A review on Use of Reclaimed Asphalt Pavement (RAP) in Asphalt Mix with Polyethylene Terephthalate (PET)

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Abstract - *Transportation is an important indicator of a country's development. India, being a developing country, need well-developed highways for improved connectivity, which encourages faster growth. A bituminous mix requires aggregates, binder, and filler, with 95% of the aggregate being used to create the full bituminous mix. Reclaimed asphalt pavement is increasingly being used as a replacement for natural aggregates in order to conserve the natural aggregates. RAP substitution in bituminous concrete lowers the cost of flexible pavement construction while also gives satisfactory results. This review paper's goal is to provide information on the suitability and application of reclaimed asphalt pavement in bituminous mixes, as well as PET (Polyethylene Terephthalate) as a bitumen modifier. Researchers conducted laboratory studies to examine the Marshall stability, durability, fatigue, and rutting performance of Hot Mix Asphalt (HMA) with varying percentages of RAP and PET. According to the comprehensive studies the maximum Marshall stability, rutting, and fatigue achieved at 30%-50% RAP and PET at 7% and 8%.*

Key Words: **Reclaimed Asphalt Pavement (RAP), Polyethylene Terephthalate (PET), Rutting, Fatigue, Marshall stability, Durability.**

1. INTRODUCTION

The most common form of road paving, utilized all over the world is asphalt pavement. Due to degradation and failures in the form of fatigue, rutting, and moisture damage, maintaining asphalt pavements places a significant financial strain on transportation authorities. One of the most frequent failures in asphalt pavements is rutting or deformation **[1].** In terms of constructing the roads, it mostly pertains to the ingredients of mineral asphalt mixtures are natural aggregates and bitumen (made from crude oil). In order to preserve natural resources, it is essential to look for ways to use waste materials in asphalt pavement and to create circular economic systems that use recycled materials like Reclaimed Asphalt Pavement (RAP), steel slag etc **[2].** Pavement recycling is a logical and practical way to conserves our diminishing of construction supply materials and to reduce the cost preserving our existing pavement network. Recycling of pavements by re-using the existing materials will protect natural resources for future generation **[3]**. RAP materials have proved to be a cost-impactive and useful resource due to rising construction and pavement maintenance costs **[5]**. To utilize such wastes, pavement researchers and engineers have strived to develop novel ideas to apply and recycle the industrial-pavement wastes in constructing new pavements, rehabilitation works, trenches, embankment fillings **[6].** The waste generation of PET is increases due to the highly use of water bottle, juice bottle, shampoo container and other plastic storing PET container. The use of polymer, fiber and other waste can enhance the property of virgin binder. The addition of waste plastic materials such as polyethylene terephthalate (PET) into asphalt pavement may potentially improve the durability and overall performance of pavement mixtures **[7]**. Polymer modification of asphalt binders is becoming more common in the design of high-performance pavements. The addition of polymers to bitumen has a significant impact on the engineering qualities of asphalt binders **[8].**

1.1 Reclaimed Asphalt Pavement (RAP)

Asphalt and aggregate containing removed and/or reprocessed pavement components are referred to as reclaimed asphalt pavement (RAP). These materials are created when asphalt pavements are removed for construction, resurfacing or to gain access to subsurface systems. After being meticulously crushed and screened, high quality, well graded aggregates are used to create RAP. Asphalt pavement removal typically involves milling or full depth removal. A milling machine is used to remove the pavement surface during milling, and it is capable of removing up to 50 mm of pavement thickness in a single pass. The pavement may be broken and shattered using a bulldozer's rhino horn or pneumatic pavement breakers during full-depth removal. A front-end loader typically picks up the broken pieces, loads them onto haul trucks, and transfers them to a processing facility. This facility uses a variety of techniques to handle RAP, including crushing, screening, conveying, and stacking **[U.S. Department of Transportation, Federal Highway Administration Research and Technology].** RAP image is shown in Figure 1. The table 1 below shows the physical properties of RAP aggregates **[9].**

Table 1 Physical properties of RAP aggregates **[9]**

Property	Reclaimed asphalt pavement
Moisture content (%)	0.23
Specific gravity (SSD)	2.12
Water absorption (%)	1.0
Los Angles abrasion (%)	33.6

Fig 1 Reclaimed Asphalt Pavement

1.2 Polymer

There are various polymers that can be recycled in bitumen **[10**]. These include low and high density polyethylene (LDPE, HDPE), which are frequently used in packaging and plastic bottles; and polypropylene (PP), which is commonly used in straws, sweet wrappers, textile, vehicle, and furniture sectors **[11].** Polyvinyl chloride (PVC) is utilized in plumbing pipes and fittings; polyethylene terephthalate (PET) is commonly used in water and soft drink bottles; and acrylonitrile butadiene styrene (ABS) is used in electronic equipment such as laptop computers and mobile phones. Some of these elements would be ineffective in the production of recycled polymer modified bitumen **[12].**

1.2.1 Polyethylene Terephthalate (PET)

PET is a thermoplastic polymer that is widely utilized throughout the world. PET garbage includes items such as bottles, foils, and cables. Recycling leftover PET plastics can help reduce environmental pollution, conserve natural resources, and save energy and money **[13].** Virgin PET is a superior material for certain applications. This material offers a high tensile strength, adequate thermal stability, chemical resistance, processing capability, color capability, and clarity **[14].** It can be created under normal pressures and temperatures. PET can be made from petroleum hydrocarbons by reacting ethylene glycol with Terephthalate acid **[15].** The basic physical and chemical properties of commercially-used PET plastics are indicated in Table 2 **[14].** Figure 2 shows an image of PET in shredded form

Table 2 Physical and chemical properties of PET **[14]**

Property	Test Method	Value (Unit)
Molecular weight	-	192 (g mol^{-1})
Density	-	1.41 (g cm^{-3})
Melting temperature	(DSC)	265 (^{o}C)
Tensile Strength	-	1700 (MPa)
Yield strain	Tensile	4 (%)
Impact strength	ASTM D256-86	90 (J m^{-1})
Water absorption	-	0.5 (%)

Fig 2 Polyethylene Terephthalate

2. LITERATURE REVIEW

T. A. Pradyumna, et.al. (2013) investigated the mechanical characteristics of hot mix asphalt with incorpation of RAP (20%) to improve the performance of mix. Various tests were conducted such as Modulus test, moisture content, resilence rutting test, susceptibility test and it was found that mixes which was prepared with 20% RAP gave higher results than the conventional mixes under same conditions **[16].**

R Izaks, et.al. (2015) conducted study on mixtures with high RAP content to fulfil local volumetric properties with and without RAP(30% and 50% RAP)and fatigue and rutting characteristics were investigated. The results showed that there was a minor improvement in rutting and fatigue resistance when compared to standard mixes, but no visible changes in flow, hence it was suggested that up to 50% RAP may be used to meet the volumetric characteristics and performance requirements **[17].**

Mahendra S. P., et.al. (2016) evaluated the performance of asphalt mixes with varying amounts of PET waste as a bitumen modifier (2%, 4%, 6%, 8%, and 10%). Laboratory tests such as the Marshall test were performed with varied percentages of bitumen and 8% PET was found to be optimal based on Marshall stability and flow. Except for PET 10%, Marshall stability improved by 25% as compared to conventional mix. It was discovered that increasing PET percentage decreased flow value,% air void and voids in mineral aggregates, and increased the number of voids filled with bitumen **[18]**.

Anand Sreeram, et.al. (2018) evaluated the performance of asphalt mix prepared with PET and RAP at 15%, 30% and 50% and mixtures were undergone for Marshall stability test and indirect tensile stiffness modulus test, it was discovered that mixtures containing 2% PET and RAP showed enhancement in Marshall stability and Marshall quotient as well as greater resilience to permanent deformation **[7]**.

Ponnnada Sudheer, et.al. (2019) examined the rheological parameters of asphalt mixes with PET incorporation to improve bitumen properties. To determine the optimal % of PET, various laboratory tests such as softening point, ductility value, elastic recovery, specific gravity flash, fire point, penetration, and Marshall stability were done. It was discovered that 5% and 7.5% PET can be utilized to improve the rheological properties of bitumen **[19].**

Umar Hayat, et.al. (2020) studied the use of PET in percentages (2%, 4%, and 6%) and recycled asphalt in percentages (20%, 30%, and 40%) in asphalt mix. Penetration and softening point tests were carried out to determine the optimum content of PET and marshall stability, and DSR tests were carried out on samples prepared with the above contents to determine their properties. It was concluded that 4% PET and 30% RAP improved rutting resistance and Marshall stability **[20].**

Prabhakar Kumar, et.al. 2019) incorporated the RAP into asphalt mix, samples with 15% and 25% RAP were prepared and optimum binder content was determined. Test such as Marshall stability was conducted and results showed the increment in Marshall stability at 15% RAP **[21].**

P. Gireesh Kumar, et.al. (2020) Studied the effect of RAP material over virgin material in asphalt mix. A marshall test was performed on mixtures prepared with RAP at 0%, 30%, 40%, 50%, and 100%. Marshall stability was found to be increased by 13.71% with 50% RAP as compared to a standard mix made without RAP. It was also discovered that using RAP 100% leads in weak and unstable pavement since the flow and total stability values are significantly lower than the limitation value **[22].**

Tuleshwar Choudhary, et.al. (2022) investigated the use of RAP mixed with plastic trash as a road pavement material. RAP was used as coarse aggregate, and plastic (6%, 8%, 10%, and 12% by weight of bitumen content) and 25% RAP content were used to make the mix. According to the requirements, the maximum Marshall stability value was increased by 20% at 8% plastic content and at 25% RAP **[23].**

Table 3 Comparison of literature reviews

S. No	Author	Year	Material	% of RAP	% of PET	Optimum values	Strength Tests	Results
1	Pradyumna et.al.	2013	RAP	20%	-	20% RAP	Fatigue resistance Rutting resistance	Fatigue resistance increased by 67.2%, Rutting resistance increased by 7.14%
2	Mullapudi et.al.	2015	RAP	0%,15%,25%, 35%,50%	-	35% RAP	Fatigue resistance	Fatigue resistance increased by 20.08%
3	Izaks et.al.	2015	RAP	30%, 50%	-	30% RAP	Rutting resistance	Rutting resistance increased by 47.05%
4	Mahendra S.P. et. al.	2016	PET	-	2%, 4%, 6%, 8%, 10%	8%PET	Marshall stability and flow	Marshall stability increased by 57.61%, Flow decreased by 7.35%
5	Anand Sreeram et. al.	2018	RAP PET	15%, 30%, 50%	2%, 4%	50%RAP 2% PET	Marshall stability Rutting resistance	Marshall stability increased by38.83%, Rutting resistance increased by 5.59%
6	Ponnanda Sudheer et. al.	2019	PET	-	0%, 2.5%, 5%, 7.5%10%	7.5% PET	Marshall stability	Marshall stability increased by 19.22%
7	Umar Hayat et. al.	2019	RAP PET	20%,30%, 40%	2%,4%,6%	30% RAP 4% PET	Rutting resistance Marshall stability	Rutting resistance increased by 66.67%, Marshall stability increased by 25%
8.	Prabhakar kumar et. al.	2019	RAP	15%, 25%	-	15% RAP	Marshall stability	Marshall stability increased
9	Gireesh kumar et. al.	2020	AP	0%,30%,40%, 50%,100%	-	50% RAP	Marshall stability	Marshall stability increased by 13.71%
10	Tuleshwar choudhary et. al.	2022	RAP PET	25%	6%, 8%, 10%, 12%	8%PET	Marshall stability	Marshall stability increased by 23.67%

3. CONCLUSIONS

In this review paper, different laboratory tests were conducted by researchers to evaluate the combined effect of PET and RAP in asphalt mix. On the basis of literature reviews and studies, the conclusions are as follows.

1. The use of RAP in conventional mix could solve the problem of disposal of RAP and using RAP in certain percentages reduces the use of natural aggregates and also reduces the cost of construction of flexible pavement.

2. The partial replacement of PET at certain percentages enhances the mechanical and rheological properties of virgin binder. The addition of PET (waste plastic bottle) can be an alternative strategy for decreasing pavement deterioration and increasing asphalt mix properties.

3. The use of RAP up-to 30% shows positive results towards fatigue resistance in asphalt mix and RAP up to 50% gives satisfactory results towards rutting resistance. Rutting resistance increases as percentage of RAP increases.

4. It was found that the use of RAP up to50% could be used in asphalt mix to achieve satisfactory results of Marshall stability, rutting, resistance and fatigue resistance.

5. Plastic addition to bitumen should be limited to the optimum amount; over this level, rheological qualities and stability value decreases, which is not recommended for appropriate pavement design.
6. The use of PET as a bitumen modifier up to 8% improves the Marshall stability as well as rutting resistance of asphalt mix.

7. When combined with RAP, PET provides excellent rutting resistance up-to 66% and increases Marshall stability up to 38%.

According to the literature comparison in Table 3, the overall performance of asphalt mix has improved with the incorporation of RAP as a partial replacement of natural aggregates and PET as a bitumen modifier. Using RAP and PET enhances the Marshall stability by 6% to 57%, the rutting resistance increased by 6% to 66% and fatigue resistance was increased by 20% to 67%.

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