International Journal of Advance Scientific Research
(ISSN – 2750-1396)
VOLUME 04 ISSUE 09 Pages: 17-25
OCLC – 1368736135

Journal Website: http://sciencebring.com/index.php/ijasr

Research Article

INVESTIGATING THE IMPACT OF AEROSIL-380 SUSPENSIONS ON CELLULOSE FABRICS VIA THERMAL METHODS

Submission Date: Sep 19, 2024, **Accepted Date:** Aug 24, 2024,
Published Date: Sep 29, 2024
Crossref doi: https://doi.org/10.37547/ijasr-04-09-03

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ABSTRACT

This article presents the results of a comprehensive thermal analysis of cellulose-containing fabrics treated with stable suspensions derived from both unmodified and surface-modified Aerosil-380 nanoparticles. The study aimed to investigate the influence of nanoparticle treatment on the thermal behaviour and fire-resistant properties of the fabrics. The thermal tests, including techniques such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC), revealed that the application of Aerosil-380, particularly the modified versions, significantly enhanced the thermal stability and fire-technical characteristics of the treated textiles. These improvements were particularly notable in increased resistance to ignition and reduced combustion rates, indicating that the modified nanoparticles contributed to superior fire-retardant properties. The findings suggest that integrating modified Aerosil-380 nanoparticles into cellulose-based fabrics could provide a promising approach for developing advanced materials with enhanced safety features for fire-prone environments.

KEYWORDS

Nanoparticles, nanosuspension, Aerosil-380, modification, cellulose-containing fabrics, thermal analysis, flammability, level of smoke generation.

INTRODUCTION

The use of cellulose-containing fabrics has a long history, spanning various industries such as textiles, packaging, and construction. However, their inherent flammability remains a significant limitation, especially in applications requiring enhanced fire resistance. In recent years, the development of nanotechnology has opened up new avenues for improving the fire-technical properties of such materials. Among the numerous nanomaterials, silica-based nanoparticles, including Aerosil-380, have attracted considerable attention due to their unique properties, such as high thermal stability and large surface area, which can significantly influence the performance of treated fabrics in fire-prone environments.

Aerosil-380, a type of fumed silica, has been widely used in the modification of materials to enhance their mechanical, thermal, and surface properties. When incorporated into cellulose-based fabrics, Aerosil-380 nanoparticles create a protective barrier that slows down thermal degradation and combustion. Additionally, modified versions of these nanoparticles offer even greater potential for enhancing fire resistance due to their ability to better interact with the fabric fibers at a molecular level, forming more robust protective coatings [1].

Despite these advantages, research on the thermal behavior of cellulose-containing fabrics treated with both unmodified and modified Aerosil-380 nanoparticles remains relatively limited [2]. This study aims to fill this gap by evaluating the thermal properties of such fabrics using established thermal analysis techniques, including thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). The results of this study provide valuable insights into how nanoparticle modification can influence the thermal stability and fire resistance of cellulose-containing materials, paving the way for their use in safety-critical applications.

2. Materials

The primary material used in this study was cellulose-containing fabric, which is commonly employed in the textile industry due to its biodegradability and widespread availability. The fabric samples were obtained from a standardized supplier to ensure uniformity in the base material properties.

The nanoparticles used for treatment were Aerosil-380, a fumed silica nanopowder. Two types of Aerosil-380 were utilized:

1. Unmodified Aerosil-380 nanoparticles, which served as the control in this study.

2. Modified Aerosil-380 nanoparticles, which were surface-functionalized to enhance their interaction with cellulose fibers and improve the

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fire-technical properties of the treated fabrics. The modification process involved functionalizing the nanoparticle surface with specific organic groups to increase adhesion and thermal stability.

2.1. Preparation of Suspensions

Stable suspensions of both unmodified and modified Aerosil-380 nanoparticles were prepared. The nanoparticles were dispersed in deionized water under vigorous stirring to form stable colloidal suspensions. A sonication process was employed to ensure homogeneous dispersion of nanoparticles, which helps prevent agglomeration and maximizes the surface area interaction with the fabric.

2.2. Fabric Treatment

The cellulose-containing fabric samples were immersed in the prepared Aerosil-380 nanoparticle suspensions. The treatment was conducted using a dip-coating method, where the fabrics were submerged in the suspension for a predetermined period to allow sufficient nanoparticle adsorption. The samples were then removed and dried at 80 °C for several hours to remove excess moisture and ensure adhesion of the nanoparticles to the fabric surface.

The treated fabric samples were categorized as follows:

 Sample A: Treated with unmodified Aerosil-380 nanoparticles.

 Sample B: Treated with modified Aerosil-380 nanoparticles.

 Control sample: Untreated fabric, used for baseline comparisons.

2.3. Thermal Analysis

The thermal properties of the untreated and treated fabric samples were evaluated using the following methods:

1. Thermogravimetric Analysis (TGA): TGA was performed to assess the thermal degradation behavior of the samples. Approximately 10 mg of each fabric sample was heated at a rate of 10°C/min in a nitrogen atmosphere from room temperature to 800°C. The weight loss as a function of temperature was recorded to determine the thermal stability and onset of degradation.

2. Differential Scanning Calorimetry (DSC): DSC was conducted to measure the heat flow associated with the physical and chemical changes in the fabric samples. Small fabric specimens (approximately 5 mg) were subjected to heating and cooling cycles at a rate of 10°C/min under an inert nitrogen atmosphere. The data obtained from DSC provided insights into phase transitions and heat-resistant behaviour.

3. Limiting Oxygen Index (LOI) Test: The fire-retardant properties of the treated fabrics were evaluated using the LOI test, which measures the minimum concentration of oxygen required to sustain combustion. Higher LOI values indicate better fire resistance. The treated and untreated fabrics were tested following ASTM D2863-19 standards, and the results were

compared to assess the impact of nanoparticle treatments on flammability.

2.4. Statistical Analysis

All experiments were performed in triplicate to ensure data reliability. The results were statistically analysed using analysis of variance (ANOVA) to determine the significance of the differences in thermal properties between untreated, unmodified, and modified Aerosil-380 treated fabric samples. A p-value of <0.05 was considered statistically significant.

Analysis and statistics of fires show that the flammability of various materials and the high speed of fire spread lead to less time to evacuate people during fires and, as a result, people die. Therefore, by increasing the fire resistance of substances and materials, including textile materials, the evacuation of people in case of fire and, as a result, increasing the time of rescue, as well as the elimination of fire at the initial stage of development, are urgent issues [4,5,6].

It is of great scientific and practical importance to reduce the flammability of textile materials by modifying the fiber composition and structure of textile materials with flame retardant, environmentally friendly (mainly inorganic compounds resistant to high temperatures) components at the stages of certain technological processes of textile production [7,8] .

In the research work, the thermal effects on cellulose-containing fabrics obtained as a result of treatment under the influence of ultrasound in various conditions (from 100 to 400 W) with modified suspensions of silicon IV oxide nanoparticles (aerosil-380) obtained at the initial stage of scientific research [9-10] the changes that occur in them as a result and the changes in their flammability properties as a result of this were studied.

It is known that thermal analysis methods are widely used in the research of fire safety properties of substances and materials in recent years [11]. At this stage of the research work, as mentioned above, various samples of modified cellulose-containing fabrics [9, 10] were tested using differential-thermal analysis and differential-scanner calorimetry thermal methods.

3. Results and discussion

As a result of the tests, the following results were obtained:

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Crossref doi Google Scholar WorldCat MENDELEY
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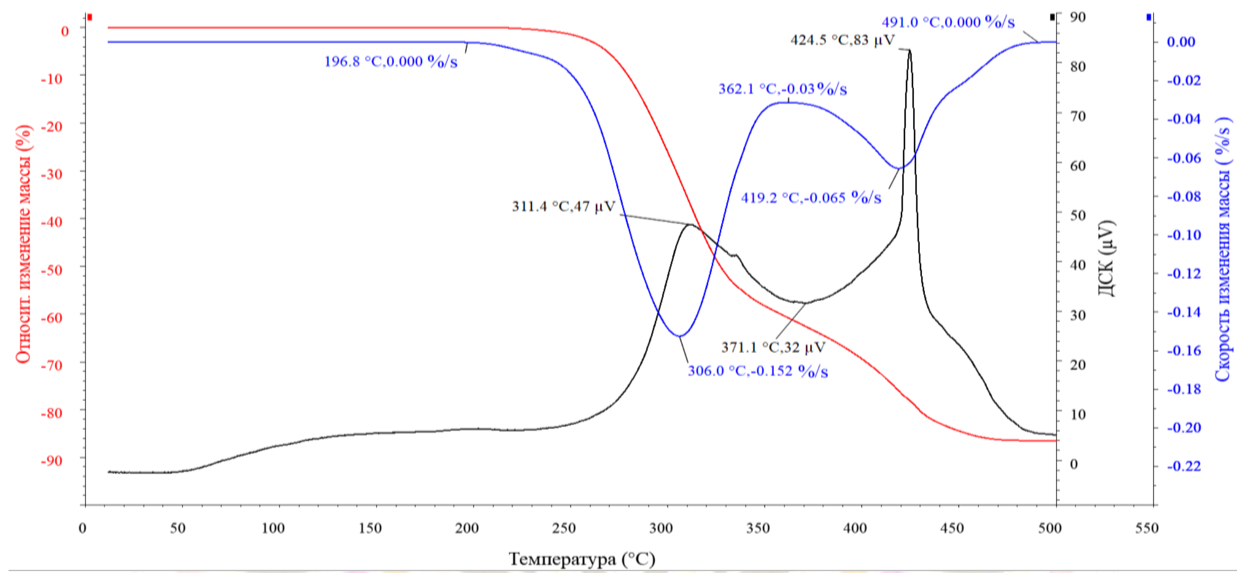

Fig. 1. TG, DTG and DSK curves of a fabric sample treated with a mixture of Aerosil-380 and magnesium hydroorthophosphate (0.1:0.1 ratio).

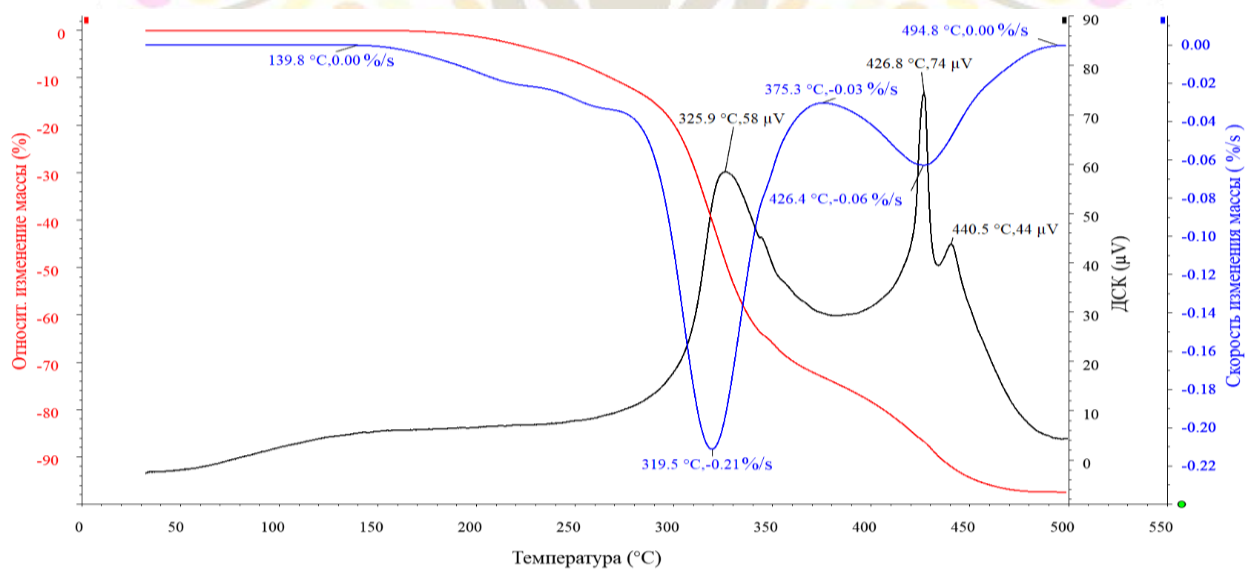

Fig. 2. TG, DTG and DSK curves of a fabric sample treated with a mixture of Aerosil-380 and magnesium hydroorthophosphate (ratio 1:0.1).

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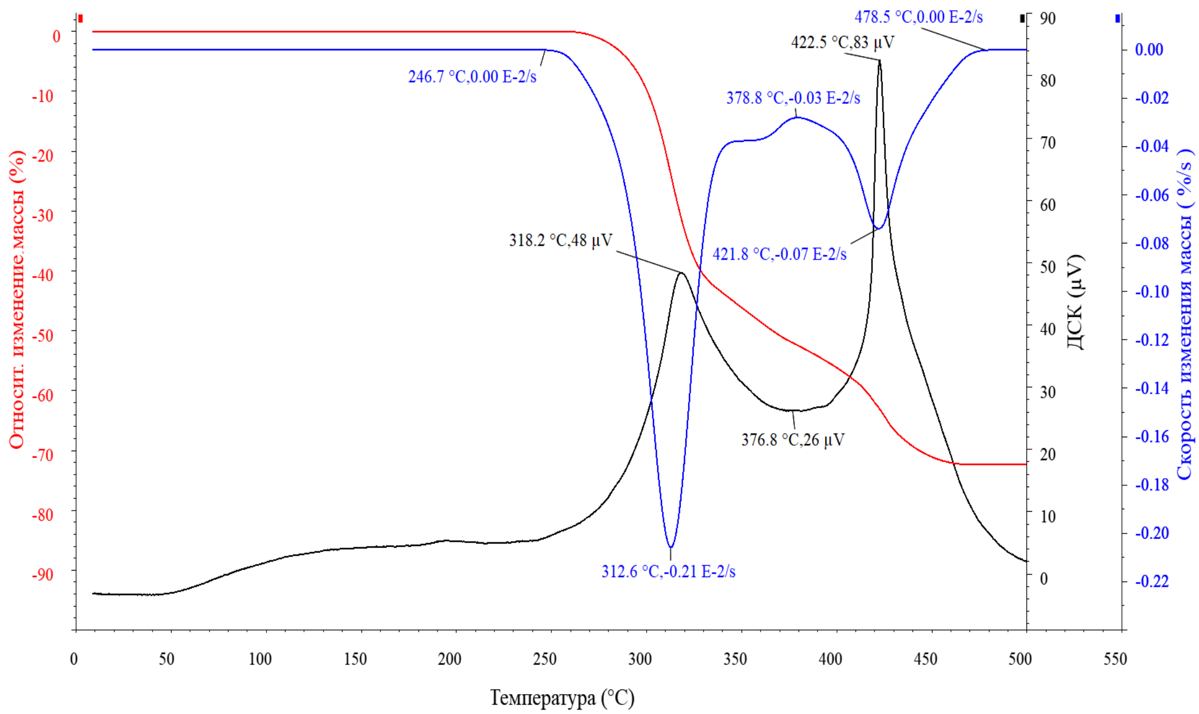

Fig. 3. TG, DTG, and DSK curves treated with a 0.1:0.1 mixture of Aerosil-380 and polypropylene glycol.

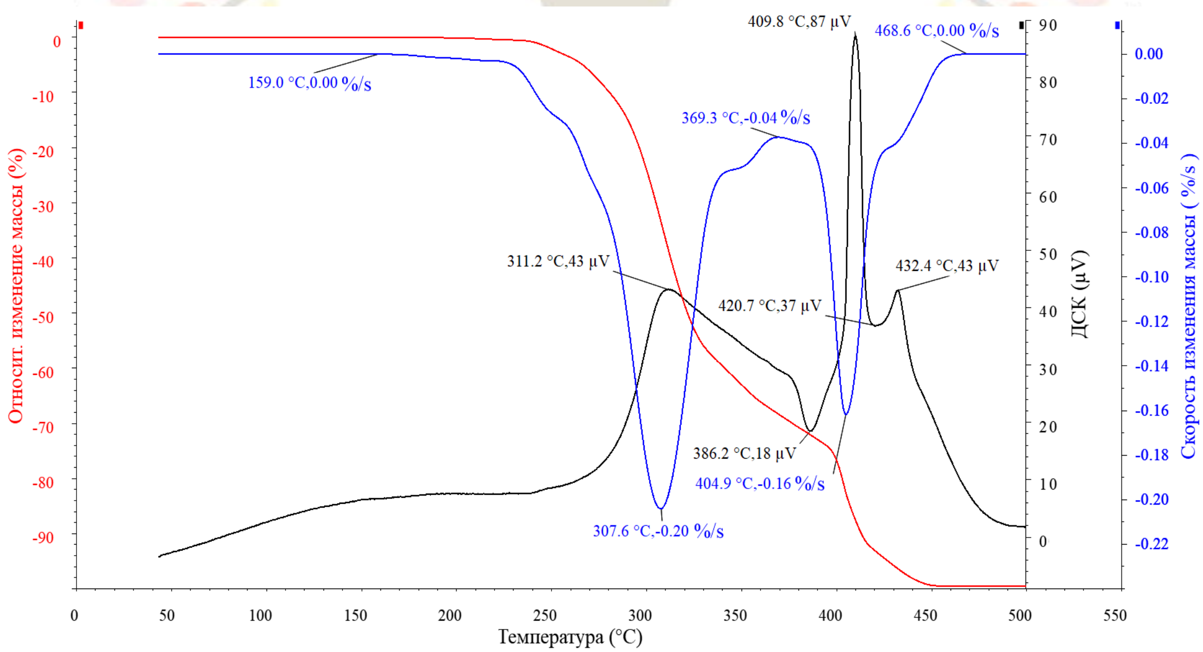

Fig. 4. TG, DTG, and DSK curves treated with a 1.0:0.1 mixture of Aerosil-380 and polypropylene glycol.

From the results obtained during the research, it became known that the samples of cellulose-containing fabrics treated with stable suspensions obtained on the basis of unmodified and modified (magnesium hydroorthophosphate, sodium acetate, sodium tetraborate, polypropylene glycols) particles of silicon IV oxide nanoparticles (aerosil-380) and prepared for testing were thermally from the results of the tests, we can see that these modification processes have a positive effect on the fire-technical properties of the fabrics (Tables 1 and 2).

Table 1. A fabric treated with a mixture of Aerosil-380 and magnesium hydroorthophosphate

No	Fabric treated content	Temperature, °C	Rate of change of sample mass, %
1.	Aerosil-380 and magnesium hydroorthophosphate (0.1:0.1 ratio)	196.8	0
		306.0	0.152
		362.1	0.030
		419.0	0.065
		491.0	0
2.	Aerosil-380 and magnesium hydroorthophosphate (1:0.1 ratio)	139.8	0
		319.5	0.21
		375.3	0.03
		426.4	0.06
		494.8	0

Table 2. A fabric treated with a mixture of Aerosil-380 and polypropylene glycol

No	Fabric treated content	Temperature, °C	Rate of change of sample mass, %
1.	Aerosil-380 and polypropylene glycol (0.1:0.1 ratio)	246.7	0
		312.6	0.21
		378.8	0.03
		421.8	0.07
		478.5	0
2.	Aerosil-380 and polypropylene	159.0	0

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	glycol (1:0.1 ratio)	307.6	0.20
		369.3	0.04
		404.9	0.16
		468.6	0

Based on the results of the tests (Tables 1 and 2), the rate of mass loss due to thermal effects in treated samples of cellulose-containing fabrics was 0.19% on average at 311.42 °C, while the rate of mass loss of untreated fabric samples was at 100 0S in some samples. It was 0.20%.

Also, in the tests, it was observed that the burning process continued in the samples of modified fabrics during exposure to open flame, and the burning process also stopped when the exposure to the source of fire was stopped. In the samples of unmodified fabrics, it was observed that ignition and burning processes continued even after the exposure to the open flame source was stopped. We can see that the level of smoke production (according to GOST 12.1.044-89) of these samples is also reduced.

Conclusions

From the results of the conducted studies, it was known that the treated tissues increased their resistance to thermal effects and the effects of open fire. From this it can be concluded that as a result of the conducted research, as a result of the treatment of cellulose-containing tissues in a new way, i.e. with the help of ultrasound, an increase in fire resistance was achieved due to the penetration of nanoparticles to the microscopic components of these tissues.

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