A review Study on Sustainable Utilization of Reclaimed Asphalt Pavement (RAP) in Asphalt Mix with Binder Additives

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Abstract

To mitigate the impact of road transport on the environment, new environmentally friendly construction techniques have to be developed in response to its explosive growth. The construction of a new roads uses a significant amount of energy and resources, which has a wide range of environmental effects. Additionally, the primary source of bituminous binder “crude oil” has seen a significant increase in price in recent years. As a result, bituminous mixtures are now more expensive overall. The use of Reclaimed asphalt pavement (RAP) materials has seen a sharp rise in recent years due to the growing demand for sustainable paving materials. The performance of the binder in asphalt mix such as stiffness, workability, etc. can be negatively impacted when RAP is combined with virgin asphalt mix, especially if the percentage is large. To reduce the negative effects, it is necessary to identify and assess the various types of additives in advance, so that this substitution of sustainable materials is capable of performing well in the field. In the present study two components of asphalt mix i.e. RAP and additive are highlighted and reviewed. Furthermore, the study provides a brief outline of RAP and various additives which has been used in the bituminous mix of flexible pavement. Review findings suggest that using secondary materials not only provides an efficient method of disposing of waste, but it also reduces the need for traditional materials and decreases building costs overall. The aim of this review study is to establish applicability and effectiveness of the RAP with various additives so, that it can help in incorporating suitable additives, keeping in mind variations in properties of different additives compared to the natural asphalt mix, also different combinations can be used according to the need and environmental conditions of that region.

Keywords: Recycled asphalt pavement (RAP), Binder additive, Asphalt mix, Sustainable materials

1. Introduction

In today’s world a lot of new road developments are taking pace in India as well as in every part of world, many of which are development of existing roads which leads to generation of huge amount of reclaimed asphalt pavement (RAP), also for paving new roads huge number of natural aggregates are used which leads to utilization of huge number of natural resources and energy [1]. The main goal of a sustainable development is broken by the massive quantity of pavement construction and maintenance that is done worldwide. Depletion of non-renewable natural resources, global warming, and rise in greenhouse gas emissions is one of the effects of this kind of carelessness [2]. As we know most of the highways in India are flexible pavements made by hot mix asphalt (HMA) which comprises of blend of aggregates and bituminous binder in which Aggregate serves as the structural framework, while bituminous binder acts as a glue. The design life of flexible pavements is intended to be 20 years but with rapid growth in traffic in both urban & rural area and inclusion of large heavy axial loads led bituminous pavements to fail too early then designed life [1]. Natural aggregates nowadays are used widely in every construction project and it is most important construction material which is responsible for most of the strength in the structure, also the demand for this much quantity of natural aggregates is fulfilled from natural stone deposits which comes from mining [3]. Engineers and researchers are continuously finding ways to incorporate waste such as RAP to utilize in the construction of flexible pavement which can help in reducing the need of virgin aggregates and decrease the waste production [4].

Incorporating RAP in the asphalt mix has various challenges as the RAP materials has gone through long term aging and mechanical properties have been changed during usage period of pavement, hence using RAP in asphalt mix can

affect the life of new asphalt pavement. Previously researchers have used around 15%-20% of RAP (by total mass), but recently engineers and researchers has shown interest in using high percentage of RAP in the mixture [2]. The long aging of binder in the RAP can negatively impact the asphalt mix as the aged binder in stiff as compare to the virgin binder which can reduce workability and flexibility of the new asphalt mix, leading to initial cracking and reduced durability [5]. The mechanical qualities of the asphalt mix, such as its resistance to rutting, fatigue, and thermal cracking, might be adversely affected by a high RAP component [6]. It can be difficult to guarantee that the performance is on par with or better than virgin blends. Aged binder property which are changed during the time can be restored with the use of right binder additives and rejuvenators selecting the appropriate type and quantity is crucial for achieving desired property of the asphalt mix. Numerous studies demonstrated that binder additives might extend the virgin asphalt mixture's fatigue life and perform better at low temperatures.

2. Materials

In this review paper our main focus is on utilizing RAP which is piled up in huge amount whenever the old flexible pavements are dismantled, in current scenario the generation of RAP is increasing which is a major problem, now to reduce these stocks of RAP we must come up with some innovative ideas use this. One of the ways to use RAP is incorporating it in flexible pavements using high rap content, some of the researchers have found that 40% of RAP can be use get the desired property and durability in flexible pavement. While to achieve better performance binder additives can be used with high RAP content.

2.1 Recycled Asphalt Pavement (RAP)

RAP is a material which are milled and crushed from existing old flexible pavements. RAP comprises of aged binder, aggregates and other materials form the old pavements. It can be reused to reduces the demand for new raw materials, such as bitumen and aggregates, but also significantly lowers the environmental impact by minimizing waste and conserving natural resources. Additionally, the use of RAP can lead to cost savings for contractors and municipalities, making it a sustainable and economical choice for modern infrastructure projects [7]. National Highway Authority of India (NHAI) has made it mandatory to adopt RAP, and recommends using RAP up to 30% within the mixture design [8].

(a) (b)

Fig.1 (a) Recycled Asphalt Pavement (b) Processing of RAP into Fine and Coarse Aggregate

2.2 Binder Additives

To enhance the performance of RAP in the Asphalt mix binder additives are used, binder additives which can include polymers, fibers, rejuvenators, and chemical modifiers, are designed to improve the mechanical properties of asphalt, such as elasticity [9]

Table-1 Various Additives (Binders, Thickeners, etc.)

Water and Solvent Based Binders	ZycoTherm, Styrene-butadiene rubber (SBR), Polyvinylidene fluoride (PVDF), latex, acrylic resins, rubber, and etc.
Thickeners	Polyethylene oxide (PEO), Polyvinyl alcohol (PVA), and etc.
Conducting Agents	Graphite, Furnace black, Carbon nanotubes, and etc.

Flexibility as well as resilience against cracking and deformation. These additives assist pavements endure extremes in temperature, high traffic volumes, and environmental pressures by altering the asphalt binder; this increases the pavements' lifespan and lowers maintenance costs [9]. In order to create high-performance asphalt mixtures that allow for the building of more resilient and long-lasting roads, highways, and other infrastructure projects, binder additives are essential. By increasing the efficacy and efficiency of road construction and maintenance, their use promotes sustainability in addition to strengthening the structural integrity of pavements [10].

3. Guidelines for Recycling Waste in Bituminous Layers of Flexible Pavement

Every country has rules and specifications about what materials can be used to build pavements. Every recycled material used in construction should always undergo a property test similar to that conducted on traditional materials [1]. This guideline helps in understanding the properties of the RAP and binder which should meet the general requirement for the pavement design along with the minimum criteria for the strength, durability, stability and other required characteristics, also it must be free form pollution and harmful components. Some of the required characteristics for materials according to the guidelines are outlined in Table-1 and Table-2 for utilization in flexible pavements [11].

Table -2 Aggregates and Fillers Physical Property Tests

Test Name	Evaluated Properties	IS-Code	Reference
Sieve analysis	cleanliness	IS:2386 part-I	[12]
Los Angles Abrasion Value	Hardness	IS:2386 part-IV	[13]
Combined Flakiness and Elongation Index	Particle shape	IS:2386 part-I	[12]
Soundness Test	Durability	IS:2386 part-V	[14]
Aggregate Impact Value	Toughness	IS:2386 part-IV	[13]
Water absorption Test	Water Absorption	IS:2386 part-III	[15]
Specific Gravity	Density of aggregates	IS:2386 part-III	[15]

Table -3 Binder Physical Property Tests

Test Name	Evaluated Properties	IS-Code	Reference
Penetration @ 25℃	Hardness and Consistency	IS:1203	[16]
Viscosity @ 60℃ & 135℃	Flow and Performance	IS:1206 Part II, III	[17]
Flash and Fire point	Temperature Study	IS: 1209	[18]
Softening Point	Elevated temperature	IS: 1205	[19]
Ductility	Adhesive and Ductility	IS: 1208	[20]
Specific Gravity	Density of bitumen	IS: 1202	[21]

4. Some of the Research Studies Incorporating Binder Additives and Aggregate Replacement

Nemours studies and research has been conducted on incorporating both binder additives and aggregate in the asphalt mix, many of which are focused on using sustainable materials because of the growing need of natural materials. These studies aimed at improving the qualities of asphalt mixtures have been conducted as a result of the need for long-lasting and sustainable paving materials [22]. Two main strategies have gained traction: adding binder additives and substituting alternative ingredients for conventional aggregates. Asphalt binders' performance qualities are enhanced by binder additives, which include rejuvenators, polymers, and nanomaterials. These additives address problems with ageing, cracking, and moisture susceptibility [23]. Some of the prominent research work is summarized in table no.3 below.

Table-3 Shows Tests and Conclusion of Different types of Materials used.

Sr. No.	Author Name and Year	Materials	Replaced as	Test Parameters	Conclusion
1	Zhu et al. (2020) [22]	Basalt fiber (BF), Polyester fiber (PF) and RAP	Binder additive and natural aggregate	mechanical property tests on fiber modified RAP mixtures	BF customized mix having 40% RAP provided the maximum dynamic modulus and least rut depth.
2	Yousefi et al. (2020) [24]	RAP and WMA additives like Sasobit, Kaowax, and PAWMA	Natural aggregate and binder additive	mechanical property tests	The combinations with the strongest resistance against moisture damage were those including RAP and PAWMA. Overall, the results point to potential benefits for pavement construction from the application of WMA technology and RAP.
3	Muniz et al. (2018) [25]	Crumb rubber and RCA	Virgin binder and natural aggregate	Physical and rheological property tests on binders and mechanical property	HMA mixes with 100% RCA are inappropriate, and it is also advised to adjust the mixture's dosage by volume rather than mass in order to assess the impact of RCA on the properties of HMA.

4	Wang et al. (2021) [26]	RAP	Conventional aggregate	Uniaxial Tension Compression Test	The research findings suggest that careful consideration should be given to the ageing protocol of RAP to ensure desired material performance. The study supports the use of re-recycled RAP up to 40% in asphalt mix design.
5	Obaid et al. (2022) [27]	RAP and additives like Sasobit, Aspha-Min, and ZycoTherm	Natural aggregate and binder additive	Rheological, Physical and mechanical property tests	The outcomes demonstrated that the additions enhanced the mixtures' mechanical qualities, and that particular addition percentages produce the greatest results.
6	Ding et al. (2019) [5]	Stable Crumb Rubber & RAP	Binder and natural aggregate	Mechanical property tests on asphalt mixtures.	When it comes to recycling old asphalt mixtures with a high RAP percentage, stable crumb rubber is more effective than virgin asphalt.
7	Gautam et al. (2018) [28]	Numerous recycled materials	Natural material in flexible pavement	Recommendation of usage of waste in flexible pavements.	There are several potential waste materials that may be employed in flexible pavements.
8	Liang et al. (2020) [29]	SSB latex and crumb rubber	Binder additive	Visco-elastic property tests, and mechanical property tests like rutting.	Diatomite and rubber particles can enhance the viscoelastic, high temperature and low temperature properties of bituminous mixes
9	F. Meroni et al. (2020) [30]	Reclaimed Asphalt Pavement	Natural aggregate	Indirect tensile cracking test, and life cycle cost analysis.	It is possible to produce high recycled content mix (45% RAP) capable of attaining better overall laboratory performance than traditional mixes.
10	Chaudary et al. (2020) [31]	Agricultural wastes, industrial wastes, and Construction and demolition waste	Fine and coarse aggregate	Physical and chemical property test.	Reducing the environmental effect and increasing the sustainability of pavement construction are two potential benefits of using waste materials as fillers in asphalt mixtures.
11	Mhaya et. al. (2023) [32]	Polymer modified bitumen and RAP	Aggregate	Cracking test, fatigue test and mechanical properties	It is possible to mix 30% RAP in polymer modified bitumen having similar properties as compare to 0% RAP conventional mix.
12	Jiangmiao et. al. [7]	RAP and RAS	Fine and coarse aggregate	Moisture damage along with thermal and fatigue cracking.	Recycling agents can be used to improve resistance to thermal cracking, improves durability of high recycled asphalt mixture.
13	Abuaddous et al. (2020) [33]	Recycled polyethylene terephthalate (RPET)	Binder additive	Physical property tests and rheological property tests	RPET used as modifier improves temperature operating and decreasing the low temperature working grade

14	Zhu et al. 2020 [34]	Fiber asphalt & RAP	Aggregate and binder additive	Rutting test and wheel tracking test	The addition of both fiber and RAP improves rutting resistance, the mixture having 40% RAP shows lowest rut depth.
15	Picado et al. (2020) [35]	Crumb Rubber	Binder additives	Mechanical properties like thermal cracking	Incorporating crumb rubber in the asphalt improves performance and environmental benefits.

5. Challenges and Suggestions

As a sustainable substitute for conventional pavement construction techniques, the utilization of recycled materials in asphalt pavements has attracted a lot of interest. Even though using recycled materials in asphalt pavements has advantages, there are a few issues that need to be resolved to guarantee the pavements' long-term durability and performance, our objective is to make a valuable contribution to the continuous endeavors aimed at creating infrastructure systems that are more resilient and sustainable, some of the challenges and suggestions are mentioned below:

5.1 Challenges

1. One of the biggest hurdles is being able to use recycled materials with the aggregates and binders already used in pavements. Accurate characterization and testing are required to ensure pavement performance and longevity.
2. Ensuring that waste-derived products consistently meet quality and performance standards can be difficult. It is important to have reliable sources of information, processing, and quality control procedures in place to reduce the likelihood of unfavorable outcomes.
3. When evaluating how garbage consumption affects the environment, caution must be used. Throughout the course of a product's life cycle, environmental factors such as the possibility of contaminant leaching and air emissions from manufacture must be taken into account.

5.2 Suggestions

1. Extensive research is required to understand the behavior and long-term performance of waste materials in flexible pavements. The impact on engineering quality, durability, and pavement performance under different conditions should be investigated.
2. In order to determine whether or not the waste is suitable for use in pavement applications, it is crucial to completely characterize it. The equivalency of physical, mechanical, and chemical qualities needs to be verified through testing.
3. The behavior and structural integrity of waste-containing pavements must be evaluated by a battery of performance testing, including field and laboratory studies.

5. Conclusions

Enhancing the performance and capacity of bituminous pavement with environmental and cost benefits has increased researchers to the concept of utilization of sustainable materials in pavements. Because the alternative binder modifies the rheological properties of the asphalt binder, it increases the pavement's demolition efficiency. In summary, promising solutions with high sustainability performance, such as considerable use of RAP and alternative binders, can be fulfilled for broad usage under the right conditions. Some results obtained from previous studies regarding binder modification and aggregate replacement are mentioned below:

1. It was found that using 40% RAP gives better performance in terms of moisture resistant and mechanical properties.

2. Crumb Rubber is more effective than virgin asphalt when recycling aged RAP with high content.

3. The use of rejuvenators in asphalt mix can restore properties of aged binder improving their mechanical properties and rheological properties such as flow and behavior.

4. It was found that using 100% of RAP is not suitable for use in asphalt pavement.

5. The use of RAP, supported by appropriate binder additives, not only reduces material costs but also decreases the environmental footprint of asphalt production.

6. Using polymers like styrene-butadiene-styrene (SBS) improves the elastic resistance to deformation making RAP mix more durable.

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