

Mineral Fibres in the Textile Industry: A Sustainable Approach



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Abstract

Mineral fibers have garnered considerable attention within the textile industry due to their distinctive attributes and potential applications. This abstract offers an informative overview of the role played by mineral fibers in the textile sector. These fibers, primarily composed of natural minerals such as basalt, glass, and asbestos, possess remarkable properties like exceptional strength, fire resistance, and insulation capabilities. Their incorporation into textile materials has spurred the development of pioneering products that cater to a wide spectrum of industrial and consumer demands. This article delves into the various categories of mineral fibers employed in textile applications, emphasizing their unique characteristics and benefits. It investigates the manufacturing processes entailed in integrating mineral fibers into textiles, underlining their contributions to bolstering longevity and performance. Furthermore, the abstract addresses the environmental considerations linked to mineral fibers and their sustainability within the textile industry. Moreover, this overview briefly touches upon the extensive range of applications for textiles based on mineral fibers, spanning diverse sectors such as automotive, construction, protective clothing, and geotextiles. It also discusses the challenges and opportunities associated with the utilization of mineral fibers, encompassing aspects related to health and safety, regulatory compliance, and prevailing market trends. Finally "Mineral Fibres in the Textile Industry: An Insight" sheds light on the promising prospects and evolving landscape of mineral fibers in the textile industry. As this innovative field continues to advance, a deeper comprehension of the potential of mineral fibers and their impact on the textile sector becomes paramount for researchers, manufacturers, and stakeholders aiming to harness their advantages and navigate emerging challenges.

Keywords: Mineral Fibres; Textile Industry; Properties; Asbestos; Mining

Introduction

Mineral fibers are produced from minerals, typically non-organic substances like rock, slag, or glass. This term commonly refers to various insulation materials crafted from these minerals, including asbestos, fiberglass, and rock wool. Asbestos plays a vital role in the textile industry due to its diverse applications. The process involves melting the mineral material and converting it into fibers. Mineral fibers are renowned for their outstanding thermal and acoustic characteristics, making them a favored option for tasks like building insulation, soundproofing, and fire protection. Typically, these fibers are created by melting minerals, then spinning or blowing them into threads, which are subsequently formed into mats or batts for insulation purposes. Mineral fibers are often preferred for their fire resistance, durability, and capacity to endure high temperatures. Nevertheless, it's crucial to recognize that certain types of mineral fibers, such as asbestos, can pose health hazards when inhaled.

Consequently, it's imperative to observe appropriate safety precautions when working with them. On the other hand, natural fibers derived from biological sources, including plant-based (cellulosic) and animal-based (protein) fibers, known as biofibers, stand out for their renewability, biodegradability, diverse range, adaptability, carbon dioxide neutrality, and recyclability. They align exceptionally well with the principles of sustainability, a paramount objective in contemporary society. Anticipating an estimated annual production of approximately 40 million tons by the mid-21st century, biobased fibers emerge as a burgeoning category of materials for fostering a circular and ecologically conscious economy [1].

Properties of Mineral Fibres

Mineral fibers typically exhibit excellent heat resistance, are non-flammable, and possess a relatively low permeability. The

most noteworthy physical attributes of mineral fibers include their exceptional thermal stability and remarkably high tensile strength. While they can undergo melting, this transformation occurs only at extremely high temperatures, ranging from 1450°C to 1500°C (equivalent to 2580°F to 2670°F), which is comparable to the temperature of molten lava in a volcanic eruption. Importantly, the tensile strength of mineral fibers surpasses that of steel. Mineral fiber, characterized by its impressive insulating capabilities, has become a versatile material with a wide range of applications. Its exceptional fireproofing properties make it a valuable component in clothing and conveyor belts, enhancing safety in various settings. Furthermore, mineral fiber's remarkable soundproofing qualities contribute to creating quieter environments. Beyond these attributes, it exhibits resistance to acids and rust, ensuring durability in challenging conditions. With low electrical and thermal conductivity, it is an efficient insulator. Importantly, mineral fiber maintains its integrity in normal usage and remains unharmed by insects or microorganisms. Its uses are extensive, encompassing applications in brake linings, gaskets, industrial packing, and electrical windings. However, it's worth noting that mineral fiber, once widely used, has been recognized as a serious health hazard and subsequently removed from the textiles market, highlighting the importance of safety considerations in material choices. This fibrous form of silicate incorporates magnesium, calcium, iron, aluminum, and other minerals, offering a mix of properties that have both benefits and risks associated with its use. Mineral fibers have several physical and chemical properties that make them useful for various applications. Here are some of the properties of mineral fibers:

Strength: Some mineral fibres, such as glass wool and rock wool, are strong and durable, making

them suitable for use in construction, insulation, and reinforcement materials.

Heat Resistance: These fibers are highly resistant to heat, making them ideal for use in high-

temperature applications, such as insulating pipes, ducts, and industrial equipment.

Fire Resistance: Many mineral fibers are non-combustible and have low smoke generation,

making them ideal for use in fireproofing and firestopping systems.

Insulation Properties: These fibers have excellent insulation properties, which makes them ideal

for use in buildings and industrial applications to reduce heat loss.

Acoustical Properties: Some mineral fibres, such as rock wool, have good acoustical properties,

making them suitable for use in soundproofing materials.

Chemical Resistance: Glass wool, are resistant to certain chemicals, such as acids and alkalis,

which makes them suitable for use in industrial applications.

Low Water Absorption: Some mineral fibers, such as rock wool, have low water absorption,

which makes them suitable for use in applications where moisture resistance is important.

Long Service Life: These fibers have a long service life, making them a cost-effective choice for

many applications.

Types of Mineral Fibres

Various kinds of mineral fibers find utility across a range of applications, encompassing uses in insulation, construction, and industrial sectors. These natural fibers are primarily categorized based on their origin into vegetable fibers, animal fibers, and mineral fibers. As defined by the International Mineralogical Association and the French Agency for Environmental and Occupational Health Safety (AFSSET), mineral fibers are derived through a process of melting and subsequent fibrillation of diverse mineral sources. Inorganic natural fibers encompass mineral fibers like asbestos [2], basalt fibers, and Silexil (siliceous needles derived from Spongolite, as described by Saliba [3], boasting a composition that is nearly 100% SiO₂. In particular, inorganic basalt fibers exhibit exceptional resistance to corrosion and mechanical properties on par with glass fibers, as indicated by [4,5]. The mechanical characteristics of basalt fibers fall within the range of 89 to 95 GPa for the modulus of elasticity, 2800 to 4900 MPa for tensile strength, and 3.00% to 5.00% for ultimate strain. Generally, the mechanical attributes of FRP (fibers and polymers) are contingent on several factors, including the fiber volume fraction, fiber orientation, manufacturing method, temperature, cure cycle duration, and the age of the polymer composite. This observation is in line with findings by Hollaway & Teng [6] and Fiore et al. [7]. The typical fiber volume fraction in most FRP bars is estimated to be in the range of 50% to 60%, while for FRP strips, it tends to fall between 60% and 70%, as reported by [4].

Natural inorganic basalt fibers are extracted from volcanic deposits through a single-melt process and offer superior attributes compared to glass fibers, including enhanced thermal stability, heat and sound insulation capabilities, resistance to vibrations, and exceptional durability [8]. Unlike granite, basalt is characterized as a fine-grained extrusive rock with higher iron and magnesium content, resulting in a density ranging from 2.7 gr/cm³ to 2.8 gr/cm³. Notably, it exhibits extreme hardness, ranking between five and nine on Moh's scale, thereby boasting remarkable resistance to abrasion [9]. Continuous basalt fibers can be efficiently manufactured using the same technology

employed for glass fibers, making the extrusion process highly energy-efficient and more straightforward than that of its competitors Dhand et al. [5]. Furthermore, the raw materials for basalt fibers are globally accessible (Di Ludovico et al. [9]). These fibers are stable, inert, environmentally friendly, non-toxic, and unreactive as reinforcement materials [5]. By modifying the chemical composition, basalt fibers can exhibit a wide range of mechanical properties, underscoring the significance of stringent quality control measures in the production process to achieve basalt fibers with minimal dispersion. Basalt fibers, boasting a higher modulus of elasticity compared to glass fibers, offer a notable advantage in terms of mechanical properties [5,8]. Moreover, a significant aspect of basalt fibers lies in their potential for high bio-solubility, indicating a propensity for biodegradability, setting them apart from many advanced synthetic fibers [5,8]. This attribute of biosolubility holds substantial importance for basalt fibers, as inorganic fibers with exceptional mechanical properties, akin to those of glass or carbon fibers, inherit qualities from their natural origins, such as recyclability and non-toxicity, which align with eco-friendly retrofitting efforts. Advanced basalt fiber reinforcements exhibit a superior ecological footprint when compared to alternative materials with similar structural capabilities. The prospect of substituting steel fibers or steel rebar with basalt counterparts in future construction applications holds promise for reducing energy consumption and the emission of CO₂ into the atmosphere. It's worth noting that there are two primary types of mineral fibers: those directly derived from rocks in fiber form, with asbestos being the sole naturally occurring mineral fiber. Notable examples of natural mineral fibers include asbestos, wollastonite, and sepiolite. These represent some of the most commonly encountered varieties of mineral fibers.

Asbestos

Asbestos (AS) stands out as the most significant mineral fiber material, with a historical usage dating back as far as 2500 years ago. Comprising silica, magnesium, lime, and iron oxides as its fundamental components, asbestos fibers exhibit exceptional durability, flexibility, and relatively substantial length. Their inherent resistance to combustion positions them as promising candidates for fire-resistant and fire-retardant materials or fabrics. In comparison to both synthetic and natural fibers, asbestos fibers are exceptionally fine, featuring diameters ranging from 0.02 to 0.2 μm .

However, its utilization has faced substantial restrictions and bans in many countries due to its association with severe lung diseases, notably mesothelioma and lung cancer. Asbestos fibers represent the sole naturally occurring mineral fibers, akin to serpentine, amphiboles, and anthophyllite. The recovery of asbestos occurs from rocks that have solidified in a fibrous configuration. Dating back over two millennia, asbestos was renowned for its remarkable fire resistance, rendering it

invaluable for fire protection in construction. Additionally, it demonstrated effectiveness in mitigating electrical and chemical damage. Traditionally, ironing boards featured hard mats made from asbestos; however, contemporary versions employ synthetic materials. The primary asbestos mining regions, commanding 46% of the market share, are located in Russia, with China and Kazakhstan each holding 16%, followed by Brazil at 10%, and Canada at 8%. These fibers are extracted from rocks and can be spun into yarns, subsequently processed into various textile fabrics, including wovens, knits, and more. Moreover, asbestos fibers are versatile additives for materials like concrete and exhibit remarkable insulation properties. Their standout quality lies in their exceptional heat resistance and fireproof nature, coupled with robust resistance to acids, alkalis, and various chemicals. As a result, they find applications in the production of specialized fire-resistant and industrial fabrics. In terms of fineness, asbestos fibers surpass both natural and synthetic counterparts, with elementary fiber diameters ranging from 0.02 to 0.2 μm .

Additional advantages of asbestos include its high-temperature stability and cost-effectiveness. Consequently, significant quantities of asbestos have been mined and processed globally. In 1987, worldwide production reached approximately 4 million tons, although this figure has seen a decline in recent years. The historical use of asbestos dates back to ancient times when it was employed as lamp wicks. Extensive research efforts have sought alternatives to asbestos in various applications, such as work and fire protection, heat and electrical insulation, sealing, filtration, friction linings, construction materials like asbestos concrete, and various chemical products.

Asbestos finds its application in a wide array of protective equipment, including firefighting gear, fire screens, and insulation for steam and hot pipes. It's also utilized in brake linings, insulating building materials, electrical tapes and braids, as well as in products where non-combustibility is a critical requirement. On occasion, asbestos fibers are combined with glass to create decorative fabrics for curtains and draperies, as well as for enhancing heat insulation properties. It's important to note that fine asbestos dust and dust containing asbestos are recognized as carcinogenic. In this context, the size of the dust particles and fibers, rather than the asbestos material itself, presents health concerns. Consequently, the use of asbestos has substantially decreased in Germany, and globally, health-related apprehensions have led to its prohibition in many countries.

Fiberglass

Fiberglass production involves the melting of silica sand and additional raw materials like soda ash and limestone. The molten blend is subsequently spun into delicate fibers, which are woven into a mat-like material. This versatile material serves a multitude of purposes, including insulation, construction, and industrial applications.

Rock Wool

Rock wool, a type of mineral fiber, originates from basalt rock, which undergoes a process of melting and subsequent conversion into fibers. It is a widely employed material for various purposes, including insulation, fireproofing, and soundproofing. Basalt, being naturally abundant worldwide, is environmentally friendly in its sourcing. The fibers are crafted through the drawing and winding of material from the molten state. Rock wool demonstrates commendable fire resistance, chemical inertness, and resilience against impact loads. It stems from basalt, a natural mineral derived from volcanic rock lava, which can yield products highly resistant to high temperatures and chemically stable characteristics. When extracted from volcanic rocks, basalt fibers exhibit near-amorphous properties, crystallizing partially at elevated temperatures depending on the cooling process. Its composition primarily consists of plagioclase and pyroxene, corresponding to SiO_2 and Al_2O_3 compounds, respectively, rendering it chemically robust against strong alkalis while showing lower stability in strong acids. Basalt stands as a non-polymeric fiber, translating into a low elongation-to-fracture property at 3.15%. Other notable attributes include a tensile strength of 2.8 GPa and a density of 2.8 g/cm^3 .

Rock wool insulation primarily comprises fibers produced from a blend of aluminosilicate rock, typically basalt, along with blast furnace slag, limestone, or dolomite. Notably, the slag is a byproduct of steel production, diverting it from landfills. The use of binders may vary depending on the specific product. Typically, rock wool insulation is composed of a minimum of 70% to 75% natural rock, with the remaining raw material volume primarily consisting of blast furnace slag.

Ceramic Fibers

Ceramic fibers represent mineral fibers renowned for their exceptional resistance to high temperatures, and they are crafted from materials like alumina, silica, and zirconia. They are extensively employed in applications requiring high-temperature insulation and fireproofing. Ceramic fibers encompass various inorganic materials, including glass, silicon carbide, boron carbide, and aluminum oxide. A notable distinction lies in the crystalline or partly crystalline and opaque structure of the primary constituent, silicon dioxide tetrahedra, in ceramics, as opposed to the random and amorphous tetrahedra arrangement in glass. Glass is recognized as a transparent amorphous solid, characterized by its high viscosity due to cooling-induced changes, which render it rigid. Glass typically comprises 50% silica along with boron oxide, aluminum, and other minerals. Examples of ceramic fibers encompass glass fibers, aluminum oxide, silicon carbide, and boron carbide, while glass wool and quartz fall under the glass fiber category. Ceramic fibers, often referred to as 'Alumino-Silicate Ceramic Fibers' and 'Refractory Fibers,' stem from the same alumino-silicate materials employed in the ceramic

industries. Their production dates back to the 1940s, involving exposure to temperatures of 2000°C . These manufactured materials exhibit resilience at temperatures ranging from 1260°C to 1400°C . Additionally, they demonstrate resistance to water and a wide range of chemicals, making them suitable for crafting high-temperature refractory linings, as well as thermal insulation blankets, felts, ropes, gaskets, and papers.

Slag Wool

Slag wool, categorized as a mineral fiber, originates from the by-products generated during the steelmaking process. Its predominant applications include insulation and fireproofing. Slag wool insulation primarily comprises fibers produced by melting the core constituent, which is blast furnace slag, coupled with a mix of certain natural rock elements. The use of binders may or may not be involved, contingent on the specific product in question. Generally, slag wool insulation utilizes roughly 70 percent blast furnace slag, with the remaining portion of raw materials consisting of natural rock.

Glass Wool

Glass wool, a mineral fiber variant, is crafted from molten glass, which undergoes a spinning process to form fibers. Its widespread applications encompass building insulation, along with acoustical and fireproofing purposes. The production of glass fiber employs diverse techniques tailored to the specific final product desired, whether it's in a solid form, mat, or rope. For instance, it can be transformed into a mineral wool mat, suitable for insulation purposes like loft insulation and soundproofing. Alternatively, the mineral wool mat can be subjected to increased density and structural reinforcement to yield pre-formed rigid sections, ideal for use in pipe insulation.

Man-made Mineral Fibres

Man-made mineral fibers, abbreviated as MMMF, encompass a diverse range of inorganic materials transformed into fine fibers, serving purposes like structural reinforcement and insulation. Various types of MMMF exist, each with distinct names, including mineral wool (encompassing rock wool, slag wool, and glass wool), continuous filament, superfine, and refractory or ceramic man-made mineral fibers. These designations originate from different sources and are not necessarily exclusive categories. The overarching term "Man-Made Mineral Fibers (MMMF)" serves as a generic descriptor for a wide array of manufactured fibrous materials, often characterized by a woolly texture and typically derived from molten glass, rock, or slag. Individually, they may be referred to as glass wool, rock wool, or slag wool, depending on the materials used in their production. Notably, this category excludes naturally occurring silicate fibers like asbestos and also does not encompass man-made organic fibers such as nylon and rayon. There is a wide variety of MMMF available. Man-made mineral fiber is widely used.

Mineral fibers serve a diverse range of crucial applications across various industries. They are commonly employed as both thermal and acoustic insulation in buildings and process plants, enhancing energy efficiency and creating comfortable environments. In the realm of safety, mineral fibers are utilized for structural fire protection, ensuring the integrity of structures in the event of fire. These fibers are also employed for pipe insulation, effectively maintaining temperature stability in industrial settings. Their application extends to high-efficiency filtration systems, where they aid in the removal of fine particulate matter. Importantly, mineral fibers have emerged as a safer alternative to asbestos, which is now banned in many countries. They find extensive use in insulation boards, blankets for heat treatment processes, electrical insulation applications, and reinforcing materials in the production of plastics and cement, showcasing their versatility and significance across multiple sectors.

Uses of Mineral Fibres

Mineral fibers constitute a group of materials derived from naturally found minerals such as asbestos, glass, and rock wool. These fibers are renowned for their remarkable robustness, longevity, and inherent ability to withstand elevated temperatures and fire hazards. They are extensively utilized across a diverse range of industries, including:

Protective Clothing: Fire safeguarding. They are utilized in the manufacturing of firefighters' ensembles, heat-resistant gloves, aprons, and other safety attire designed for professionals working in high-temperature sectors like foundries and steel mills.

Insulation: Mineral fibers are widely utilized for thermal and sound insulation in residential, commercial, and industrial settings. They excel at inhibiting heat dissipation and diminishing noise pollution.

Fire protection: Certain mineral fibers, such as rock wool and glass wool, possess outstanding fire-resistant qualities and are employed in fireproofing and firestopping systems for both buildings and marine vessels.

Friction products: Historically, mineral fibers such as asbestos found application in crafting friction components like brake linings, clutch facings, and gaskets because of their resistance to heat and long-lasting nature. Nevertheless, the utilization of asbestos in these items has been prohibited in numerous nations due to its health risks.

Filters: Mineral fibres especially glass fiber is used in air and liquid filters due to their high porosity and ability to trap particles.

Reinforcement: These fibres are used as reinforcements in

composites, building materials, and

construction products, such as fibre-reinforced plastics and concrete.

Construction materials: Rock wool and glass wool are used as insulating and fireproofing

materials in construction and as components in roofing and wall systems.

Application of Mineral Fibres

Mineral fibers constitute inorganic materials, typically consisting of assorted naturally sourced minerals. These fibers possess distinctive characteristics that render them valuable across a diverse spectrum of uses, encompassing insulation, reinforcement, and filtration. Here are some noteworthy properties associated with mineral fibers:

Inorganic Composition: Mineral fibers are primarily composed of inorganic materials, such as

silica (SiO_2), alumina (Al_2O_3), calcium carbonate (CaCO_3), or basalt. This inorganic nature makes them resistant to heat and chemicals.

High Temperature Resistance: Mineral fibers are known for their excellent resistance to high

temperatures. They can withstand temperatures much higher than organic fibers without degrading, making them suitable for applications in furnaces, kilns, and other high-temperature environments.

Fire Resistance: Due to their high-temperature resistance, mineral fibers are also highly fire-

resistant. They do not readily ignite, and when exposed to flames, they do not contribute to the spread of fire. This property is crucial in building materials like fire-resistant insulation.

Low Thermal Conductivity: Mineral fibers have low thermal conductivity, which means they are

efficient insulators. This property makes them valuable for use in thermal insulation applications, helping to conserve energy by reducing heat transfer.

Chemical Resistance: Mineral fibers are generally resistant to most chemicals, including acids and

bases. This resistance makes them suitable for use in filtration systems where exposure to corrosive chemicals is a concern.

Mechanical Strength: Depending on the specific type and processing of mineral fibers, they can

exhibit varying degrees of mechanical strength. Some mineral fibers, like basalt fibers, have high tensile strength and can be used as reinforcement materials in composites.

Sound Absorption: Mineral fibers also have sound-absorbing properties, which makes them

useful for acoustic insulation applications. They can help reduce noise transmission and improve indoor sound quality.

Non-Combustibility: Mineral fibers are non-combustible, meaning they do not burn or support

combustion. This property is essential for materials used in fire-resistant applications.

Dimensional Stability: Mineral fibers generally have good dimensional stability, meaning they

maintain their shape and size over a wide range of temperatures and humidity levels.

Low Toxicity: Unlike some organic fibers, mineral fibers are typically non-toxic when

exposed to heat or fire. They do not release harmful gases or smoke, which is crucial in fire safety applications.

Biological Resistance: Mineral fibers are not a food source for microorganisms, such as

bacteria and fungi and are generally resistant to biological degradation. Common types of mineral fibers include rock wool, glass wool, basalt fibers, and ceramic fibers. Each type has its own specific properties and is suited to different applications based on their unique characteristics. These properties collectively make mineral fibers versatile materials with numerous industrial and commercial uses.

Advantages of Mineral Fibres

Mineral fibers have several advantages, which make them a popular choice for use in a variety of applications. These mineral fibers possess a remarkable combination of properties that make them highly sought after in various applications. They are characterized by their high strength and durability, ensuring longevity and reliability in diverse settings. Additionally, they exhibit low shrinkage and exceptional dimensional stability, maintaining their form over time. Their resistance to heat and fire makes them invaluable for fireproofing and thermal insulation. Not only do they offer good insulation properties and low thermal conductivity, but they also excel in providing effective acoustic insulation. With low water absorption and chemical resistance, they remain robust in challenging conditions. Moreover, these fibers are non-combustible and generate minimal smoke, enhancing safety. Their long service life is complemented by their versatility, making them suitable for a wide range of textile products.

Disadvantages of Mineral Fibres

The utilization of certain mineral fibers, such as asbestos, has raised significant concerns due to the associated health hazards

when inhaled, making safety a paramount issue. Additionally, there are environmental implications stemming from their production and disposal, contributing to ecological concerns. These materials often come at a higher cost compared to alternative insulation materials, further affecting their feasibility. Furthermore, mineral fibers can be sensitive to moisture, potentially diminishing their insulation performance and promoting mold growth. Their chemical sensitivity can lead to deterioration over time, compromising their effectiveness. Installation can also prove challenging, especially in inaccessible areas. Lastly, waste management poses notable challenges due to potential health risks linked to their disposal, necessitating careful handling and disposal protocols.

Conclusion

Mineral fibers represent a distinctive category of materials that have garnered increasing attention within the textile industry. This abstract provides a comprehensive overview of the role and significance of mineral fibers in textile production, offering insights into their unique characteristics, manufacturing processes, and various applications. Mineral fibers, such as asbestos, basalt, and glass, have demonstrated remarkable attributes that contribute to enhanced durability, heat resistance, and fire-retardant properties in textile products. This paper explores the historical context of mineral fibers in textiles and delves into their contemporary applications, ranging from protective clothing to automotive and aerospace textiles. Furthermore, this abstract discusses the challenges associated with the use of mineral fibers, particularly concerning health and environmental concerns, and highlights the ongoing research and development efforts aimed at mitigating these issues. The integration of mineral fibers into the textile industry represents a promising avenue for innovation and diversification in textile product offerings. Understanding the properties and potential of mineral fibers in textiles is crucial for both industry professionals and researchers alike as they navigate the evolving landscape of sustainable and high-performance textile materials. This abstract offers a concise overview of the key aspects surrounding mineral fibers in the textile industry, laying the foundation for further exploration and advancement in this field.

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