

Application of Sodium silicate as a halogen-free flame-retardant and evaluate its effectiveness on the flame-retardancy of Polypropylene fabric

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ABSTRACT – REZUMAT

Application of Sodium silicate as a halogen-free flame-retardant and evaluate its effectiveness on the flame-retardancy of Polypropylene fabric

A halogen-free flame-retardant was synthesized using Silica gel and Sodium hydroxide within the scope of the study. The Polypropylene (PP) fabric was treated with the synthesized Sodium Silicate to investigate its thermal behaviour. The limiting oxygen index (LOI) value of the Polypropylene fabrics dramatically increased after finishing with Sodium silicate and the 50.4% noteworthy LOI value was achieved. The Sodium silicate-treated PP fabrics exhibited a 30.1% LOI value even after washing, compared to the neat PP LOI value which was reported to be 16.4%. The surface modification of the Polypropylene fabric following the plasma treatment was evaluated by elemental mapping, surface topography images, and contact angle measurements and the homogeneity of the Sodium silicate coating was evaluated by Scanning electron microscopy.

Keywords: flame-retardancy, intumescence, modification, polyolefins, poly(propylene) (PP)

Aplicarea silicatului de sodiu ca material ignifug fără halogen și evaluarea eficienței acestuia în ceea ce privește ignifugarea țesăturilor din polipropilenă

Scopul prezentului studiu a fost sintetizarea unui material ignifug fără halogen folosind silicagel și hidroxid de sodiu. Țesătura din polipropilenă (PP) a fost tratată cu silicat de sodiu sintetizat pentru a investiga comportamentul său termic. Valoarea indicelui limită de oxigen (LOI) al țesăturilor din polipropilenă a crescut dramatic după finisarea cu silicat de sodiu și a fost atinsă valoarea LOI demnă de remarcat de 50,4%. Țesăturile PP tratate cu silicat de sodiu au prezentat o valoare LOI de 30,1% chiar și după spălare, comparativ cu valoarea LOI pură a PP care a fost raportată a fi de 16,4%. Modificarea suprafeței țesăturii de polipropilenă în urma tratamentului cu plasmă a fost evaluată prin cartografiere elementară, imagini topografice de suprafață și măsurători ale unghiului de contact, iar omogenitatea acoperirii cu silicat de sodiu a fost evaluată prin microscopie electronică de scanare.

Cuvinte-cheie: ignifugare, intumescență, modificare, poliiolefine, poli(propilenă) (PP)

INTRODUCTION

The term “flame-retardant textiles” refers to textile materials that maintain their shape and physical characteristics at temperatures above 200°C. A significant percentage (such as 79%) of residential fires result in death or serious injury. Upholstery fabrics and furnishings pose the greatest fire danger in residential. According to reports, suffocation or poisoning accounts for 50% of fire-related fatalities in the United Kingdom. Therefore, materials that will be used to prevent fires should be both flame retardant and low in harmful gas emissions. Human skin is extremely heat-sensitive; at 45°C, it starts to hurt, and at 72°C, it starts to burn. A person should be able to flee a fire in 3 to 10 seconds under typical circumstances.

Typically, textile fibres are easily combustible. For instance, cotton that does not have a flame-retardant finish ignites instantly and needs a temperature of

360–420°C to burn. Flame retardancy is sought after in a variety of products, including clothing for workers, household textiles, children's clothing, upholstery fabrics, textiles for public transportation and vehicles, sleeping bags, upholstery, and furniture used in public spaces due to the growing number of state regulations. To offer flame retardancy in textile materials, numerous compounds have been utilized throughout history. These substances include halogen, phosphorus, metal hydroxide, intumescent (swelling), boron, nitrogen, silicon, carbonizing, and smoke-suppressing agents. According to studies, there is a surge in the use of flame-retardant chemicals in the global market for textile materials and the building and construction, electrical and electronic, and transportation industries. Regulations for fire safety and prevention have increased the usage of materials based on flame-retardants, particularly in these industrial

branches. The purpose of applying a flame retardant is intended to expedite the suppression of a fire, especially for the protection of people and property. Flame-retardant textiles could be produced by utilizing naturally flame-resistant textile fibre, acquiring flame-resistant fibre, and treating the fabrics with flame-retardant chemicals. Introducing the application of clay and plaster pigments in colouring to prevent burning, Sabbatini provided the first important reference work on the flame retardancy of textiles in 1638. Subsequently, Obadjah Wyld developed a flame retardant that he utilized and patented in England in 1735 by combining borax, ferrous sulfate, and alum. By applying ammonium phosphate, ammonium chloride, and borax components to linen and jute fabrics in France in 1821, Gay-Lussac invented the first systematic study of flame retardant finishing. The historical evolution of flame retardant compounds was outlined by Vahabi et al. [1]. Despite having high flame retardancy characteristics, some compounds also have drawbacks. The fact that the chemicals utilized in the market for flame retardancy are not ecologically friendly, their low washing resistance due to the migration of chemicals in the applied structure, and the decline in the mechanical qualities of the textile product are some major drawbacks. Moreover, halogen combustion produces poisonous and toxic fumes. Saeidi et al. [2] summarized the studies conducted to develop halogen-free compounds as polypropylene flame retardants. They identified the chemicals utilized as being phosphorus, nitrogen, mineral, carbon, and bio-based, as well as their combinations. They illustrated the superiority of the synergistic effect compared to the usage of each component alone [3]. The most popular flame-retardant treatments applied in PP matrices, including flame-retardant chemicals, application methods, and flame suppression mechanisms, were outlined by Zhao et al. [3]. They also concentrated on recent advancements and forecasted the prospects for such applications in the future. The effects of natural fibre reinforcement on the flammability and strength of PP composites were investigated by Bazan et al. [4]. Chen et al. [5] examined the impact of a synergistic flame-retardant system that included strontium carbonate (SrCO_3) as a synergistic agent and epoxy resin microcapsule-modified ammonium polyphosphate (MAPP) as a flame-retardant. According to their findings, the LOI was 36.1% when strontium carbonate addition was 1.5 wt%. Dohor-6000A, a brand-new halogen-free intumescent flame retardant, was used by Xu et al. [6] in melt spinning to produce halogen-free flame retardant PP fibre. The reported LOI value was 29.1% and the developed fibres had strong melt drop resistance when Dohor-6000A content approached 25%. He et al. [7] created various bio-based phytic acid-basic amino acid salts (PaArg, PaLys, and PaHis) using three different forms of basic amino acids: arginine, lysine, and histidine. When it comes to imposing flame retardancy on PP,

PaArg reported a better efficiency than PaLys and PaHis. They underlined that the LOI value of PP at 22% PaArg by weight was 26.0%. Bourbigot [8], summarized the uses of intumescent in the field of flame protection and flame retardancy. As a more cost-effective approach, Kahraman et al. [9] concentrated on the synergistic effect of mica mineral and intumescent flame-retardant chemical in increasing the flame retardancy of PP. To generate 30% by weight of the total mass of the polymeric compounds, they added various ratios of the mineral mica and the intumescent flame-retardant chemical to PP. Dodecyl sulfate intercalated CaMgAl-hydroxylated layered double hydroxides [LDHs] were successfully prepared by Shen et al. [10] using the co-precipitation method. According to their findings, the LOI value of the material rose to 31.5% when the flame retardant contained 2% by weight of organic anion dodecyl sulfate (O-SDS-LDHs) and 23% by weight of intumescent flame retardant chemicals. Phosphate-loaded chicken feather fibres with layered silicate exterior coatings were performed by Jung et al. [11] as a successful intumescent flame retardant material solution for PP. It has been noted that to maintain the same level of flame retardancy for PP, a tiny silicate component (0.4% by weight) results in a 27% wt reduction in phosphate. Song et al. [12] increased the fire retardancy performance of intumescent flame-retardant PP that contains hydroxymethylated lignin by applying coal dust as a synergist. It was claimed that the dripping issue of PP composites was effectively resolved by adding coal powder. It was found that adding coal dust to the PP composite at a 0.5% loading amount significantly improved the flame retardancy with increased LOI values from 28% to 33%. Wu et al. [13] produced a new and environmentally friendly lignin-based surfactant sodium lignosulfonate (SLS) by co-precipitation method with modified layered double hydroxide (LDH) flame retardant (LDH-LS), subsequently, they were incorporated into the PP matrix by melt mixing method to obtain PP and LDH-LS composites (PP/LDH-LS). According to reports, PP/LDH-LS exhibits an LOI of 29.4%, whereas PP/LDH exhibits an LOI of just 25.2% with a 20% additive ratio [14]. Through the application of nano- SiO_2 particles to the surface and the interlamination of graphite lamellas, Wang et al. (2021) successfully designed and synthesized an eco-friendly nanohybrid expandable graphite (nHEG) in situ using a one-pot technique of the first flame retardant PP. To increase the flame retardancy of PP, Peng and Yang [15] produced cerium nitrate-supported silica as a new kind of catalytic synergist. They underlined that the addition of 1% cerium nitrate-supported silica raised the LOI value of PP composites to 33.5%. To increase the fire safety of nonwoven PP fabric, Qi et al. [16] used surface polarity followed by a conventional finishing procedure. The surface of the nonwoven PP fabric was modified in an ultrasonic medium

with a surfactant solution containing cetyltrimethylammonium chloride and then impregnated with an aqueous solution of ammonium polyphosphate and pentaerythritol to increase its hydrophilicity. It has been observed that the contact angle of PP fabric treated with 0.2% cetyltrimethylammonium chloride dropped from 130 of the control sample to 71. Additionally, the LOI value increased from 18.1% to 23.5%. Six novel s-triazine-based bishydrazino and bishydrazido-based polymers were synthesized by Aldalbahi et al. [17] by condensation of bishydrazino s-triazine derivatives with terephthaldehyde or nucleophilic substitution of dichloro-s-triazine derivatives with terephthalic acid hydrazide. They underlined that, depending on their LOI values, these polymers can be categorized as self-extinguishing and flame-retardant materials. Tang et al. [18] prepared phosphorylated MXene/polypropylene (PP) composites by coating phosphorylated MXene on PP fabric, followed by spraying polyethyleneimine (PEI) and heat pressing. Yang et al. [19] prepared more efficient and hydrophobic modified ammonium polyphosphate (M-APP) and charring agent (M-CA) according to the sol-gel method and used them in the preparation of water-resistant and flame-retardant polypropylene (PP) composites. They reported that the contact angles of M-APP and M-CA were 135.11° and 137.89°, respectively. They noted that the flame retardancy of PP loaded with 30% by mass with intumescent flame retardant (M-APP/M-CA = 3:1) significantly increased. The LOI value was found to be 36.8%. A star-shaped coal-forming material (BTETP) with phosphorus and nitrogen was produced and investigated by Qin et al. [20]. Yan et al. [21] used the single pot method and applied phytic acid (PA), melamine (MEL), and layered double hydroxides (LDHs-C) to develop and use an interlayer/surface-modified flame retardant (LDHs@PA-MEL). Thus, they developed a new flame-retardant agent for PP. Yuan et al. [22] used a nucleophilic substitution procedure to create a novel linear polymeric charring agent (PEPAPC), which was then applied to PP to enhance its flame retardancy and anti-drip capabilities. To create an intumescent flame retardant system that would stop the burning of polypropylene (PP), Tian et al. [23] created a triazine-based charcoal-forming agent (PTPA) and combined it with ammonium polyphosphate (APP). They stated a LOI of 29.5%. Zhu et al. [24], prepared decabromodiphenyl ethane/diantimony trioxide (DBDPE/Sb₂O₃) and decabromodiphenyl ethane/hexabromo-

cyclododecane/diantimony trioxide (DBDPE/HBCD/Sb₂O₃) to improve the flame retardancy of polypropylene. They prepared a halogen-free flame retardant PP by using flame retardant systems and single-component intumescent flame retardant PNP1D. The manufacturing of detergents, ceramics and pottery, fireproof paper, and the woodworking sector all employ sodium silicate. In addition to these, it is also utilized in concrete hardening, lumber processing, and clothing dyeing. Cleaning products are one of the common uses for sodium silicate. The rust solvent sodium silicate, which is used in cleaning products, works exceptionally well. To the best of our knowledge, sodium silicate has not been solely applied to PP fabric in the literature to investigate its effect on the flame-retardancy of PP fabric. The objective of this study was to synthesize sodium silicate as a halogen-free flame retardant chemical that would be effective in PP fabric and to retard its combustion behaviour.

MATERIALS AND METHODS

Materials

Silica gel and Sodium Hydroxide chemicals were purchased from Bursa Teknik Kimya (Turkey). 100% PP fabric was supplied by the İpekiş factory and the fabric characteristics are given in table 1.

METHODS

Synthesis of Sodium Silicate

The synthesis of Sodium Silicate involved the stoichiometric ratios of Silica gel (SiO₂) and Sodium Hydroxide (NaOH). Silica gel was added to the bath after sodium hydroxide was completely dissolved in water, and the reaction was then carried out for 2.5 hours in a closed system to prevent the water from evaporating. The balanced chemical equation for the reaction between SiO₂ and NaOH is given in the equation.



Confirmation of Sodium Silicate Synthesis by Chemical Garden method

The synthesis of sodium silicate was confirmed utilizing the chemical garden method. Cartwright et al. [25] investigated chemical garden formation in different sodium silicate solutions from cations and various metal ion salts. By adding metal salts like copper sulfate or cobalt(II) chloride to an aqueous solution of

Table 1

PP FABRIC PROPERTIES					
Fabric composition	Mass per unit area (g/m ²)	Number of threads per unit length (number/cm)		Yarn count (Tex)	
		Weft	Warp	Weft	Warp
100% PP	227	12	15	81.4	73.4



Fig. 1. Formation of chemical garden in Sodium Silicate solution

sodium silicate (also known as water glass), a chemical garden forms. In this experiment, simple or branched plant-like shapes develop over a few minutes to many hours. Copper sulfate was employed to confirm the synthesis of Sodium Silicate, and figure 1 illustrates the formation of the chemical garden.

Surface modification of PP fabric

Surface modification utilizing plasma technology provides numerous advantages over conventional methods when it comes to adding functionality to textile materials [26]. Plasma surface modification was employed to facilitate the treatment of the PP fabric with the synthesized structure. The PP fabric surface structure alterations were measured to determine the efficiency of the plasma treatment: Untreated, 1 and 3 min. plasma-treated (Diener plasma Pico model, 100W power, Oxygen gas flow rate 25 sccm (standard cubic centimetres flowing per minute)) PP fabrics were gone through contact angle measurement. Using an Evident Olympus DSX1000 digital microscope, the surface topography of untreated and plasma-treated fabrics was evaluated.

Treatment of PP fabric with Sodium Silicate

The synthesized halogen-free flame-retardant substance was applied to the PP fabrics during the finishing process. The transfer involved the use of impregnation and coating techniques, which are among the conventional application methods. Utilizing the impregnation method, sodium silicate was applied to plasma-treated PP textiles and allowed to cure for 20 minutes in a 100°C oven. Following the Sodium Silicate synthesis, surplus water was removed by boiling the Sodium Silicate solution at various intervals (3, 5, 7, 15, 30, and 60 minutes), and all fabrics were impregnated for 30 minutes. After oven-drying the Sodium Silicate-impregnated fabrics, the burning test was carried out in the laboratory, and no discernible difference was found between the burning behaviour of the samples, except for the 3 minutes treated sample, but as the time increased, the hand of the fabric was adversely affected, especially for 30 and 60 minutes, which led to the occurrence of hardness in the fabric. Therefore, the ideal solution boiling time was determined to be 5 minutes.

Morphological observations

The surface morphologies were investigated by a Hitachi TM3030Plus Desktop SEM. At three different magnifications of $\times 30$, $\times 100$, and $\times 600$, SEM micrographs of the samples were taken.

RESULTS AND DISCUSSIONS

Contact angle measurement

Since there are no functional groups in the structure of PP, it is difficult to treat it with the synthesized substance to the desired extent, so the adhesion of the Sodium Silicate to the fabric is ensured by surface modification via plasma treatment. Following plasma treatment, contact angle measurements were carried out to observe the changes in the hydrophilicity of the PP fabric. The advancing and receding angles are established at the left (lower) and right (higher) sides of the droplet, respectively, due to the direction of unit rotation. The results are summarized in table 2.

Table 2

CONTACT ANGLE MEASUREMENT RESULTS OF FABRICS		
Treatment type	θ (left)	θ (right)
Prior plasma treatment	123.11	140.05
1 min. plasma treatment	85.13	97.06
3 min. plasma treatment	65.17	45.76

The contact angle is measured between 0–180°. Untreated PP fabric exhibits a higher hydrophobicity, according to table 2. The PP fabric acquired hydrophilic properties after being plasma-treated for 1 and 3 minutes. This effect occurred at a higher rate following plasma treatment for 3 minutes.

Surface topography measurement

Surface topography measurements were performed via Nanosurf Flex Atomic Force Microscope at Bursa Technical University Central Research Laboratory to further reveal the impact of the plasma treatment, and the outcomes are illustrated in figure 2. The average roughness (Sa) and root mean square roughness (Sq) values, known as surface roughness parameters, of the AFM images before and after the plasma treatment are summarized and compared in table 3.

Table 3

SURFACE ROUGHNESS PARAMETERS OF AFM IMAGES			
Sample No.	Sample description	Sa	Sq
a	Prior plasma treatment	1614.7 nm	1958.1 nm
b	Post plasma treatment	3002.7 nm	3366.2 nm

When the results were compared, the Sa and Sq values of untreated and plasma-treated PP fabrics increased from 1614.7 and 1958.1 nm to 3002.7 and 3366.2 nm, respectively. An almost double increase in surface roughness parameters is observed. These results demonstrate the effectiveness of plasma treatment on the surface roughness values of PP fabric.

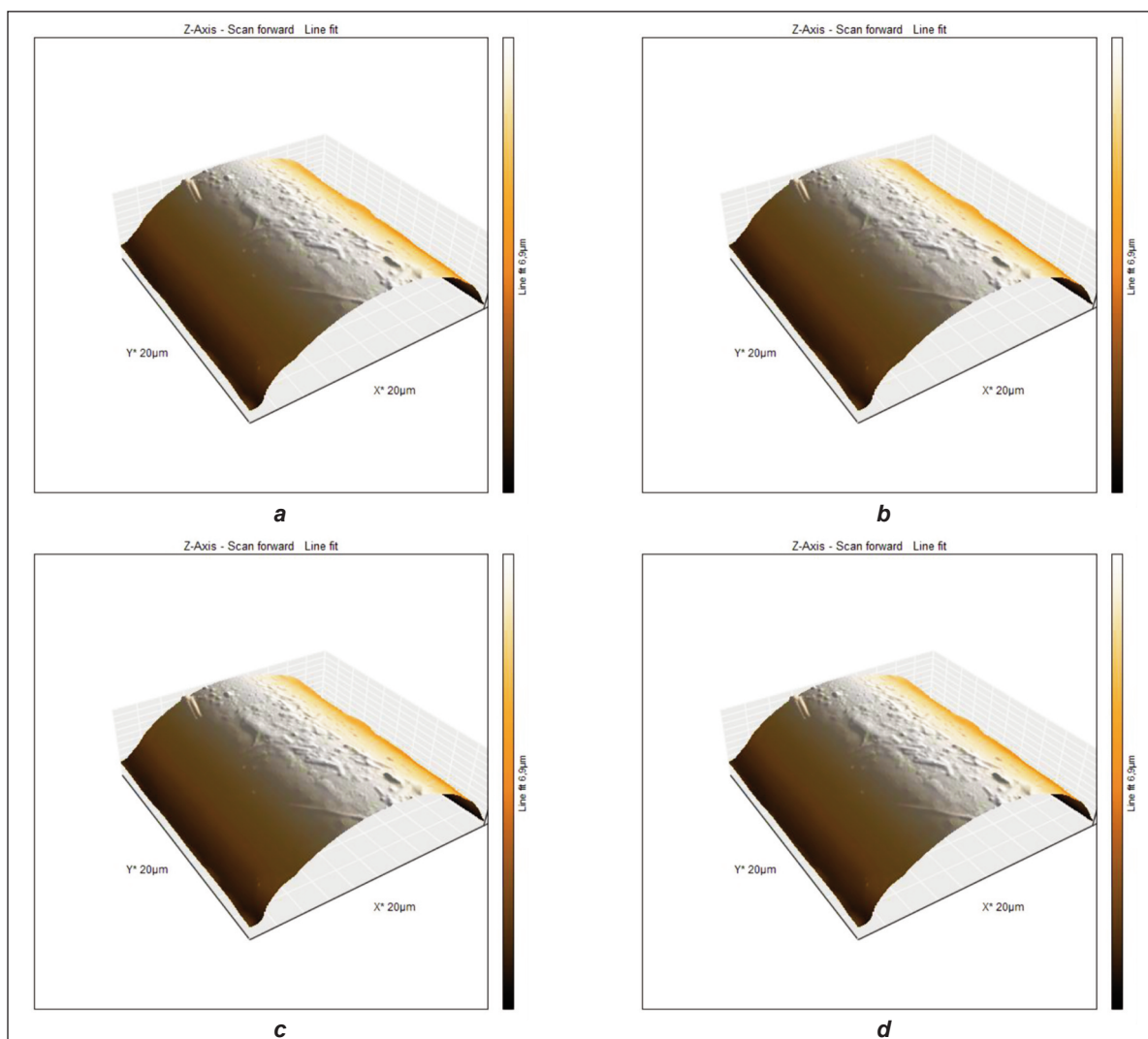


Fig. 2. Surface topographies of fabrics: *a* – prior plasma treatment; *b* – post plasma treatment; *c* – Sodium Silicate treated following plasma application; *d* – Sodium Silicate treated prior plasma application

LOI measurement

According to the TS EN ISO 4589-2 standard, the flame-retardancy of the fabrics was put through the LOI test to ascertain its efficacy. To evaluate the durability of the flame retardancy effect, the fabrics were rinsed with detergent-free water and oven-dried. The LOI test results before and post-detergent-free water rinsing are compared in table 4. It is known that when the LOI value is between 18 and 21%, the material has no flame-retardant effect. According to the

results of our study, the fabric does not lose its flame-retardant feature even after a single rinsing with detergent-free water. This demonstrated the efficacy of the applied halogen-free flame-retardant.

Fourier Transform Infrared Spectroscopy (FTIR)

The IR spectrum of Silica gel is illustrated in figure 3. The spectrum exhibited a broad peak at 3439 cm^{-1} caused by the superimposed stretching modes of Si-OH groups and the hydroxyl groups of physically adsorbed water (figure 4). Peaks at 1626 cm^{-1} , and 1480 cm^{-1} , were assigned to the bending vibrations of water and silanol, respectively. Peaks at 1102 cm^{-1} and 969 cm^{-1} reflected the Si-O-Si stretch vibration modes of the silica gel (figure 5).

The existence of characteristic peaks of Silica gel and Sodium Hydroxide in the IR spectra of Sodium Silicate, as illustrated in figure 6, indicates the successful synthesis of Sodium Silicate.

The IR spectrum of untreated PP fabric is illustrated in figure 7. The IR spectrum exhibited peaks at 2950 and 2920 cm^{-1} caused by the asymmetrical stretching of CH_3 and CH_2 groups, respectively. The peak at 2870 cm^{-1} could be attributed to the stretching of the

Table 4

LOI TEST RESULTS BEFORE AND POST-DETERGENT-FREE WATER RINSING			
Measured value	Untreated	Treated before rinsing	Treated post rinsing
Oxygen Index (%OI)	16.4	50.4	30.1
σ (Expected Std. Deviation)	0.287	0.400	0.315
Sequential Oxygen concentration difference (%d)	0.3	0.3	0.3

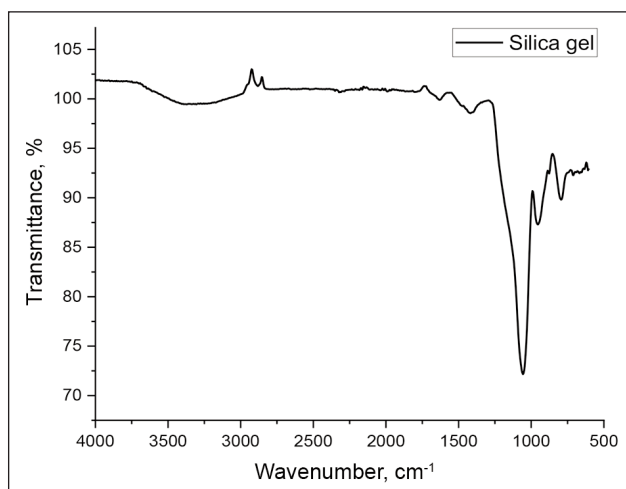


Fig. 3. The IR spectrum of Silica gel

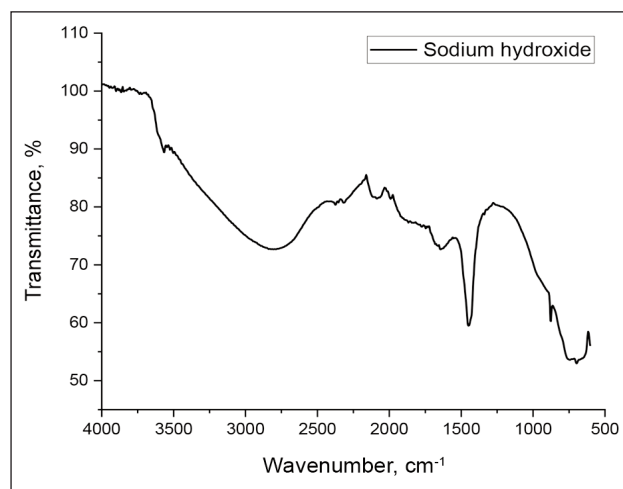


Fig. 4. The IR spectrum of Sodium Hydroxide

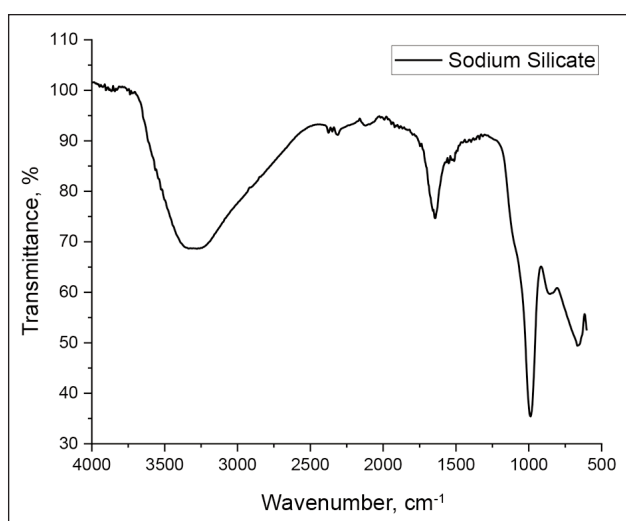


Fig. 5. The IR spectrum of Sodium Silicate

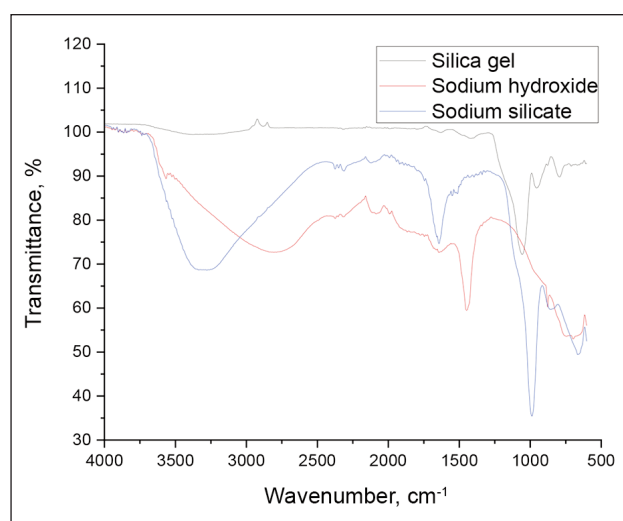


Fig. 6. Joined FTIR spectra of Silica gel, Sodium Hydroxide and Sodium Silicate

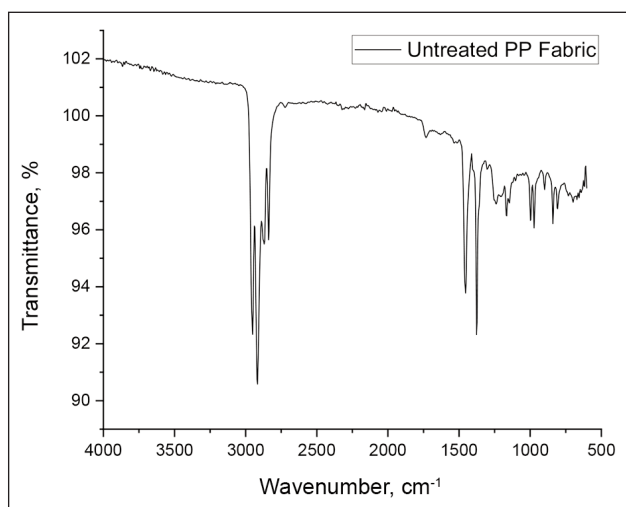


Fig. 7. The IR spectrum of Untreated PP Fabric

CH_3 group. Peaks at 1456 and 1376 cm^{-1} , were assigned to the symmetrical bending of the CH_3 group. Peaks at 1166 , 996 , and 973 cm^{-1} reflected the CH_3 rocking vibration modes of the PP. The peak

at 1166 cm^{-1} could be assigned to the wagging vibration of the C-H group. The peaks at 1166 , 973 , and 808 cm^{-1} are caused by the stretching vibration of the C-C group. The rocking vibration of the C-H group could be assigned to the peak at 840 cm^{-1} .

Scanning Electron Microscopy (SEM)

The SEM micrographs of the Untreated PP fabric are shown in figure 8, *a-c*. SEM micrographs of plasma-treated PP fabric are given in figure 8, *d-f*. The fibrils migrate toward the surface and roughness increases in the PP fabric following the plasma surface modification, which can be observed in micrographs at magnifications of $\times 30$ (*d*) and $\times 100$ (*e*). SEM micrographs of Sodium Silicate-treated PP fabric are given in figure 8, *g-i*. Micrographs demonstrate the uniform dispersion of sodium silicate on the surface of the PP fabric. Figure 8, *j-l* illustrates the SEM micrographs that were taken from the ignition zone following the LOI test. The micrographs reveal that sodium silicate crystallized and created a thermal insulating barrier on the surface of the PP fabric.

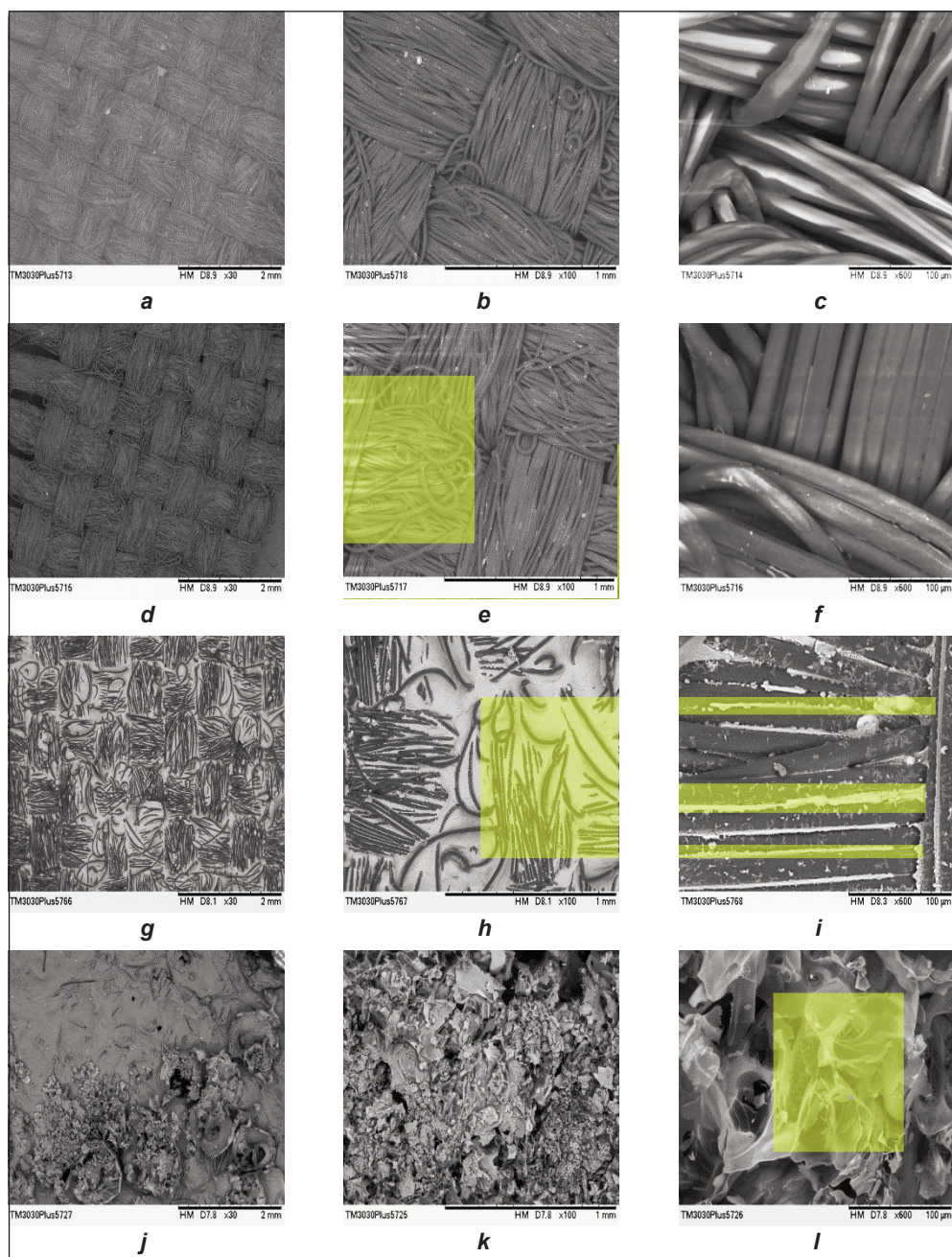


Fig. 8. SEM micrographs: *a* – untreated PP fabric $\times 30$; *b* – untreated PP fabric $\times 100$; *c* – untreated PP fabric $\times 600$; *d* – plasma-treated PP fabric $\times 30$; *e* – plasma-treated PP fabric $\times 100$; *f* – plasma-treated PP fabric $\times 600$; *g* – Sodium Silicate-treated PP fabric $\times 30$; *h* – Sodium Silicate-treated PP fabric $\times 100$; *i* – Sodium Silicate-treated PP fabric $\times 600$; *j* – ignition zone $\times 30$, *k* – ignition zone $\times 100$; *l* – ignition zone $\times 600$

Elemental mapping

The untreated PP fabric, the plasma-treated PP fabric, the Sodium Silicate-treated PP fabric, and the ignition zone post-LOI measurement all underwent elemental mapping. The corresponding images are given in figure 9. Figure 9, *a, c, e, j* shows SEM images, and *b, d, f, g, h, i, k, l, m, n* exhibits the elemental mapping of C, C, Na, O, Si, C, Si, O, Na, C elements, respectively. Since there is no functional group in the structure of PP, only the C atom is observed in its elemental mapping, as illustrated in figure 9, *b*. After the plasma modification, the fibrils open under the influence of plasma power and migrate towards the surface, as seen in figure 9, *d*.

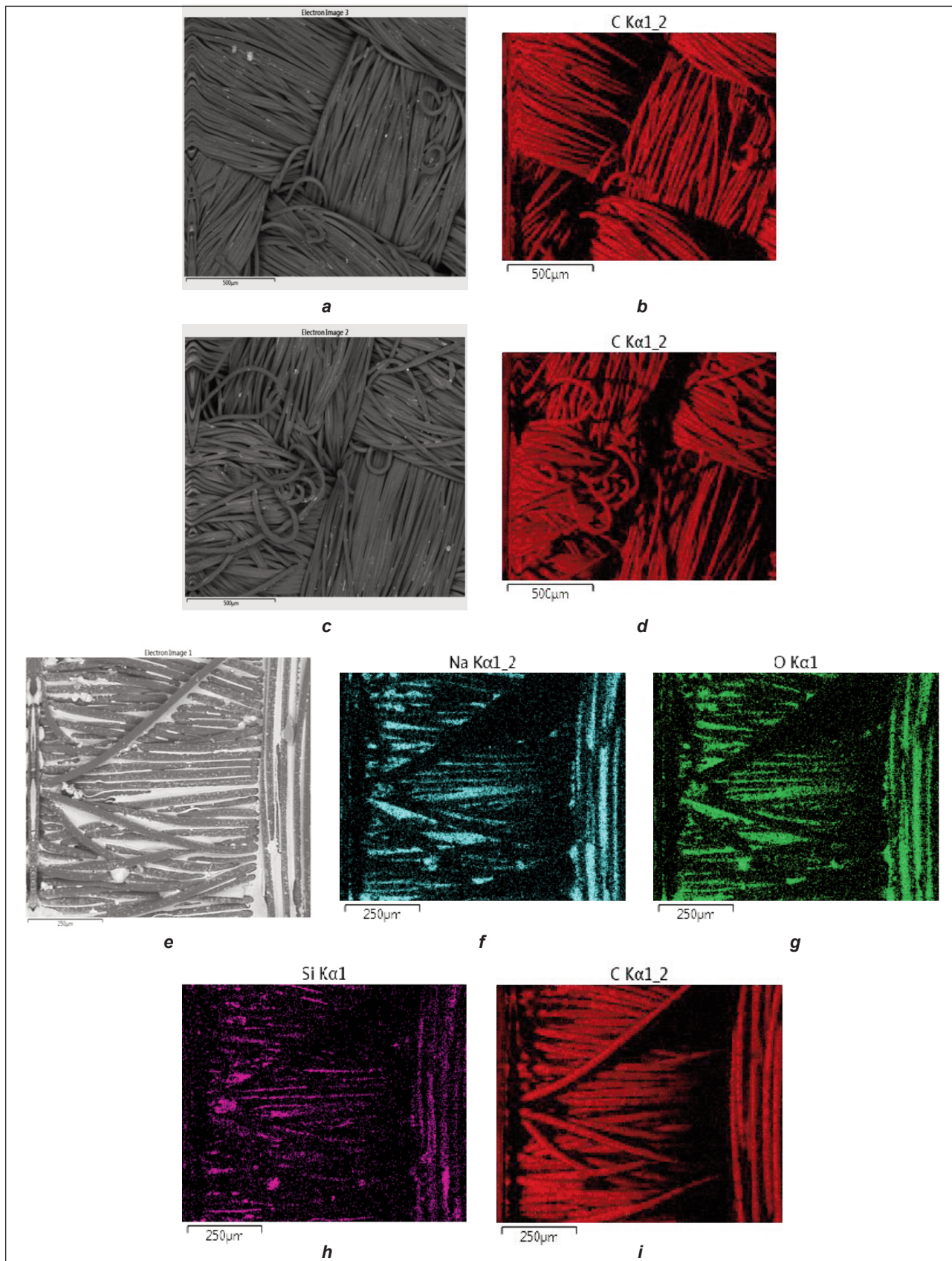
Figure 9, *f–k* confirms that the synthesized halogen-free flame retardant chemical is evenly distributed on the PP fabric surface. Considering the elemental mapping of the ignition zone in figure 9, *l–o* the presence of Sodium Silicate forming elements (Na, Si, and O) subsequent LOI measurement exhibits that Sodium Silicate creates a thermal barrier and protects PP fabric from flame.

Energy dispersive X-ray spectroscopy (EDS)

EDS is a technique used for the elemental analysis or chemical characterization of samples. It is a technique based on the interaction of the X-ray excitation source with the sample. Similar to other spectroscopic

techniques, the characterisation principle states that distinct peaks in the electromagnetic emission spectrum can be used to identify the atomic structure of each element. EDS analysis results of untreated PP fabric (Sample 1), plasma-treated PP fabric (Sample 2), halogen-free flame-retardant chemical-treated PP fabric (Sample 3) and the ignition zone post-LOI

measurement (Sample 4) are given in table 5. It is anticipated that Sample 1 would only show C as a consequence of the EDS analysis because PP does not contain a functional group, although trace amounts of Ti, S, and Al are observed. The structures used in the melt-spinning process are assumed to be the cause of the presence of these elements. The



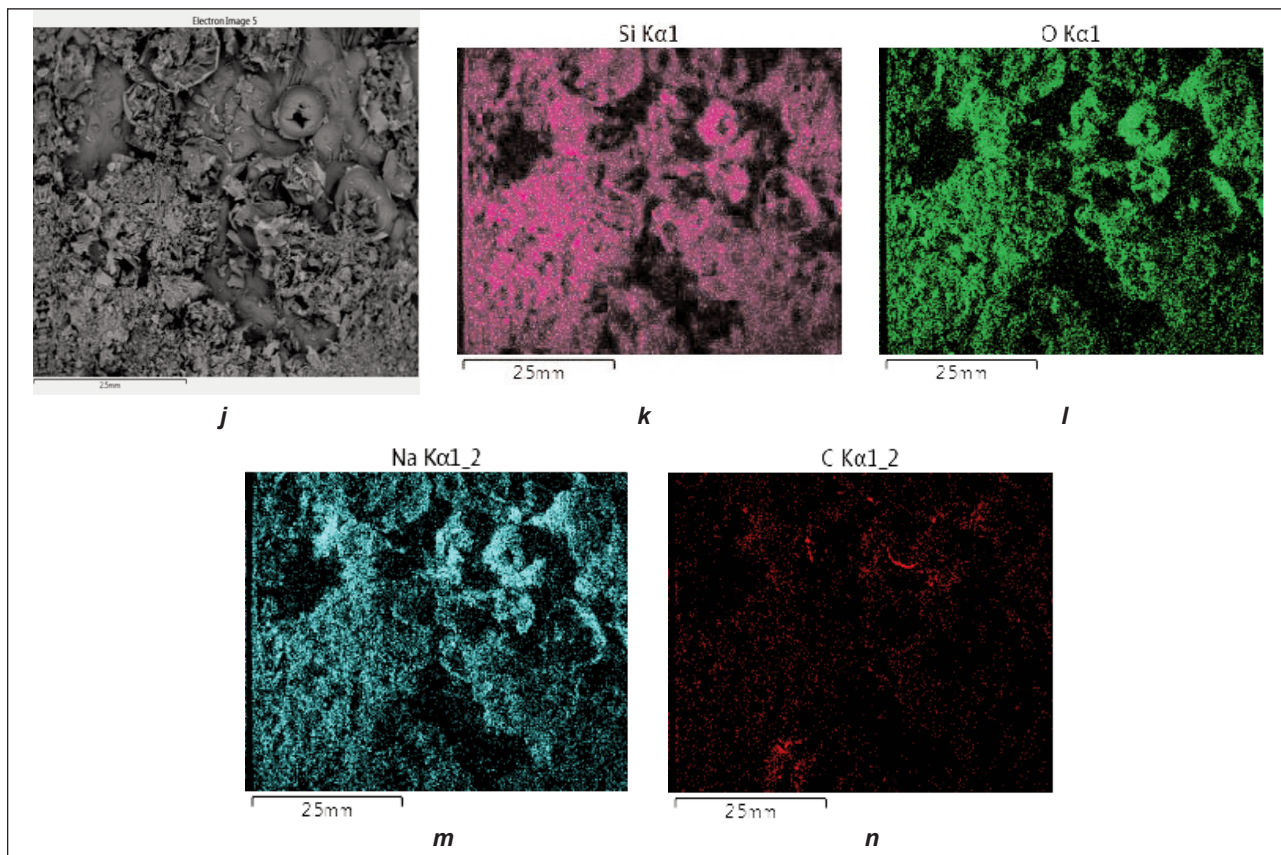


Fig. 9. Elemental mapping: *a, b* – untreated PP fabric; *c, d* – plasma-treated PP fabric; *e–i* – Sodium Silicate-treated PP; *j–n* – ignition zone

Table 5

EDS ANALYSIS RESULTS				
Sample no.	Element	Line type	Weight (%)	Sigma weight (%)
1	C	K-series	99.5	0.1
	Ti	K-series	0.3	0.1
	S	K-series	0.1	0.0
	Al	K-series	0.1	0.0
2	C	K-series	95.2	0.1
	O	K-series	4.4	0.1
	Ti	K-series	0.3	0.0
	S	K-series	0.1	0.0
3	O	K-series	47.7	0.1
	Na	K-series	26.6	0.1
	C	K-series	17.2	0.2
	Si	K-series	8.3	0.0
	S	K-series	0.2	0.0
4	O	K-series	50.5	0.3
	Na	K-series	16.7	0.1
	C	K-series	16.8	0.4
	Si	K-series	16.0	0.1

presence of the O element in the EDS analysis of Sample 2 indicates that the plasma surface modification was successful. The presence of Na, Si, and O elements in the EDS results of Sample 3 demonstrates that the PP fabric surface is successfully

treated with Sodium Silicate. Due to the low and ignorable weight per cent loss of element C in samples 3 and 4, the EDS results indicate that sodium silicate successfully forms an insulating thermal barrier between the flame and the PP fabric.

CONCLUSIONS

The halogen-free flame retardant, Sodium Silicate, was successfully synthesized using the Silica gel and Sodium hydroxide. According to the results of all elemental analyses, the PP fabric was successfully treated with sodium silicate, raising the LOI value to 50.4%. The Sodium Silicate treatment has been observed to have a self-extinguishing effect on the PP fabric along with avoiding dripping during combustion. It is a significant and noteworthy finding that the LOI value is still 2 times greater than the untreated PP even though the LOI value dropped to 30.1% after the washing process was applied to the PP fabric.

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