ISSN: 2754-4982

Journal of Civil Engineering Research & Technology

Review Article

Open Access

A Review on the Selection of Materials and Mechanical Properties of Railroad Under-Rail Pads

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ABSTRACT

The railroad has become the main pillar of the transportation industry, and the under-rail pads have a cushioning and vibration-damping effect so that the train is safe on the track. The common production materials of under-rail pads are rubber, TPU, HDPE, and EVA and rubber materials can be divided into traditional thermosetting rubber, TPE, and EPDM. Scholars also use a lot of special materials to make the under-rail pads. The different materials used to manufacture under-rail pads make their mechanical properties different. Over the past decades, scholars have never stopped researching the materials used in railroad under rail pads. This paper summarizes the research of scholars in various countries on the materials used for under-rail pads, as well as their mechanical properties and material characteristics. It puts forward suggestions and prospects for the material research of under-rail pads, which can provide references and bases for the subsequent related research.

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Received: May 27, 2025; **Accepted:** May 30, 2025; **Published:** June 13, 2025

Keywords: Railway Engineering, Under-Rail Pads, Plate Stiffness, Rubber Materials, Resource Utilization

Introduction

In recent years, with its many advantages, the railroad has become the main pillar of the transportation industry, with an irreplaceable key position and role in passenger and freight transportation. Ensuring adequate safety and comfort for trains traveling on the bridge is the top priority of the railroad work. Under-rail pads are an important part of the fastening system for passenger and freight railroads and heavy-duty railroad track structures, installed between the rails and concrete sleepers to buffer the vibration and impact generated by the passage the train, to protect the roadbed and sleepers, and to electrically insulate the signaling system [1]. Currently used at home and abroad under the rail rubber pads according to the material can be divided into traditional thermosetting rubber pads, thermoplastic polyester elastomer (TPE) pads, EPDM (ethylene propylene diene monomer) pads, the traditional thermosetting rubber pads can be divided into the nature of the rubber and the natural rubber (NR), cis-polybutadiene rubber (BR), styrene-butadiene rubber (SBR), as well as will be used in conjunction with them [2-5]. Other common pads are thermoplastic polyurethane (TPU) pads, high-density polyethylene (HDPE) rail pads, and EVA (ethylene vinyl acetate) pads [6]. Over the decades, scholars have never stopped researching the materials used in pads, and many new materials have been used to develop the corresponding rail pads [7,8]. The protective effect on train movement varies with the different materials used to manufacture under-rail pads. Therefore, this paper summarizes and discusses the commonly used materials of under-rail pads and the performance of their mechanical properties, and develops the outlook on the use of new materials.

Rubber Pads

The perfect rubber pad formulation needs to take into account four components: rubber, reinforcing system, antioxidant, and vulcanization system, and some also need to consider the foaming agent and plasticizer [9,14]. The additives in rubber, their function, and their common classification are shown in Table 1 [10, 15-22].

Table 1: Additives in Rubber

Additives		Function	Common classification
reinforcement system	Reinforcing Fillers	Form a network structure with the rubber, improve the mechanical properties of rubber, but will make the product resistivity decrease.	Carbon black, White carbon black, Fly ash
	Inorganic fillers	Improve the processability of rubber mixing, reduce costs, and make the working resistance of the under-rail pads meet the requirements.	Nano kaolin, Precipitated silica, Calcium carbonate Calcined clay
	Coupling agent	Combined with inorganic filler, it participates in the vulcanization reaction of rubber, which makes the inorganic filler and rubber molecules tightly bonded through chemical bonding, so that the rubber obtains better properties.	Silane coupling agent Polyethylene glycol Dodecyl benzene sulfonate Graphene oxide
antioxidant		Stop and slow down the aging of rubber, so that rubber products can be used for a long time.	Ketamine, Phenylenediamine, Heterocyclic
Vulcanization system		Cross-linking of rubber to form a network structure, which greatly improves the mechanical properties of rubber.	Sulfur vulcanization (including sulfur, catalysts, activators, and others), Non-sulfur vulcanization (for saturated rubber)
foaming agent		Releasing gas makes the material form microporous so that the rubber has a small apparent density, is lightweight, and has good damping performance, heat insulation, sound insulation, and other advantages.	Physical blowing agent and chemical blowing agent; AC, OBSH, and NaHCO3 are representative
plasticizer		Reduce the force between rubber molecules, reduce the glass transition temperature of rubber, and increase the plasticity, fluidity, and flexibility of rubber.	Petroleum-based, Coal tar-based, Pine oil-based, Fatty oil-based plasticizers

Thermosetting Rubber Pads

The aging resistance of thermosetting rubber material is general. In the process of long-term use, the hardness and static stiffness of the rubber pads increases. Its fatigue resistance is general, and it's prone to pressure collapse breakage, affecting the service life of the rubber pads. The common thermoset rubbers are NR, BR, and SBR, and using them together tends to produce better-performing pads [23]. The characteristics of their three rubber types are described below:

NR: It has good elasticity, high mechanical strength, and good fatigue resistance, but its thermal stability is poor, which is due to the high content of double bonds in the NR molecular chain.

BR: It has good dynamic performance, flexural resistance, and cold resistance; abrasion resistance and elasticity are particularly excellent because it has molecular chain flexibility, less heat under dynamic load, and better-aging resistance.

SBR: The low-temperature static stiffness change rate is smaller, the static and dynamic stiffness ratio is lower, and wear resistance is better, especially in high-temperature environments; Its heat and oxygen aging performance is better

TPE Pads

TPE pads have high toughness and high resilience, excellent impact, creep resistance, wear and aging resistance, easy processing, and hard to crush. After long-term service, the change rate of static stiffness is small [24]. But its heat resistance is not as good as rubber. In the long-term use of the process, it's prone to thermal deformation and leads to a large dimensional change rate and other problems, and TPE material has high hardness, which will lead to serious wear and tear of the bearing grooves of the sleeper compression and permanent deformation is larger in long-term use.

TPE is a block copolymer with polybutylene terephthalate (PBT) as the hard part and polyether or polyester as the soft part (see Figure 1) By changing the type and ratio of the hard and soft segments and the crystallinity of the hard segments, the hardness, modulus, melting point, heat resistance, chemical resistance, elasticity, low-temperature flexibility, and airtightness of TPE can be adjusted.

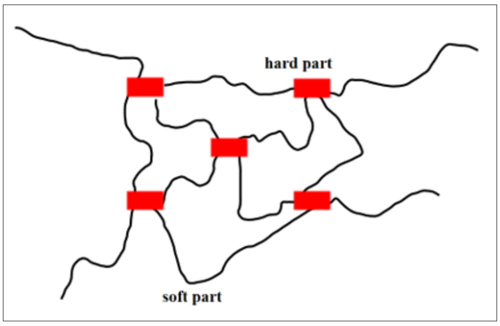

Figure 1: Structural Morphology of TPE

EPDM Pads

EPDM pads have a low density with porous structure characteristics, and the cross-section shows a small aperture-like structure. It has excellent weather resistance and long service life and also has excellent vibration-damping performance. It has excellent performance in aging, weathering, heat and water vapor resistance, etc. EPDM is an amorphous non-crystalline rubber within a certain range and can be used to develop composites for cold damping pads for high-speed railroads [25].

EPDM is a saturated non-polar rubber based on the binary random copolymerization of ethylene and propylene, with the addition of a small amount of non-conjugated diolefins, and the use of diolefin's second double bond to achieve cross-linking. It has excellent high and low-temperature resistance, but like most polymers, the hydrocarbon-rich EPDM has poor flame-retardant properties, with an oxygen index of only 18%, making it extremely flammable. And its non-polar properties lead to poor self-adhesion and inter-adhesion. The three commonly used third monomers in EPDM are ethylenic norbornene (ENB), dicyclopentadiene (DCPD), and 1,4-hexadiene (HD), the most widely used of which is ENB, whose molecular structure is shown in Figure 2.

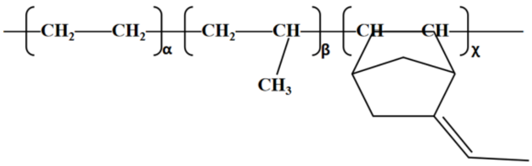

Figure 2: Molecular Structure of ENB

Other Common Pads

TPU Pads

TPU pads have the advantages of high hardness, good elasticity, and elongation, high strength, excellent abrasion resistance, high load capacity, high impact resistance, fatigue resistance vibration resistance, etc. However, their processing process is complicated, and they are prone to internal heat generation under large loads, which affects the performance of the pads. TPU pads have better strength and elasticity at the same time with lower hardness and lower stiffness. Compared with rubber pads and TPEE pads, TPU pads can realize the change of stiffness by adjusting the formulation and the structure of the bubble holes, without the need to design complex grooves and concave-convex shapes [26].

TPU, also known as polyurethane, is a complex polymer material whose structure includes a series of urethane chain segments. Those chain segments are repeatedly arranged to form a tight and complex structure, which together form a complete system. Polyurethane foaming material is often used A, B two-component (usually A component for polyol, B component for isocyanate) materials plus additives mixed reaction, through the casting foam molding.
The process making TPU pads is shown in Figure 3.

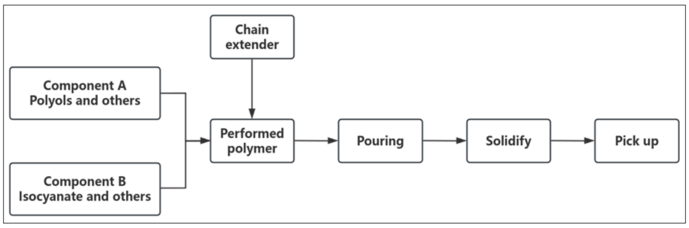

Figure 3: TPU Pads Production Process

HDPE Pads

The stiffness of HDPE pads is very high, moderately damped, and virtually unaffected by fastener preload [27]. The degree of crystallization of the injection-molded pad will increase with the extension of time, resulting in a reduction in the volume of the pad, and the shrinkage marks around the gate. The thicker the pad, the greater the shrinkage, resulting in poorer flatness of the pad. Although the inorganic filler can improve the flatness of HDPE sheets, it greatly reduces the elongation at the break of the HDPE sheet, and thus is usually dealt with by optimizing the injection molding process and machining.

HDPE is a thermoplastic resin obtained by polymerizing ethylene monomer. The ethylene monomer comes from petroleum, so the price of HDPE is relatively low, and at the same time, it has excellent comprehensive performance. However, HDPE has low heat resistance, low hardness, low heat distortion temperature, and especially poor creep resistance, and is often modified by blending, adding fillers, or heat-resistant resins.

The Process of Making Hpde Pads is Shown in Figure 4:

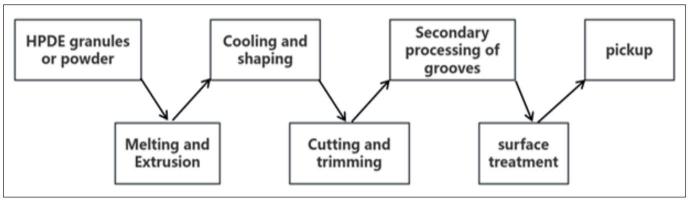

Figure 4: HPDE Pads Production Process

EVA Pads

EVA pads are thermally stable and extremely resistant to post-hydrocarbon exposure, whereas exposure of EPDM pads to hydrocarbons leads to volumetric expansion of the pads and reduces their stiffness [28]. However, the rate of change of dynamic stiffness of EVA pads changes more after long-term service.

EVA is a random copolymer of ethylene and vinyl acetate. The introduction of a short branched chain formed by a polar acetic acid group in the ethylene chain changes the original crystalline state, making EVA more flexible and elastic than polyethylene. EVA is often used as a modifier and other polymers blended, which is due to the EVA having good flexural, toughness, resistance to stress cracking, and bonding properties. EVA can modify the impact properties of other materials and resistance to environmental stress cracking properties.
The process of making EVA pads is shown in Figure 5.

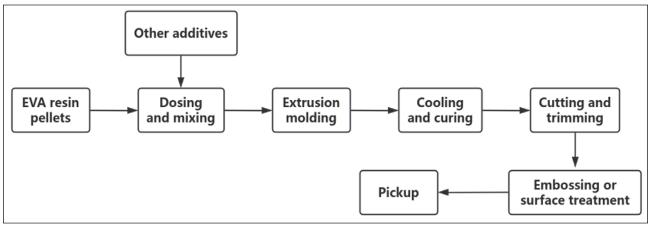

Figure 5: EVA Pads Production Process

Special Material Pads

Recycling of Old Materials

Explored the effect of pad preload and frequency on stiffness and damping values using DPHI pads consisting of polyurethane with a thickness of 6 mm and cork rubber with a thickness of 1 mm, and special reinforced polyester SRP pads made of CDM-RR or resin-bonded rubber [29,30]. explored the mechanical behavior of under-rail pads made from elastomer particles obtained from used tires combined with polymer matrix resins and considered the effects of thermal aging and water absorption on the mechanical properties. The shredding of tires and grinding of rubber increases manufacturing costs and loss of mechanical properties of the material [31]. investigated an innovative deconstruction process that does not grind the material, which allows the extraction of tire plies with different elasticities from dismantled end-of-life tires (ELT) without grinding the rubber into particles, and explored the most suitable thickness values of tire mats for high-speed railroads. The use of under-rail pads made from tire pads improves ballast track response and reduces production costs and energy consumption during material handling. combined of high-density polyethylene from recycled plastic boxes, polypropylene, and low-density polyethylene from recycled geomembranes and combined them with recycled crumb rubber from ELT to fabricate two types of pads. It was found that the static stiffness value of the high-density polyethylene pad was about 800 kN/mm while that of the low-density polyethylene was close to 150 kN/mm [32].

Use of New Materials

explored that the use of (Fiber Reinforced Foam Urethane) FFU pads currently emits more CO2 emissions as compared to concrete bearers. However, it has excellent recyclability and reuse properties, low maintenance frequency, and long service life In the long run, the use of composite materials such as FFU is a better option to achieve more sustainable goals propose metal-rubber pads with a uniform distribution of properties, which are made of stainless steel, are unaffected by hydrocarbons, water or ultraviolet rays, etc., and whose elastic behavior is guaranteed over a wide range of temperatures (between -50°C and 300°C) [33-35]. Fabricated magnetorheological elastomer (MRE) pads. MRE is a new type of functional material, generally prepared by a composite of soft magnetic particles and polymer elastomers, whose important characteristic is that the mechanical property parameters can be rapidly controlled in real-time, reversibly, and rapidly by an applied magnetic field. The pad has obvious magnetorheological effects, mechanical properties, and carbonyl iron powder type and particle size. Its dynamic and static stiffness increases with the increase of the applied magnetic field and can be used to simulate the pad stiffness characteristics of field service for 5 to 6 years.

In addition to the aforementioned materials, emerging composites offer exciting possibilities for railroad pad manufacturing [36-41]. The use of such advanced composites in railroad pad manufacturing has the potential to significantly improve the overall performance of railroad pads and introduce innovative approaches to railroad pad development.

Summary

This paper summarizes the classification of materials commonly used for under-rail pads (see Figure 6)and describes their mechanical properties. Finally, suggestions for new pad materials are provided. This paper can provide a reference for the research and development of the materials of the subsequent under-rail pads.

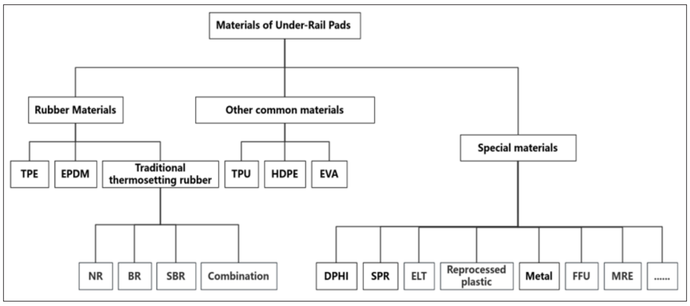

Figure 6: Summary of Under-Rail Pads Materials

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