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# A REVIEW ON THE MODIFICATION OF BITUMEN USING WASTE PLASTIC FOR SUSTAINABLE FLEXIBLE PAVEMENT CONSTRUCTION

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## ABSTRACT

As per the rising production of plastic waste and the demand for a durable and sustainable road infrastructure, the utilization of waste plastic as bitumen modifier has also been promoted. The potential of waste-plastic modified bitumen for flexible pavement construction is discussed in this review, with particular emphasis on the various types of plastic, the modification techniques and the effects on the properties of the bituminous binder and mixture. The most commonly investigated plastics are: LDPE, HDPE, PP, PET and PS, the latter of which can be used to change the stiffness and temperature sensitivity of bitumen. In general, the literature reviewed shows that plastic incorporation decreases penetration and increases the softening point, the viscosity and the stiffness, while appropriate plastic contents could increase the Marshall stability, the rutting resistance and moisture performance. However, the high plastic content can result in low ductility, poor workability and phase separation. The review also emphasizes on environmental advantages of plastic waste utilization, along with problems with aging, compatibility and release of microplastics and long-term performance. In general, the best plastic content and process conditions are needed to ensure suitable performance of pavements.

**Keywords:** Waste Plastic, Modified Bitumen, Polymer Modification, Flexible Pavement, Marshall Stability, Sustainable Road Construction.

## 1. INTRODUCTION

Road transport is central to the development, mobility and transport of people and goods. Flexible pavements represent a significant fraction of the roadway infrastructure as they are relatively easy to construct and maintain and can withstand the stresses imposed by traffic [1]. In flexible pavement systems, bitumen is an important material that has many functions, such as holding aggregate particles together and providing the pavement with cohesion, flexibility, and protection against actions of traffic and environment.

Although the use of conventional bitumen has become commonplace, it has certain drawbacks. It is highly temperature and load dependent [2]. Under repeated traffic loads at high temperature, bitumen softens, and is likely to become permanently deformed, causing rutting and shoving. If temperatures are too cold, too much stiffness can result in cracking. Various other factors contribute to pavement durability, such as long-term ageing, oxidation, water and repeated traffic loading. Modification of bitumen has therefore been an important approach to enhancing the engineering properties of the bitumen.

One of the methodology approaches which are established for providing the properties of bitumen is polymer modification. The use of conventional polymer modifiers has been found to provide properties of stiffness, elasticity and temperature susceptibility but the increasing cost of virgin polymers and their reliance on petroleum derived materials have led researchers to consider recycled and waste polymer materials. Of these materials, waste plastic is especially appealing due to its ubiquitous presence and severe disposal issues in the environment.

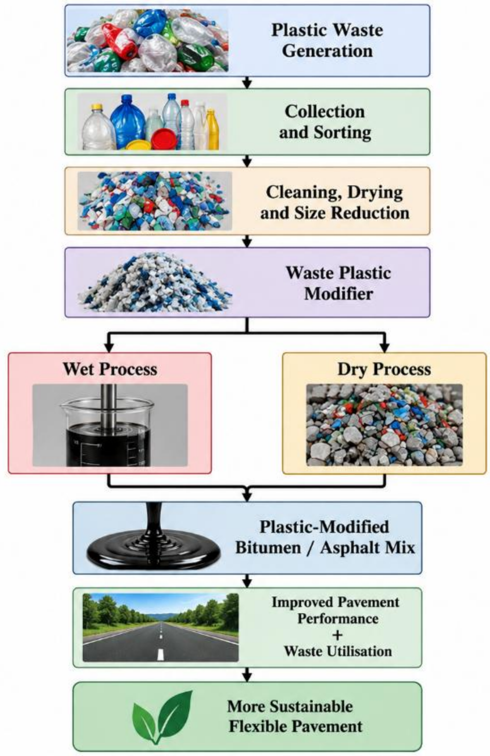


**Figure 1:** Conceptual relationship between plastic waste management and modified bitumen production [3]

Plastic wastes are very stable in the environment, and may not be significantly degraded naturally for extended periods of time. It has raised growing concerns due to its build-up in landfills, drainage, water bodies, and the environment [4]. The benefit or risk of using selected waste plastics in pavement materials is that it is an opportunity to transform a waste stream into a useful engineering resource. Some recent reviews have noted that waste-plastic modification can enhance a number of pavement properties and aid in waste diversion and achieving waste circularity goals.

The present review is thus limited to bituminisation of waste plastic to flexible pavements. The review covers waste plastics characteristics, modification mechanisms and techniques, binder and mixture properties and their effects on waste plastics, environmental aspects, limitations and future research needs.

## 2. BITUMEN AND THE NEED FOR MODIFICATION

Bitumen is a complex hydrocarbon material that is influenced by its chemical composition, temperature and loading conditions to affect its engineering behaviour. In flexible pavement, it acts as a binder to bind mineral aggregates together and to support the structure of the pavement layer. The engineering properties of bitumen are penetration, softening point, ductility, viscosity, specific gravity and temperature susceptibility.

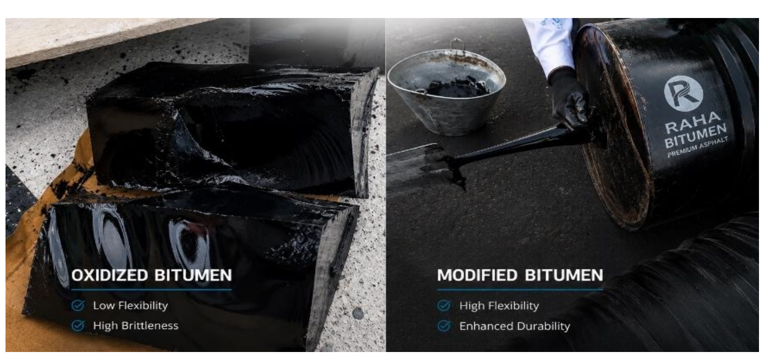


**Figure 2:** Bitumen [5]

There are some limits to conventional bitumen under different environmental and loading conditions. Its stiffness and viscosity reduce with high temperatures, leading to increased susceptibility to permanent deformation and rutting. As temperatures decrease, the stiffness and brittleness of the polymer may increase which can lead to thermal cracking. Oxidation, ageing, repeated traffic loading and moisture exposure are other factors that may impact its long-term performance [6]. Therefore, polymer and waste material modification of bitumen has received extensive research attention to enhance the engineering properties and pavement performance of bitumen.

Waste plastic has been the subject of much attention regarding its suitability to be used as a bitumen modifier, as well as being an opportunity for waste utilization. The properties of various polymeric wastes may affect the stiffness of the binder, temperature susceptibility, and other properties, and the use of these wastes in pavement materials may lead to a decrease in the amount of plastic that needs to be disposed of in the conventional manner. There are many waste plastics and modification methods that have been discussed in the previous reviews such as wet process and dry process.

**Table 1:** Review of previous studies on bitumen modification using waste plastic

| Study | Focus | Method | Key Findings |
|---|---|---|---|
| Shah et al. (2025) [7] | Plastic-modified asphalt | Wet and dry processes | Improved pavement performance; compatibility remains important. |
| Nizamuddin et al. (2021) [8] | Recycled polymers as modifiers | Polymer blending | Polymer modification improves binder properties. |
| Rahman et al. (2020) [9] | Waste materials in asphalt | Recycling and incorporation into asphalt | Waste materials have potential for sustainable pavement construction. |
| Noor & Rehman (2022) [10] | Plastic waste in bituminous mixes | Wet and dry mixing | Plastic can improve pavement performance and waste utilisation. |
| Mahida et al. (2023) [11] | Polymer additives | Polymer modification of bitumen | Polymers can improve binder and pavement characteristics. |
| Bilema (2024) [12] | Plastic type, dosage and mixing | Wet and dry processes | Performance depends on plastic type, dosage and processing conditions. |

The review literature shows that bitumen's susceptibility to plastic modification is dependent on the type of polymer, polymer concentration, particle size, mixing temperature, and the processing method and compatibility of the polymer with the bitumen. Hence, waste plastic cannot be treated as a single modifier since various types of plastic may lead to different modification effects on binder and mixture properties.

Penetration is a measure of the consistency or hardness of bitumen at a certain temperature. If penetration is reduced after the modification, then it is an indication that it will be stiffer. Softening point is the temperature at which bitumen becomes a certain degree of softness under specified conditions [13]. The higher the softening temperature, the greater the resistance to deformation at higher temperatures.

Ductility is a measure of how far a bituminous material can be stretched without failing. A good ductility is desired for the ability to withstand tensile strains, but the ductility can be reduced due to the stiffness induced by some polymers. Therefore, only one property of the binder cannot be used to assess the degree of modification; a combination of stiffness and flexibility and temperature sensitivity is needed.

Under proper processing conditions, polypropylene and other thermoplastics, which can melt when heated, can be blended into bituminous systems. The extent of interaction, however, is dependent on the type of polymer, structure of the polymer, size of particles, concentration, mixing temperature, mixing time, and compatibility with the bitumen. These factors are of importance, then, in selecting an appropriate waste plastic and in deciding the optimum level of waste plastic in the pavement.

## 3. WASTE PLASTIC AS A BITUMEN MODIFIER

Waste plastics can be used for modification of bitumen, and may come from packaging material, bags, containers, bottles or other post-consumer or industrial plastic products. The polymers most commonly investigated are low-density polyethylene (LDPE), high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS), and, in a few studies, polyvinyl chloride (PVC) [14].

Polyethylene based plastics are among the most often studied modifiers owing to their thermoplastic properties and the presence in plastic waste generated in municipal collections. LDPE and HDPE have been extensively researched for creating stiffer binder and high temperature resistance. Similarly, PP has also been shown to increase the stiffness, and PET has been tested as both a binder modifier and as an asphalt mixture component.

The behaviour of different plastics is not identical. The dispersion and performance of the pavement are affected by differences in melting properties, polarity, crystallinity and compatibility with bitumen. As a result, it has been noted that there is a need to take into account the type of plastic and the processing method used when interpreting the results as not all waste plastics will have the same effect.

**Table 2:** Common waste plastics investigated for bitumen modification [15]

| Waste plastic | Typical source | General effect on bitumen | Potential advantage | Major concern |
|---|---|---|---|---|
| LDPE | Plastic bags, packaging films | Reduces penetration; increases stiffness and softening temperature | Improved high-temperature performance | Phase separation at excessive dosage |
| HDPE | Containers, bottles, packaging | Increases stiffness and softening point | Improved rutting resistance | Compatibility and storage stability |
| PP | Packaging, household products | Generally, increases stiffness | Improved deformation resistance | Processing and dispersion |
| PET | Bottles and containers | Can improve stiffness and mixture strength | Waste utilisation and strength improvement | High melting temperature and compatibility |
| PS | Packaging and consumer products | Can increase stiffness | Potential high-temperature benefit | Brittleness and processing concerns |
| PVC | Pipes, packaging and other products | May significantly modify penetration and softening behaviour | Potential waste utilisation | Thermal degradation concerns |

Another important factor is the quantity of plastic added to the bitumen. The literature values show a wide range of values depending on the type of plastic and the modification method used. There are a number of quantitative studies reporting that in general, plastic additions have a negative effect on penetration and a positive effect on softening point and viscosity of the mixtures, although the observed changes vary significantly between these studies [16]. For polyethylene binders, it has been found through some systematic analyses that the amount of plastic, typically 4–5% by weight of the binder, is commonly reported as the effective range, but this should not be taken as indication of a universal optimum since optimum amount of plastic depends on the material and processing condition.

## 4. METHODS OF WASTE PLASTIC MODIFICATION AND ITS EFFECT ON BINDER PROPERTIES

Waste plastic can typically either be added as a wet process or a dry process to asphalt systems.

The wet process involves shredding or pulverizing the plastic and mixing it directly with the heated bitumen prior to mixing the modified bitumen with the aggregates. The aim is to achieve good dispersion of the polymer in the binder [17]. Mixing parameters, such as temperature, mixing time and shear level, are important because the mixing may be insufficient to achieve an even dispersion and high enough temperature can result in undesirable degradation of some polymers.

The dry process introduces waste plastic mainly when asphalt mixture is being prepared, which is frequently by mixing heated aggregates with plastic and then adding the asphalt cement. In this method, depending on the form and processing conditions, plastic can be used in part as a modifier or in part as a coating or as an aggregate-related material [18].

Some studies have shown that both methods can enhance the performance of an asphalt, depending on the behaviour tested and the plastic properties and order of addition. In a critical assessment of plastic waste in asphalt mixtures, it was found that the addition of HDPE and LDPE typically improves the Marshall stability of an asphalt mixture and can also decrease the air voids, with the optimum binder content potentially needing to be re-optimized for modified mixtures.

a) **Penetration:** Reduction in penetration has been a consistently reported effect of waste plastic incorporation. That means that the modified binder is harder or stiffer than the unmodified binder. A decreased penetration value may be beneficial in hot weather as the stiffer the binder, the less it will deform [19]. Reduced penetration is a common overall reaction to plastic addition, but it is dependent on the type of plastic, the amount of plastic added, plastic processing conditions, etc.
b) **Softening Point:** Generally, the softening point rises after plastic modification. This is especially important for flexible pavements under conditions of high pavement temperatures. The higher the softening point the more heat resistant the binder will be before it becomes too soft. The increase is often associated with the formation of a polymer-rich phase or polymer network within the bitumen. However, if too much polymer is added, it could lead to insufficient dispersion or phase separation and therefore decrease the desired effect.
c) **Ductility:** Plastic can be introduced which makes the binder stiffer and reduces ductility. Careful consideration is required in this response as too much reduction in ductility can result in the pavement cracking under low temperature or repeated tensile loading [20]. So, there should be an optimum plastic content between enhanced high temperature stiffness and acceptable flexibility.
d) **Viscosity and Workability:** The viscosity of plastic is usually increased by modification. Increased viscosity may provide greater resistance to deformation, but may also make pumping, mixing and compaction more difficult. Thus, the temperature at which the modification should take place and the length of the mixing period should be carefully monitored. The increase in viscosity is particularly important when relatively high plastic dosages are used. Literature reviews have thus suggested a way to control the amount of plastic, instead of maximizing it.

## 5. EFFECT ON MARSHALL AND PAVEMENT PERFORMANCE

The binder properties mentioned in the above are all important factors that affect the performance of the complete bituminous mixture. Marshall testing is commonly used to test the stability and flow of asphalt mixtures and is especially relevant to the laboratory evaluation of modified bitumen systems.

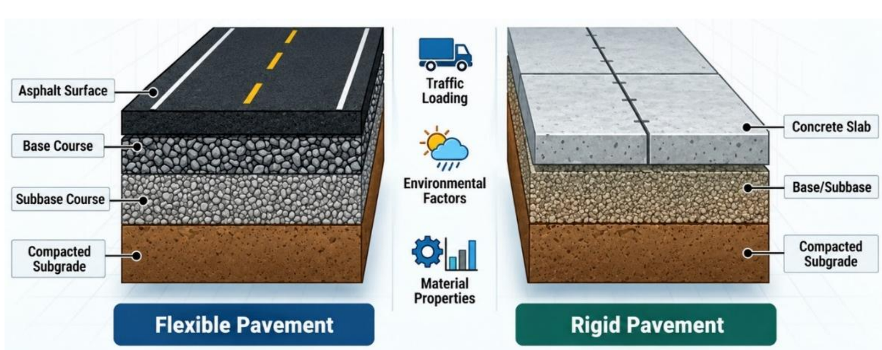


**Figure 3:** Pavement Design [21]

Marshall stability is the maximum load of a compacted specimen when subjected to standard loading. Some research has indicated improvement in the Marshall stability after adding appropriate waste plastics. This improvement is generally linked to the increased stiffness and the enhancement of the binders-aggregate bond.

But the more stable the mixture, the harder it is to say whether it is the best mixture. If the stiffness is too great, the chances of cracking are higher and flexibility will be lower. Therefore, the Marshall stability should be analyzed in conjunction with flow, density, air voids and other volumetric properties [22].

Marshall flow is the deformation at maximum load. Depending on the type of polymer and dosage, plastic modification can increase or decrease the flow. Low flows may be related to stiffness, but too low flows may be attributed to a too stiff mixture.

Important too are bulk density and air voids. The addition of plastic may change the packing and coating properties of the mixture. Reduction in air voids after using LDPE and HDPE has been reported in some studies, depending on the mixing method and dosage of plastic.

Rutting resistance is one of the major potential advantages of plastic modification, beyond Marshall properties. Higher temperature stiffness may help to minimise permanent deformation when subjected to repeated loading. Recent reviews also indicate that the selection of these types of plastic and the dosage thereof may yield potential benefits in terms of fatigue and moisture-related performance.

However, these enhancements are not across the board. There are significant differences in the experimental studies in the literature due to variations in binder grade, aggregate type, plastic characteristics, particle size, mixing temperature, and testing procedures. Thus, caution should be used when making comparisons between studies.

## 6. ENVIRONMENTAL AND SUSTAINABILITY IMPLICATIONS

The environmental rationale behind waste-plastic modified bituminous is to achieve both the goals of waste utilisation and pavement material improvement at the same time. Waste plastic could be a valuable ingredient in road construction.

Circular-economy viewpoints are that the use of appropriate waste plastic in pavement materials can be a way to extend the value of polymeric materials for longer than as waste. It could also lead to the decrease of the usage of virgin polymer modifiers [23].

Recent reviews have highlighted the need for assessing the environmental advantages of plastic modified asphalt throughout the entire life cycle. The environmental outcome is determined by collection, sorting, cleaning, shredding, transportation, processing temperatures, pavement service life and end-of-life management. Therefore, it is not always an environmental benefit to reuse waste plastic in all scenarios.

Environmental benefits may be: less plastic waste for disposal, savings in virgin polymer, and possibly longer pavement life. Potential gains in material and energy savings may occur if durability decreases maintenance/repair needs.

Meanwhile, the environmental hazards have to be taken into consideration. Emissions or degradation products are undesirable when certain plastics are thermally processed. Microplastic release and the end-of-life behaviour of plastic pavements are also emerging research issues. Microplastic release and recyclability, and the need for region specific life cycle assessments, have been identified as key research gaps in recent comprehensive reviews.

Hence, sustainability assessment should not just address the waste utilisation benefit, but the entire life cycle of the modified pavement.

## 7. CHALLENGES, RESEARCH GAPS AND FUTURE SCOPE

Although the performance of waste-plastic-modified bitumen has proven to be significant, a number of issues have to be resolved to make this material suited for wider use. Compatibility of plastic–bitumen is one of the prime issues. The mixing may not be uniform, and various plastics can have different interactions with bitumen, which can lead to non-uniform binder properties [24].

The choice of optimum plastic content is another important issue. Higher amounts of plastic do not necessarily mean better pavement performance. Too much plastic can cause the material to become stiffer and more viscous, and make it less ductile and workable. Thus, the best content should be determined by considering several properties of the binder and mixture.

There is the issue of low temperature performance, too. While increased stiffness may help resist rutting at high temperatures, too high a stiffness can increase the risk of thermal cracking. Likewise, the impact of ageing, moisture, traffic loading and temperature variations over time would benefit from additional laboratory testing and field trials.

Other factors that contribute to this difficulty in comparing results from various studies include variations in plastic types, particle sizes, preparation processes, testing methods, and temperatures during testing. Standardized testing and preparation, thus, is required.

Long-term ageing, rutting and fatigue resistance, moisture susceptibility, low temperature cracking, storage stability, microplastic release, field testing, life cycle assessment and economic feasibility are suggested for future research [25]. The standardization of the preparation and use of waste-plastic modified bitumen would further aid the use of waste plastics in the development of sustainable pavement solutions.

## 8. CONCLUSION

The review concludes that the waste plastic has a good potential to use as a bitumen modifier in sustainable flexible pavement construction. The use of appropriate plastic types, especially pel and polyethylene-based types, can help to enhance the desirable properties of binders and mixtures, including penetration and softening point, viscosity, stiffness and, within an acceptable range, Marshall stability and rutting resistance. Meanwhile, the benefits are greatly influenced by the type of plastic, dosage, particle size and mixing process and conditions. Modifications must be avoided beyond a certain limit because they can decrease ductility, create workability difficulties and lead to phase separation, thus it is important to choose the right plastic content. Waste-plastic modification also offers a chance to decrease plastic waste, and help conserve resources and achieve circular-economy goals. But there are worries about aging, low-temperature cracking, storage and shelf life, microplastic leaching and long-term field performance. In summary, waste-plastic-based bitumen can play a role in the creation of long-lasting and environmentally friendly pavements, provided that material compatibility, optimum dosage, processing conditions, and long-term environmental and engineering performance are properly considered.

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