Development of High Flame-Retardant Fabric Using Aerogel-Based Coating for Improved Comfort and Thermal Protection

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ABSTRACT

Textiles are used in many parts of everyday life, but most fabrics can catch fire easily and let flames spread quickly. Linen and polyester, which are often used in clothes and home textiles, are no different.Linen burns quickly because it is a natural fibre. Polyester, on the other hand, melts and drips when it gets hot. This is why it is important to find ways to make these fabrics safer for fires without making them less comfortable.This study developed and applied a straightforward aerogel-based flame-retardant coating to linen and polyester fabrics. Polyvinyl alcohol was used as a binder, ammonium polyphosphate as a flame-retardant agent, Tween-80 as a surfactant, and silica aerogel as a thermal insulator to make the coating solution.The fabrics were checked for air permeability, vertical and horizontal flammability, and wash durability after being coated.The fabrics with the coating were much better at resisting flames. The fabrics burnt more slowly and spread flames less quickly than untreated samples, and they also put themselves out better. The fabrics still let air through after being coated, which means that comfort and breathability were mostly kept. Tests that involved washing the coating showed that it still worked after being washed.In general, this study shows that coatings made of aerogel can be a simple and promising way to make flame-retardant fabrics that are safer and more comfortable for everyday and protective use.

Keyword : - Aerogel coating, flame-resistant fabrics, linen fabric, and polyester fabric Thermal insulation, air permeability, and wash durability.

1. INTRODUCTION

- Textiles are important in our daily lives, from the clothes we wear and the things we use to decorate our homes to the things we use in industry and transportation. Most textile materials are very flammable, so they can easily catch fire when they come into contact with heat or flame. Even though fabrics are comfortable and useful, they are not safe to wear. This makes studying fire safety in textiles very important, especially for clothes, upholstery, and protective clothing.

- Linen and polyester are two of the most popular fabrics because they are comfortable, long-lasting, and can be used in many different ways. Linen is a natural fiber made from flax that is known for being comfortable and letting air through. Linen, like many other natural fibers, burns quickly and helps flames spread. Polyester, on the other hand, is a man-made fiber that burns differently. When polyester is exposed to high temperatures, it melts and drips instead of burning quickly. This can cause serious burns. Because of these risks, it is now necessary to make both natural and synthetic fabrics more resistant to flames.

- People have always used flame-retardant finishes to make textiles less likely to catch fire. But many of these treatments have problems, like making the fabric less breathable, making it stiffer, being bad for the environment, and not lasting long after washing. Because of this, scientists are now working on making new flame-retardant systems that are light, breathable, and last a long time.

- In the last few years, aerogel materials have gotten a lot of attention as a way to keep heat in. Aerogels are very light and porous materials that don't conduct heat very well. Aerogels can slow down heat transfer and act as good thermal barriers because of how they are built. This means they could be a good way to make textiles more fire-resistant while still being comfortable.

- The goal of this study is to create a flame-retardant coating made of aerogel that can be easily applied to linen and polyester fabrics. Flammability, air permeability, and wash durability tests are used to see how well the coated fabrics work. The main goal is to make textile materials safer without making them less comfortable or useful

2.LITERATURE REVIEW

- For the last few decades, a lot of researchers have been trying to make textile materials more resistant to flames. Fire safety has become a big deal for clothes, cars, and home furnishings. Because of this, the need for flame-retardant finishes that work well and are comfortable has grown a lot.

- In the past, flame-retardant treatments mostly used halogen-based chemicals. These chemicals worked very well to make things less flammable, but they also caused serious health and environmental problems because they released poisonous gases when they burned. Because of this, scientists started to look for safer and more environmentally friendly options, like flame-retardant systems that use phosphorus or nitrogen.

- Ammonium polyphosphate (APP) is one of these options that has gotten a lot of attention. APP is a common flame-retardant additive because it helps make a protective char layer during burning. This char layer slows down the transfer of heat and makes it harder for oxygen to get to the fire, which keeps the flames from spreading. Numerous studies have demonstrated that APP-based systems can markedly enhance the fire resistance of textile materials

- Another important part of flame-retardant research is making binders that help the coating stick well to the fabric surface. People have used polyvinyl alcohol (PVA) a lot as a binder because it can make films, dissolve in water, and stick well to textile fibres. Studies have demonstrated that PVA can enhance the durability of flame-retardant coatings, particularly following multiple washings.

- Nanotechnology has made new things possible in textile finishing in the last few years. Researchers have looked into nanomaterials like nano-clays, graphene, and silica particles to see if they can make things more flame-resistant. Silica aerogel has gotten a lot of attention because of its unique properties. Aerogels are very light, very porous materials that don't conduct heat very well. Aerogels can be great thermal insulation barriers because of how they are made. They also slow down heat transfer during combustion.

- Several researchers have said that adding aerogel particles to coatings can make them better at keeping heat in and slowing down the spread of flames. Aerogel has a porous structure that traps air and slows down heat transfer, which helps keep things from catching fire and burning. Aerogel coatings can also keep things breathable because they are porous, which makes them good for use on textiles.Even with these benefits, there aren't many studies on flame-retardant coatings made of aerogel for both natural and synthetic fabrics. Most of the work that has been done before has looked at either natural fibers or synthetic fibers on their own. Consequently, additional research is required to assess the efficacy of aerogel-based coatings on various fabric types and to investigate their comfort and durability characteristics.This study aims to create a straightforward aerogel-based flame-retardant coating and apply it to linen and polyester fabrics, addressing a notable research gap. Flammability, air permeability, and wash durability tests are used to find out how well the coated fabrics work

3. METHODOLOGY

This part of the paper discusses the materials, methods of manufacturing a coating, how fabrics were coated, and the testing methods used in the research.

3.1. Materials

Used Two fabric types have been chosen for the research, an example of a natural fiber and an example of a synthetic fiber, to evaluate how well the coating performed on these very different types of fabric.

Linen:

Linen, a natural fiber made from flax, has good breathability and comfort, but is easy to ignite and burnsquickly, therefore it is a good candidate for testing flame retardant treatments.

Polyester:

Polyester is a synthetic fiber that has many desirable properties, including durability and resistance to wrinkling. When polyesters ignite, they tend to melt and drip, and therefore, if the melting is not prevented, may cause serious burning injuries. Therefore, it is necessary to improve the flame resistant characteristics of polyesters.

3.2 Chemicals Underutilized

The following chemical compounds have been utilized in preparing the flame-retardant coating

1. PVA — Polyvinyl Alcohol; used as a binder for enhancing adhesion of the coating to the fabric surface.
2. APP — Ammonium Polyphosphate; this is the primary flame-retardant chemical and creates char when exposed to flame.
3. Tween-80 — used as a surfactant in order to create an even dispersion of aerogel particulates within the solution.
4. Silica Aerogel — serves as thermal insulation and reduces the transfer of heat energy.

3.3 Preparation of Coating Solution

To produce the coating solution, a simple process of mixing has been utilized which produces a homogeneous mix.First, dissolve the Polyvinyl alcohol in distilled water while stirring and heating continuously until a clear homogeneous solution has formed.The next step is to add Ammonium Polyphosphate slowly and agitate thoroughly until fully dispersed to achieve a uniform coating solution. As a surfactant to increase wetting and distribution of the particles, Tween-80 was added. Silica aerogel particles were added to this mixture gradually, with continuous stirring, to create a uniform coating suspension.

3.4 The fabric coating procedure

The applicator for the fabric coating was a controlled laboratory type of coating machine. The fabric samples were cut to meet standard testing size. Using the prepared coating solution, the fabric surfaces were coated with a uniform layer, and the coating was cured by drying under controlled temperatures and levels of moisture. Prior to testing, the coated fabrics were conditioned at room temperature under normal conditions.

3.5 Testing procedures

Test procedures were used to evaluate the performance characteristics of the coated and uncoated fabrics using the following tests:

- Air Permeability Test: Used to measure breathability and comfort of fabric.
- Vertical Flammability Test - The purpose of this test is to evaluate flame spread, after-flame time, & char length.
- Horizontal Flammability Test - The purpose of this test is to evaluate burning rate and ignition resistance.
- Wash Durability Test - The purpose of this test is to assess how durable the coating will be after multiple laundering.

4. TESTING METHODS

We used standard textile testing methods to look at the breathability, flame resistance, and durability of the aerogel-based coating on both coated and uncoated linen and polyester fabric samples.

4.1.Air Permeability Test:

To see how the coating affected the fabric's breathability and comfort, we did an air permeability test. The test checks how much air can get through the fabric when the pressure difference stays the same. We put the fabric sample on the air permeability tester and measured how fast air flowed through it. To see how the coating affected ventilation and comfort, we compared the results of coated samples to those of untreated fabrics.

4.2.Test for Vertical Flammability:

The vertical flammability test was done to see how the fabric would burn when it was near a vertical flame source. The fabric sample was hung up and set on fire for a certain amount of time. After the flame was put out, the after-flame time and char length were measured. This test helps figure out how well the coated fabrics put out fires and how well they resist flames.

4.3.Test for Horizontal Flammability:

We did the horizontal flammability test to see how quickly the flame spread across the fabric's surface. One end of the fabric sample was set on fire while it was lying flat. We measured how long it took for the flame to travel a certain distance and then figured out the burning rate. This test tells you how well something can stop flames from spreading.

4.4.Test for wash durability:

Testing for wash durability was done to see how stable the coating was after washing. The coated fabric samples were washed several times in a controlled setting. After washing, flammability tests were done again to see if there were any changes in performance and to find out how long the flame-retardant finish would last .

5. RESULTS AND DISCUSSION

We tested the performance of aerogel-coated linen and polyester fabrics by comparing samples that were coated and those that weren't in terms of how well they let air through, how flammable they were, and how long they lasted in the wash.

5.1 Air Permeability Results

To see if the aerogel-based coating changed how breathable the fabrics were, air permeability testing was done. The results showed that the coated fabrics let in less air than the untreated samples. This decrease is expected because the coating partially blocks the pores in the fabric. But the drop wasn't big enough to matter, and there was still enough air flow. The reason for this behavior is that silica aerogel has a very porous structure that lets air through but still keeps heat in. So, the coating did improve flame resistance without making comfort and breathability too bad.

5.2 Results of Vertical Flammability

Testing for vertical flammability showed that coated fabrics were much better at resisting flames. In comparison to samples that were not treated:
* The time after the flame went out was much shorter.• The length of the char was shorter.
* Coated fabrics put themselves out when they caught fire
Linen fabrics that hadn't been treated caught fire quickly and burnt quickly because they have cellulose in them. The flame spread more slowly after coating, and the fabrics stopped burning faster.
Polyester fabrics that weren't treated melted and dripped while they burnt. The coating helped stop the melting and spreading of flames, which means better thermal protection.
The main reason for the improvement is that ammonium polyphosphate expands when it burns, creating a protective char layer. This layer of char acts as a barrier that keeps heat and oxygen from getting through.

5.3 Results for Horizontal Flammability

The results of the horizontal flammability test showed once again that the coating worked.Compared to untreated samples, the burning rate of coated fabrics went down a lot. The flame spread across the fabric's surface more slowly and in a more controlled way.
The reduction in burning rate is attributed to two main mechanisms:
The APP makes a protective char layer.
Silica aerogel provides thermal insulation.
The aerogel particles slowed down the combustion process by making it harder for heat to move through the fabric structure.

5.4 Results for Wash Durability

Testing for durability showed that the flame-retardant coating still worked after being washed many times.
After being washed many times, the coated fabrics did show a small drop in flame resistance, but they still worked much better than untreated fabrics.
This shows that PVA worked well as a binder, making the coating stick better to the fabric and making it last longer when washed.
For real-life textile uses, wash durability is very important, and the results show that the coating that was developed has a lot of potential.

5.5 Analysis of Overall Performance

The results of the tests show that the aerogel-based coating improves safety, comfort, and durability in a balanced way.
Important things that the coating did:

- Better resistance to flames
- Slower burning and shorter char length
- Kept the ability to breathe
- Lasts a long time after washing

The coating worked well on both natural (linen) and synthetic (polyester) fabrics, which shows how flexible it is

5.CONCLUSION

This study successfully created a simple and effective flame-retardant coating made of aerogel for linen and polyester fabrics. The coating made the material much more fire-resistant by slowing the spread of flames, the rate at which they burn, and the length of the char, while still allowing air to flow through it. The wash durability tests showed that the coating stayed effective even after being washed many times because PVA binds strongly to things.

Overall, the coating that was made is a good mix of fire safety, comfort, and long-lastingness. The results show that this could be very useful for protective clothing, home textiles, and

industrial safety textiles. Future research may concentrate on enhancing coating thickness and investigating extensive industrial applications.

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