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Functionalized Polypropylene Filaments for Flammability

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Abstract

A large number of textiles and indoor decorations including carpets, curtains, wallpaper, and so on are all easy to burn. Textile materials that are readily combustible can serve as one of the ingredients in a fire and pose a serious threat to human life and property in fire accidents. The demands for flame-retardant textile fabrics have a steady growth for the past decades and have become an urgent exigency. In this research, two new eco-friendly boron chemicals, boric acid, and borax decahydrate, were used as flame-retardant. The flame-retarding functions for bulked continuous filaments polypropylene (BCF PP) yarn are investigated through the applications of boron chemicals. It is determined that applying boron chemicals improves fire retardance.

Keywords: bulked continuous filaments (BCF), polypropylene (PP), boric acid, borax decahydrate, flame-retardant, flammability

1. Introduction

Fibers are the basic elements of a textile. They can be classified as belonging to one of the following two classes: (a) natural and (b) synthetic. Manufacturing of synthetic fibers was started in 1930. Even now, synthetic fibers are widely used in many applications. Annual consumption of synthetic fibers is increasing day by day because of using a large number of industrial, technical, and engineering applications. Total world output of man-made textile materials has sharply increased, whereas natural textile materials have reduced.

Synthetic fibers are manufactured with organic compounds which are obtained from coal, oil, and petroleum. These mentioned raw materials are abandoned in nature in large quantities. Advantages of synthetic fibers are as follows:

- manufacturing of synthetic fibers is produced in any climate zones and at any time of the year,
- less capital investment and labor,
- cost of synthetic fibers is higher than natural fibers,
- synthetic fibers may be used for many applications,
- can be manufactured with desired requirements, and
- better physical and mechanical properties [1–6].

Polyolefin fibers have polymer chains with higher molar mass, saturated, aliphatic, and hydrocarbons. The Federal Trade Commission (FTC) in the USA approves two names “olefin fibers” and “polyolefin fibers” in order to describe manufactured fibers. Synthetic polymer is composed of approximately 85% by mass polyolefin units. PP is the major commercial man-made fiber. The commercial advantages are summarized as follows:

- low densities (lighter than water),
- high cover power comparison with other textile fibers,
- simplest production and mostly used production method,
- high performance/cost ratio,
- low melting point,
- comfortable to skin,
- good tensile properties,
- good abrasion resistance [7].

PP is the first synthetic stereo regular polymer to achieve industrial importance. BCF is widely used in machine-woven carpet manufacturing industry such as pile yarns, apparel, upholstery, floor coverings, hygiene medical, geotextiles, car industry, automotive textiles, various home textiles, wall covering, and so on. This is expected that this trend will continue in the near future [8–10].

BCF yarn production is a continuous process, consisting melt spinning, drawing, and texturing (**Figure 1**). After extrusion from the spinneret, the molten polymer starts solidifying. Finishing oil is applied to the solidified multifilament yarn, and the yarn is subsequently stretched by about three times in the drawing zones, so that it acquires enough orientation and consequently proper mechanical properties. Texturizing of the continuous filament yarn emerging from the drawing zone follows next. This process imparts volume and softness to the yarn. After leaving the texturizer, the plug rests on a rotating cooling drum, where the process of setting the rather three-dimensional coils formed as a result of the compression in the plug gets completed. Parameters such as air pressure, air temperature, and cooling air play an important role in specifying the final properties of textured yarns [11].

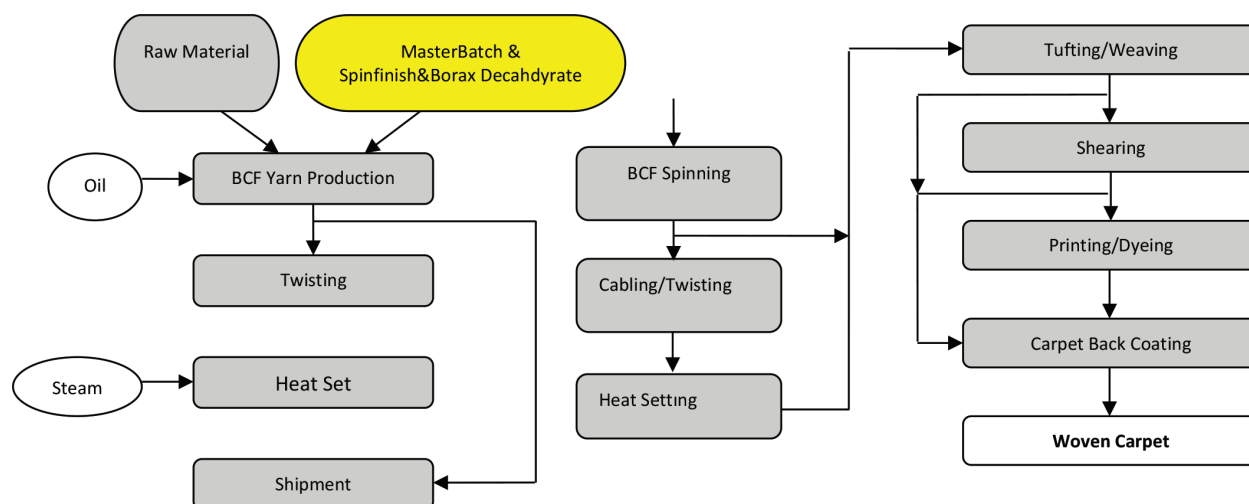


Figure 1. BCF carpet production process [11].

1.1. Flame-retardant

Flame-retardant (FR) fabrics are among few most profitable niche markets in the textile industry. Most of the textile materials are flammable, therefore applying flame-retardants to textile fabrics becomes necessary to assure humans safety under many circumstances. Most recently established federal regulations on the flammability of the fabric indicate that FR textiles will steadily increase in the near future. The increasing use of FR materials in industry has put lots of thrust on the scientific community to develop new polymer materials, FR chemicals, and fiber combinations to a wide range of end-use applications [12–14].

From 1980 to about 2000, very little new research was made about flame-retardant, which were shown chemical, physical, and performance properties and environmental problems (**Table 1**). The major development during these periods about flame-retardant began in 1980, and also amended in 1983 which required cigarette ignition resistance of outer cover fabrics. These were superseded in 1988 by the requirement that all UK domestic furnishing fabrics must have both cigarette and simulated match resistance when tested over unmodified polyurethane foam. These regulations promoted the development of flame-retardant back-coating which could be applied to any fabric thereby enabling many rich upholstered fabric designs to be rendered flame-retardant in spite of the fibers used [15].

Phosphorus compounds having flame-retardant properties in polypropylene may be both inorganic and organic as shown below. It is also common for them to be used in the presence of halogen- or nitrogen-containing compounds and especially those that generate intumescent char-forming characteristics. The range of phosphorus-containing flame-retardants is extremely wide since the element exists in several oxidation states. Phosphines, phosphine oxides, phosphonium compounds, phosphonates, elemental red phosphorus, phosphites, and phosphate are all used as flame-retardants in polymers [17].

Textile materials	Generic formulas	Comments
Cellulose (cotton, viscose) nondurable	Ammonium phosphates and mixtures with other salts, for example, ammonium bromide and sulphamate, ammonium polyphosphates, diammonium phosphate, dimethylphosphono (N-methylol) propionamide (Pyrovatex CP), guanidine phosphates, organophosphorus oxyanion salt, organic nitrogen-containing compound, organic N-and P-containing compounds, borax and combinations of the above	Available as proprietary formulations; semi-durability may be developed by postcuring to achieve-cellulose phosphorylation; addition of resins. dimethylphosphono (N-methylol) propionamide (Pyrovatex CP) bonds to cotton fibers covalently with high durability
Cotton-durable	Tetrakis (hydroxymethyl) phosphonium salt (THPX), tetrakis (hydroxymethyl) phosphonium salts-urea-ammonia (Proban CC), adduct condensates N-methylol and N,N'-dimethylol dialkyl phosphono-propionamides and derivatives	Typified by the ammonia-cured Proban® (Ciba/Huntsman) its variations and equivalents. Requires presence of cross-linking resins
Wool-durable to dry cleaning	Zirconium and titanium hexafluoride complexes tetrabromophthalic anhydride (TBPA)	Typified by Zirpro® may be used alone or with Zirpro® to reduce after flame times
Polyester-durable	Cyclic organophosphonate	Based on Antiblaze 19 (formerly mobil) and subsequently Antiblaze or Amgard CU (Rhodia) applied by thermofixation
Polyamide-durable	N- and S-containing polycondensates typically based on thiourea derivative-formaldehyde formulations	Applied in technical textiles
Acrylics	Back-coatings based on halogen-ATO formulations	The only commercial alternatives to using modacrylic fibers, for example, Kanecaron
Synthetic fibers-PP and PE	Phosphinic acid derivatives (Terevira CS), bisphenol-S oligomer (Toyobo GH) and melamine phosphate pentaerythritol	It can be applied on synthetic textiles as additives during polymerization and/or fiber extrusion
Synthetic fibers-PA, polyolefin, and nylon	Decabromodiphenyloxide, hexabromocyclododecane	It can be applied by coating. This shield acts as a barrier for heat, oxygen and mass transfer

Table 1. Examples of FR used in textiles [15, 16].

Only few of these chemicals are applicable to polyolefin especially polypropylene which are as follows:

- halogen phosphate,
- phosphine oxides and ammonium polyphosphates,
- phosphite,

- phosphonitrilic ester,
- phosphonopropionic acid amines,
- alkyl-aryl phosphonates,
- cyclic phosphonate esters,
- phosphonate isocyanurate,
- phosphoric acid,
- ammonium phosphate and tetrakis hydroxymethyl phosphonium hydroxide,
- Inorganic phosphoric acids such as ortho, meta, or pyrophosphoric acids,
- phosphonate ester, and
- organic phosphinate.

The reason for rapid expansion of PP as a fiber is easy processing, low production cost, and excellent properties [12]. However, PP is easily flammable and burns in air with a very hot and clean flame without giving any char residue. Its inherent flammability restricts its usage in many fields. For this reason, it is necessary to make PP flame-retardant, wherever required. Different methods can be used to obtain flame-retardant [13]. Additive is widely used for PP. In this approach, boron is used for flame-retardant.

The main purpose of present work is to investigate the combustion characteristics of flame-retardant borax decahydrate chemical compositions.

1.1.1. Boric acid

Boric acid (commercially known as Optibor) is a white triclinic crystal in water (5.46 wt%), alcohols, and glycerin [18]. It has the chemical formula H_3BO_3 (sometimes written as $B(OH)_3$), and exists in the form of colorless crystals or a white powder that dissolves in water. The three oxygen atoms form a trigonal planar geometry around the boron. The B—O bond length is 136 pm and the O—H is 97 pm. The molecular point group is C_3H . Crystalline boric acid consists of layers of $B(OH)_3$ molecules held together by hydrogen bonds of length 272 pm. The distance between two adjacent layers is 318 pm [19]. It is a weak acid and has a pH of 4 (saturated at room temperature). It is derived from boron. Upon heating in air to above 75°C, it loses part of its water.

Boric acid is found natively in its free state in some volcanic districts, for example, in the Italian region of Tuscany, the Lipari Islands, the US state of Nevada and in Turkey. In these volcanic settings, it issues, mixed with steam, from fissures in the ground. It is also found as a constituent of many naturally occurring minerals—borax, boracite, ulexite (boronatrocaltite), and colemanite. Boric acid and its salts are found in seawater. It is also found in plants, including almost all fruits.

Boric acid was first prepared by Wilhelm Homberg (1652–1715) from borax, by the action of mineral acids, and was given the name *sal sedativum Hombergi* (“sedative salt of Homberg”).

However, borates, including boric acid, have been used since the time of the Greeks for cleaning, preserving food, and fire retardants in wood/cellulosic such as timber, plywood, particle board, wood fiber, paper products, textiles, and especially cotton products. Boric acid has also been used as fire retardant in epoxy intumescent coating, foam, and so on. When necessary, boric acid can be coated with silicone oil to alleviate its water solubility in water-based coating [18].

1.1.2. Borax decahydrate (*disodium tetraborate decahydrate*)

Boron is widely distributed on the earth, mainly in the form of boric acid or borate salts. World Health Organization (WHO) is reported that no any harmful effect is obtained [18]. It exhibits excellent buffering property. As a crystalline material, borax decahydrate is stable under normal storage conditions. It will slowly lose water of crystallization if exposed to a warm and dry atmosphere. Conversely, exposure to a humid atmosphere can cause recrystallization at particle contact point, thus resulting in cracking. A mixture of ammonium chloride and borax was one of the treatments of cellulosic fabrics reported by Gay-Lussac in 1821. Due to its low dehydration, temperature, and waste solubility, sodium borates are only used as flame-retardants in cellulose insulation, wood timber, textiles, urethane foam, and coatings [18]. Borax decahydrate is environmentally friendly as flame-retardant for textile materials.

2. Material and methods

2.1. Material

For this research, 10 bobbins of BCF polypropylene yarns (1300, 1600, 1900, and 2500 dtex, 40 filaments) are produced on an industrial production line (**Table 2**). It is produced by changing only flow rate of pump. The natural color with trilobal filaments are produced by gravimetric feeding of 97% polypropylene granulates (MFI = 22) and 3.1% master batch to a Neugmac BCF machine (Neugmac S+) (**Figures 2–4**).

The temperature profile of the six heating zones of extruder is 180, 190, 220, 225, 227, and 229°C, respectively. Extruder pressure is 132 bar, extruder revolutions is 54 rpm and extruder load is 23 kW. Pressure of spin pump before spinning is 45 bar and after spinning is 35 bar. Draw ratio in the drawing zone is 1:2.84. The temperature and pressure of hot air feeding, the

Melt flow index (MFI at 228°C)	21
Melting point (°C)	154
Polymer density (kg/L)	0.75
Heat conduction coefficient (J/ms °C)	0.18
Specific heat (kJ/kg °C)	2.34

Table 2. Properties of polypropylene granulates.



Figure 2. General view of Neugmac BCF machine.



Figure 3. Front side of machine.



Figure 4. Rear side of machine.

yarn to the texturizer are 138°C and 8.0 bar, respectively. Cooling air temperature, humidity, and velocity is 22°C, 72% rH, 0.9 m/s, respectively. Yarn is fed to the texturizer at a speed of 1100 m/min and is collected on cylindrical bobbins (1.5 kg) without intermingling. All yarns are twisted (110 turns/m) by a Volkman (Model: 0-5-0-C 8.02) two for one twister. Winding speed was 53.1 m/min. After twisting, the heat setting of the samples is carried out using the Rieter heat-setting machine (Model: Power Heat-Set GKK2500). Forty-five heat-set BCF polypropylene yarns were produced four levels of setting temperatures (100, 120, 130, and 140°C).

Boric acid and borax decahydrate were purchased from MERCK Chemicals (Gaziantep/TURKEY). Borax decahydrate (also called borax) is slightly soluble in cold water (4.71–12.83% by wt in 20°C), and highly soluble in hot water (30% at 60°C). Boric acid is soluble in water (5.25–15.9% by wt in 23°C). These are added to BCF PP yarns during the spin finish operations at the same time of master batch because of decomposition temperature. The amount of applied boric acid and borax decahydrate was prepared according to chemical properties, which were written on the information chart of chemicals. The ratio is chosen 9.65 for borax decahydrate and 8.37 for boric acid. First, borax decahydrate (9.65 g at 20°C) and boric acid (8.37 g at 23°C) is resolved in 500 ml warm water at 25°C and 500 ml spin finish oil at 20°C separately (**Figure 5**). Two different solutions were prepared, one liquid solution contains boric

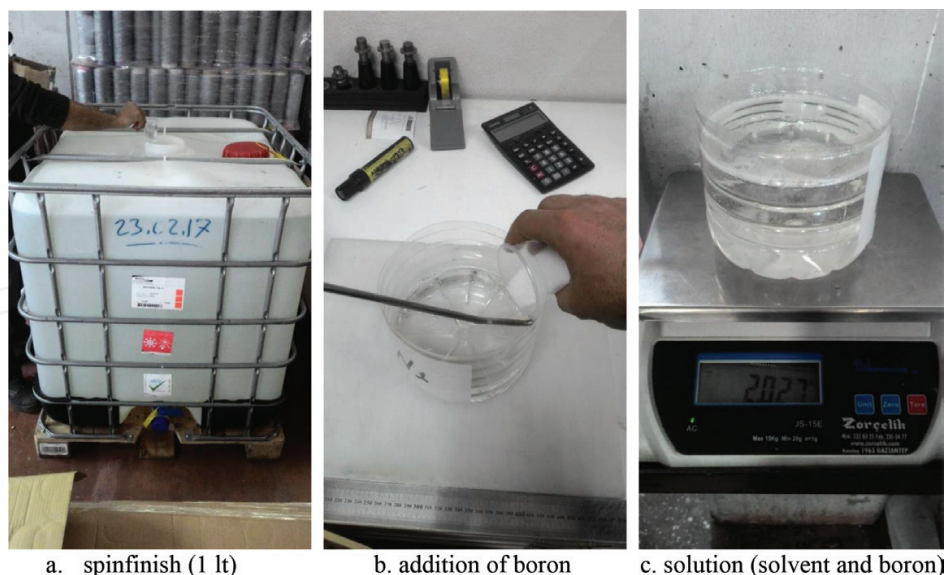


Figure 5. Preparation of solution. (a) spinfinish (1 L), (b) addition of boron and (c) solution (solvent and boron).

acid, water, and spin finish, one liquid solution contains borax decahydrate, water, and spin finish. Technical properties of boric acid and borax decahydrate are given in **Tables 3** and **4**.

2.2. Method

Flammability test express as percent volume that supports flaming combustion in flowing mixture of oxygen and nitrogen (**Figure 6**). In this test, minimum value of the oxygen index is obtained under controlled conditions response of heat and flame. Oxygen index is the mini-

Component	Content
B_2O_3	36.47% min
$Na_2B_4O_7 \cdot 10H_2O$	99.90% min
Na_2O	16.24% min
SO_4	200 ppm.max.
Cl	70 ppm.max.
Fe	15 ppm.max.
Vapor pressure	<0.0000001 hPa in 25°C
pH	4 in 20°C
Density	1.489 g/cm ³
Distribution coefficient	-1.09 in 22°C
Decomposition temperature	70°C
Shape	Powder
Particle size	-0.0063 mm

Table 3. Technical properties of borax decahydrate.

Component	Content
B ₂ O ₃	56.50% min
Equivalent H ₃ BO ₃	99.93% min
SO ₄	300 ppm.max.
Cl	5 ppm.max.
Fe	5 ppm.max.
Vapor pressure	<0.0000001 hPa in 25°C
pH	4 in 23°C
Density	1.376 g/cm ³
Distribution coefficient	-1.18 in 20°C
Decomposition temperature	70°C
Shape	Granules
Particle size	-0.0128 mm

Table 4. Technical properties of boric acid.

imum concentration of oxygen that will just support flaming combustion of a material initially at $23 \pm 2^{\circ}\text{C}$ under the test conditions. However, these conditions do not hold true under actual fire conditions for fire hazard or fire risk materials. It is responsibility of the user of this standard to establish appreciate safety and health practices and determine the applicability of regularity limitations prior to use [20].

A small test specimen is supported vertically in a mixture of oxygen and nitrogen flowing upward through a transparent chimney. The upper end of the specimen is ignited and



Figure 6. Devotrans LOI.

subsequent burning behavior of the specimen is observed to compare the period for which burning continues or the length of specimen burn with specified limits. Limited oxygen index is obtained by conducting using top surface ignition or propagation ignition. The test chimney consists of a heat resistant glass tube of 75–100 mm inside diameter and 450–500 mm height. The opening at the top of the chimney shall be restricted to provide an outlet of 40 ± 2 mm diameter. The bottom of the chimney, or the base to which the tube is attached, shall contain noncombustible material to evenly mix and distribute the gas mixture entering at the base. Glass beads 3–5 mm in diameter in a bed 80–100 mm deep have found suitable. The chimney shall be mounted securely on the base to prevent air leaks. Specimen holder is small holding device that will support the specimen at its base and hold it vertically in the center of the chimney. Gas measurement and control devices shall be suitable for measuring the concentration of oxygen in the gas mixture entering the chimney with an accuracy of $\pm 0.5\%$, by volume, of the gas mixture and for adjusting the concentration of oxygen in the precision of $\pm 0.1\%$, by volume, of the gas mixture, when the gas velocity through the chimney is 40 ± 2 mm/s at $23 \pm 2^\circ\text{C}$. The system for gas measurement and control involves needle valves on individual and mixed gas supply lines, a paramagnetic oxygen analyzer that continuously samples the mixed gas, and a flow meter to indicate when the gas flow through the chimney is within the required limits [20].

The specimen was prepared by hand in 100 mm length, 10 ± 0.5 mm width, and 2 ± 0.25 mm thickness. Surface of the specimens shall be cleaned and free from flaws that could affect burning behavior, for example, peripheral molding flash or burrs from machining. The edges of the specimens shall be smooth and free from fuzz or burns of material left from scissors. Specimen was mounted vertically in the center of the chimney so that the top of the specimen is at least mm below the open top of the chimney and lowest exposed part of the specimen is at least 100 mm above the top of the gas distribution device at the base of the chimney. Gas mixing was set to flow controls so that an oxygen/nitrogen mixture. The gas flow purge is let for at least 30 s prior to ignition of each specimen, and the flow was maintained without change during ignition and combustion of each specimen. At the end of the test, burning behavior was noted as dripping, charring, erratic, burning, and glowing combustion or after-glow [20].

The limited oxygen index (LOI) was applied to investigate the ignition and ease of extinction of a yarn. LOI was performed according to the international standard ASTM D2863.

In addition to flammability test, mechanical properties of 100% PP carpet yarns have been tested according to ISO and ASTM Standards to finished and unfinished filaments. Yarn linear density is measured ISO 2060: 1994 Textiles; yarn from packages—determination of linear density (mass per unit length) by the skein method. Yarns are randomly selected from the BCF specimens. Test results are reported and tex are calculated. Yarn strength and elongation are measured according to ISO 2062:1993 standards titled textiles; yarns from packages—determination of single-end breaking force and elongation at break. Crimp contraction and shrinkage are measured textured yarn tester (TYT) by Lawson Hemphill by ASTM D-6774-02; crimp and shrinkage properties for textured yarns use a dynamic textured. In addition, longitudinal views of the samples were taken by scanning electron microscope (SEM) (**Figure 7**) and examined. For this examination, JEOL JSM 6390LV SEM is used in the University of Gaziantep.

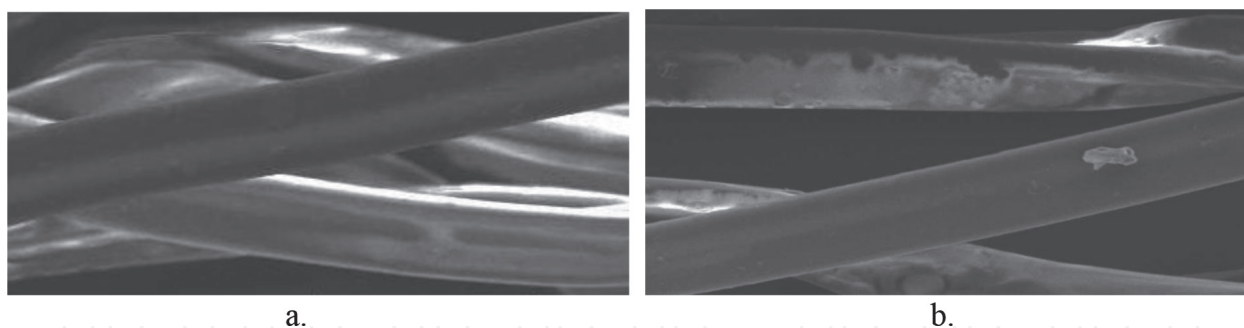


Figure 7. SEM view (a) without flammability chemical and (b) with flammability chemical.

Before examination, samples are coated with Au-Pd. It must be reflective material for surface display. The thickness of this reflective material must be at least 100 Å. First samples are located into two-sided adhesive on metal stabs tape. The coating is placed on the spray coating device. The coating takes place in 90 s with 5 mA, 8 Pa.

3. Experimental results

3.1. Flammability (LOI)

In **Figure 8** shows that limited oxygen index (LOI) versus four different yarn number (1300, 1600, 1900, and 2500 dtex) of BCF PP carpet yarn. When the figures are examined, it can be observed that LOI value of BCF PP yarns increase from 5.20 to 9.04 for non-boric acid and borax decahydrate, from 10.5 to 21.6 for boric acid and from 17.2 to 28.3 for borax decahydrate.

From the LOI data, LOI of BCF PP without boron is approximately 6.95 and increases with the increasing boric acid and borax decahydrate. It also shows that borax decahydrate has maximum beneficial effect in terms of flammability properties and highest fire performance.

3.2. Mechanical properties

Strength and Elongation: mechanical properties of fibers are probably their most important properties for end products. The purpose of tensile test is to estimate how strength pile yarns for carpet. Yarn properties and to estimate their suitability in terms of strength for pile to estimate how strength.

Crimp: crimp is a physical change in the structure of the individual filament. Crimp is a relatively unstable mechanical structure of individual filaments, which together with other filaments have a volume. Changes in crimp result in variations of the yarn's geometry (bulk). The crimp structure has a decisive influence on the appearance of the yarn in the carpet. The introduction of yarns with different crimp levels into the same fabric will change the reflectance of light off the surface of the fabric, producing dye shade differences. The shrinkage level influences the dye uptake or the dispersion of dyestuff particles into the molecular spacing, causing an increase or decrease of adhesion of the dyestuff particles into noncrystalline regions.

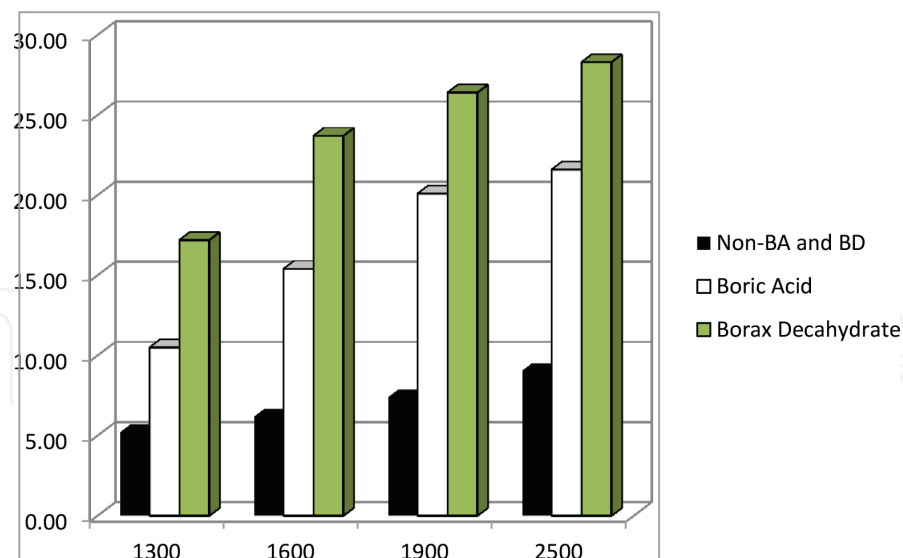


Figure 8. Limited oxygen index.

Shrinkage: nonheatsetting and/or nonuniform heatsetting can induce disorientation in the fiber morphology and is responsible for the fiber length change, leading to problems in applications, such as streaks in finished carpets. Therefore, shrinkage is a useful property for determining dimensional stability. The amount of fiber shrinkage will affect the processing behavior of yarns and dimensional changes in the fabrics made from these yarns. Differences in shrinkage behavior of threads may lead to cockled appearance in the fabric after finishing of carpets.

Yarn linear density: according to yarn count system yarn linear density is shown like that $\text{dtex} = x \text{ g}/10,000 \text{ m}$. dtex is depend on metric system.

In **Table 5**, the mechanical test results which performed according to standard is shown. As can be seen in the table, the mechanical properties of yarns cannot be affected with chemical additions.

		Without boron	Boric acid	Borax decahydrate
1200 dtex	Strength (cN/tex)	2.3	2.2	2.3
	Elongation (%)	41	47	46
	Crimp (%)	15.4	14.5	14.7
	Shrinkage (%)	2.6	2.8	2.6
	Yarn number (dtex)	1142	1136	1137
1600 dtex	Strength (cN/tex)	2.3	2.3	2.2
	Elongation (%)	47	47	42
	Crimp (%)	17	16.1	17.2
	Shrinkage (%)	2.9	2.6	2.8
	Yarn number (dtex)	1591	1611	1595

		Without boron	Boric acid	Borax decahydrate
1900 dtex	Strength (cN/tex)	2.6	2.5	2.9
	Elongation (%)	51	50	53
	Crimp (%)	18.6	17.9	16.8
	Shrinkage (%)	3.2	3.5	3.0
	Yarn number (dtex)	1984	1916	1910
2500 dtex	Strength (cN/tex)	3.8	3.9	3.7
	Elongation (%)	55	54	52
	Crimp (%)	20.0	21.5	22.6
	Shrinkage (%)	4.5	4.2	4.1
	Yarn number (dtex)	2493	2498	2517

Table 5. Mechanical test results.

4. Statistical analysis (ANOVA)

The experimental results have been statistically evaluated by using the design expert Analysis of Variance (ANOVA) software with *F*-values of the significance level of $\alpha = 0.05$, with the intention of exploring whether there is any statistically significant difference between the variations obtained. We evaluated the results based on the *F*-ratio and probability of *F*-ratio (prob >*F*). The lower the probability of *F*-ratio, it is stronger the contribution of the variation and the more significant the variable. The best models for each fabric were obtained and the corresponding regression equations and regression curves were fitted. The test results of the related samples were entered into the software for the analysis of the general design [11].

Table 6 summarizes the statistical significance analysis for all data obtained in this study. In the table, parameters yarn number (dtex) and flame-retardant (boric acid and borax decahydrate). **Table 6** also indicates that significant interactions between yarn number and fire retardant. The term *A* (yarn number-dtex) and *B* (fire retardant-boric acid and borax decahydrate) in this table is independent variables, where as the LOI value is dependent variable. And also, the linear design is suggested by the software for flammability behavior of yarns.

While ANOVA table is checked, yarn number and fire retardant have significant impact on LOI values. In addition, according to the table, the *R*² values of model come to be approximately 0.96. At this stage, the model accounts for this circumstances in the model at 96% ratio. This relation displaced that the model devised for response value can express with rather high accuracy the relation between independent and dependent parameters and that experimental studies are admissible as precise.

A normality test was also applied on the inputs derived from LOI by changing yarn number (dtex) and fire retardant (boric acid and borax decahydrate). The results are demonstrated in **Figure 3**. In general, probability plotting is a graphical technique for determining whether

Source	Sum of squares	DF	F-Value	Prob >F	
Model	7020.39	5	637.87	<0.0001	Significant
A	1155.37	1	524.88	<0.0001	Significant
B	5704.39	2	1295.75	<0.0001	Significant
A × B	160.62	2	36.49	<0.0001	Significant
Residual	250.94	114	2.20		
Lack of fit	246.93	6	41.15	1108.75	Significant
Pure error	4.01	108	0.037		
R^2	96.55				
R_p^2	96.40				
R_{adj}^2	96.20				

Notes: A: yarn number (dtex), B: fire retardant (boric acid and borax decahydrate), R_p^2 : predicted R^2 , R_{adj}^2 : adjusted R^2 . Here, the P values of models must be smaller than 0.005 if it is accepted as significant.

Table 6. ANOVA.

specimen data confirm to a hypothesized distribution based on a subjective visual examination of the data. The estimation is very easy. As can be seen in **Figure 9**, data is distributed around the normality axis. This figure confirms the selected model.

DESIGN-EXPERT Plot
LOI

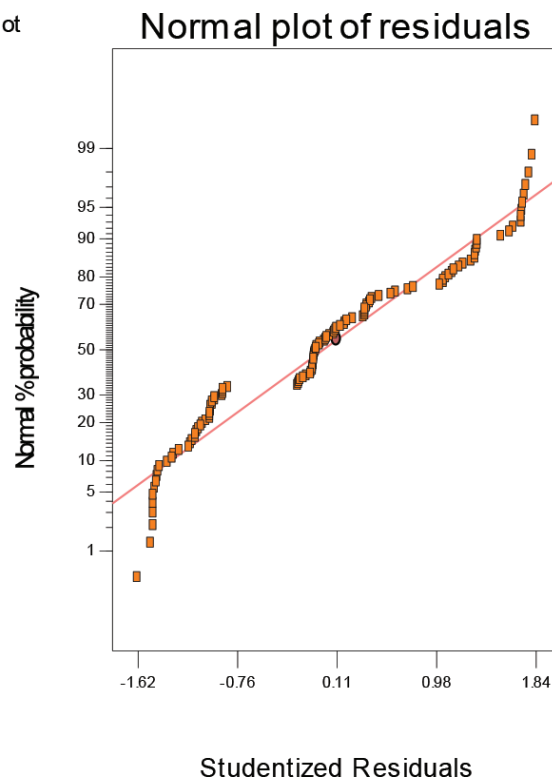


Figure 9. Normality test.

The regression equations of the model determined was found as:

$$\text{LOI} = +16.47 + 4.20A - 8.05B - 0.99AB \quad (1)$$

where A is the yarn number and B is the fire retardant in the equations.

5. Discussion and conclusion

One way to better protect combustible materials against initiating fires is the use of flame-retardants. Every day we come across new innovations, particularly, in the areas of flame-retardant fibers and chemicals. Boric acid and borax decahydrate are two new eco-friendly boron chemicals used for flame-retardant. Boron is highly resistant to fire due to the melting temperature of 2300°C. Because of this property, it is used as a flame-retardant material.

The research on the flammability behavior of samples can be summarized as follows:

- It can be inferred that borax decahydrate shows better flame-retarding effect rather than boric acid.
- Addition of flame-retardant changes the flammability behaviors of BCF PP yarns produced by conventional methods without flame-retardant.
- LOI value of the samples is also affected by the presence of additives.
- In the last few years, green or eco-friendly chemicals have been used because of increased human safety and the search for alternative environmentally materials. Efficient use of borax mines can contribute to the solution of waste accumulation problems of environment and flammability behavior by the aid of applying with adequate quantity.

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References

- [1] Usenko V. Processing of man-made fibres. In: Chernyshova N, editor. Translated from the Russian. Moscow: Mir Publishing; 1979

- [2] Corbman BP. Textiles fiber to fabric. 6th ed. McGraw Hill Inc.; 1983
- [3] Elsasser VH. Textiles, 2nd ed. Fairchild Publication Inc.; 2007
- [4] Wynne A. Textiles, Macmillan Education Ltd.; 1997
- [5] Tortora PG, Collier BJ. Understanding textiles. 5th ed. Prentice Hall; 1997
- [6] Klein W. Processing of man-made fibres. The Textile Institute; 1994
- [7] McIntyre JE. Synthetic fibres. Woodhead Publishing Limited; 2005
- [8] Gupta VB, Kothari VK. Manufactured fibre technology. Chapman & Hall; 1997
- [9] Fourné F. Synthetic fibers. Hanser Publishers; 1999
- [10] Mostashari SM, Mostashari SZ. Verification concerning the relative superiority of a cellulosic fabric with regard to polyester in terms of flammability. *Polymer-Plastics Technology and Engineering*. 2008;**47**:313-317. DOI: 10.1080/03602550701870008
- [11] Kalebek NA, Babaarslan O. Effect of Heat Setting Process of Polymers. In: Mendez-Vilas A, Salona A, editors. *Polymer Science; Research Advances, Practical Applications and Educational Aspects*. Spain: Formatex Research Center; 2016. pp. 199-207
- [12] Shekar RI, Kotresh TM, Damodhara Rao PM, Kumar MN, Rahman S. Flammability behaviour of fiber-fiber hybrid fabrics and composites. *Journal of Applied Polymer Science*. 2011;**122**:2295-2301
- [13] Shi Z, Fu R, Agathopoulos S, Gu X, Zhao W. Thermal conductivity and fire resistance of epoxy molding compounds filled with Si_3N_4 and $\text{Al}(\text{OH})_3$. *Materials and Design*. 2012;**34**:820-824
- [14] Yang CQ, He Q, Lyon RE, HuY. Investigation of the flammability of different textile fabrics using micro-scale combustion calorimeter. *Polymer Degradation and Stability*. 2010;**95**:108-115
- [15] Horrocks AR. Flame retardant challenges for textiles and fibres; new chemistry versus innovatory solutions. *Polymer Degradation and Stability*. 2011;**96**:377-392
- [16] Papaspyrides CD, Pavlidou S, Vouyiouka SN. Development of advanced textile materials: Natural fibre composites, Anti-microbial, and flame-retardant fabrics. *Journal of Materials: Design and Applications*. 2009;**223**:91-102
- [17] Zhang S, Horrocks AR. A review of flame retardant polypropylene fibres. *Progress in Polymer Science*. 2003;**28**:1517-1538
- [18] Charles AW, and Alexander BM. Fire retardancy of polymeric materials, CRC Press, Taylor Francis Group; 2010
- [19] Web site. https://en.wikipedia.org/wiki/Boric_acid [Accessed: 12.02.2017]
- [20] ASTM D2863-13, Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastic (Oxygen Index). West Conshohocken, PA: ASTM International; 2013

