State-of-the-Art Review in Micro-Surfacing: Harnessing Reclaimed Asphalt Pavement (RAP) for Sustainable Pavement Preservation

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Abstract- Micro-surfacing involves rejuvenating the existing pavement through the application of a thin layer comprising polymer-modified emulsion, aggregates, filler, water, and additives. It is recognized for its rapid curing, resource efficiency, and eco-friendliness. The literature review encompasses a comprehensive analysis of existing studies, methodologies, and findings related to micro-surfacing technology, recycled asphalt usage etc. It was found that using Reclaimed Asphalt Pavement (RAP) in micro-surfacing can reduce the use of emulsion and natural aggregates by using RAP binder and fine aggregate. This process also helps in improving the compatibility of the virgin aggregate with emulsion and decreasing fossil energy consumption and greenhouse gas emissions. Further, it was found that optimal asphalt content (OAC) decreases as RAP content increases. Moreover, the addition of RAP is shown to extend the mixing time, enhance moisture and freeze-thaw resistance, and improve skid resistance.

Keywords– Micro-surfacing, Road Maintenance, Pavement Preservation, Surface Treatment, Road Surfacing Techniques, Rutting and Cracking Prevention, Preventive Maintenance, Asphalt Resurfacing.

1. INTRODUCTION

Road transportation is widely recognized for its cost-effectiveness and popularity in both passenger and freight movement. In the country, it dominates with 87% of passenger traffic and 60% of freight traffic [1]. India boasts the world's second-largest road network, covering 63.73 lakh km (as of December 31, 2022). This network includes:

- National Highways spanning 1,44,634 km,
- State Highways covering 1,86,908 km,
- and Other Roads, comprising Major District Roads (MDR), Other District Roads (ODR), and Village Roads (VR), totaling 59,02,539 km.

Regular maintenance of roads is crucial for ensuring their longevity, safety, and efficiency. Over time, roads are subjected to wear and tear caused by factors such as weather conditions, heavy traffic, and natural deterioration. Without proper timely measures, these roads can develop potholes, cracks, and uneven surfaces, which not only inconvenience commuters but also pose serious safety risks. According to Kumar et al. (2016) [2], road maintenance encompasses a range of activities aimed at either preventing or slowing down the degradation of pavements. These efforts are directed towards mitigating or repairing pavement deterioration through actions like sealing cracks and resurfacing. These measures help in preserving the structural integrity of the road, preventing further damage, and extending its lifespan. Moreover, well-maintained roads contribute to smoother and safer travel experiences for motorists, cyclists, and pedestrians alike. They reduce the likelihood of accidents and vehicle damage caused by poor road conditions. Additionally, efficient road maintenance enhances traffic flow, reduces congestion, and supports economic activities by facilitating the movement of goods and people.

According to IRC:82-2015 [3], maintenance operations are divided into three main types. First, routine maintenance involves ongoing tasks like filling potholes and repairing cracks, along with ensuring pavement markings are clear for road safety. Second, periodic maintenance occurs at scheduled intervals or based on road condition, traffic, and climate, using treatments such as surface dressing and asphalt mixes to preserve pavement quality. Third, preventive maintenance aims to extend pavement lifespan by treating surfaces like micro-surfacing, reducing the need for frequent repairs and enhancing durability in the long term.

Micro-surfacing is a type of preventive maintenance where a mixture of modified bitumen emulsion (including polymer or rubber latex), well-graded mineral aggregate, water, filler, and optional additives is blended, mixed, and evenly spread over an existing pavement. This method is typically used on pavements that are in good structural condition but show signs of wear, such as decreased riding quality, cracks, and polishing. While usually applied in a single layer, multiple layers are recommended for highly polished or cracked surfaces. Micro-surfacing is commonly used to improve the surfaces of roads, taxiways, and runways. For cement concrete surfaces, applying two layers of micro-surfacing is recommended. Micro-surfacing serves as a versatile method for treating pavements, addressing various concerns such as longitudinal and transverse cracking, as well as issues like ravelling, bleeding, roughness, reduced friction, and moisture penetration. While it offers some structural reinforcement, its main purpose lies in enhancing the pavement surface. Additionally, it can temporarily seal small fatigue cracks and fill the exsting ruts if they are stable.

Micro-surfacing is a cost-effective method used for maintaining and rehabilitating pavement surfaces. According to the Federal Highway Administration (FHWA) report [16], it emphasizes the importance of both structural and functional conditions of pavements. The report explains that preventive maintenance and surface rehabilitation techniques like micro-surfacing can enhance pavement performance and extend its lifespan at a low initial cost. Introduced in the United States in 1980, and is recognized for improving surface friction, addressing wheel ruts, and correcting minor surface defects on roads of various traffic volumes [4].

Micro-surfacing, originating in Germany in the late 1960s and gaining global recognition in the 1980s, addresses pavement issues like rutting and cracks while protecting against water and aging, thus prolonging pavement life [5]. The paper underscores the importance of quality control, its applicability for minor repairs, and showcases successful project implementations, advocating for global adoption of micro-surfacing in pavement preservation strategies.

According to standards like ISSA A-143 (International Slurry Surfacing Association) [6] and IRC SP: 81: 2008 (Indian Road Congress), micro-surfacing comes in two main types differentiated by thickness. Type II micro-surfacing ranges from 4 mm to 6 mm thick, while type III micro-surfacing is thicker, ranging from 6 mm to 8 mm.

As per IRC type – II micro-surfacing typically used on roads with lower traffic volumes under 1500 Commercial Vehicles per Day (CVPD), while type – III micro-surfacing is applied on roads with higher traffic volumes, ranging from 1500 CVPD to 4500 CVPD, such as collectors, arterials, and major highways. ISSA A-143 emphasizes that type – II micro-surfacing employs a gradation suited for filling surface voids, addressing surface distresses, and providing a durable surface for wear. On the other hand, type – III micro-surfacing utilizes a gradation aimed at enhancing skid resistance and ensuring the longevity of the wearing surface. This type is preferred for heavily trafficked pavements, where it can fill ruts and provide a textured surface that requires larger aggregates to fill voids effectively.

2. COMPOSITION OF MICRO-SURFACING

The composition of micro-surfacing mix includes polymer-modified emulsion, mineral aggregate, mineral filler, water, and optionally additives. The quality of these materials plays a crucial role in determining the mix's performance, making it essential to comprehend their behavior and the factors that affect their properties. This understanding is vital for ensuring the long-term durability of micro-surfacing.

2.1 Emulsion

An emulsion is a combination of two or more liquids that usually do not dissolve in each other. In micro-surfacing, it plays a crucial role by dispersing one liquid in the form of tiny droplets throughout another liquid. This emulsion is a fundamental ingredient used to formulate the mixture applied to roads for maintenance and rehabilitation purposes.

During micro-surfacing, the emulsion is typically blended with aggregate, mineral fillers, and additives to produce a slurry mixture. This mixture is applied onto road surfaces to seal cracks, enhance friction, and restore surface qualities. The emulsion serves as a binding agent that binds the other components together and ensures they adhere effectively to the road surface once applied and cured.

The results of tests from various studies are fragmented into the following table for comparative analysis. In Table 1, the test results obtained by various studies for each parameter are listed alongside the corresponding regulatory guidelines. These results provide a basis for evaluating the micro-surfacing mix's quality and performance in relation to established standards.

2.2 Mineral Aggregate

The selection of aggregate for micro-surfacing is critical as it directly influences the performance and longevity of the pavement. The composition and quality of the aggregate play a significant role in determining how effectively the pavement functions and maintains its overall effectiveness. It is imperative that the aggregate is meticulously screened to ensure it is free from dust, organic residues, and any loose or unstable materials that could deteriorate over time. This meticulous selection process guarantees that the micro-surfacing application retains its integrity and durability throughout its lifespan.

According to ISSA A-143 guidelines, micro-surfacing is categorized into two types based on traffic intensity: Type II and Type III. Type II, typically 4 to 6 mm thick, is commonly used for preventive maintenance on urban and rural roads such as residential streets. On the other hand, Type III, with a thickness of 6 to 8 mm, is applied to main highways, inter-state roads, runways, and primary routes to enhance skid resistance and renew surface characteristics. The aggregate gradation for both types is precisely defined in the ISSA A-143 guideline during the mix design phase, ensuring consistency and optimal performance.

Table 1: Comparison of emulsion test results across various studies and recommended guideline values

Parameters	**IRC SP-81-2008** [7]	**ISSA A-143** [6]	**Poursoltani et al.** [8]	**Robati et al.** [9]	**Esfahani et al.** [10]	**Talha et al.** [11]	**Cui et al.** [12]
Residue on 600 micron IS Sieve (% by mass), Maximum	0.05	0.1	0.02	0.04	—	0.1	0.05
Viscosity by Say Bolt Furol Viscometer, at 25˚C, in second	20 – 100	20 – 100	18	28	—	49	30
Coagulation of emulsion at low temperature	NIL	—	—	—	—	—	—
Storage Stability after 24h, % maximum	2	1	—	—	—	0.35	0.6
Particle charge, +ve/-ve	[+ve]	[+ve]	[+ve]	—	—	—	[+ve]
Test on Residue:							
Residue by evaporation, % minimum	60	62	63.9	65.1	—	67	64
Penetration at 25˚C/100g/5s	40 – 100	40 — 90	62.7	75	65	51	65
Ductility at 27˚C, cm, minimum	50	40	100+	110+	100+	—	100+
Softening Point, in ˚C, minimum	57	57	75	63	49	64.4	—
Elastic Recovery*, %, minimum	50	—	—	—	—	57.5	—
Solubility in tri-chloroethylene, %, minimum	97	97.5	—	—	—	99.1	—
Coating Test, %	—	—	90	90	—	—	—
Settlement, 5 days, %	—	—	1	0.9	—	—	—

2.3 Filler

These particles, typically finer than 0.075 mm (No. 200 sieve), are used in micro-surfacing to improve the mixture's workability and fill small voids and surface imperfections. As per ISSA A 143, the filler should constitute between 0 to 3% of the weight of dry aggregates. It is included in aggregate gradation and treated as part of the aggregate components.

2.4 Water

Water, when combined with other micro-surfacing components, forms a viscous mixture that can be uniformly applied to the pavement surface. As the mixture is applied, the water evaporates, leaving a durable surface layer with enhanced skid resistance.

For micro-surfacing, the water used should have a pH ranging from 6 to 8 and must be free from impurities such as sediment, organic matter, oils, and other substances. These contaminants could otherwise affect the adhesion and performance of the micro-surfacing material.

Thanaya et al. (2009) [13] investigated cold-mix asphalt's properties and performance relative to traditional hot asphalt mixes. They aimed to improve cold-mix emulsion qualities, addressing issues like high air voids, low early strength, and extended curing times of up to 24 months. Despite these challenges, cold mixes offer production simplicity and are suitable for low-to-medium traffic, with easy application. Their study used carboniferous limestone and a by-product of red porphyry stone crushing as aggregates, with fly ash as a filler, known for its beneficial pavement properties. Results showed that with proper curing and cement addition, cold mixes can match hot mixes in stiffness and fatigue resistance, highlighting micro-surfacing as a viable cold mix technology.

Micro-surfacing rejuvenates old pavement by applying a thin layer of mix containing filler, aggregates, water, polymer-modified emulsion, and additives. It's praised for its fast drying, conservation of resources, and eco-friendly properties. Zulu et al. (2019) [5] extensively discuss micro-surfacing as an economical approach to maintaining and preserving pavements. They highlight that initiating a pavement preservation program can yield substantial cost benefits, suggesting that investing $1 in preservation at the right time can result in savings of $6 throughout the pavement's lifespan. Broughton et al. (2012) [14] analyse micro-surfacing as a preventative maintenance method for roads. The paper highlights its benefits, including cost-effectiveness and capability to enhance pavement conditions like rutting and friction, emphasizing the importance of applying it at the right stages of a road's life cycle. It also discusses limitations such as reduced effectiveness on heavily cracked or structurally deficient roads and poorer performance in extreme climates without appropriate modifications. Micro-surfacing is noted for its ability to meet both economic and environmental demands, its potential for improvement, and its suitability for preventative maintenance under specific conditions.

Table 2: Tests on aggregates and their specifications as per ISSA: A-143 and IRC SP: 81 – 2008

S. No.	Test	ISSA A 143			IRC SP:81 - 2008	
		Test Method		Specification	Test Method	Specification
		AASHTO	ASTM			
1	Sand Equivalent Value	T 176	D 2419	65 Min.	IS 2720 (Part 37)	50 Min.
2	Soundness of Aggregate	T 104	C 88	15% Max. with Na_2SO_4	IS 2386 (Part 5)	12% Max. with Na_2SO_4
				25% Max. with $MgSO_4$		18% Max. with $MgSO_4$
3	Resistance to Degradation of small size coarse aggregate by Abrasion and Impact in the Los Angeles Machine[1]	T 96	C 131	30% Max.	-	
4	Water Absorption[2]	-			IS 2386 (Part 3)	2 Max.

[1]The Abrasion test is run on the parent aggregate.

[2]In case water absorption exceeds 2% but less than 4%, same may be permitted subjected to conformity of soundness test and wet stripping test

Table 3: Gradation of aggregate as per ISSA: A-143 [6]

Sieve Size (mm)	Type II (4 to 6 mm)		Type III (6 to 8 mm)	
	Minimum	Maximum	Minimum	Maximum
9.5	100	100	100	100
4.75	90	100	70	90
2.36	65	90	45	70
1.18	45	70	28	50
0.6	30	50	19	34
0.3	18	30	12	25
0.15	10	21	7	18
0.075	5	15	5	15

Esfahani et al. (2020) [10] investigated the impact of different types and concentrations of emulsifiers on the performance of micro-surfacing mixtures. The study focused on Bitumen Polymer Emulsion (BPE) and evaluated three levels of emulsifier percentages, examining factors like mixing time, cohesion, abrasion resistance, and adhesion. The BPE composition included 62% pure bitumen and 3% liquid Styrene Butadiene Rubber (SBR) polymer, with three types of cationic emulsifiers type I, II and III, based on fatty amines, are selected. Emulsifier type I is Cationic Slow Setting (CSS), and type II and type III are Cationic Quick Setting (CQS), and emulsifiers added at rates of 0.9%, 1.2%, and 1.5% for Types I, II, and III, respectively. Results underscored that varying the emulsifier type and concentration significantly influences micro-surfacing properties. Specifically, higher emulsifier levels and BPE content improved adhesion and bitumen coating on aggregates, while also increasing sand adhesion and mixing time. Type I emulsifiers generally outperformed Type II in specific tests, although Type II required less optimal bitumen content than Type I. Type III emulsifiers showed comparatively lower effectiveness.

Labi et al. (2007) [15] studied micro-surfacing as a preventative maintenance treatment using Indiana pavement data. They evaluated its effectiveness in both the short and long term, focusing on changes in international roughness index (IRI), rutting depth, and pavement condition rating (PCR). The research shows that micro-surfacing initially improves pavement conditions significantly, with varying short-term outcomes depending on the pavement's initial state. On average, micro-surfacing reduces IRI by 0.442 meters per kilometer, decreases rut depth by 4 millimeters, and increases PCR by 6.2 units. Long-term benefits are influenced by factors such as traffic volume and climate, with micro-surfacing typically extending pavement life by about 5 years based on improved IRI, over 15 years for rutting reduction, and around 7 years for PCR enhancement. The study concludes that micro-surfacing effectively prolongs pavement lifespan and enhances ride quality, particularly under conditions of low traffic and mild weather, providing valuable insights for pavement preservation strategies and long-term management plans. Bhargava et al. (2019) [16] extensively review the design and effectiveness of micro-surfacing in road maintenance. They find that micro-surfacing significantly reduces wet road crashes across different road types, improves ride quality, and slows down the progression of roughness. The study emphasizes that micro-surfacing leads to notable reductions in (IRI) values, thereby enhancing road smoothness. The paper discusses how factors like aggregate type, binder content, and application methods influence micro-surfacing outcomes, highlighting improvements in skid resistance and reductions in issues such as cracking and rutting. Challenges like reflective cracking are acknowledged, and the study explores additional aspects such as noise levels and permeability. In summary, micro-surfacing is presented as an effective road maintenance technique with performance varying depending on multiple factors.

Talha S (2019) [11] studied the effectiveness of tack coat in enhancing the bond between micro-surfacing layers and existing pavement. The research aimed to develop a laboratory test for measuring bond strength and to conduct field tests. In the lab, experiments varied tack coat application rates and residual binder content, using "Pull-off" and "Torque" tests for bonding strength assessment. Field testing included in-situ evaluations and laboratory analysis of extracted cores. Results demonstrated that tack coat significantly improved bond strength, although dilution with water reduced this effect. Bond strength decreased notably at higher temperatures but gradually increased over time post-construction. Nascimento et al. (2023) [17] investigated the adhesion characteristics between micro-surfacing and asphalt concrete layers, focusing on factors influencing shear strength at their interface. The study used the

Leutner shear test to assess adhesion under various conditions, including the presence of an adhesion layer and different emulsions. Results highlighted temperature as a critical factor affecting adhesion, with higher temperatures weakening the bond between layers. Applying a bonding paint layer was found to enhance shear strength at lower temperatures. The application rate of micro-surfacing did not significantly impact shear strength. The study emphasized the importance of cautious application in regions experiencing high temperatures to mitigate risks of reduced adhesion between micro-surfacing and asphalt concrete layers.

Khafajeh et al. (2023) [18] extensively analyses how different components such as pure bitumen types utilized for preparing bitumen emulsion, aggregates type, and the percentages of bitumen emulsion and emulsifier and their quantities impact the quality and performance of micro-surfacing mixtures. The study focuses on determining the optimal bitumen content through experimental tests such as mixing time, cohesion, wet track abrasion, sand adhesion, and displacement tests. It also evaluates the physical and chemical properties of materials used, including limestone and siliceous aggregates, along with various types of bitumen. The research adheres to guidelines set by the International Slurry Surfacing Association for type II micro-surfacing mixtures typically applied in urban areas with moderate traffic. Findings recommend using limestone aggregates paired with a bitumen emulsion derived from a tougher, purer form of bitumen to enhance bonding between bitumen particles and aggregate surfaces. This approach strengthens adhesion and helps prevent issues like rutting, stripping, bleeding, and aggregate polishing within micro-surfacing mixtures.

Nikolaos Oikonomou (2007) [19] explores the use of alternative fillers in slurry seal, a cost-effective method for road maintenance and construction. Traditionally, Portland cement serves as the filler, but due to its expense and high energy requirements during production, the study investigates industrial by-products as potential substitutes. Tested alternatives include fly ash, marble dust, cement kiln dust, and ladle furnace slag, all of which are by-products posing challenges for environmental disposal. The research concludes that these alternative fillers can meet slurry seal standards and exhibit favourable characteristics such as consistency, mixing time, setting time, and cohesion. Utilizing these by-products offers a dual benefit: reducing environmental waste and conserving raw materials and energy typically used in cement manufacturing. Madane et al. (2019) [20] investigated Type III micro-surfacing using various fillers for pavement preservation. The study examined stone dust, Ordinary Portland Cement (OPC), foundry sand, cement kiln dust, marble dust, fly ash, ladle furnace slag, and rice husk ash as potential fillers. Laboratory tests including modified marshal test, set time assessment, and wet track abrasion test were conducted. Results showed that mixes containing fly ash outperformed those with OPC due to fly ash's active properties at lower temperatures, resulting in faster setting times and reduced need for additives. Additionally, fly ash was found to be more environmentally friendly, cost-effective, and potentially beneficial for micro-surfacing quality compared to other fillers. The study noted that while some fillers like marble dust improved mixture stiffness, rice husk ash, despite its cost-effectiveness, did not enhance micro-surfacing quality sufficiently for high-traffic roads. In conclusion, the research suggests that fly ash is a viable alternative to cement as a filler in micro-surfacing applications, offering both economic and environmental advantages. Fooladi et al. (2021) [21] studied the impact of various filler materials on micro-surfacing asphalt mixtures. The research focused on comparing the performance of micro-surfacing mixtures using alternative fillers with traditional Portland cement Type II. The alternative fillers tested included quicklime, micro-silica slurry, and a mixture of cement and quicklime. Laboratory tests evaluated essential properties such as breaking time, asphalt emulsion curing, cohesion, and prevention of aggregate separation. Findings revealed that the use of different fillers significantly influenced the performance of micro-surfacing mixtures by accelerating breaking time and asphalt emulsion curing, enhancing mixture cohesion, and reducing damage and aggregate separation. Optimal proportions of water, filler, and bitumen emulsion were determined through iterative testing based on mixing time, wet cohesion, and additional factors like wet track abrasion and loaded wheel tests. The study emphasized that fillers play a critical role in controlling mixture porosity, stability, compressibility, and friction between aggregates. Moreover, fillers influenced reaction rates in micro-surfacing, impacting moisture damage, stiffness, oxidation, rutting, cracking behaviour, stability, and asphalt pavement density. Increased filler content was observed to increase mortar viscosity due to physical and chemical interactions with bitumen.

Recently, there has been increasing attention towards integrating RAP due to its beneficial environmental effects [22]. However, finding the optimal RAP ratio in recycled mixtures for micro-surfacing is challenging due to the intricate interactions among aggregates, cement, and emulsion.

Using RAP in micro-surfacing provides several benefits. It promotes sustainability by recycling existing asphalt, reduces waste, and conserves natural resources. Wang et al. (2019) [22] highlight three advantages of incorporating RAP into micro-surfacing:

1. It allows for the utilization of RAP binder and fine aggregate, reducing reliance on emulsion and natural aggregate.
2. It mitigates the reactivity of fresh aggregate, enhancing its compatibility with emulsions.
3. It lowers fossil energy consumption and reduces greenhouse gas emissions.

Furthermore, integrating RAP can lead to cost savings by reducing the need for new asphalt materials.

Robati et al. (2014) [9] conducted a study on the blending conditions and rutting behaviour of micro-surfacing mixtures containing different proportions of RAP. The research involved testing cohesion, wet track abrasion, and displacement to evaluate the properties of mixtures that combined RAP with virgin aggregates. The study concluded that it is feasible to formulate micro-surfacing mixtures using 100% RAP.

Wang et al. (2019) [22] conducted research on modifying the design process for micro-surfacing mixtures incorporating RAP. The study aimed to enhance pavement maintenance sustainability by reducing greenhouse gas emissions, conserving natural resources, and maintaining pavement performance, particularly in rutting resistance.

- **Aggregate Loss:** Aggregate loss in micro-surfacing refers to the amount of aggregate material that becomes dislodged or wears away from the surface over time due to traffic and environmental factors. It is important to minimize aggregate loss to maintain the desired texture and skid resistance of the micro-surfacing layer.
- **Sand Adhesion:** Sand adhesion refers to the ability of the micro-surfacing material to adhere to the underlying pavement. The sand adhesion test assesses the amount of excess asphalt in slurry surfacing system mixtures by measuring the weight of sand that adheres to a sample.
- **Asphalt Aggregate Ratio:** This represents the proportion of the asphalt binder in an asphalt mixture. This ratio significantly influences the pavement's strength, durability, and overall performance.

Figure 1 (a-e) illustrates that as the asphalt aggregate ratio increases, aggregate loss decreases, and sand adhesion values increase across various RAP usage levels. Furthermore, Figure 1 (a-e) shows that aggregate loss initially decreases with increasing RAP content up to a certain threshold (40%) before rising again. The study indicates that OAC decreases with higher RAP content, as depicted in Figure 2 (c), suggesting reduced reliance on new materials and cost savings. Additionally, Figure 2 (a) demonstrates that adding RAP extends mixing time up to a specific limit of RAP content before declining. Figure 2 (b) indicates improved skid resistance with increased RAP content. Figure 2 (d) shows reduced aggregate loss after freeze-thaw cycles and soaking conditions for micro-surfacing at varying RAP content levels. The study also assessed rejuvenators, highlighting their potential in restoring RAP binder properties to enhance mixing and rutting resistance. Introducing laboratory compaction during design improved mixture consistency and performance, simulating field rolling more effectively. In conclusion, the research suggests that incorporating high RAP content in micro-surfacing can yield environmental and engineering benefits, provided that proper mix design considerations are applied.

According to Wang et al. (2021) [23], as the proportion of RAP increases, the mixing time for micro-surfacing mixtures also increases, suggesting that incorporating RAP enhances the workability of these mixtures. Moreover, higher RAP content leads to a decrease in curing rate and an improvement in noise reduction performance. Garfa et al. (2017) [24] conducted an experiment with nine different blends using only 100% RAP. Poursoltani et al. (2020) [8] investigated the integration of RAP in micro-surfacing mixtures. The study aimed to assess the feasibility of replacing virgin aggregate with RAP and evaluate the mixtures according to ISSA guidelines. Key findings include: (1) Micro-surfacing mixtures incorporating RAP can meet ISSA's mix design criteria, (2) Higher RAP content increases water demand but reduces the need for additives, (3) RAP mixtures exhibited lower performance in cohesion and Wet Track Abrasion Tests compared to 100% virgin aggregate mixtures but showed improvements in bitumen flushing resistance and performance at higher temperatures, (4) The OAC for RAP mixtures was higher than for 100% virgin aggregate mixtures, indicating that RAP contributes significantly to mix properties rather than acting solely as filler, (5) A mixture containing 69% RAP demonstrated superior overall performance across various tests compared to mixtures with 43% and 95% RAP. The study concluded that while integrating RAP in micro-surfacing poses challenges, it offers environmental benefits and can enhance certain mix properties. The authors recommended further research to optimize RAP utilization in micro-surfacing, suggesting the use of water-reducing agents and rejuvenators to improve mix performance.

The study observed that Percent Vertical Displacement (PVD) and Percent Lateral Displacement (PLD) initially decreased with higher emulsion content before subsequently increasing. PLD refers to the horizontal shift or movement of the micro-surfacing material from its intended placement during application. It indicates how much the material has shifted sideways (laterally) from where it was originally intended to be applied. Lateral displacement can occur due to various factors such as improper equipment operation, uneven application, or external forces during or after application. PVD refers to the vertical shift or movement of the micro-surfacing material from its intended thickness or height after application. It measures how much the applied material deviates in thickness or elevation from the desired level. Vertical displacement can occur due to factors such as inconsistent material spreading, settling during curing, or inadequate compaction. Additionally, the research suggested that the addition of a rejuvenator could potentially restore the original properties of the RAP binder in micro-surfacing.

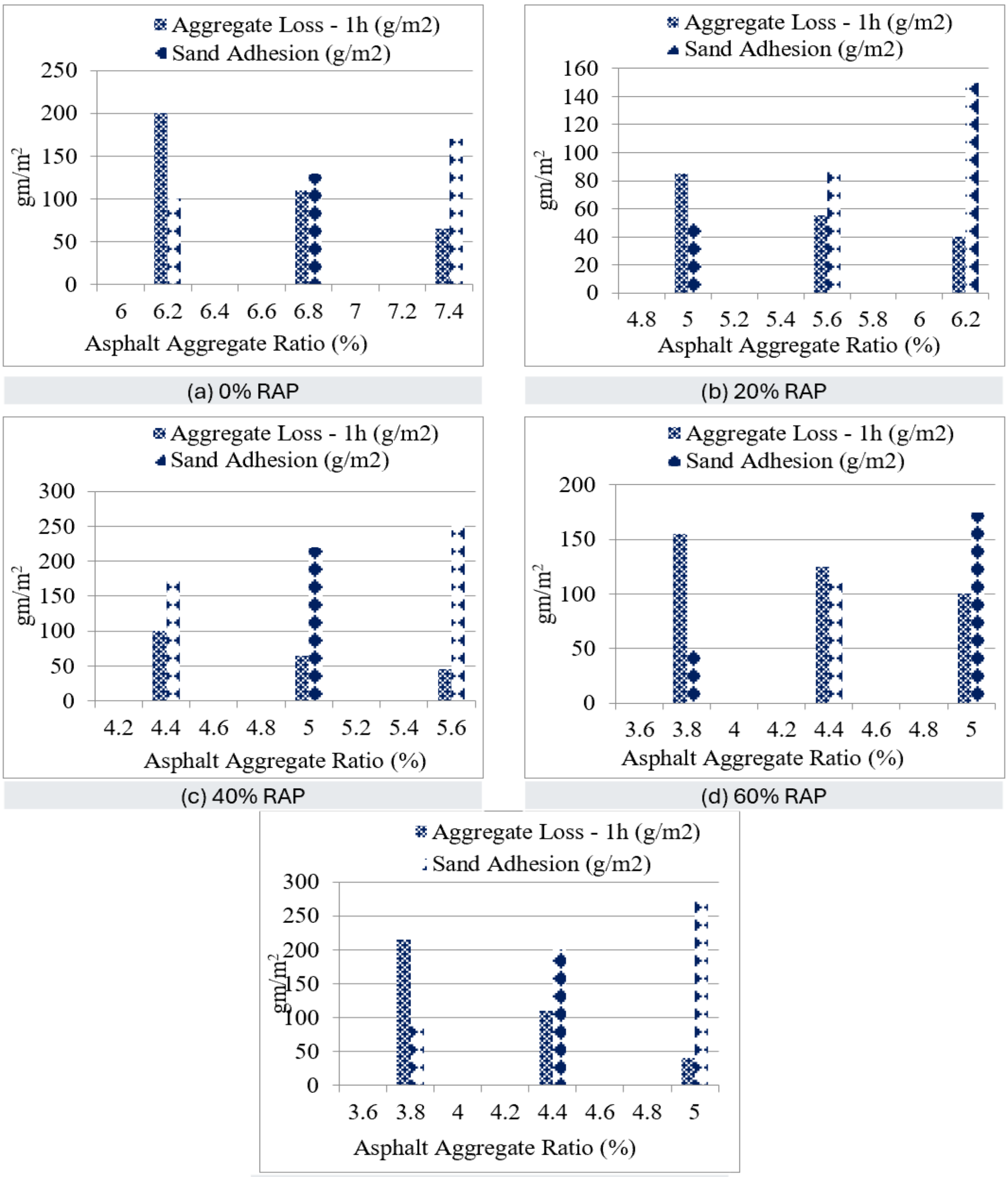


Figure 1: (a-e) Aggregate loss at 1 hour and sand adhesion of micro-surfacing containing different amount of RAP (a) 0%, (b) 20%, (c) 40%, (d) 60%, and (e) 80% with respect to asphalt aggregate ratio [22]

3. CONCLUSION

Micro-surfacing is a versatile and cost-effective preventative maintenance technique for enhancing pavement surfaces. Originating as a method to address minor surface distresses, it has evolved into a crucial tool for extending pavement life, improving skid resistance, and mitigating issues like rutting and cracking.

1. Micro-surfacing improves pavement conditions by reducing roughness, enhancing ride quality, and extending the pavement's service life, offering cost savings through early maintenance and preservation.
2. Different micro-surfacing types are used depending on traffic volume and pavement condition, with Type II for low traffic and Type III for high-traffic areas, ensuring optimal performance.
3. The choice of materials, including aggregates, emulsions, and additives, is crucial for determining the performance and longevity of micro-surfacing.
4. Incorporating RAP into micro-surfacing reduces the need for new materials, lowers energy consumption, promotes resource conservation, and reduces landfill waste, supporting environmental sustainability.
5. Study indicates that RAP can effectively enhance the mechanical properties of micro-surfacing mixtures when appropriately formulated and tested. Studies have shown improvements in rutting resistance, moisture susceptibility, and overall pavement durability with increased RAP content. This demonstrates its potential to maintain or even enhance pavement performance while reducing life cycle costs.

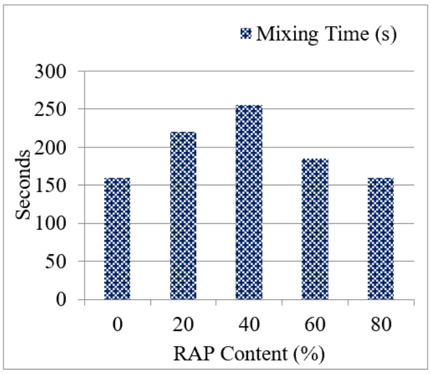
Moreover, micro-surfacing stands out as a proven method for pavement preservation and rehabilitation, offering substantial benefits in terms of cost-effectiveness, performance enhancement, and environmental sustainability. Adopting micro-surfacing as part of comprehensive pavement maintenance strategies can significantly contribute to safer and more efficient road networks.

4. CHALLENGES AND CONSIDERATION

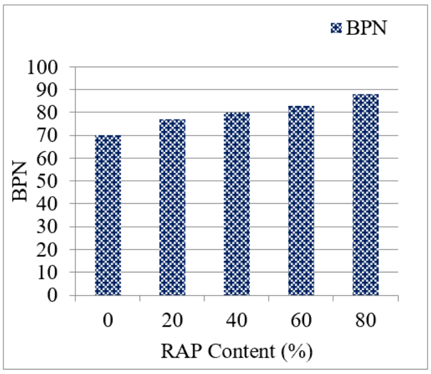
1. While micro-surfacing offers numerous benefits, its effectiveness can vary based on factors like climate, traffic volume, and pavement condition. Proper design, application, and quality control are essential to maximize its benefits and ensure long-term performance.
2. Despite of RAP benefits, challenges such as variability in RAP quality, potential for aged binder stiffness, and mix design adjustments must be carefully addressed to optimize performance. Proper characterization of RAP materials, including binder rejuvenation techniques and compatibility testing, is essential to ensure the desired engineering properties and long-term performance of micro-surfacing mixtures.

5. FUTURE SCOPES

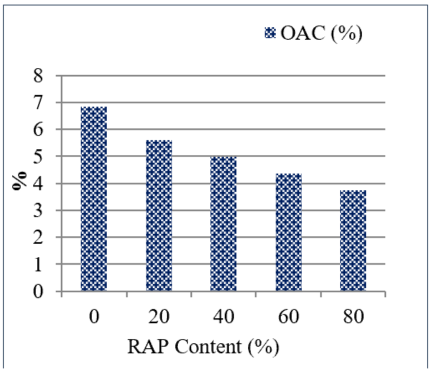
1. Investigate innovative mix designs incorporating alternative materials and additives to enhance the performance and sustainability of micro-surfacing. This includes exploring the optimal combination of aggregates, emulsions, and fillers, as well as incorporating advanced technologies for better durability and environmental benefits.
2. Further research into optimizing the use of RAP in micro-surfacing to maximize its benefits. This includes studying the effects of varying RAP content on performance metrics such as rutting resistance, fatigue life, and moisture susceptibility. Develop guidelines and standards for RAP utilization to ensure consistent and reliable performance.
3. Address the impact of climate change on pavement performance and explore how micro-surfacing can be adapted to withstand extreme weather conditions. Research should focus on developing climate-specific formulations and application techniques to enhance resilience and longevity in diverse environmental settings.
4. Conduct comprehensive lifecycle assessments (LCA) to quantify the environmental, economic, and social impacts of micro-surfacing compared to traditional pavement maintenance techniques. Investigate ways to further reduce carbon footprint, energy consumption, and resource depletion through improved materials selection and construction practices.



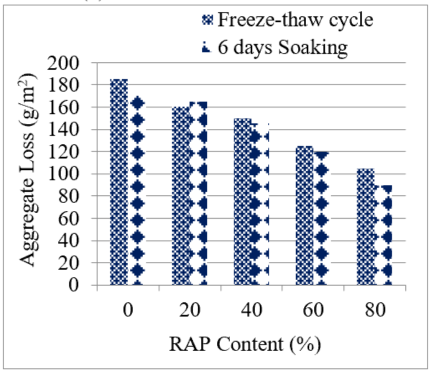
(a) Mixing time (sec.) at different RAP content



(b) BPN at different RAP content



(c) OAC at different RAP content



(d) Aggregate loss of freeze-thaw cycle and 6 days soaking condition of micro-surfacing at different RAP content

Figure 2: (a-d) Result of various tests such as (a) Mixing time; (b) BPN; (c) OAC; and (d) Aggregate loss at freeze-thaw cycle and six-days soaking condition of micro-surfacing

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