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# A Review on utilizing waste Polyethylene terephthalate in composite bituminous mixes

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## *Abstract*

*Rapid ascend in population growth has led to a corresponding rise in annual Polyethylene Terephthalate waste and others Polymers production. This underscores the urgent necessity to reuse discarded polymers like Polyethylene Terephthalate, Poly Vinyl Acetate, Low Density Polyethylene etc. When discarded polymers isn't recycled, it typically finds its way into landfills, contributes to oceanic garbage patches, or undergoes incineration, each of which poses distinct environmental challenges. Moreover, controlling pollution from incineration facilities adds significant costs, rendering them unaffordable for many countries. Incorporating Thermoplastic waste including Polyethylene Terephthalate into flexible pavement presents an appealing solution as It lessens environmental problems while simultaneously improving pavement performance. Molten PET bottles and others thermoplastic waste can serve a dual purpose by coating aggregates and partially replacing bitumen in bituminous mixes. Utilizing this combination of polymer-coated aggregates and modified bitumen results in improved strength. Incorporating such mixes in road construction offers an effective means of utilizing polymers waste. Although the concept of utilizing waste polymers (Polyethylene Terephthalate) in bituminous road building is not new, its practical application is still lacking. While considerable efforts have been devoted to integrating waste into bituminous mixes, this review paper focuses on studies that use of Polyethylene Terephthalate (Thermoplastics) as modifiers in the bituminous mixture of flexible pavement.*

***Keywords:*** *Polyethylene Terephthalate, Low density polyethylene, Dry Process, Wet Process, Composite bituminous pavement.*

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## 1. Introduction

**Polymers waste a Problem-**

Energy conservation is the main focus in today's world and it is achieved by the implementing the use of composite waste materials. Polymers are lies in the category of lightweight materials and it is also the major threat of pollution in today's world. As per the state pollution control board (SPCB) the estimated polymers waste generation during year 2020-21 41,26,297 Tons per Annum (TPA). As we know plastic waste cannot be disposed by dumping or burning, because the contaminate the earth and vegetation also.

The waste produced from polymers will remain in environment for thousands of years. Polymer is also a major threat to water bodies also. Of all the polymers produced, just 8.7% are recyclable. Meanwhile, 75.6% end up in landfills, and 15.7% are burned for energy recovery [1].

**Types of Polymers -**

Polymers can be classified as thermoplastic or thermosetting based on their physical properties. Thermoplastic materials may be formed into the appropriate shapes by applying pressure and heat, hardening when cooled, and then being reshaped in the same way. In contrast, once thermosetting materials are shaped, they cannot be softened or reshaped through heat application. Thermosetting materials are not used in pavement. Polymers can also be categorized based on their chemical origins. There are four primary groups according to polymer sources: Fibers, cellulose plastics, protein plastics, natural resins, elastomers, and synthetic resins.

*Table 1. (Type of Thermoplastic and Thermosetting resins)* [2]

| **Thermoplastic** | **Thermosetting** |
|---|---|
| (PET) Polyethylene Terephthalate | Melamine |
| (PP) Polypropylene | Polyester |
| (PVA) Poly Vinyl Acetate | Bakelite |
| (PVC) Poly Vinyl Chloride | Epoxy |
| (PS) Polystyrene | Alkyd |
| (LDPE) Low Density Polyethylene | Polyurethane |
| (HDPE) High Density Polyethylene | Urea Formaldehyde |

**Polymers modified flexible pavement-**

In the development of nations like India, the construction of flexible pavements holds significant importance. Highway construction primarily comprises three components: the Subgrade, Base course, and Surface course, with the latter also referred to as the pavement layer. The Surface course can be categorized into two main types: Rigid and Flexible pavement. Bituminous pavement, a type of flexible pavement, is created using a blend of aggregates (both coarse and fine), binder, and filler, where bitumen serves as the binding material once again.

Pavement construction should only use polymers that comply with the requirements for PET, Polyurethane, high-density polyethylene (HDPE), and Low-Density Polyethylene (LDPE).

Many research on the use of polymers debris in bituminous pavement have been carried out throughout the years. The bulk of papers are research studies that examine different polymers materials—such as waste-derived polypropylene (PP), polyvinyl chloride (PVC), and polyethene (PE)—that are used as modifiers. These studies employ diverse modification techniques, including wet, dry, or modified processes.

Consequently, there arises a necessity for a comprehensive review paper that synthesizes and consolidates the findings and methodologies employed across existing literature. Therefore, this study provides a brief summary, concentrating on the use of waste plastic as an ingredient modifier for the bituminous mix of flexible pavement.

Methods of polymers waste consumption-

- By using polymers waste in base and subbase for road constructions.
- By using as component in asphalt mix.
- Use as stabilizing agent in subgrade layer.
- Replacement of wood.

## 2. Objective of Study

The purpose of this study is to do a comprehensive evaluation of the literature on the use of different polymers in both wet and dry methods to change bituminous pavements. It starts by looking at bitumen changed with plastics using a wet method, exploring the altered effects, processes of modification, and possible difficulties. The various methods for improving the characteristics of mixes with binders modified with polymers are next summarized. The paper also describes common polymers by varying melting points, as well as bitumen mixed with plastic through a dry process. Finally, it suggests future ideas for bituminous mixes including plastics. The general format for this literature review is shown in Figure 1.

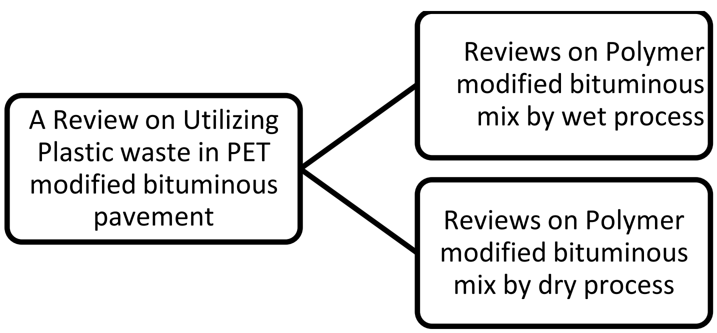


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*Fig. 1 Layout of Literature Review*

## 3. Reviews on Polymer modified bituminous mix by wet process.

The wet process of integrating polymer waste into bituminous mix involves initially sorting and preparing the plastic waste by shredding or granulating it into smaller pieces. The hot bitumen is then heated to a specific temperature range to ensure fluidity, typically between 150°C to 170°C (300°F to 340°F). Next, the shredded or granulated polymer waste is combined with the heated bitumen and thoroughly mixed until a uniform blend is achieved. This mixture is then combined with aggregate, such as crushed stone or gravel, to form the asphalt mix. Following mixing, the asphalt mixture undergoes compaction using standard equipment to ensure proper distribution and density. Finally, the polymer-modified bituminous mix is laid on the road surface and compacted again to achieve the desired thickness and smoothness. Figure 2 illustrate the wet process as follows-

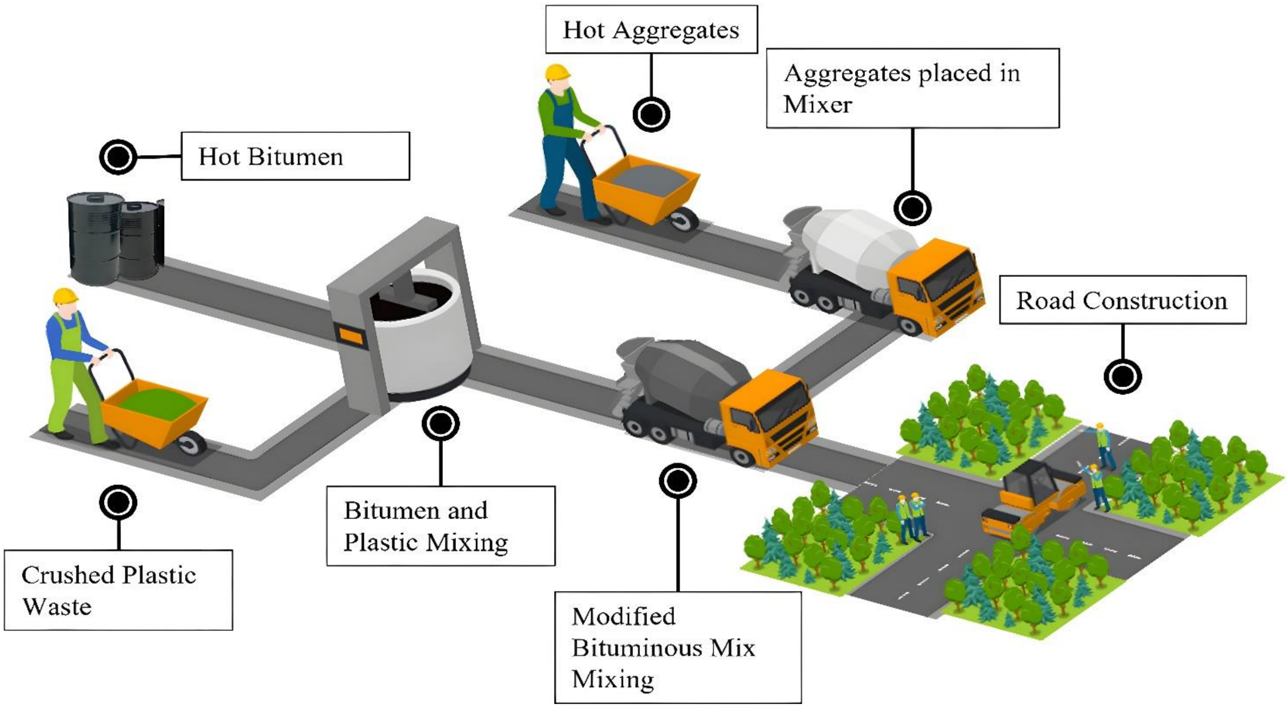


*Figure 2 Wet process* [3]

El-Rahman et.al explores how adding thermoplastic waste EVA copolymer (WEVA) to blown asphalt affects its elasticity. The study examines blending WEVA at 3%, 5%, and 7% by weight. It analyzes physico-chemical characteristics such as FTIR and TGA, and investigates physical properties like penetration, softening point, ductility, and elastic recovery, as well as the chemical composition, including oils, resins, and asphaltenes fractions. Flow properties are evaluated using a dynamic viscometer, and mechanical properties are assessed with a dynamic mechanical analyzer. Blending with 5% WEVA is found to enhance storage modulus and elastic recovery while reducing tan d. Overall, blending with 5% WEVA significantly enhances the performance of blown asphalt binder. [1]

Karmakar et.al research delves into utilizing waste plastic and tire rubber as substitutes for expensive polymer modified bitumen (PMB) in the construction of cost-effective roads. It addresses the pressing issue of escalating waste production, particularly plastics and tires, which pose environmental challenges in urban settings. Findings demonstrate that introducing 1% plastic mix to hot 60/70 grade bitumen enhances temperature resistance, viscosity, achieving congruency and cohesion akin to PMB 40 standards. [4]

EI- Naga et. al examines the effects of PTP on the characteristics and performance of asphalt pavement, aiming to quantify its benefits. KENPAVE software was used for quantification. Results showed improved binder characteristics and increased mixture strength with PTP. Optimal PTP percentage was found to be 12%, 2.8 times the lifespan of the pavement and a 20% reduction in the thickness of the asphalt layer. [5]

Garcıa-Morales et. al investigates modifying petroleum bitumen using four waste polymers sourced from recycling plants. Rheological testing and microscopy were among the analytical methods used to assess the modified bitumen's. Findings indicate that tire rubber and its blends enhance flexibility and resistance to traffic loading, while the EVA/LDPE blend shows promise at high temperatures due to polymer network development. Compatibility between bitumen and polymers varied, as revealed by calorimetry tests. [6]

Dechong Ma et al. investigated the process of grafted maleic anhydride (MAH) onto reclaimed polyethylene (RPE) (RPE-g-MAH) utilizing dicumyl peroxide (DCP) as the initiator in order to enhance the RPE polymer-modified asphalt mixture. The grafting is validated by the Fourier transform of infrared spectra (FTIR). The study examined the performance of the reformulated asphalt mixture with respect to several aspects such as gradation type, mixed temperature, wet mixing periods, DCP and MAH content, rutting depth (RD), dynamic stability (DS), and high-temperature stability. The findings demonstrate that RPE-g-MAH improves rutting resistance, low-temperature performance, and high-temperature stability. A proposed mechanism explains the modification process. [7]

In order to include plastic trash into BC mixes, Mishra Brajesh et al. used two different methods: the wet technique (WM) and the dry method (DM). The use of low-density polyethylene shredded plastic waste carry bags in BC mixes for flexible pavements with both WM and DM is compared in this study. Indirect tensile strength, flow value, Marshall stability value, and other tests were performed, and the outcomes were compared. According to the results, DM is the most successful approach since it is easy to use, economical, environmentally friendly, and produces better results. [8]

Polacco et.al crafted two PMA formulations: one for practical road paving applications and the other, with a high polymer content, for scientific inquiry. Direct observation of reaction within rheometer-loaded samples wasn't possible, materials were assessed after varying curing times to compare properties at different reaction stages. Curing notably increased viscosity and dynamic moduli in both formulations, indicating a propensity towards chemical gelation in asphalt-polymer systems. [9]

Gupta et.al research aims to explore Bakelite's impact on bitumen binder properties. Bakelite, with its polymer amorphous structure, enhances strength, hardness, and rigidity. Previous studies indicate its positive effects on modified bitumen mixes. Testing Bakelite in bitumen mixes from 1% to 5% increments shows promising results environmentally and economically. Incorporating Bakelite extends pavement lifespan, offering longer-lasting road surfaces. [10]

Vasudevan et. al studied that between 110°C and 140°C, plastics soften without emitting toxic gases. On the other hand, they usually produce a structure resembling a film when applied to aggregate at 160°C. This Polymer-Modified Composite Aggregate (PCA) improves flexibility in pavement construction. Combined with various types of hot bitumen, PCA enhances binding properties, though wetting properties are reduced. Roads constructed with PCA-bitumen mixes since 2002 have shown excellent performance, demonstrating increased load-bearing capacity and no pothole formation. This eco-friendly and cost-effective process has proven successful. [11]

## 4. Reviews on Polymer modified bituminous mix by dry process.

First, the aggregate mix is heated mixing facility to 150–175°C. utilizing an adequate dosing mechanism to guarantee that the waste plastic is not overheated close to the burner flame and adding the designated % of polymer waste to the drum of a drum mix plant. prior to the bitumen addition, covering the hot aggregates with used plastic. A binder's temperature that corresponds to the binder grade and mix type. Heat the bitumen to 150°C to 170°C and mix the plastic-coated aggregate for about 15 seconds, then transfer the mixture for road building. Applying hot bitumen and maintaining consistent coating quality may be achieved by utilizing a central mixing unit for improved temperature control and mixing. [2]. Fig 3 explains the dry process-

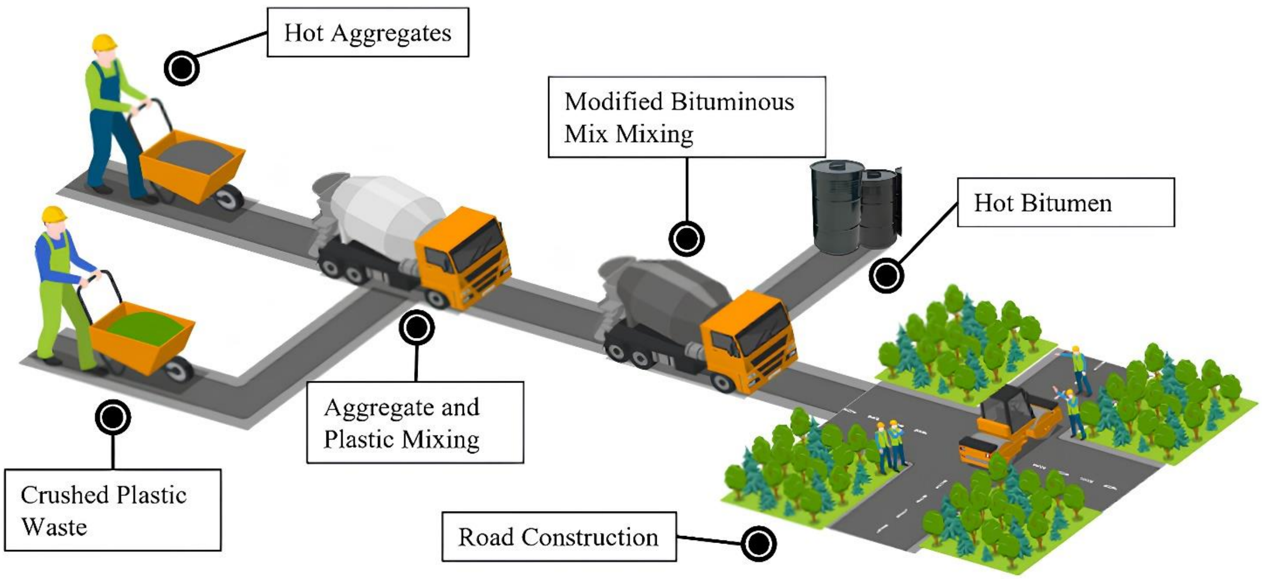


*Fig. 3 Dry process* [3]

The integration of polymer waste into asphalt mixes using a dry technique as a bitumen alternative was evaluated by Quesada et al. Two plastic scrap sizes—coarse and fine—were investigated. 10% less binder was used to create an AC16S semi-dense mixture, and 10% and 20% more plastic waste binder was added in coarse and fine size, respectively. The results of the Marshall stability and flow test showed a 2% decrease in the preserved tensile strength ratio, less moisture damage, improved indirect tensile strength, and more air void content. Moreover, in robust modulus and rutting tests, significant decreases in plastic deformations were seen in comparison to standard values. [12]

Khalid et. al incorporating PET filler in porous asphalt outperforms limestone filler in enhancing water-related effects, with stability measured at 16.9% versus 4.7% over a 4-day period. This indicates PET's potential to improve PAM behavior, thus reducing the environmental impact of plastic waste. The indirect tensile strength of the combination is increased by 27.16% for wet-conditioned samples and 29.08% for un conditioned samples when PET filler is added, due to its physical and chemical characteristics interacting with the binder, ultimately enhancing the mixture's performance. [13]

Wahhab et. al studied that the municipal solid waste (MSW) generation in Saudi Arabia surpasses 14 million tonnes annually, with plastic waste constituting about 10%. Local asphalt performance is challenged by high pavement temperatures exceeding 64°C. His study explores the effects of incorporating recycled plastics—high-density polyethylene (RHDPE). Improving high-temperature performance and dynamic storage stability is the goal. Results indicate improved performance, especially when combining RHDPE and RLDPE with SBS. However, excessive RPP content destabilizes the binder. [14]

Ameri & Nasr in their study examined the impact of TPE polymer modifications, derived from crumb rubber and recycled PET, on asphalt binders. Key findings include: Samples with modified binder demonstrated higher softening point and decreased penetration, with PMB-15 demonstrating higher resistance to rutting failure due to a higher PET percentage. Polymer modifications failed to meet Superpave binder specification limits for storage stability. Devulcanized PET enhanced asphalt binder fatigue resistance at intermediate temperatures. [15]

In Mikhailenko et al.'s study, unprocessed mechanical crushed CR and PET were used as substitutes for semi-dense bitumen (SDA) sand at 2.5 percent and 5.1% of the overall constituent mass, respectively. PET needed greater energy for compaction. While PET performed comparably to the control, particularly in FE, CR drastically lowered ITS, FE, and ITSR%. Air voids had a stronger correlation with sound absorption than did material type. CR notably reduced pavement texture, whereas texture remained consistent for PET despite porosity differences. Subsequent testing used aggregate volumes at 5.1% in place of PET, demonstrating a comparable compact ability but a worse resistance to deformation and breaking than the control. [16]

Rahman & Wahab studied asphalt mixtures were modified with recycled PET pallets, comprising 5% to 25% of the asphalt mixture weight, alongside 5% bitumen content. These underwent RLAT loading and ITSM to evaluate permanent deformation and stiffness, respectively. While stiffness decreased with PET modification, it improved permanent deformation properties. PET-modified asphalt mixtures are deemed suitable for road pavements from environmental and economic standpoints. [17]

According to Baradaran et al., adding an additive made of recycled PET improved the material's resilience to cracking, moisture damage, and rutting at low temperatures. In tests of ITS as well as SCB, the asphalt mixture containing 2% recycled PET outperformed the 1% mixture, however in tests of dynamic creep, the 1% mixture excelled. Statistical analysis confirmed the significant impact of recycled PET additive on asphalt mixture mechanical properties. [18]

Mashaan et al. used a hybrid additive consisting of waste polyethylene terephthalate (PET) and nano-silica (NS) to improve fatigue and rut in (SMA). SMA mixes were created by blending them with the C320 bitumen binder using a wet-mix technique. Nano-silica was added in different quantities (2%, 4%, 6%, and 8% percent weight of the binder). Based of the findings, overall performance enhanced by adding 4-8% Nano-silica to 6% waste PET. [19]

Utilizing reclaimed PET (polyethylene terephthalate) waste in asphalt mixes with highly-vesiculated leftover aggregates—which are usually rejected in the quarry manufacturing process—is examined by Franesqui et al. They examine the mechanical, compaction, and physical characteristics of these mixes with different binder concentrations with PET substituting a portion of the aggregate. The findings show that small quantities of waste PET (up to 1%), when added to base course and low-traffic paved surfaces, improve certain engineering features including water resistance and rutting. [20]

The usage of rubber asphalt with foliated quartzite debris in road pavements is examined in research by Gandhi et al. These substitute materials are nonetheless able to preserve structural integrity, even when they deviate from suggested norms in certain areas. In comparison to conventional combinations, mechanical testing reveals that the asphalt mixture including rubber and quartzite waste exhibits higher tensile strength and resilience, suggesting improved load-bearing capability and deformation resistance. The report advocates for more research on these materials and their usage to lessen environmental impact and reliance on traditional aggregates by highlighting their potential for sustainable pavement construction. [21]

Recycled manhole covers flour (CMC) and medium- density fiberboard (MDF) sawdust were investigated by Ayrilmis et al. for usage as fillers in recyclable polypropylene (PP) composites. In spite of a minor drop in tensile strength, the results indicated that adding fillers up to 40% increased modulus and bending strength. Maximum thermal stability was proven up to 400°C, and water absorption was negligible. The study proposes a sustainable and economical production technique for recycled PP composites by adding up to 40 weight percent of waste CMC and MDF flour to improve the composites' strength and water resistance. [22]

Palanisamy et. al. studied that composite made from natural fibers (NFRCs), which have gained popularity as environmentally acceptable substitutes for conventional substances like glass fiber in recent years. Natural fiber composites (NFRCs) made of bamboo, PALF, and other natural fibers have favorable characteristics such competitive mechanical strength, biodegradability, and light weight, which makes them attractive options for biomaterials. This article gives a quick introduction to NFRCs, going over their characteristics, developments, and variety of uses with an emphasis on how they benefit the environment. [23]

## 5. Conclusion

Waste made of polymers is harmful to the environment because it pollutes the air and fuels global warming. Incorporating polymer waste into bituminous mixtures (BM) offers potential benefits such as improved mechanical strength and chemical compatibility.

In summary, the report offers a thorough analysis of the literature on the use of polymers in pavements made of asphalt. It includes the polymers that are frequently used to alter asphalt through either wet and dry methods.

- The ensuing conclusions are as follows:
- The wet process resulting in effective for low melting points plastic. As it improves the rutting resistance and fatigue resistance in modified bitumen mix.
- The improved bituminous mix's resistance to moisture is further enhanced by the wet procedure.
- By adopting wet process in high melting point plastics results in increased in viscosity but it tends to decrease the ductility of the blended mix.
- Asphalt pavements may be made more resistant to moisture and rutting by using different types of polymers with the dry process. Higher melting point plastics are usually used to replace aggregates,

whilst lower melting point plastics can form a thin layer to improve adhesion between aggregates, asphalt, and plastics.

- Coating in a dry process is simple, and the needed temperature is the same as that of road laying.
- Dose of waste polymer in dry process is more as compared to wet process.
- The aggregate is to be mixed with waste polymers using the same machinery that makes bituminous mix.
- Wet mix is suitable only for low melting points plastics.
- Every kind of Thermoplastic may be used using the dry mix method.

**Future Scope**

For future studies the wet mix process is thoroughly studies for high melting points plastics. For better understanding the road section made with Polymers waste composite bituminous mix is to be studies thoroughly.

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