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Uses of Vermiculite and Perlite in Fire-Retardant Textile Applications

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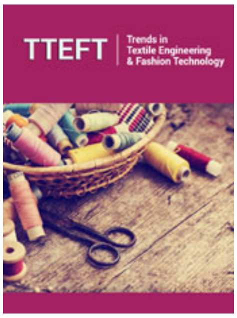

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Abstract

In parallel with industrialization, concerns about human safety have noticeably grown. Consequently, there have been advancements in the fields of functional and protective textiles. Minerals such as vermiculite and perlite are widely accessible, lightweight, environmentally friendly, cost efficient, and inert, which makes it possible to create composite structures that are immensely useful. Vermiculite and perlite are potential candidates for fire protection since they are non-combustible. In this context, the previous research on developing flame-resistant textile materials using vermiculite and perlite has been summarized in this article.

Keywords: Minerals; Vermiculite; Technical textiles

Introduction

The concern about human safety has increased with industrialization. As a result, functional fibers, fabrics, and protective equipment have undergone a number of recent advances, particularly in the field of technical textiles [1-3]. If subjected to an irradiative heat flux or a flame, polymeric materials, such as bulk polymers, textiles, and foams, will readily ignite and burn rapidly if they are not naturally flame-retardant. Hence, the drawback of such materials emerges in all applications that require complete fire resistance [4]. To circumvent this limitation, almost from the beginning of the 19th century, both academics and industry actors began to develop, manufacture, and successfully utilize compounds called flame-retardants (FRs). These additives can be performed through a variety of mechanisms as outlined below:

A. Char formation: FRs promote the formation of a stable layer of carbonaceous deposits on the surface, which protects the polymer's surface from heat and air.

B. Intumescence: FRs swell along with the degrading material, creating a barrier against heat, air, and pyrolysis byproducts.

C. Reactions in the gas phase: Vapor phase flame-retardants can hamper the free radical reactions that are effective in flame propagation.

D. Cooling (heat sink mechanism): The pyrolysis zone at the combustion surface cools when the flame-retardant decomposes endothermically.

E. Dilution: This could happen in the gas phase or the condensed phase. In the former, FRs function to dilute the polymer and lessen the concentration of combustible gases caused by decomposition. In the second case, the activation of FRs results in the formation of inert gases, which dilute the flammable gases [5-7].

In this regard, many flame-retardants that greatly increase thermal resistance of fabrics, raise their ignition temperature, slow combustion, and restrict heat release have been generated to promote the performance of textiles in fire situations [8]. For instance, due to their slight influence on the environment, halogen-free flame-retardant chemicals that primarily comprise phosphorus- or phosphorus/nitrogen compounds have been proposed [7]. Furthermore, particle fillers have a significant impact on the way a polymer burns, including how resistant it is to ignition and the volume and kind of smoke and harmful gas emission products. This might be the result of merely diluting the combustible fuel source, which would delay the rate of oxygen diffusion and the production of flammable pyrolysis products. It would also alter the melt rheology of the polymer, which would change the polymer's inclination to drip [9].

The development of ecologically acceptable, non-toxic flame-retardant systems that enhance the comfort attributes of textiles has been a real concern for coatings and fabrication technologies for the manufacturing of flame-retardant textiles [10,11]. In current study, it is aimed to give information about the effects of Vermiculite and Perlite particles on the fire resistance properties of textile materials. Firstly, the influence of heat on textile products will be discussed.

The effect of heat on textile materials

Heat can cause both chemical and physical transformations in a textile material. The physical changes in thermoplastic fibers arise at the second order transition (Tg) and melting temperature (Tm), whereas the chemical changes happen at pyrolysis temperatures (Tp), which is where thermal degradation takes place. As a complex process, textile combustion involves heating, decomposition that results in gasification (the release of fuel), ignition, and flame propagation. Heat causes fiber to pyrolyze at Tp, where flammable volatile liquids and gases serve as the fuel for further combustion. Following pyrolysis, flammable volatile liquids burn in the presence of oxygen to create products such as carbon dioxide and water if the temperature is equivalent to or higher than the combustion temperature Tc. Heat emanating from an external source boosts the temperature of a textile once it has been ignited, forcing it to deteriorate. The rate of this initial temperature increment is influenced by the fiber's heat capacity, thermal conductivity, latent heat of fusion (for melting fibers), and heat of pyrolysis [11].

Vermiculite as flame-retardant filler for textile materials

Vermiculite is a naturally occurring mica mineral that is formed from biotite. It has a water content between 11% and 21%, and when heated, it can expand up to 30 times its original volume. Vermiculite's adjacent silicate layered structure can inhibit non-flammable gases from escaping, enhancing the expansion of the coating under fire, and effectively protecting the underlying substrate from heat and fire. Furthermore, the majority of vermiculite is constituted of heat-resistant substances including SiO_2, MgO, Fe_2O_3 and Al_2O_3, which can promote the coating's thermal stability and the char's oxidation stability at high temperatures [12]. It may also be chemically delaminated to produce oriented films with a nanometric thickness; ICI and Fothergill Engineered Textiles have employed this ability in a technique where vermiculite lamellae are placed on glass fibers for extreme heat resistance [13].

Vermiculite exhibits natural heat insulation properties and is chemically and physically stable enough to endure a flame that is roughly 1200 °C in temperature. It has thus been reported to boost composites' capacity to withstand flames when used as a filler. In this context, flame-retardant nanocomposites produced from vermiculite modified polymer have been announced. Limited oxygen index, thermogravimetric analysis and carbonization rate under actual fire have been utilized to assess the performance of flame-retardant nanocomposites based on polymers [14]. It has also been reported that vermiculite is specifically incorporated into hydrogel materials, because of its recognition as a charring promoter and a physical barrier against heat and mass conduction [15].

Previous studies recorded that vermiculite and other nano clays, such montmorillonite, have been employed as fillers or fire-resistant coatings in polymers. It has been asserted that the gas barrier property, fire retardancy, and mechanical performance can all be enhanced by the orderly distribution of nanosized clay particles [16,17]. To expand the examples, untreated glass fiber melts at around 1000 °C, making it inappropriate for applications that require higher temperatures. But, by adding finely dispersed vermiculite and other involving aluminum salts, it can be treated to increase its endurance to such temperatures (above 1500 °C) [11]. Another study provided that fiber vermiculite-concrete composites by using air-entraining agent from saponified wood resin (WSR) developed a higher degree of fire resistance in reinforced concrete slabs compared to cement-vermiculite concrete. This is because the composite structure is reinforced with randomized basalt fibers. In addition, the porous structure of the basalt fiber vermiculite-concrete composite created more air circulation, and the fire-retardant property was improved [18].

Recently, a unique treatment technique, Layer-by-layer (LBL) deposition, has undergone a thorough evaluation to demonstrate its usefulness in enhancing flame retardancy. This method utilizes nanomaterials such as montmorillonite, vermiculite, carbon nanofiber and polymers including chitosan, poly (acrylic acid), poly (ethylene imine), ammonium polyphosphate and alginate to generate flame-retardant nanocoating on fabric or foam materials in an environmentally friendly way [19]. Technically, via molecular self-assembly processes, anionic clay vermiculite can combine with cationic elements to create new materials. Using LBL deposition procedure, researchers have combined highly arranged clay nanosheets with cellulose nanofibers to create thin films with the structure of a nano-brick wall to enhance the flammability and gas barrier properties of cellulose-based films. The wall construction made of nano bricks has been found to be highly flame resistant and increasingly oxygen-permeable [20].

Another study used LBL deposition to apply polyelectrolyte solutions/suspensions of cationized starch, vermiculite and TiO_2 nanoparticles to cotton fabric. To construct thin layers of flame-retardant nanocomposite on cotton fabric, a hybrid system containing cationized starch and vermiculite clay as cationic species and TiO_2 nanoparticles as anionic species were used. The functionalized fabric that was created using seven bilayers exhibited a 30% reduction in pyrolysis [21]. On the other hand, Rehman et al. used anionic sources such montmorillonite and vermiculite clay and cationic starch to create LBL coatings on cotton fibers. Only 23.2% of LOI for cotton fabrics was achieved [21]. It has been reported that for the coatings to achieve an acceptable level of flame retardancy, multiple layers must typically be assembled. The hand-feeling and washing durability of cotton materials with LBL coating, however, are rarely recorded [22].

Perlite as flame-retardant filler for textile materials

Perlite is a siliceous volcanic rock of the rhyolite family. According to estimates, the top four perlite producers worldwide are China (47%), Greece (20%), Turkey (16%), and the United States (13%) [23]. It has an amorphous structure with a very low density and high porosity. Perlite could be a useful flame-retardant modifier due to its low thermal conductivity and strong fire resistance [24]. The chemical composition of perlite is approximately composed of 75% SiO_2 with oxides of Al (14.8%), K (4.8%), Na (2.9%), Ca (0.9%), Mg (0.1%), Fe_20_3 (1.5%) and bound water (3.0%). When perlite particles are heated rapidly to temperatures exceeding 870 °C (1600 °F), they expand to 4-20 times of their original volume [25]. The specific characteristics of the expanded perlite are the following: 50~250 (density, mg/cm^3), 0.03~0.05 (thermal conductivity, W/(m•K)), and -200~800 (service temperature, °C) [26]. The pH of expanded perlite is roughly 7.2 and it is chemically inert. It is non-toxic, insoluble in water, non-flammable, and easy to handle. Therefore, perlite has been the subject of many studies in various fields such as construction, medicine, chemistry, agriculture and so on [27].

Although studies on flame-retardant textile applications of perlite are limited in the literature, some related conducted research will be summarized in this review. For instance, it has been reported that the complex epoxy mastic that has been created and commercialized as a coating for protection and contains boric acid, APP, a triaryl phosphate, tris (2-hydroxyethyl) isocyanurate (THEIC), silica, perlite and ceramic fibers, combines reactive and additive-type FR systems to achieve the desired flame-retardant property [28]. On the other hand, many studies have focused on using additions of expanding materials, which can expand because of heating and endothermic processes, to develop fire-resistant curtains. Such materials include vermiculite, perlite, and oxidized graphite [29]. In another study, Anhui Jianzhu University has reported the satisfactory fireproof performance of recycling thermosetting polyurethane plastics, whose outer side of the board is a fireproof layer composed of nonwoven fabric and inorganic paste, and whose middle is rigid polyurethane foam [30].

A patent has been developed to solve the technical problems of commercialized perlite slabs, such as being small in size, not waterproof, and brittle due to its low density. This patent relates to the technology of preparation of fire-resistant composite core plate based on expanded perlite. This composite core sheet is composed of nonwoven fabric on an upper layer and nonwoven fabric on a lower layer, with a wire mesh in the middle, expanded perlite, high temperature resistant inorganic aggregate and high temperature resistant inorganic binders. Additionally, it is environmentally benign and has A1 level fireproof performance. Some specific properties of this composite are as follows; compression strength of 0.35-0.8MPa, density of 260-300 kg/m^3, hydrophobic rate of 92%, bulking factor of smaller than or equal to 0.25 and heat conductivity of smaller than or equal to 0.046 [31].

Perlite has a wide range of industrial applications, and in a PhD thesis, its applicability in the textile industry and the characteristics it imparts to a fabric were examined. For this purpose, raw and expanded perlite was coated on 100% cotton gabardine fabric in an industrial type of blade coating machine. Moreover, four layers of coating were applied to both sides of the fabric in the manual coating system (by hand). The burning behavior of the fabrics was investigated by vertical, horizontal, inclined burning tests and LOI measurement. The results of vertical burning tests revealed that the flame propagation time increased by up to three times. Also, it has been observed that the flame propagation times of the fabrics coated with raw perlite were better than those of the expanded perlite coated fabrics. Results from horizontal burning tests indicated that perlite-coated fabrics increased overall burning time by 10-65% while reducing flame propagation speed by 10-40%. In addition, it was determined that the flame spread more slowly, and the burning time lasted longer in raw perlite coated fabrics compared to expanded perlite coated fabrics. The inclined burning test showed that the flame propagation time increased by 125% in fabric coated with raw perlite and by 25% in fabric coated with expanded perlite, respectively. The LOI value of cotton fabric, which was 19%, was found to increase to 20.6% in fabrics coated with perlite in one layer. The LOI value of fabrics coated using the manual coating mechanism with 3 and 4 layers on one side and 3 layers on both sides was found to be 21.35%; the value of the double-sided 4-layered fabric was determined to be 22.1%. In the literature, fabrics giving these LOI value are described as slowly combustible. It has also been observed during the experiments that the LOI value enhanced as the coating repetition increased [32].

Conclusion

For coatings and fabrication processes used to obtain flame-resistant textiles, the development of environmentally friendly, non-toxic flame-retardant systems that improve the comfort characteristics of textiles has been a critical issue. Due to their incombustibility, vermiculite and perlite are possible choices for fire protection. Although their use in the development of flame-retardant protective textiles is limited, several experimental studies show that satisfactory results have been achieved so far. Therefore, obtaining sustainable and environmentally friendly fireproof fabrics or textile reinforced composites using vermiculite and perlite is an open field for innovative research.

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