International Journal of Automotive Manufacturing and Materials (IJAMM)

Scilight

Review

Non-Asbestos Fiber Gasket Materials & Their Applications in Automobile Powertrain Sealing

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Received: 19 March 2024; Revised: 27 May 2024; Accepted: 19 June 2024; Published: 25 June 2024

Abstract: Non-asbestos fiber gasket material is a ternary composite mainly composed of fibers, rubber, and fillers. Due to the carcinogenic risks associated with asbestos fibers, research and development of non-asbestos materials have become increasingly active. The manufacturing technologies of non-asbestos gasket materials primarily include calendering and papermaking processes. These materials, especially the gasket made by the papermaking method, are mainly applied for sealing in engines, transmissions, and water pumps, playing a crucial role in improving emission standards, safety, and the sustainability of automobiles. The sealing mechanism and relevant properties of asbestos-free fiber gasket materials are also introduced in this article. In the future, there should be a focus on developing high-performance non-asbestos gasket materials to provide more efficient and highly cost-effective sealing solutions for the automotive industry.

Keywords: non-asbestos fiber gasket materials; papermaking method; automotive powertrain sealing; sealing mechanism

1. Introduction to Fiber Gasket Materials

Fiber gasket materials are a type of ternary composite material primarily composed of fibers, fillers, rubber adhesives, and additives [1]. The fibers mainly enhance and improve heat resistance and anti-creep relaxation properties, directly affecting the molding process and cost of the gasket materials. The rubber bonds the components together organically and provides medium resistance and the necessary density, compression & recovery for sealing. Fillers aim to improve certain material properties and reduce costs. Different fiber gasket materials have varying compositions and contents based on performance requirements. To improve the performance-to-price ratio, fiber gasket materials often combine several materials for reinforcing fibers, elastomer adhesives, and fillers [2,3].

2. Materials and Methods

Fiber gasket materials are classified into asbestos fiber gasket materials and non-asbestos fiber gasket materials based on whether asbestos fibers are added. Asbestos fiber gasket materials primarily use asbestos fibers as the reinforcing fibers [4]. Asbestos is a natural silicate mineral fiber with high strength, heat resistance, and chemical corrosion resistance. Gasket materials made with asbestos have excellent heat resistance, medium resistance, anti-creep relaxation, and sealing properties and are cost-effective [5]. Austrian engineer Richard Klinger invented compressed asbestos fiber rubber sheets in 1890 [6]. Since then, asbestos-reinforced rubber materials have been successfully used for over a century in automotive powertrains, petrochemicals, electromechanics, and other industries due to their high mechanical strength, good temperature resistance, chemical resistance, and low production and application costs.

Despite asbestos's excellent overall performance, studies have shown that asbestos is biologically active and pathogenic. Long-term inhalation of asbestos can lead to asbestosis and cancer, and prolonged contact can harm the skin, eyes, and mucous membranes. Therefore 1950, asbestos was officially recognized internationally as a dangerous carcinogen [7, 8]. The United States restricted asbestos use in 1971, Australia completely banned asbestos-containing products in 1991, and the European Union required all member states to legislate against asbestos by the end of 2004. On March 18, 2024, the U. S. Environmental Protection Agency (EPA) announced a ban on chrysotile asbestos, adding the U. S. to the list of countries with comprehensive asbestos bans. To date, 66 countries have entirely banned asbestos [9–12]. Additionally, asbestos gasket materials have several performance drawbacks, such as poor elasticity, losing elasticity at high temperatures, and limited sealing capabilities, making them unsuitable for increasingly complex working conditions [13]. Currently, asbestos fiber gasket materials are mainly used in agricultural machinery and motorcycles in Southeast Asia, the Middle East, Africa, and other regions [14].

The development of non-asbestos fiber gasket materials originated from the prohibition and replacement of asbestos. Since the 1990s, industrialized countries have driven the research, production, and extensive performance studies of non-asbestos gasket materials due to stricter environmental protection requirements [15]. Any gasket material not containing asbestos is considered non-asbestos gasket material, including rubber, PTFE, and flexible graphite. However, these materials have apparent deficiencies, such as low heat resistance for rubber, large creep and high cost for PTFE, and low strength and small recovery for flexible graphite, making them difficult to widely replace asbestos gasket materials. In contrast, non-asbestos fiber gasket composite materials developed in the 1980s have many advantages: simple production process, mature technology, good designability, a wide range of varieties, good performance, low cost, and high performance-to-price ratio. Therefore, countries worldwide focus on developing non-asbestos fiber gasket composite materials as the preferred direction for replacing asbestos rubber sheets [16].

Common non-asbestos fibers that replace asbestos include inorganic fibers (carbon fibers, glass fibers, mineral wool fibers) and organic fibers (aramid, phenolic fibers, cellulose fibers). Researchers optimize the design by considering the physical and chemical properties and cost of fibers combined with elastomer matrices and fillers, to obtain the best non-asbestos fiber gasket materials. Aramid fiber gasket materials, with high strength and good temperature resistance, are excellent substitutes for asbestos fibers, but their high cost is a drawback [17]. To reduce costs, some plant fibers can partially replace them, but they have poor heat and water resistance. Currently, high-performance non-asbestos fiber gasket materials widely used in automotive powertrains typically combine two or three types of fibers to achieve the best performance matching and optimal results [18–21].

3. Major Manufacturing Processes of Fiber Gasket Materials

Fiber gasket materials have two mature manufacturing processes: calendering and papermaking.

The calendering method (Calender Process, CA method) is the main preparation process for asbestos rubber sheets, invented by Klinger in 1890 [22]. It is a batch production process widely adopted in the asbestos industry. This process mixes various reinforcing fibers, rubber dissolved in organic solvents, and fillers to form a mixture, then continuously rolls it into sealing sheets on a double-roll mill or "sheeting machine" [23]. The CA method requires significant equipment investment and high demands on material formulations, production process parameters, and worker skills. Large amounts of organic solvents (gasoline, benzene, toluene) are needed during production, requiring a complete solvent recovery system to avoid environmental pollution. The CA method offers a wide range of material choices but produces sheet products, leading to relatively low efficiency. It is challenging to produce thin materials and ensure uniformity and stability in product performance, limiting its application in vehicles, and instruments, mainly applied widely in the petrochemical pipeline industry and other fields with special performance requirements. However, the CA method remains a major production process for non-asbestos fiber gasket materials due to its wide material selection, high sealing, and ideal stability under high temperatures and high internal pressure.

The papermaking method, also known as the latex beater-addition process (BA method), is a wet-forming process that uses modified papermaking machinery to mix water, latex, fibers, fillers, and chemical additives into an aqueous dispersion system [24]. It forms a sheet gradually through dehydration on the paper machine's wire section, then compresses, dries, calendars, and vulcanizes it into gasket materials. The BA method, using water as the processing medium, is safer and more environmentally friendly, allowing for continuous, scalable production. The production line can be equipped with automated online scanning and quality control systems, resulting in soft, stable, and uniform gasket materials with stable quality. However, due to process limitations, fiber gasket materials produced by the papermaking method generally have moderate density. In addition, they are unsuitable for high-temperature and high-pressure environments such as oil pipelines but are very suitable for automotive powertrain sealing [25,26].

4. Sealing Mechanism of Fiber Gasket Materials

Gaskets in sealing systems play a crucial role by utilizing the material's deformation (compression and recovery) under the pre-tightening force of the end cover bolts to compensate and offset the gaps caused by surface roughness, unevenness, and deformation of the joint surfaces of the cylinder head and other components, ensuring reliable sealing and preventing leaks that could affect the engine's normal operation [27].

Leaks occur when the medium flows from a limited internal space to the external space, crossing the boundary between the inner and outer spaces. The fundamental cause of leaks is the presence of gaps at the contact surface, with the pressure difference or concentration difference across the contact surface providing the driving force for leakage. As no manufacturing or processing method can create absolutely smooth ideal surfaces or achieve complete interfacial fit and blockage of sealant pores, there will always be minute gaps or channels at the contact surfaces and within the gasket material. Therefore, absolute "no leakage" in gasket sealing is almost impossible [28].

Sealing through bolts creates significant compressive stress at the flange and gasket contact surfaces and within the gasket, causing the gasket to closely fit the flange, filling micro-gaps on the flange surface, and reducing the gasket's porosity, thereby minimizing leakage channels for the sealed fluid [29]. However, a leak occurs at the sealing point when the medium passes through the bolt-flange joint under a certain pressure. The sealed medium generally leaks through interface leakage, section leakage, and blowout leakage. Interface leakage occurs when the medium passes through gaps in the sealing surface due to system pressure differences; section leakage occurs when the medium passes through the gasket's capillary channels due to pressure differences; blowout leakage occurs when uneven compressive stress distribution due to flange shape and rigidity causes parts of the gasket to crush, lose rebound capability, or separate from the flange under internal pressure, resulting in radial pressure forcing the medium through the sealing surface.

5. Basic Performance of Fiber Gasket Materials

Leakage can cause fires, explosions, and environmental pollution, not only depending on the gasket but also related to the entire gasket-bolt-flange connection system, including gasket installation, bolt load, medium pressure, temperature, and material properties [30]. However, the gasket's performance remains the primary factor. The drop in bolt load and gasket compressive stress due to mechanical integrity or thickness loss can convert seepage into significant leakage. As sealing requirements and safety considerations for the environment increase, preventing or delaying bolt load and gasket compressive stress drops and improving the overall performance of gasket materials has become a key focus in sealing technology research.

(1) Adequate mechanical strength, primarily including longitudinal and transverse tensile strength and high-temperature compressive strength, to resist the pressure of the sealing medium and prevent gasket crushing.

(2) Suitable compressibility and good recovery with minimal compression set to compensate for imperfections in the sealing surface and maintain good elastic compensation.

(3) Good anti-creep relaxation performance to ensure that the flange bolt sealing system has sufficient residual load to maintain the necessary sealing pressure, ensuring long-term sealing performance of the gasket [31,32].

(4) Good sealing performance (low leakage rate) to guarantee the effectiveness of the gasket material.

(5) Good resistance to medium corrosion, ensuring the material can withstand general fuels, lubricants, coolants, and other media.

(6) Good resistance to high and low temperatures, capable of withstanding environmental temperature variations without softening or decomposing at high temperatures and without hardening or cracking at low temperatures.

Additionally, other performance indicators such as material density, anti-stick properties, flexibility, and dimensional stability must be considered. These performance indicators directly or indirectly affect the material's sealing capability and suitability.

6. Application of Fiber Gasket Materials in Automobiles

Gasket materials are typically applied between two flange surfaces and function under a certain bolt torque to prevent gas and liquid leakage. They may also help reduce noise, resist vibrations, and enhance cleanliness, ensuring the proper operation of engines and other critical components, thereby improving vehicle fuel efficiency and safety [33]. Non-asbestos gasket materials are commonly used in diesel engines, gasoline engines, transmissions, gearboxes, hubs, water pumps, oil pumps, air conditioning systems, and other joints. These include oil pan gaskets, cylinder head gaskets, oil cooler gaskets, intake and exhaust manifold gaskets, oil filter gaskets, transmission valve plate gaskets, and seals in hydraulic and transmission systems [34, 35]. These materials help reduce friction, leakage, wear, noise, and emissions, making them critical components for maintaining efficiency, performance, hygiene, and safety.

The "three leaks" issue in automobiles—air, oil, and water leaks—directly affects driving safety and is a major concern for powertrain designers, manufacturers, and users [36]. As demands for energy savings, emission reductions, noise reduction, lightweight construction, and cleanliness increase, the structure of automobiles becomes more complex. This complexity, including higher temperatures, changing sealing media, and variations in flange materials, increases the demands on gasket materials [37]. When selecting fiber gasket materials, it is essential to consider material composition, structural design, and manufacturing processes, as well as the condition of the sealing surfaces and the operating conditions of the powertrain. Understanding the basic working conditions of the sealing components—such as bolt torque, bolt hole distribution, operating temperature, sealing medium, and sealing surface pressure distribution—is crucial to ensuring the safety and durability of vehicle operation [38].

7. Future Prospects for Fiber Gasket Materials

With the growing call for zero-emission vehicles and carbon neutrality initiatives, automotive emission standards are becoming increasingly stringent [38]. This presents both new opportunities and significant challenges for non-asbestos gasket materials. Various parameters need to be considered when selecting non-asbestos gasket materials, such as operating conditions, costs, and gasket characteristics [39]. Faced with competition from different sealing products, fiber gasket materials must continuously improve production efficiency and quality, streamline and integrate existing product lines, and optimize product portfolio design. At the same time, it is crucial to strengthen research on sealing mechanisms and application technologies, focus on developing high-performance products, and overcome the market monopoly of high-performance materials by monopolistic companies. This will provide more efficient and optimized solutions for the automotive industry.

Author Contributions: Writing—original draft preparation, W.H.; writing—review and editing, H.L.; supervision, J.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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