value test	28.04%	10-30%	Satisfactory as per IS 383-1970
Crushing value tests	26.89%	40%	Satisfactory as per IS 383-1970
Specific gravity	2.53	2.5 to 3.2	Satisfactory as per IS 383-1970
Water absorption	0.17%	0.1 to 2%	Satisfactory as per IS 383-1970
Abrasion test	38.04%	50%	Satisfactory as per IS 383-1970

The results showed that the aggregates met the required specifications for use in CMA mixtures.

3.2 Test on Bitumen Emulsion

Various tests on the bitumen emulsion, including residue on sieve, storage stability, and penetration, were carried out to ensure its suitability for the use of emulsion as CMA.

Table -2: Test on Bitumen Emulsion

Tests	Observed Value	Permissible Limits	Inference
Penetration Test	90mm	Grade A90 & S90	Satisfactory as per IS 8887-2018
Ductility Test	50 °C	30-50 °C	Satisfactory as per IS 8887-2018
Softening Test	85 cm	Minimum 15cm for A90 and 75cm for S90	Satisfactory as per IS 8887-2018
Residue By Evaporation Test	64.85%	--	Satisfactory as per IS 8887-2018
Residue on 600 Sieve	0.017%	0 to 0.05%	Satisfactory as per IS 8887-2018
Cement Mixing Test	0.96%	0 to 2%	Satisfactory as per IS 8887-2018

Table 2 presents the test results, which were found to be within the acceptable limits.

3.3 Test on Modified Aggregate

Tests were carried out to evaluate the performance of aggregates modified with 12% Recycled Asphalt Pavement (RAP). The key objectives were to construct roads that can entirely prevent cracking and maintain high resistance against various modes of failure. Accordingly, three tests were performed to assess the efficiency of the modified aggregates in comparison to conventional aggregates.

Table -3: Test on Modified Aggregate

Tests	Observe d Value	Permissible Limits	Inference
Impact Value Test	14.50%	10-20%	Strong as per IS 383-1970
Crushing Value Test	18.8%	30%	Strong as per IS 383-1970
Abrasion Test	21.9%	40%	Strong as per IS 383-1970

Table 3 presents the test results, which were found to be within the acceptable limits.

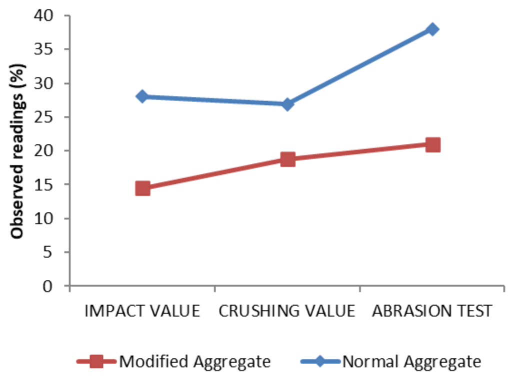

Chart 1: Comparison of aggregate properties

Chart 1 represents the comparison of impact, crushing and abrasion of normal and modified aggregate.

3.3 Characterization of RAP

The bitumen content and particle size distribution of the Recycled Asphalt Pavement (RAP) material was characterized. The study determined that the RAP bitumen content was approximately 5.87%.

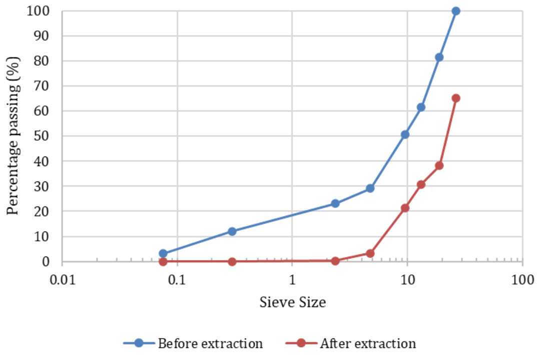

Chart 2: PSD curve for RAP

Furthermore, Chart 2 illustrates the particle size distribution (PSD) curve obtained for the gradation before and after the extraction of bitumen.

3.4 Mix Design

The study employed the Marshall mix design methodology to determine the optimum binder content for the conventional cold mix. Various mixes were prepared with emulsified bitumen percentages ranging from 4.5% to 6% to identify the optimal binder content. Subsequently, PET-modified cold mixes were created with PET contents ranging from 8% to 15% to ascertain the percentage that yielded the maximum stability value. Additionally, RAP-modified mixes were prepared with RAP contents varying from 25% to 55%.

Table -4: Mix Design of Conventional Cold Mix

Sample No.	Bitumen Content	Stability Value (kg)		Flow Value	
		Measured	Corrected	Dial reading (Div)	mm
1	4.5	1474	1681	175	1.75
2	5	1264	1441	200	2
3	5.5	1123	1280	310	3.1
4	6	1088	1240	368	3.68

The optimum binder content was identified as 5.5%. Thereafter, the PET content was systematically varied, and the corresponding stability values were analyzed to identify the PET percentage that yielded the maximum stability. This optimal PET content was then selected for further testing, as detailed in Table 5.

Table -5: PET Modified Aggregate

Sample No.	PET Content (%)	Stability Value (kg)	
		Measured	Corrected
1	8	1088	1240
2	10	1125	1282.5
3	12	1682	1917.48
4	15	1272	1450.08

Table -6: RAP Modified Aggregate

Sample No.	RAP CONTENT (%)	Stability Value (kg)	
		Measured	Corrected
1	25	1095	1248.3
2	35	1128	1285.92
3	45	1088	1240
4	55	1123	1280

Similarly, the RAP content was adjusted, and the RAP percentage providing the highest stability value was established as the optimal RAP content, which is also presented in Table 6.

3.5 Indirect Tensile Strength Test

To evaluate the moisture-induced damage resistance of conventional cold mixes, PET-modified mixes, and RAP-modified mixes, the indirect tensile strength (ITS) test was conducted. Two sets of specimens were prepared using the Marshall mix design method. Set 1 specimens were sealed in plastic bags until testing, while Set 2 specimens were moisture-conditioned. The moisture conditioning involved submerging the specimens in a distilled water bath at 60°C for 24 hours, followed by 2 hours of immersion in water at 25°C and 1 hour of oven drying.

After the conditioning, the height and weight of the specimens were measured. The specimens were then placed between the bearing plates of the testing machine, with steel loading strips positioned between the specimen and the plates. A constant load was applied by forcing the bearing plates together at a rate of 50 mm/minute. The maximum load sustained by the specimen was recorded, and the test was continued until the specimen failed.

The moisture damage resistance was then determined by the ratio of the tensile strength of the conditioned samples to the tensile strength of the unconditioned samples which is known as the Tensile Strength Ratio (TSR).

Fig – 1: Samples kept in water bath for curing.

Fig-2: Indirect Tensile Strength Test.

The tensile strength was calculated using the equation:

ITS Value = 2000P/πDt

where P is the load,

D is the diameter, and

t is the thickness of the mould.

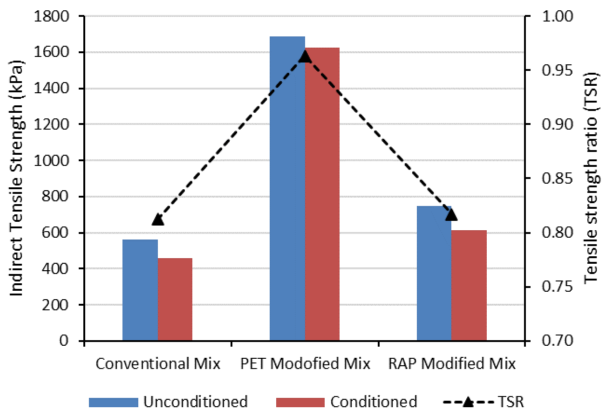

Chart 3: ITS Comparison

Tensile strength ratio (TSR) for the conventional, PET modified and RAP modified mixes were observed as 0.81, 0.96 and 0.82. For HMA, the TSR should be greater than equal to 0.80. Thus, within the acceptable limits.

3. CONCLUSIONS

The study collected the necessary materials, including emulsified bitumen, aggregates, polyethylene terephthalate (PET), and reclaimed asphalt pavement (RAP), to prepare the cold mix design. Various laboratory experiments were conducted on the selected materials, including tests on aggregates, emulsified bitumen, RAP, and PET-modified mixes. The test results were found to be satisfactory and met the relevant specifications.

Cold mixes were designed using rapid-setting emulsions. The researchers determined the stability, flow values, and optimum binder content of the conventional cold mix. Using the optimum binder content of 5.4%, they prepared PET-modified mixes with different PET contents and RAP-modified mixes with varying RAP contents. The maximum stability values were obtained at 12% PET content and 35% RAP content.

The cold mixes with high stability RAP and PET contents were then subjected to moisture-induced susceptibility testing using the indirect tensile strength (ITS) method. The results showed that the PET-modified mixes exhibited higher tensile strength compared to the other mixes in both the unconditioned and conditioned cases. The tensile strength ratio (TSR) was also estimated and found to be within the limits, but for the conventional cold mixes and RAP-incorporated cold mixes, it was near the limitation. However, it was observed that by modifying the aggregate and incorporating RAP, the TSR can be improved to enhance the mix's resistance against moisture-induced damage.

The main challenge identified in using PET-modified mixes is the potential for environmental pollution due to the release of pollutant gases during the heating and coating of aggregates with PET waste. To mitigate this, the study suggests introducing an incinerator with shredders, pug mills, air scrubbers, and electrostatic precipitators to capture, treat the pollutant emissions, ensuring only clean, pollutant-free smoke released into the atmosphere and then coating the aggregates.

Despite the higher initial cost of installing such plants, the long-term benefits of reduced environmental pollution and increased pavement life make the PET-modified cold mix a viable and sustainable option for pavement maintenance and rehabilitation.

In conclusion, the strategic incorporation of Recycled Asphalt Pavement (RAP) and Polyethylene Terephthalate (PET) into cold mixes can enhance their performance and durability, making them a more sustainable alternative for pavement maintenance work.

ACKNOWLEDGEMENT

We acknowledge our suppliers of Reclaimed Asphalt Pavement (RAP) which significantly aided the success of this research project.

REFERENCES

[1] Jain, Shobhit, and Bhupendra Singh. "Cold mix asphalt: An overview." Journal of Cleaner Production 280 (2021): 124378.

[2] Shanbara, H. K., Dulaimi, A., Al-Mansoori, T., Al-Busaltan, S., Herez, M., Sadique, M., & Abdel-Wahed, T. (2021). “The future of eco-friendly cold mix asphalt.” Renewable and Sustainable Energy Reviews, 149, 111318.

[3] Li, Linyu, Yangquan Huang, Zhutao Shao, and Dongya Ren. "An experimental investigation on the repairing performance and fatigue life of asphalt pavement potholes with an inclined interface joint." Frontiers in Materials 7 (2021): 597523.

[4] Jordaan, Gerrit J., and Wynand J. vdM Steyn. "Practical Application of Nanotechnology Solutions in Pavement Engineering: Identifying, Resolving and Preventing the Cause and Mechanism of Observed Distress Encountered in Practice during Construction Using Marginal Materials Stabilised with New-Age (Nano) Modified Emulsions (NME)." Applied Sciences 12, no. 5 (2022): 2573.

[5] Ahmad, Malik Shoeb, and Salman Asrar Ahmad. "The impact of polyethylene terephthalate waste on different bituminous designs." Journal of Engineering and Applied Science 69, no. 1 (2022): 53.

[6] Boateng, Kwadwo Appiah, Yaw Adubofour Tuffour, Daniel Obeng-Atuah, and Stephen Agyeman. "Quality of cold-mix asphalt in bituminous pavement maintenance in Ghana: Preliminary indications." Case Studies in Construction Materials 15 (2021): e00769.

[7] Bruno, Marco, Piergiorgio Tataranni, and Cesare Sangiorgi. "Experimental application of fully recycled asphalt concretes produced with chemical additives for patch pavement rehabilitation." Construction and Building Materials 363 (2023): 129807.

[8] Ferrotti, G., Emiliano Pasquini, and F. Canestrari. "Experimental characterization of high-performance fiber-reinforced cold mix asphalt mixtures." Construction and Building Materials 57 (2014): 117-125.

BIOGRAPHIES

“Akshaya Anil is a Civil Engineering student with a keen interest in Transportation Engineering and Planning. She is passionate about new technologies and innovation.”

“Akhil R is a Civil Engineering student who is very passionate about the career and a rapid learner. He is passionate in Green Technologies and construction materials. “

“Ruksana B is a civil engineering student who can perform well in management and Quantity Surveying “

“Varsha franklin is a civil engineering student who looks forward for more technologies and opportunities in the field of Transportation Engineering.”