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Review ETCE

Comprehensive Review of EPDM (Ethylene Propylene Diene Monomer) Rubber

Sandeep Rai[1,*], Pradeep Uthale[2]

Abstract

The terpolymer elastomer known as ethylene propylene diene monomer (EPDM) is made up of ethylene and propylene with trace amounts of a non-conjugated diene as a third monomer. This elastomer was created using the idea of limited olefinic functionality, which is brought about by diene monomer incorporating unsaturation into the polymer backbone. This random elastomeric copolymer, which has a fully saturated polymer backbone, has intriguing qualities such as good heat resistance and weathering stability, good insulating qualities, and good resistance to chemicals, moisture, and steam. The synthetic elastomer known as EPDM rubber is a member of the thermoset rubber family. It is extensively utilized in a variety of industries, including roofing, electrical, construction, and automobiles. EPDM rubber exhibits exceptional resistance to weathering, aging, and extreme temperatures, along with good electrical insulating properties and resistance to water, ozone, and harsh chemicals. This review aims to provide an in-depth understanding of EPDM rubber, including its composition, manufacturing process, properties, applications, and future prospects.

Keywords: Ethylene propylene diene monomer (EPDM), rubber, weather resistance, roofs, solution polymerization

INTRODUCTION

The demand for lightweight, versatile elastomeric materials with suitable hardness, a large range of useful properties, lower cost of production, and ability to modify their chemical and physical properties when subjected to external harsh and severe environments has grown manifolds in recent years [1, 2]. Polymer-based materials, particularly those based on synthetic rubber matrices, like natural rubber (NR) [3–5], ethylene propylene diene monomers (EPDM) [6, 7], and styrene–butadiene–styrene (SBS) [8, 9], are important. The most researched and utilized synthetic rubber in a wide range of industrial applications is EPDM [10]. Propylene and ethylene are solution polymerized with a little amount of non-conjugated diene (unsaturated diene monomer) (about 3–9%) to create EPDM rubber, a synthetic rubber based on unsaturated polyolene [11–14]. The chemical structure of EPDM, which has a saturated hydrocarbon backbone, is shown in Figure 1.

***Author for Correspondence**
Sandeep Rai
E-mail: sadeep1964@yahoo.co.in

[1]General Manager R&D, Dyne Chemicals LLP, 3312/18, Chhatral GIDC, Phase-IV, Kalol, Gandhinagar, Gujarat, India
[2]Application Manger, Dyne Chemicals LLP, 3312/18, Chhatral GIDC, Phase-IV, Kalol, Gandhinagar, Gujarat, India

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EPDM RUBBER: CHEMICAL STRUCTURE [15]

Ethylene, propylene, and a diene component—which offers locations for cross-linking or vulcanization—make up EPDM rubber, a synthetic rubber. A highly adaptable elastomer that can be customized to satisfy certain performance requirements in a range of industrial applications is the outcome of the special combination of these monomers.

- *Ethylene (C_2H_4):* Ethylene contributes to the overall molecular structure of EPDM, imparting its low-temperature flexibility, high wear resistance, and high insulation properties.

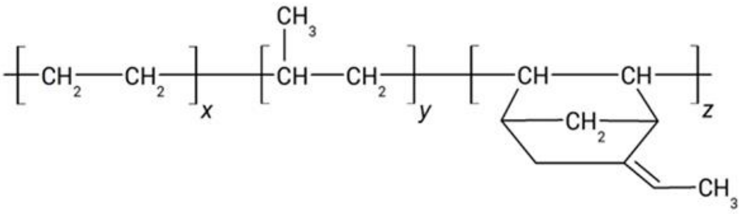

Figure 1. Chemical structure of ethylene propylene diene monomer (EPDM) rubber [15].

- *Propylene (C_3H_6):* The addition of propylene improves the polymer's resilience and ability to withstand stress and fatigue over time.
- *Diene (C_4H_6):* The diene component, often a combination of ENB (ethylidene norbornene) or DCPD (dicyclopentadiene), introduces sites for cross-linking, which gives EPDM its superior strength, elasticity, and heat resistance.

The resulting EPDM polymer is vulcanized through a vulcanization, which significantly enhances its mechanical properties, particularly its weather resistance to environmental factors like ozone, ultraviolet (UV) radiation, and temperature extremes.

PROPERTIES OF EPDM [16]

Because of its qualities, EPDM is perfect for a variety of uses. Here, we will break down the key characteristics of EPDM that contribute to its widespread use:

1. *Excellent weathering resistance:* EPDM is highly resistant to environmental degradation, particularly due to ozone and UV radiation. This makes it a great option for exterior uses like sealants and roofs. Unlike other rubbers, EPDM does not degrade when exposed to sunlight, offering longevity even in harsh environments.
2. *Temperature resistance:* The capacity of EPDM to function in both high and low temperature extremes is one of its main advantages. It can withstand temperatures as low as -50°C (-58°F) and as high as 150°C (302°F), making it suitable for a range of climates and industries.
3. *Chemical resistance:* A wide range of substances, such as acids, alkalis, and water-based fluids, are resistant to EPDM. It is less resilient to solvents and oils derived from petroleum, though. This makes EPDM a go-to material in applications where exposure to water and certain chemicals is expected but not necessarily oils or fuel.
4. *Flexibility and elasticity:* Even at low temperatures, EPDM retains its good elasticity and flexibility, which is very helpful in applications like hoses, gaskets, and seals. Additionally, it features a low compression set, which allows it to regain its former shape after compression.
5. *Electrical insulation:* Because it is non-conductive, EPDM is perfect for electrical insulation applications, such as wiring and cables. It prevents the transmission of electric currents and protects electrical systems from damage due to environmental exposure.
6. *High durability:* Due to its vulcanized structure, EPDM exhibits a high level of durability. It has excellent resistance to cracking, tearing, and abrasion, ensuring a long service life in many applications.

MANUFACTURING PROCESS OF EPDM [17]

The production of EPDM involves several steps, including polymerization, compounding, and curing. Let's take a closer look at each step in the manufacturing process. Three main steps make up the production of EPDM rubber from polymer-grade (PG) propylene and ethylene: (1) polymerization; (2) purification; and (3) finishing (Figure 2).

Polymerization

EPDM is produced through a process called "solution polymerization," where the ethylene, propylene, and diene monomers are polymerized in a solvent at elevated temperatures. This procedure guarantees the consistency of the polymer's composition and characteristics.

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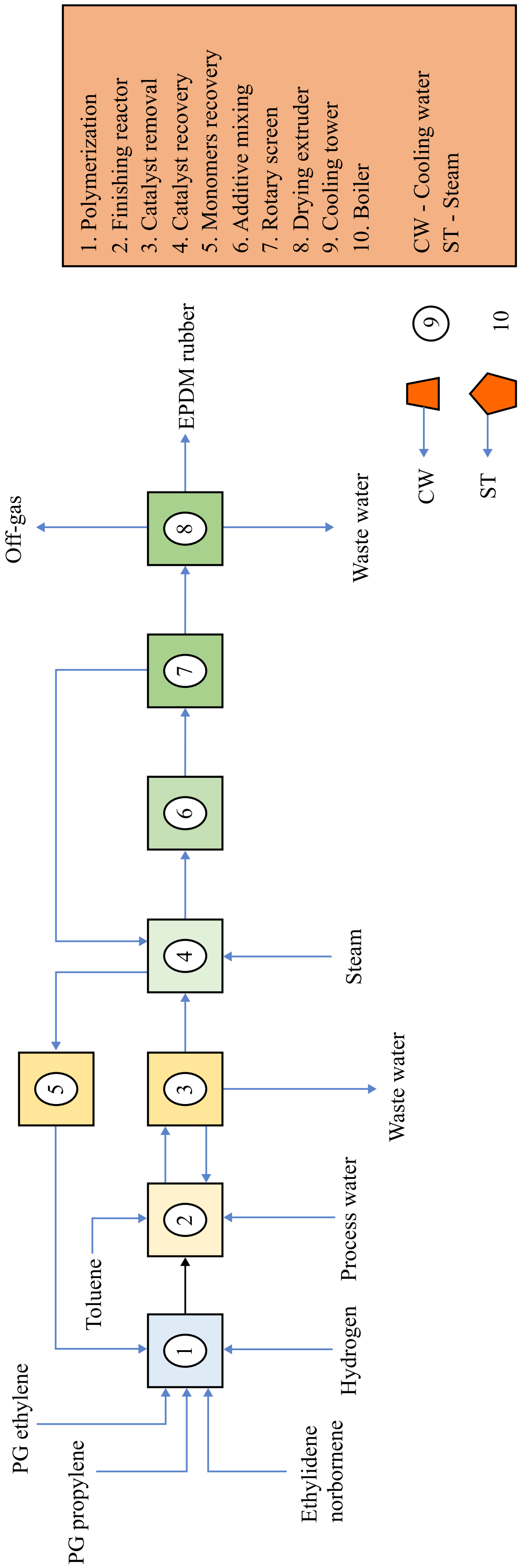

Figure 2. Process flow diagram of ethylene propylene diene monomer (EPDM) production [17]

The physical characteristics of the final EPDM product are determined by the amount and kind of unsaturated diene monomer as well as the ratio of ethylene to propylene. First, a solution containing the catalysts is added to the treated and combined monomers, which are then continuously fed into a jacketed, stirred reactor. With an excess of liquid propylene utilized as a diluent, the reaction takes place mostly in the liquid phase. The catalyst solution's rate of addition regulates the polymerization rate, while the propylene's regulated evaporation regulates the temperature. The resulting EPDM polymer precipitates out of the reaction medium.

Purification

After pumping the EPDM crumb slurry into a vessel, the reaction is stopped and the slurry is combined with water and a little amount of toluene. The catalyst contained in the polymer particles can be extracted by the water thanks to the toluene. After that, the catalyst-free polymer slurry is steam stripped using water as a dispersion medium to recover the unreacted residual monomers and solvent, which are then reintroduced back into the polymerization reactor.

Finishing

To ensure that copolymer particles adhere to one another and form a large lump that can withstand further processing steps, the rubber polymer that is obtained as wet crumbs in water is fed into a drum with auxiliary agents like an anti-agglomerates/anti-sticking agent (to prevent agglomeration of wet rubber crumbs). A rotary screen is used to remove the majority of the free water from the high-moisture crumb slurry. To lessen the amount of water in the polymer, the wet polymer is passed through a single screw extruder. The extruded dried EPDM crumbs, containing less than 0.5 wt.% water, is subsequently cooled, baled and packed with proper identification.

Compounding [18–20]

Finished EPDM is mixed with various additives such as carbon black, plasticizers, antioxidants, and curing agents to improve the performance and processability of the rubber. These rubber compounds significantly enhance properties like tensile strength, heat resistance, and color stability.

Along with its exceptional heat resistance, low-temperature elasticity and flexibility, weathering qualities, resistance to oxidation, ozone, and aging, EPDM has been used for a wide range of purposes, such as weather-stripping for cars, radiators, belts, tubes, sealants, roofing membranes, electrical and thermal insulation, and sealants. By employing sulfur as the vulcanizing agent and chemical accelerators to create a crosslinked structure, vulcanization usually improves the characteristics of EPDM rubber.

Vulcanization [21]

Vulcanization is a crucial step in the manufacturing of EPDM. In this process, the rubber is heated with sulfur or peroxide cross-linking agents, which create bonds between the polymer chains. This transforms the rubber from a soft, moldable material into a tough, durable elastomer. Vulcanization increases the tensile strength, elasticity, and weather resistance of the EPDM rubber.

APPLICATIONS OF EPDM [22, 23]

EPDM is extensively utilized in a variety of business sectors, including the automobile industry, where it is found in brake components, hoses, tubes, weather stripping, isolators, mounts, and grommets. Additionally, EPDM can be found in construction materials, including roofing membranes, glass sealers, gaskets, and tapes, as well as in polymers like impact-modified polypropylene and thermoplastic olefins. O-rings, mounts, cable jacketing, insulation, cable filler, connections, shoes, and carpet underlayment are some further industrial uses for EPDM. Because of its adaptability, EPDM may be used in a wide range of industries, including construction and automotive. Here are a few of the most popular applications:

1. *Automotive industry:* In the automobile industry, EPDM is widely utilized in the production of hoses, weather stripping, gaskets, and seals. It is perfect for automotive parts exposed to harsh environments because of its resistance to ozone and UV deterioration, capacity to handle extreme temperatures, and flexibility.

2. *Construction:* Because of its exceptional weather resistance and longevity, EPDM is frequently utilized in roofing materials in construction. Additionally, expansion joints, door seals, and window seals employ it. EPDM roofing membranes are particularly well-liked for their durability, energy efficiency, and little maintenance needs.
3. *Electrical and electronics:* EPDM is a popular option for electrical wire insulation due to its superior electrical insulating qualities. In power cables and connectors, where flexibility and resistance to environmental deterioration are crucial, it is also utilized.
4. *Consumer goods:* EPDM is found in many everyday consumer products, such as garden hoses, footwear, and even inflatable products, thanks to its resistance to wear, water, and environmental degradation.
5. *Industrial applications:* EPDM is used in the manufacture of industrial products like belts, washers, gaskets, and diaphragms, thanks to its good resistance to chemicals and high durability. It is also used in fluid handling systems in the food, beverage, and pharmaceutical industries.

EPDM'S COMPETITORS [24]

EPDM rubber, popular for its durability and versatility, has several elastomers as competitors, including TPVs (thermoplastic vulcanizates), silicone, and neoprene, each possessing their own strengths and weaknesses. Salient features of each are as follows:

1. *TPVs (Thermoplastic Vulcanizates):* TPVs are considered a primary alternative to EPDM due to their more or less similar properties and added benefits like part weight reduction (due to up to 40% lower density), recyclability (100% recyclability of TPVs), and simplified manufacturing processes. Changing from EPDM rubber to TPV in applications, offers customers numerous technical and economic benefits which include part weight reduction, recyclability or simplified manufacturing processes. The excellent recyclability of TPV offers customer to achieve in-process recycling.
2. *Silicone:* Silicone is another elastomer that offers added benefits and generally provides a longer service life than EPDM. Although silicone can be recycled, its recycling requires a special type of recycling plant and conventional recycling methods are not effective. On the other hand, EPDM is much easier to recycle. Hence, the reuse of EPDM materials significantly reduces scrap/waste and also need to manufacture new raw materials. EPDM can also be recycled by degrading the waste EPDM material into smaller components (split and punch) for use in rubber mats, running tracks, and so on. Generally, silicone costs more than EPDM. Therefore, EPDM could be a better choice when looking for a budget-friendly synthetic rubber for industrial applications.
3. *Neoprene:* While both EPDM and neoprene possess good resistance to weathering and abrasion, EPDM is generally superior to neoprene in UV and ozone resistance and more suitable for heat resistant applications.
4. *Polyvinyl chloride (PVC):* PVC chemically contains ethylene and chlorine in polymeric chain and it costs less than silicone or EPDM and is relatively less toxic to the environment.
5. *Other rubber types:* Other rubber types like NBR (nitrile butadiene rubber) and Viton also have their uses and can be considered competitors depending on the specific application. NBR offers excellent resistance to oil and solvents and lower UV and ozone resistance as compared to EPDM.

ADVANTAGES AND DISADVANTAGES OF EPDM [25]

Advantages

1. *Weather and UV resistance:* When it comes to resistance to ozone, UV rays, and severe weather, EPDM performs better than many other rubber varieties.
2. *Outstanding thermal stability:* From extremely cold to extremely hot temperatures, EPDM maintains its characteristics.
3. *Environmental sustainability:* EPDM supports sustainability initiatives since it is frequently manufactured from recycled components.
4. *Long lifespan:* EPDM goods frequently have a long service life because of their strength and resistance to weather, which eventually makes them cost-effective.
5. *Elasticity:* EPDM does not readily crack and retains its elasticity at low temperatures.

Disadvantages

1. *Oil and solvent sensitivity:* EPDM is not suitable for applications involving oils, fuels, and certain solvents, limiting its use in automotive fuel systems.
2. *Limited high-temperature performance:* While it performs well in a wide range of temperatures, EPDM does not handle extreme high temperatures as well as some other elastomers like silicone.
3. *Processing complexity:* The manufacturing process for EPDM can be more complex than for some other types of rubber, requiring specialized equipment and attention to detail.

SUSTAINABILITY ASPECTS OF EPDM [26]

EPDM rubber roofing is a sustainable option being considered due to its 100% recyclability and long-life during usage, means reduction in waste generation and the need for frequent replacements. Here is a more detailed look at the sustainability aspects of EPDM:

1. *100% recyclability:* EPDM is fully recyclable, meaning that at the end of its lifespan, it can be reincorporated into production of fresh products, thus minimizing waste generation and aligning with circular economic principles.
2. *No bitumen usage:* Bitumen, a material made from crude oil and categorized as hazardous, is found in roofing felt, the most common roofing material. In addition to having a detrimental effect on the environment, this makes getting rid of scrap roofing challenging and costly. EPDM roofing felt is bitumen-free, in contrast to other roofing felts.
3. *Low global warming potential (GWP):* EPDM's GWP is at 6.93 kg CO_2 per square foot, which is very low and nearly half of the nearest material. Service life, material manufacturing inputs, material installation inputs, and end-of-life impacts are some of the factors that affected this GWP computation. It was concluded that EPDM remains the world’s most recyclable low-slope roofing options.
4. *Longer lifespan and durability:* Usage of EPDM in roofs are well known due to their durability and long application lifespan, which means they require relatively less replacement frequency as compared to other roofing materials. This will reduce the overall environmental impact associated with manufacturing and disposal of roofing materials.
5. *Low maintenance cost:* EPDM being a weather resistance rubber and therefore its roofs require very low maintenance and this fact further contributes to their sustainability by reducing the need for resources and labor for upkeep and production of fresh EPDM roofing.
6. *Energy efficient:* By assisting in the regulation of indoor temperatures, EPDM roofs are anticipated to boost energy efficiency by lowering the demand for excessive heating and cooling.
7. *Low-impact installation:* EPDM roofing systems have low-impact and easier installation processes, which further reduces the environmental footprint associated with their applications.
8. *Cost-effective:* EPDM roofs may be cost-effective as compared to other roofing materials, making them a financially viable option for sustainable building practices.

FUTURE OUTLOOK OF EPDM RUBBER [27]

As industries continue to push for more durable, versatile, and sustainable materials, the demand for EPDM is expected to grow. Advances in polymer chemistry and manufacturing techniques could lead to improved performance characteristics, such as better oil resistance and enhanced temperature stability. The push toward sustainability will likely increase the use of recycled EPDM, further reducing the environmental impact of manufacturing. In particular, the construction and automotive sectors are likely to continue driving demand for EPDM due to its exceptional durability and performance under extreme conditions. Additionally, EPDM's use in electric vehicles (EVs), which require high-performance materials for seals and insulation, could further fuel growth in the coming years.

CONCLUSION

EPDM rubber is proven to be a highly versatile, durable, and excellent weather-resistant material across various industrial sectors. Its exceptional resistance to environmental factors such as ozone, UV radiation, and temperature extremes, combined with its good mechanical properties, make it a highly preferred choice in automotive, construction, electrical, and other industrial applications. However, there are some limitations, like sensitivity to oils and solvents, the overall benefits of EPDM outweigh its drawbacks in many critical applications. With ongoing developments in material development science and much increased focus on sustainability, EPDM's role in modern industry is set to grow significantly in future.

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