TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Study of combustion of thermal bonding nonwovens

Master Thesis

Study programme: N3106 Textile Engineering
Study branch: Nonwoven and Nanomaterials

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Thesis Supervisors: Ing. Jiří Chaloupek, Ph.D.
Department of Nonwovens and Nanofibrous materials

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Master Thesis Assignment Form

Study of combustion of thermal bonding nonwovens

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1. Study the flammability of textile materials. Study available literature
2. Desing a proces for the production of thermall bonded nonwoven fabric and produce a series of samples of different bulk weight and compositions
3. Test the flammability of manufactured samples according to standarts. Use vertical and horizontal flammability test
4. Discuss the results and suggest further solutions to the problem

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1. W. Albrecht, H. Fuchs, W. Kittelmann: Nonwovens Fabrics, Wiley-VCH, Weinheim 2003, ISBN: 3-527-30406-1
2. RUSSELL, Edited by S.J. Handbook of nonwovens. Boca Raton, Fla. [etc.] :Cambridge: CRC press ; Woodhead, 2007. ISBN 978-185-5736-030
3. Jirsák, O., Wadsworth, L.C. Nonwoven Textiles, Carolina Academic Press, Durham, NC 1999, ISBN 0-89089-978-8

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ABSTRACT

Nonwovens are used in a wide range of technical applications, so high demands are placed on them. This work deals with the study of flame propagation in classical nonwovens. These materials were made by thermal bonding and conventional polyester fibers were used. The work is divided into a theoretical part and a practical part. In the practical part, 16 different samples were produced, which differed in composition and bulk density. The samples were subjected to a horizontal and vertical combustion test. Burning time, burning time and burning rate were monitored. The results of the experiment will help for further studies on the topic.

Keywords : Nonwovens, Flame propagation, Burn time, Burn length, Burn rate.

ABSTRAKT

Netkané textilie se používají v široké škále technických aplikací, proto jsou na ně kladeny vysoké nároky. Tato práce se zabývá studiem šíření plamene v klasických netkaných textiliích. Tyto materiály byly vyrobeny termickým pojením a byla použita klasická polyesterová vlákna. Práce je dělená na teoretickou část a praktickou část. V praktické části bylo vyrobeno 16 různých vzorků, které se lišili složením a objemovou hmotností. Vzorky byly podrobeny horizontálnímu a vertikálnímu testu hoření. Sledována byla délka hoření, doba hoření a rychlost hoření. Výsledky experimentu pomohou pro další studie týkající se daného tématu.

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1. INTRODUCTION

Nonwovens, as we know, require the creation of cloth without the development of thread. Nonwoven products are primarily made using synthetic fibers such as polyolefin, polyester or nylon, which are highly flammable products. Even the use of natural fibers does not serve the purpose of flame retardation and are mainly ideal in terms of comfort properties except for fur, which has stronger flame retardant properties compared to traditional natural fibres. Thus, the use of nonwovens made with synthetic fibers can lead to an increased risk of fire in many situations. This must be taken into account even more today, as there is a desire to substitute high-cost materials with low-cost materials like polypropylene, for example. Flame retardation of nonwovens can be accomplished by a variety of processes, the major ones of which are those of coating and also by the alteration of fibers or by the use of additives.

2. DEFINITION

Generally, textile materials are vulnerable to flames and respond quickly to flames. There are, however, some types of fabrics which do not respond to fire and display resistance to fire and which are referred to as flame retardant textiles or materials. This property can be induced by fibres or by the use of chemicals by a number of methods [1].

3. LIMITING OXYGEN INDEX

The Limiting Oxygen Index (LOI) is the minimum oxygen concentration expressed as a percentage that will support the combustion of a polymer. It is determined by moving a combination of oxygen and nitrogen over a burning specimen, and by reducing the oxygen level until a critical level is reached [1].

LOI limits the oxygen index as calculated by ASTM D 2863, which is defined as the oxygen content of the oxygen/nitrogen mixture. In this respect, fabrics with a LOI index greater than 20 would not be charred [2].

4. TYPES OF FIBRES

These can be divided into two classes:

(i) Inherently fire-retardant fibres - Aramid, modacrylic, polybenzimidazole fibres, semicarbon and phenolic fibres

(ii) Chemically modified fibres and fabrics - Flame-retardant cotton, wool and synthetic fibres.[3]

4.1. INHERENTLY FIRE-RETARDANT FIBRES

4.1.1. NOMEX

Nomex has been developed for fighter pilots, tank drivers, other military forces, astronauts and personnel employed in some advanced manufacturing applications. Nomex is chemically poly (m-phenylene isophthalamide) fabric. Aramid fibers do not contain FR chemical elements as described above, but their chemical composition is such that they do not readily break down into FR molecular fragments. Since they are charcoal on exposure to flame, such fibers have flame protection. Any aramid fabrics, however, shrink and crack open under extreme sun. It was also proposed that the fiber blend (Nomex III) be obtained by combining standard nomex with 5 percent Kevlar fiber [3].

4.1.2. LENZING P84

A polyimide fiber such as Lenzing P84 developed by the Austrian company has excellent thermal stability. This fiber has a Tg value of 315°C and a decomposition temperature of approximately 500°C. It has a LOI of 36-38%. These fibers are not melting. Fire retardant substance 71 which can tolerate continuous use without any noticeable modification in mechanical properties at temperatures up to 260°C in the air [3].

4.1.3. PBI FIBRES

Polybenzimidazole (PBI) fibers are formed by Celanese. It demonstrates tolerance to high temperatures and chemicals with outstanding fiber and comfort characteristics. PBI fiber materials have been used for firefighting uniforms, rescue suits for astronauts and aircraft furnishings for the aerospace industry. They are believed to have better fire protection than aramid fiber fabrics and, respectively, to remain versatile, to preserve their dignity and to show no afterglow (Jeffries 1988). A variety of subjective wearer tests have shown that PBI fabric has comfort ratings equal to 1009/o cotton. In high-temperature applications, PBI fiber was also found to be suitable as a substitute for asbestos. Phenolic fibers (Novoloid fibers) are extremely flame retardants with a LOI of 30-35. The temperature of their combustion is over 2500°C. These fibers are generated by spinning and post-curing phenol-formaldehyde resin precondensate. The fiber is smooth and golden in color, with a moisture recovery of 6%. As intensely heated or put in an open flame, the phenolic cloth is slowly carbonized, resulting in a lack of strength at high temperatures [3].

4.1.4. PHILINE

Philene, a new phenolic fabric, has been developed in France. This new fiber is said to have excellent flame tolerance and has been suggested as a precursor to general purpose carbon fibres. Philene is a heavily cross-linked phenolic resin (resit) and is an aromatic glass polymer with a high carbon content of 72 per cent by weight. The moisture recovery of the fiber is 7.3 per cent and is said to be non-flammable and self-extinguishing with a LOI of 399/0. There is no improvement in the tensile properties after being heated for 24 hours at 140°C or for 6 hours at 200°C [3].

4.1.5. CHLOROFIBRES

Chlorofibres-PVC fabrics are relatively non-flammable. They do not burn or emit flames or unleash molten incandescent drops capable of transmitting fire to fuel materials. As exposed to extreme heat, PVC fibers disintegrate, but the debris may be touched because it is not hot and so there is no chance of burning the flesh. Polyvinylidene chloride fibers have a similar behavior to

PVC fibres. Their flame retardance can be further strengthened with the use of antioxidants, by copolymerizing with phosphorus-containing monomers and by covering with FR finishes. Rhovyl, chlorofibre was used for thermal clothing. Chlorofibres is said to be completely untouched by temperature, i.e. neither shrinks nor swells in water. Non-flammable curtains made from them are in use and have also been used in sports apparel for its thermal comfort [3].

4.1.6. PPS FIBRES

Polyphenylene sulphide fibers (PPS) are created by melting with traditional machinery. It's got a LOI value of 34-35. It does not facilitate combustion under normal atmospheric conditions. In addition, its chemical resistance and ability to maintain its physical properties under highly unfavorable conditions have made it useful for protective garments [3].

4.1.7. POLYACRYLATE FIBRES

A non-combustible polyacrylate fiber (Inidex from Courtaulds) has recently been launched. It is a cross-linked polyacrylate fiber with a LOI of 43. Or exposed to a blaze, it does not smoke or melt. It emits almost no smoke or poisonous gases. FR properties thus suggest that it should be the best fiber for protective fabrics, but there are concerns as to its longevity. Semicarbon fibers formed by partial carbonization of polyacrylonitrile fibers have excellent heat resistance and heat stability, do not burn in air, do not melt. There is no after-glow after exposure to flame, and the fabrics remain versatile. Due to their outstanding properties, they are used in protective clothing where protection against naked flame is necessary [3].

4.1.8. PANTOX FIBRES

Pantox fiber fibers can withstand flame temperatures of more than 1000°C, are resistant to most traditional acids and strong alkali and are extremely durable, but "breathes" like wool and are claimed to be easy to wear [3].

4.1.9. SEMI CARBON FIBRES

Semi-carbon fabrics Firotex and Asgard, based on viscose fibres, have also been produced by means of partial carbonisation. However, in 100% pure condition, Firotex and Asgard fabrics are not adequately abrasion resistant to warrant their use in active protective clothing. For this purpose, blending of Firotex with aramid fibers has been suggested to mitigate this issue [3].

4.1.10. CARBON FIBRE

Although a significant range of polymeric precursors have been tested for modern carbon fibres, PAN, coal-based pitch and rayon are the three primary precursors used commercially to limit existing use [4]. The main use of carbon fibers is in polymer matrix composites; however, they are also used in metal matrix and carbon matrix composites. For eg, Toho Tenax (Japan) produces many grades of carbon fiber under the trademark Besfight or Toray (Japan) under the trademark Toraylon [5]. Carbon fibers are highly resistant to high temperatures: their melting temperature is 4000C. They can also be called flame resistant because they fire only at extremely high temperatures. They are also a substance of choice for applications at exceptionally high temperatures, for example in the filtration of molten iron [6].

4.1.11. GLASS FIBRE

There is a wide variety of glass formulations available to fit many textile fibres [7,8]. Glass fibers made from different compositions have softening points in the range 650–970C. At temperatures above 850C, these fibers partly devitrify and form polycrystalline material that melts at 1225–1360C, which is high enough to hold fires for several hours [8].

4.1.12. CERAMIC FIBRES

Ceramic fibers are often used as refractory fibers in applications above 1000C and are distinguished by a polycrystalline rather than amorphous form. This fibers have extraordinary high temperature properties. Different formulations result in a change in the temperature of the

end-use from around 1050C or higher for kaolin-based products to 1425C and above for zirconium-containing materials [8].

4.1.13. ADVANCED FIBRES

Toho also launched a new family of specialized fibers, Pyromex carbon fiber. This pre-oxidized fabric is said to provide an outstanding efficiency in fire and defense protective garments [9].

5. FLAME RETARDANT COATINGS

They are widely classified as

- Halogen based
- Nitrogen based
- Inorganic flame retardants
- Intumescent coatings
- Phosphorus based

5.1 HALOGEN BASED

This class of flame retardants includes chlorine-based systems, but the most widely known are Bromine Flame Retardants (BFRs). BFRs are widely used in the electronics industry as well as in textiles, building materials and coatings. Bromine is used because it introduces activated bromine atoms into the gas phase before the substance reaches its combustion temperature, which suppresses the chemical reactions that occur within the blaze. This may deter the burning process from taking place or may slow it down in such a way that more steps may be taken to extinguish the flames. This is an example of an approach to inhibiting the vapor phase. One big problem with this form of flame retardant is that it is increasingly forbidden inside goods because of safety issues. For example, the RoHS Directive explicitly restricts the quantity of polybrominated biphenyls and polybrominated diphenyl ethers that can be found inside, among

other product categories, appliances, IT equipment, lighting equipment, medical devices, toys and semiconductors [10].

5.2 INORGANIC FLAME RETARDANTS

Many inorganic compounds are used as flame retardants or catalysts in a flame retardant system. Where it comes to flame retardants, these chemicals also have to be used in broad quantities in order to produce the optimal effects. Alternatively, they must be used in combination with other forms of flame retardants in order to be efficient. For eg, antimony oxides do not have flame retardant properties of their own, but they act as synergists when combined with bromine or chlorine-based flame retardants. This means that antimony oxides serve as a catalyst that allows bromine or chlorine to break down much further, releasing active bromine atoms into the gas phase at a faster rate. Antimony oxides also react with bromine or chlorine compounds to create volatile halogen antimony compounds. While antimony oxides do not have flame retardant properties, volatile antimony halogen compounds do so because they eliminate high-energy radicals that fuel the gas process of the fire [10].

Inorganic flame retardants which can be used separately include aluminum and magnesium hydroxides. These compounds interfere with the process of burning by releasing inert gasses (like water vapor), forming a protective carbon coating, or absorbing steam (meaning the amount of energy available for the fire the spread is reduced) [10].

5.3 NITROGEN FLAME RETARDANTS

Melamine-based products are the most widely used flame retardant nitrogen products. When melamine is in the condensed phase, the molecular structures are converted into cross-linked structures. This transition facilitates the formation of carbon, which prevents the availability of oxygen. This is an example of a solid phase flame retardant [10].

5.4 INTUMESCENT FLAME RETARDANTS

The purpose of systems integrating intumescent coatings is to shield materials from fire by preventing them from burning. They are added to items such as a coat of paint, which makes them suitable for building materials such as steel beams or timber. When exposed to sun, these coatings extend to create a fireproof and insulating layer on the material. This coating shields the material from high temperatures, which can avoid or slow down structural damage. Popular components of intumescent coatings contain spumific compounds (chemicals that decompose when heated and create significant quantities of gas), a binder, an acid supply and a carbon compound [10].

5.5 PHOSPHOROUS BASED

These molecules are both chemically bound to fabrics and are also incorporated as an additive. Char is produced when the phosphorous compound is heated, thus inhibiting the production of fuel gas and inhibiting the pyrolysis process. What is especially fascinating about the formation of carbon is that it hinders the escape of fuel gasses while at the same time creating a shielding coating that protects the polymer from the heat of the blaze [10].

Many items incorporate different forms of flame retardants inside the device. This method provides the advantages of the multiple forms of avoidance or mitigation. Phosphorus and chlorine are one such mixture. Phosphorus offers a solid phase carbon layer and chlorine provides a vapor layer inhibition strategy [10].

6. METHOD OF APPLICATION

One of the most favored methods for adding FR to cotton is the "Pre-condensate"/NH3 technique. This is the application of one of many pre-condensate phosphoniums, in which the cloth is cured with ammonia, and oxidized with hydrogen peroxide. Pre-condensate is the term for Tetrakis-hydroxymethyl phosphonium salt pre-reacted with urea or other nitrogenous content. The volume of anhydrous sodium acetate is roughly 4 per cent of the pre-condensate

used. Some pre-condensates are prepared with sodium acetate. Softeners are often added along with pre-condensates. The pH of the pad bath should be roughly 5.0. The quantity of flame retardant needed depends largely on the quality of fabric, the conditions of use and the test requirements to be met. Screening tests should be performed to determine the minimum degree of application for a cloth. Application of FR to cloth may be done with traditional padding, padding with several dips and nips, preceded by 30 to 60 seconds dwelling provides decent results. The regulation of tissue moisture until ammonia is a vital element in the effective application of pre-condensate/NH3 flame retardant. Generally, moisture levels between 10% and 20% offer decent performance [11].

There are further types of application techniques:

- Knife coating or direct coating
- Direct Roll coating
- Pad dry cure method
- Calendar coating
- Hot melt extrusion coating
- Foam finishing

6.1 KNIFE COATING OR DIRECT COATING

In Knife Coating, as seen in Figure 1, the liquid coating is applied to the cloth when operating under a floating knife blade, the difference between the fabric and the knife blade defines the thickness of the coating. The blade can be bent and have different profiles to impact the coverage. In order to be successful in this process, the liquid coating must be very viscous in order to prevent it from being absorbed into the cloth, the coating is either dried or cured [11].

This technique is better used for filament yarns, as staple fibers in spun yarns can protrude on the top, producing an irregular finish, but this depends on the thickness of the coating applied. In order for this form of coating to be the most effective, the weave structure must be very close and the fabric capable of maintaining must be taught [11].

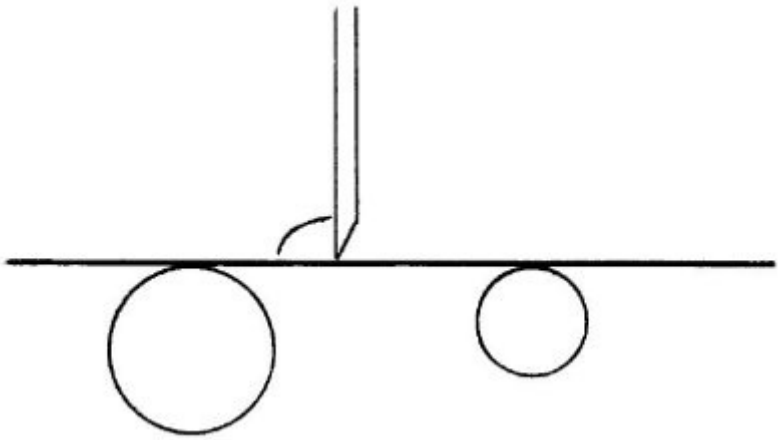

Figure 1. Knife coating[11].

6.2 DIRECT ROLL COATING

In this process, the coating liquid is rolled onto the fabric by a roller held in the coating fluid, sometimes the blade is placed close to the roller to ensure that not too much coating solution is applied [11].

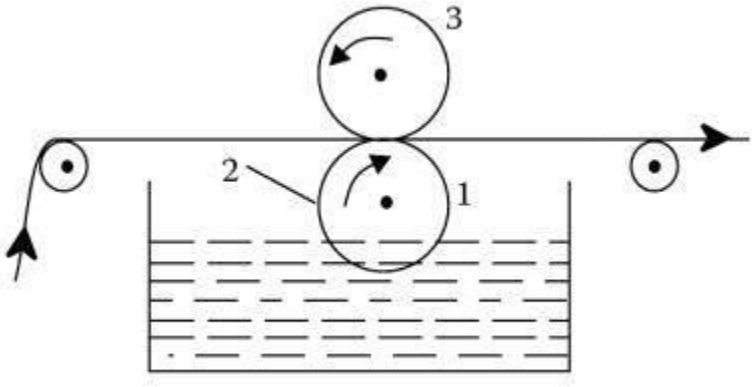

Figure 2. Direct Roll Coating [11].

6.3 PAD DRY CURE METHOD

Often referred to as padding, this method, commonly known as a textile finishing technique, can in reality be used to apply a number of coatings, although this typically refers to a fabric coating for the application of micro or Nano materials or chemical compositions [11].

As seen in Figure 3, the fabric is immersed in the coating solvent, followed by the excess pushed out in the rollers, which determines the pick-up percentage, and the fabric is then dried and cured [11].

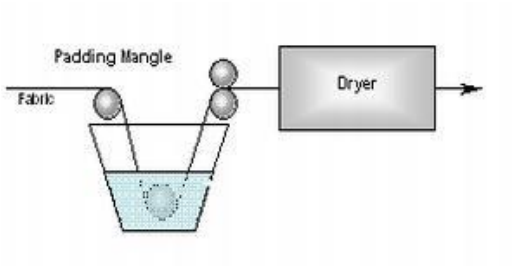

Figure 3. Pad Dry cure method [11].

6.4 CALENDAR COATING

Calendar finishing requires a fabric going through a series of heated rollers to sing every surface fiber to add luster and smoothness. Calendar coating is the same concept that the fabric moves through heated rollers, except through this method the coating is added as seen in Figure 4. This picture illustrates the simultaneous coating on both sides of the cloth with the thickness of the coating determined by the width of the nip in-between the rollers, further rollers used will have a thinner coating [11].

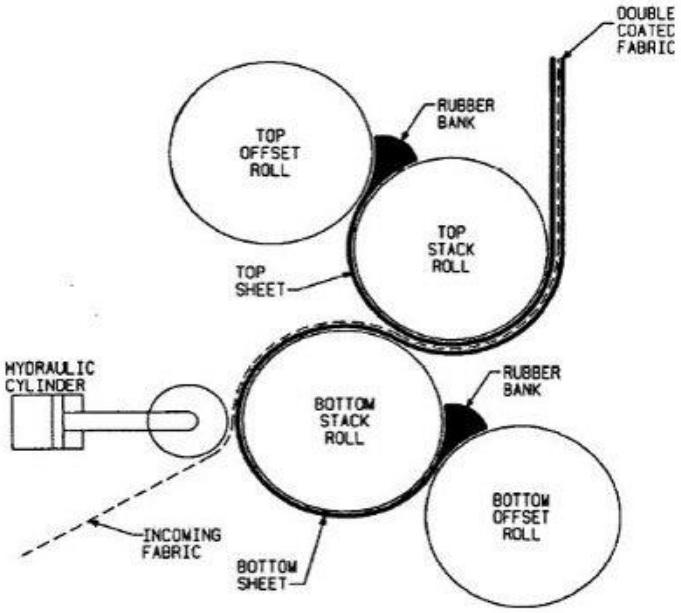

Figure 4. Calendar Coating [11].

6.5 HOT MELT EXTRUSION COATING

The hot melt extrusion coating is applied in the same way as the calendaring process, where the coating is molten from granules fed into heated rollers, and then nipple the coating onto the cloth. It is used to create unsupported films and these newly made films are applied directly to the cloth. It is primarily used for thermoplastic polymers such as polyurethane, polyolefin and PVC [11].

6.6 FOAM FINISHING

Foam finishing has been developed as a more environmentally sustainable variant of the pad-dry-cure technique, because the chemical used needs less product weight, but is equal to a high surface area. Foam also means that less moisture is used, which requires less drying; additionally, waste is minimized in terms of residual liquor. This technique is useful in the coating of hard materials such as carpets and can be used to coat only one side effectively [11].

7. APPLICATIONS

In order to ensure the protection of the public in relation to fire, the guidelines, legislation and specifications in this area are continuously discussed and updated. It is not easy to explore the labyrinth of research approaches and criteria. Harmonization has begun in the 1990s in Europe and continues to develop. The latest rules raise new obstacles for the flame retardant industry. Examples of nonwoven FR applications are given below [12].

7.1 PROTECTIVE GARMENTS

The area of protective equipment is relatively broad, with different specifications, as it includes protection for men at work and for military uses, as well as firefighter clothing. This problem is also relatively complicated, since a variety of properties are needed for the substance to be used in this area of use. Indeed, thermal safety efficiency is required, but even the heat-moisture transfer properties and comfort performance, including lightness, must be taken into consideration, for example, and an equilibrium between the heat and the moisture barrier must typically be sought. Usually, waterproof fabrics are multilayer garments with up to five or six layers of material. Fire safety gear for firefighters consists of at least four layers: outer and inner cover, moisture shield and heat liner. These layers are required to have sufficient fire, flame, fluid, chemical and mechanical protection. Nonwovens made of high-performance fabrics are usually used as thermal liners in waterproof clothing [12].

7.2 FIRE-BLOCKERS FOR SEAT AND UPHOLSTERY

Fire-blockers are typically extremely fire-resistant materials mounted underneath the outer coating of the furniture and the first sheet of cushioning materials in the seats, mattresses and upholsteries. The dense cushioning fabrics are the primary source of fuel and thus the greatest possible threat. The fire-blocker acts as a buffer between the heat source (flame, cigarette, etc.) and the cushioning materials that restrict fire growth and production. Fabric-like fire-blockers include woven and needle-shaped fabrics made from highly resistant textile fibers such as glass,

Nomex, Kevlar, PBI, etc. Some of the fabric-like fire-blockers available are engineered textile products that use a combination of different fibers and fabric treatments. The first modern generation of fire-blockers was introduced by DuPont under the trade name VonarTM during the 1970s [12,13].

7.3 OTHER APPLICATIONS

Flexible insulation panels for building construction are another use of FR nonwovens. While conventional thermal insulation materials such as mineral wool or polystyrene are commonly used, the return to ecology and nature seen in a variety of applications is also observed in the construction industry. Real fur, coconut or duck feathers are used for the construction of thermal insulation plates. However, all these materials burn quickly and FR treatments are therefore needed. Creation of needle-coated nonwovens and air-coated nonwovens based on fire retardant modified natural fibers has been documented and has been shown to satisfy the criteria for use in building applications. Finally, it should be noted that there are applications where FR properties are needed for disposable nonwovens, for example for surgical drapes used in operating rooms as well as for air filters used in the automotive industry [14].

8. EXPERIMENT

In this section we have discussed the materials and methods involved in the process.

8.1 EXPERIMENT PLAN

- Identification of fibres and the proportion of blends
- Sample preparation using various fibre compositions
- Bonding of web using hot press method
- Flaming tests using vertical and horizontal tests

- Measurement of values using NIS elements software
- Analysis of results

8.2 DEVICES USED FOR EXPERIMENT

- Carding machine – Production of nonwoven web for flame retardancy.
- Thickness Gauge – Measurement of thickness of the web produced after bonding.
- Weighing balance – Sample weight measurement.
- Hot press machine – Thermal bonding of nonwoven web.
- Flame burner – To burn the sample and measuring flame retardant properties.

Figure 5. Thickness gauge used for measuring thickness of samples.

8.3 FIBRES USED AND COMPOSITION

TYPE	FIBRE 1 (80 %)	FIBRE 2 (20 %)	BICO TYPE
TYPE 1	POLYESTER – 3.3 dTex	BICO FIBRES	PES/CO PES - CORE/SHEATH
TYPE 2	POLYESTER – 11 dTex	BICO FIBRES	PES/CO PES - CORE/SHEATH
TYPE 3	POLYESTER – 6 dTex	BICO FIBRES	PES/CO PES - CORE/SHEATH
TYPE 4	POLYESTER – 3.3 / 6 dTex	BICO FIBRES	PES/CO PES - CORE/SHEATH

Table 1. Fibres used and composition.

8.4 TECHNOLOGY USED

8.4.1 CARDING TECHNOLOGY

In carding the nonwoven web is formed using the required fibres (PES and Bico). The samples are weighed in weighing balance and are laid after opening through the feeding belt and is let to from the web. The obtained web is again introduced inorder to achieve homogenation. The corresponding nonwoven web is taken for further processes.

Figure 6. Carding machine used for manufacturing of nonwoven web.

8.4.2 BONDING TECHNOLOGY

In the bonding technology the technology we opt here is thermal bonding and in which the bicomponent fibres in the sample act as the binder fibres. The process was carried out under the temperature of 130°c and was pressed for 40 seconds and the distance between the plates are set at 5,10,15,20 mm respectively. The resulting nonwoven sheet was made to further processing.

Figure 7. Hot press machine used for thermal bonding of the fibres.

8.4.3 FLAME TEST

In this testing method we use the process parameters as in the table below. They were subjected to flame test by introducing them directly to the flame both horizontally and vertically and the burn time, lengths are also examined further.

Figure 8.Flame test apparatus used for testing of flame behaviour.

8.4.4 BURN LENGTH MEASUREMENT

For burn length measurement we used NIS elements software and for measuring the burn time a normal stopwatch was used.

9. STANDARDS USED

SL NO	PARAMETER	VALUE
1	NO OF SAMPLES / SET	5
2	DIMENSIONS	30 X 10 cms
3	BURNING TIME - HORIZONTAL	15 secs
4	BURNING TIME - VERTICAL	10 secs

Table 2. Flammability standards.

9.1. FLAMMABILITY TEST – ISO 3795

The test involves the use of a chamber with clamps facilitating the test to be carried in both horizontal and vertical positions. The sample is introduced to a low energy flame for about 15 seconds (horizontal test) and 10 seconds (vertical test) and the readings are noted based on the time of continuity of the flame. Both the time of burning and the length of the burn are measured. The setup of the apparatus for the test is provided in the figure (Figure 9) below [15].

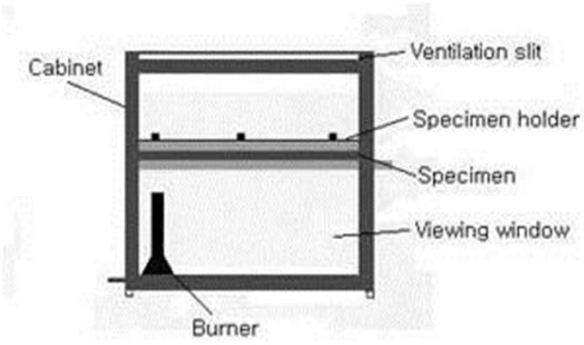

Figure 9. Flame test apparatus setup.

10. RESULTS AND DISCUSSION

In this section , all results regarding the flame retardancy has been elaborated . The experiments were conducted for PES/BiCo fibres with varied parameters, for which the varied results are being discussed below involving varied thickness and fineness of the fibres. The below table provides us the specifications of all the samples used for the flame retardancy test. 16 different materials were tested. Regarding the reaction to fire there were performed two tests namely horizontal and vertical according to standards.

		DESCRIPTION				
SL.NO	**SAMPLE NO**	**FIBRE MATERIAL**	**BLEND RATIO (%)**	**FINENESS (dTex)**	**GSM (g/m^2)**	**DENSITY ($kg/m^{3)}$**
1	S1	PES/BiCo	80/20	3.3 / 2	210	42
2	S2	PES/BiCo	80/20	3.3 / 2	279	26.5
3	S3	PES/BiCo	80/20	3.3 / 2	274	18.3
4	S4	PES/BiCo	80/20	3.3 / 2	265	14
5	S5	PES/BiCo	80/20	11 / 2	218	43.6
6	S6	PES/BiCo	80/20	11 / 2	239	27.2
7	S7	PES/BiCo	80/20	11 / 2	207	18.9
8	S8	PES/BiCo	80/20	11 / 2	221	14.4
9	S9	PES/BiCo	80/20	6 / 2	154	42.8
10	S10	PES/BiCo	80/20	6 / 2	198	25.5
11	S11	PES/BiCo	80/20	6 / 2	209	17.9
12	S12	PES/BiCo	80/20	6 / 2	271	13.8
13	S13	PES/PES/BiCo	40/40/20	3.3 / 11 / 2	172	42
14	S14	PES/PES/BiCo	40/40/20	3.3 / 11 / 2	192	26
15	S15	PES/PES/BiCo	40/40/20	3.3 / 11 / 2	249	18
16	S16	PES/PES/BiCo	40/40/20	3.3 / 11 / 2	255	14

Table 3. Sample specifications used for flame retardancy test.

10.1 BURN TIME MEASUREMENT FROM HORIZONTAL TEST

First, horizontal flammability tests were performed. The results are shown in the table below. The time given in the table correspond to the burning time after removal of the flame (15 seconds).

	Thickness in mm			
	5mm	10mm	15mm	20mm
SAMPLE 1	0			
SAMPLE 2		35		
SAMPLE 3			6	
SAMPLE 4				4
SAMPLE 5	0			
SAMPLE 6		0		
SAMPLE 7			0	
SAMPLE 8				0
SAMPLE 9	17			
SAMPLE 10		11		
SAMPLE 11			12	
SAMPLE 12				51
SAMPLE 13	59			
SAMPLE 14		28		
SAMPLE 15			49	
SAMPLE 16				24

Table 4. Horizontal test results with respect to time taken in seconds.

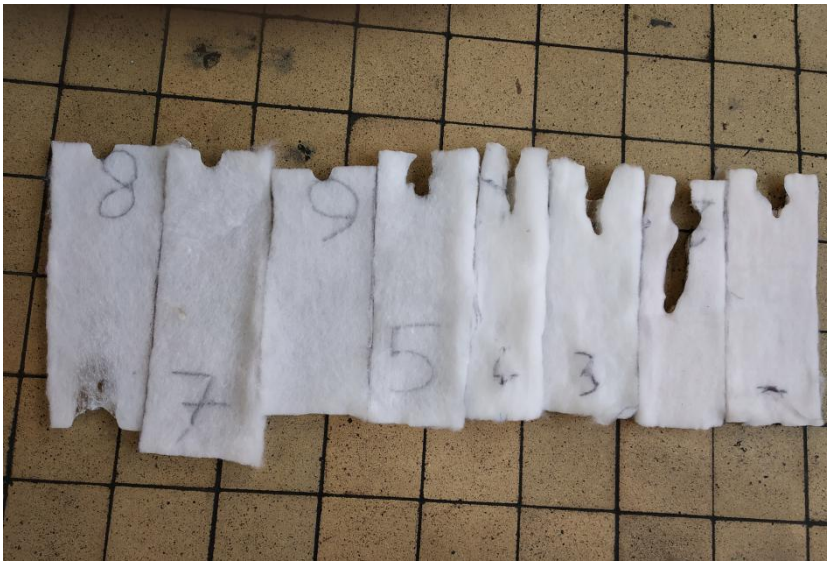

Figure 10. Horizontal test samples after the test.

Figure 11. Horizontal test samples after the test.

10.2 HORIZONTAL TEST RESULTS

The below graph shows us the results obtained for the 16 samples under horizontal flame test.

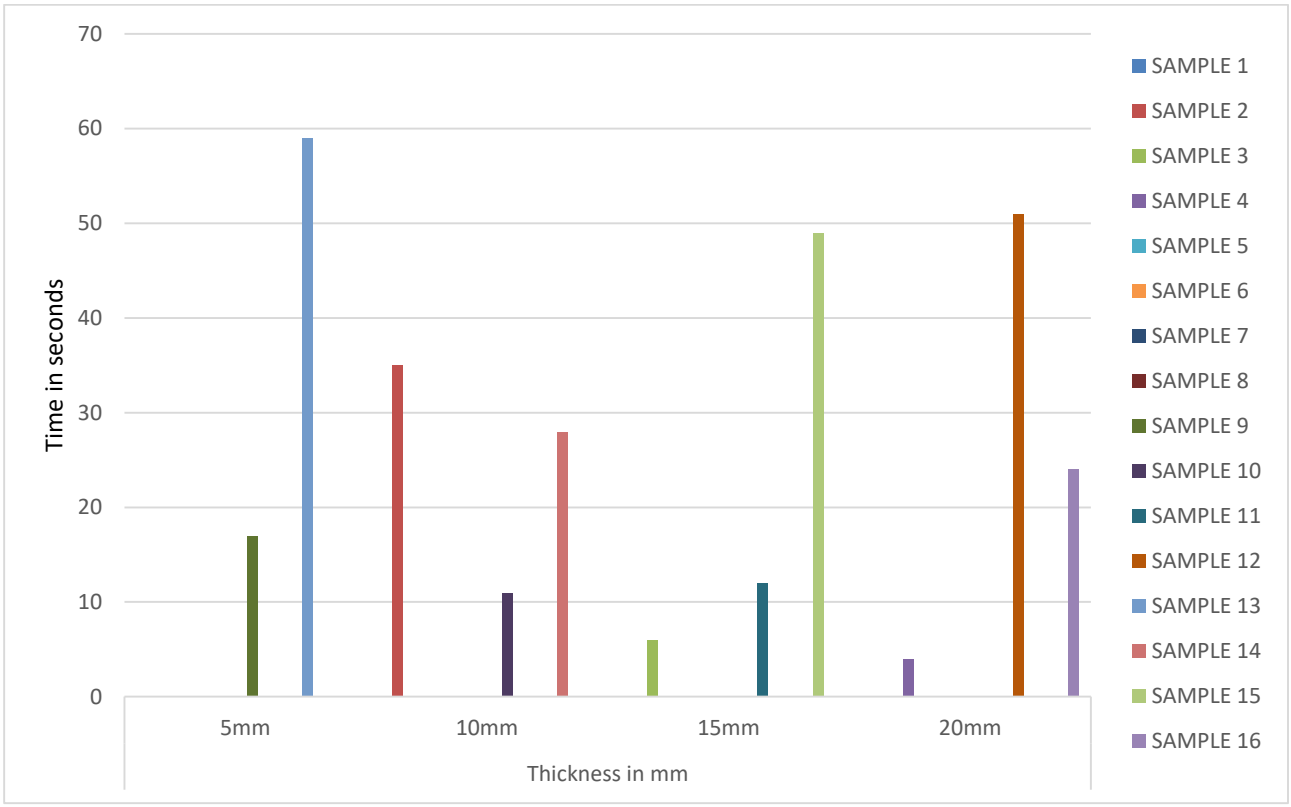

Figure 12. Thickness vs Burn time with respect to horizontal flame test.

10.3 INFERENCE

Based on the above graph we can see the various effects of burn test on the samples with respect to horizontal test. As we can infer from Figure 12, the results from horizontal flammability test does not show any significant dependence. This is caused by used method of horizontal test. Because of the fiber materials which are made of thermoplastic fibers only, the significant dripping of melted polymer occurred. It caused that the flame dripped out with melted fibers and the sample itself stopped burning. Therefore, there is no reliable data from this test.

10.4 BURN TIME MEASUREMENT FROM VERTICAL TEST

Following horizontal, next the vertical flammability tests were performed. The results are shown in the table below. The time given in the table correspond to the burning time after removal of the flame (10 seconds).

	Thickness in mm			
	5mm	10mm	15mm	20mm
SAMPLE 1	0			
SAMPLE 2		0		
SAMPLE 3			0	
SAMPLE 4				0
SAMPLE 5	0			
SAMPLE 6		0		
SAMPLE 7			0	
SAMPLE 8				0
SAMPLE 9	8			
SAMPLE 10		8		
SAMPLE 11			36	
SAMPLE 12				0
SAMPLE 13	10			
SAMPLE 14		10		
SAMPLE 15			10	
SAMPLE 16				10

Table 5. Vertical Test results obtained from Flame test for time taken in seconds.

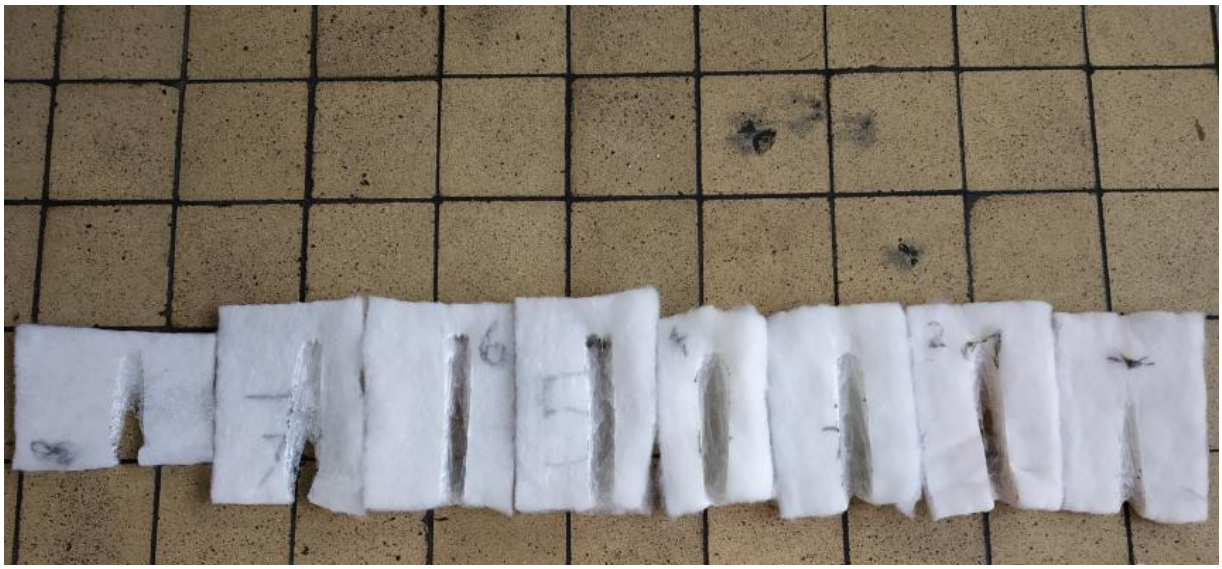

Figure 13. Vertical test samples after the test.

Figure 14. Vertical test samples after the test.

10.5 VERTICAL TEST RESULTS

The below graph shows us the results obtained for the 16 samples under vertical flame test.

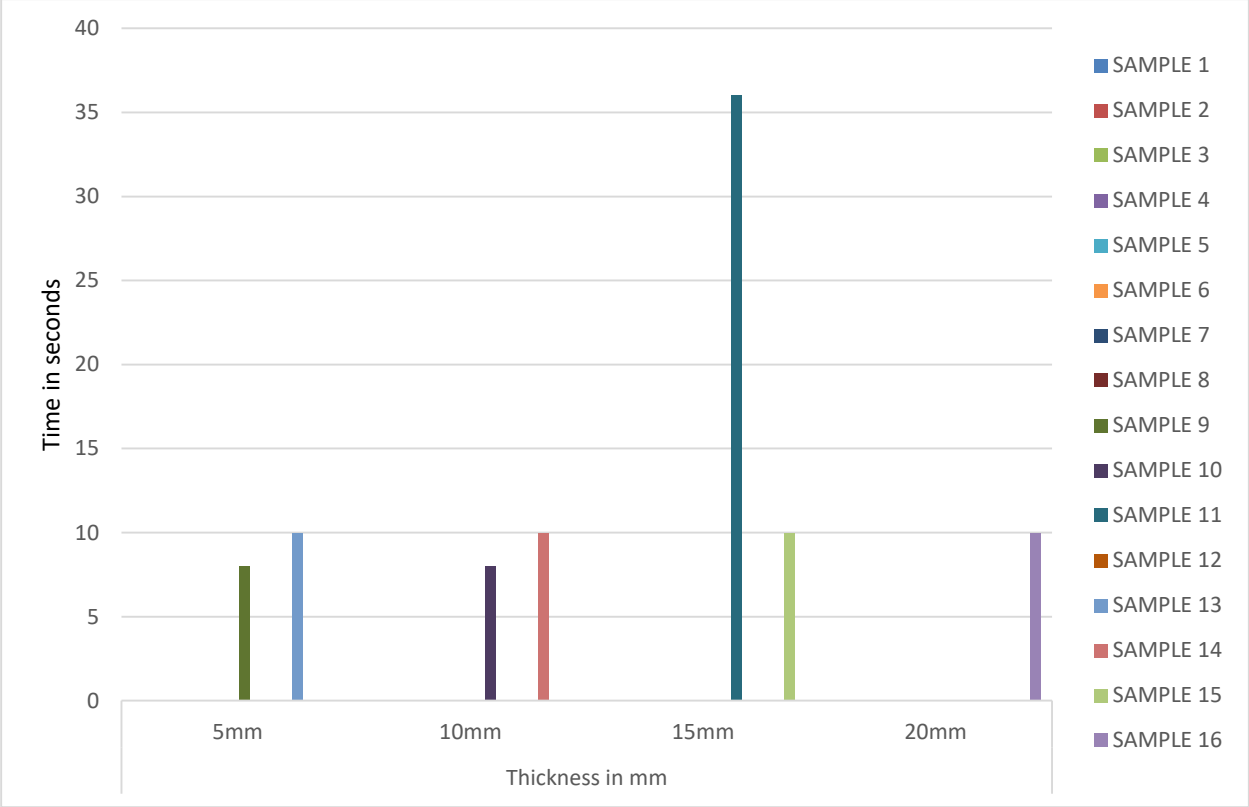

Figure 15. Thickness vs Burn time results with respect to vertical flame test.

10.6 INFERENCE

Based on the above graph we can see the effects of burn test on the samples with respect to vertical test. As we can infer from Figure 15, the results from horizontal flammability test does not show any significant dependence. This is caused by used method of horizontal test. Because of the fiber materials which are made of thermoplastic fibers only, the significant dripping of melted polymer occurred. It caused that the flame dripped out with melted fibers and the sample itself stopped burning. Therefore, there is no reliable data from this test.

10.7 BURN LENGTH MEASUREMENT FROM HORIZONTAL TEST

The below table provides us the corresponding burn lengths with respect to the various thickness of the samples. The provided data is for burn lengths from horizontal test given in centimeters.

	Thickness in mm			
	5mm	10mm	15mm	20mm
SAMPLE 1	5.2			
SAMPLE 2		15.2		
SAMPLE 3			7.8	
SAMPLE 4				6.8
SAMPLE 5	5.3			
SAMPLE 6		1.5		
SAMPLE 7			1.9	
SAMPLE 8				1.7
SAMPLE 9	3.1			
SAMPLE 10		12.8		
SAMPLE 11			7.2	
SAMPLE 12				13.6
SAMPLE 13	27.9			
SAMPLE 14		9.32		
SAMPLE 15			16.8	
SAMPLE 16				8.07

Table 6. Horizontal Test results of burn length given in centimeters.

Figure 16. 10mm Sample after the test.

Figure 17. 5mm Sample after the test.

Figure 18. 15mm Sample after the test.

Figure 19. 20mm Sample after the test.

10.8 HORIZONTAL TEST RESULTS

The below graph shows us the results of burn length obtained for the 16 samples under horizontal flame test.

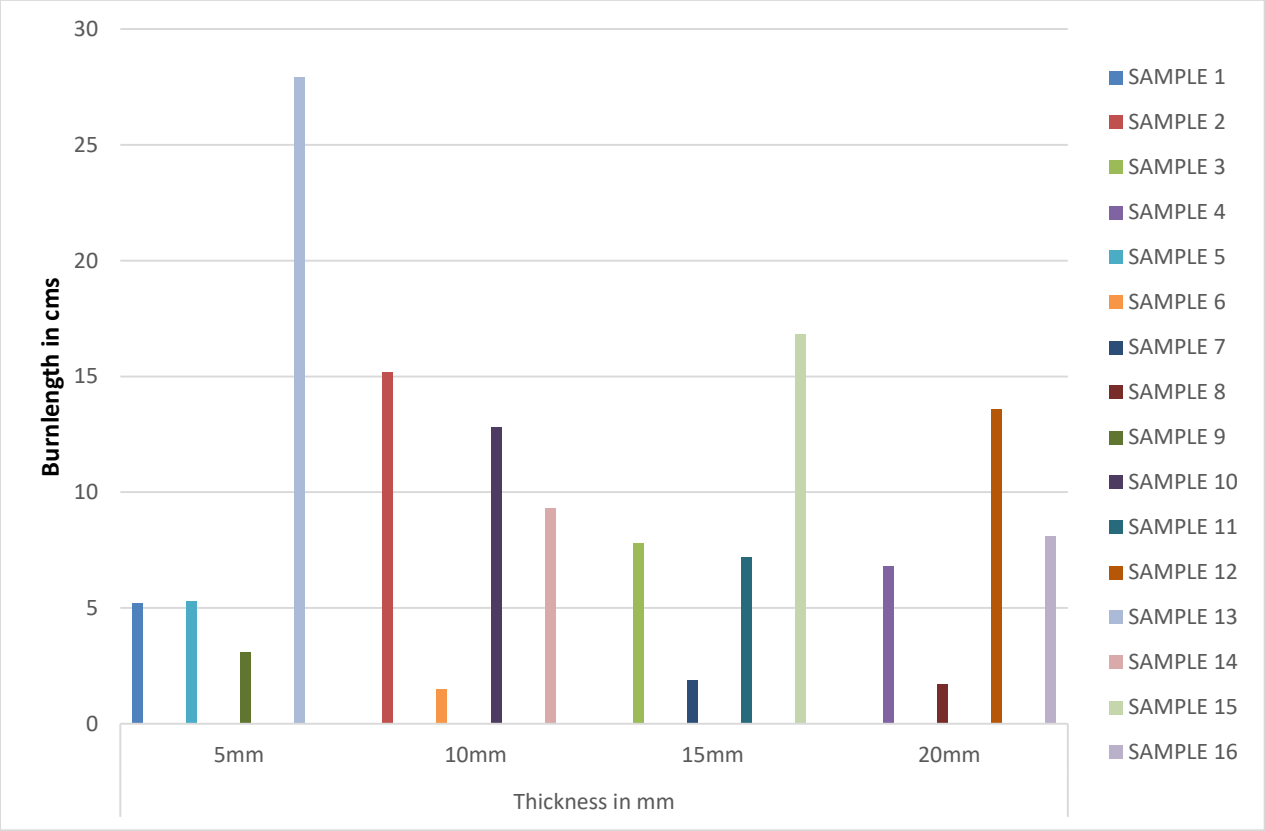

Figure 20. Thickness vs Burn length results from horizontal test.

10.9 INFERENCE

The above graph shows us the effects of flame test on the samples with respect to horizontal test. As we can infer from Figure 20, all the samples showed reaction to flame in some way i.e. drop,

smoke, burn and due to the use of thermoplastic fibres there was dropping and hence the resulting lower values of the test and hence the results were inconclusive.

10.10 BURN LENGTH MEASUREMENT FROM VERTICAL TEST

The below table provides us the corresponding burn lengths with respect to the various thickness of the samples. The provided data is for burn lengths from vertical test given in centimeters.

	Thickness in mm			
	5mm	10mm	15mm	20mm
SAMPLE 1	9.2			
SAMPLE 2		14		
SAMPLE 3			16.2	
SAMPLE 4				14.2
SAMPLE 5	19.3			
SAMPLE 6		19.7		
SAMPLE 7			19.9	
SAMPLE 8				14.2
SAMPLE 9	8.6			
SAMPLE 10		11.5		
SAMPLE 11			30	
SAMPLE 12				23.5
SAMPLE 13	14.4			
SAMPLE 14		19.4		
SAMPLE 15			15.8	
SAMPLE 16				15.3

Table 7. Vertical Test results showing the burn length measured in centimeters.

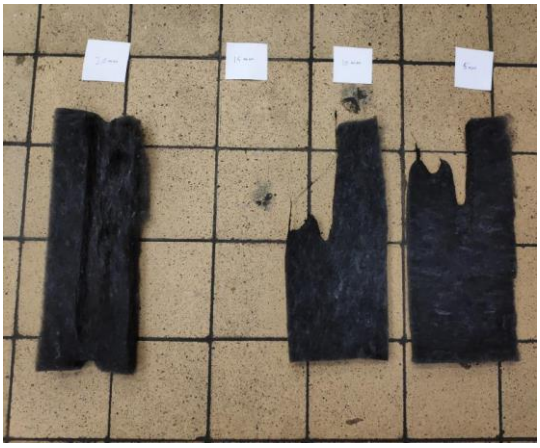

Figure 21. Vertical test samples after the test.

10.11 THICKNESS VS BURN LENGTH

The below graph shows us the results of burn length obtained for the 16 samples under vertical flame test.

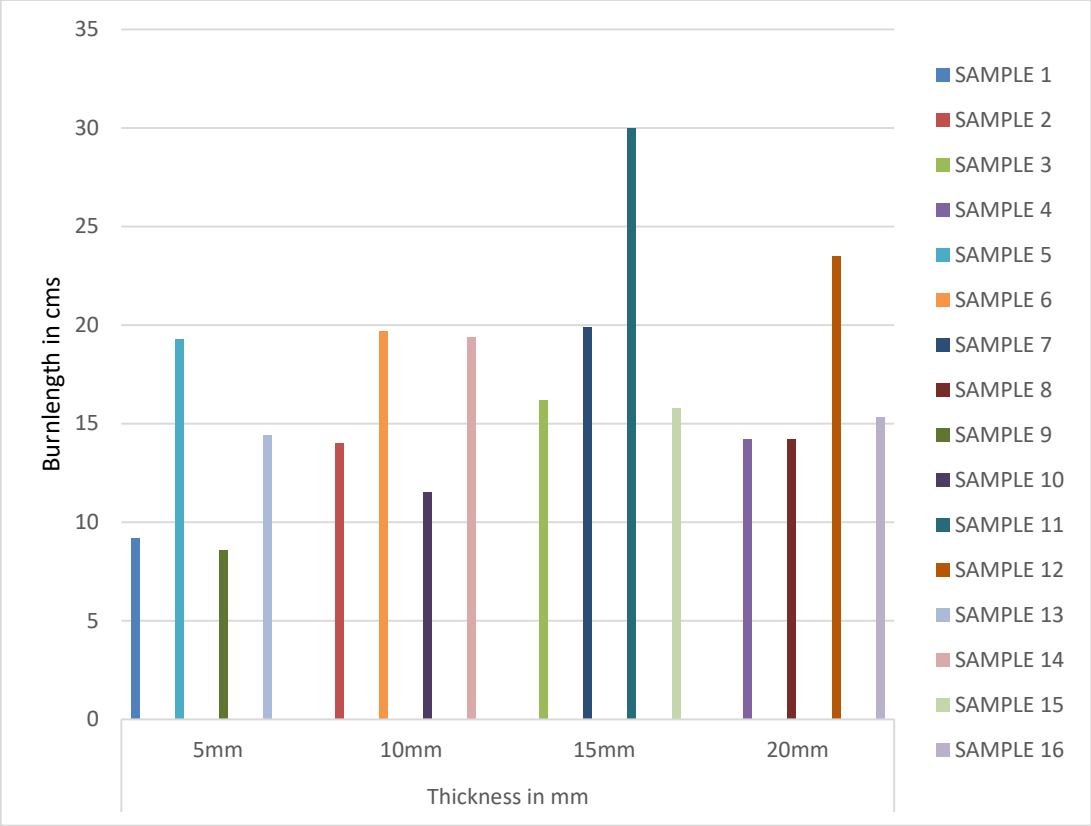

Figure 22. Thickness vs Burn length results from vertical test.

10.12 INFERENCE

The above graph shows us the effects of samples of varied thickness with respect to vertical flame testing. As we infer from the Figure 22, nearly all samples showed effects to flame test especially the samples with fineness of 6 dTex showed more time of burning and hence the resulting higher values of burn length.

11. BURN RATE

In this section, the burn rate of the samples with respect to horizontal and vertical tests are being discussed. The calculations of burn rate were carried out using the formula (Eqn 1) below,

Burn rate B = 60 * (D/T) ……. (Eqn 1)

Where, B - Burn rate (mm/min)

D – Distance travelled by flame (mm)

T – Time taken by the flame to travel distance D (secs)

11.1 BURN RATE MEASUREMENT FROM HORIZONTAL TEST

The below table provides us the corresponding burn rates with respect to the various thickness of the samples. The provided data is for burn rates from horizontal test given in millimeters/minute.

	Thickness in mm			
	5mm	10mm	15mm	20mm
SAMPLE 1	0			
SAMPLE 2		260.6		
SAMPLE 3			780	
SAMPLE 4				1020
SAMPLE 5	0			
SAMPLE 6		0		
SAMPLE 7			0	

SAMPLE 8				0
SAMPLE 9	109.4			
SAMPLE 10		698.2		
SAMPLE 11			360	
SAMPLE 12				160
SAMPLE 13	283.7			
SAMPLE 14		199.7		
SAMPLE 15			205.7	
SAMPLE 16				201.8

Table 8. Burn rate results from horizontal test given in millimeters/minute.

11.2 BURN RATE FROM HORIZONTAL TEST RESULTS

The below graph shows us the results of burn rate obtained for the 16 samples under horizontal flame test.

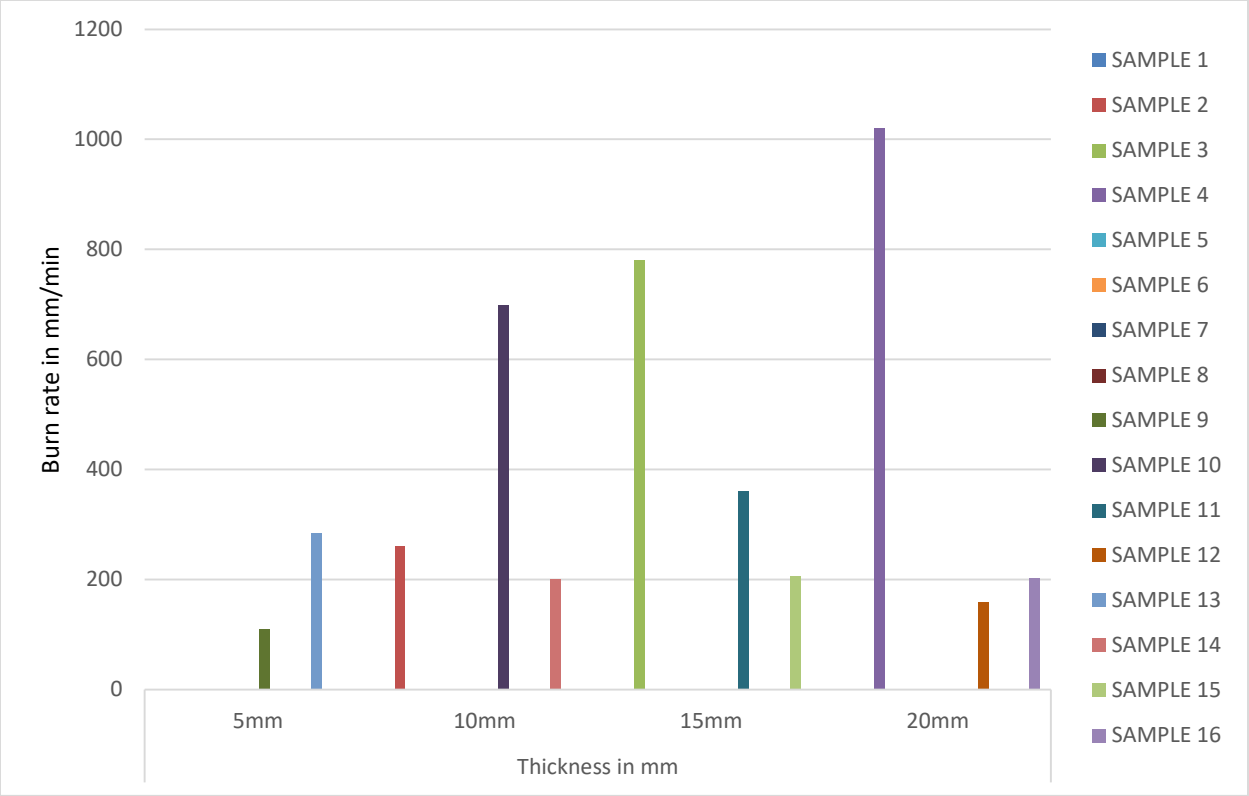

Figure 23. Thickness vs Burn rate results from horizontal test.

11.3 INFERENCE

Based on the above graph we can see the various effects of burn test on the samples with respect to horizontal test. As we can infer from Figure 23, the results from horizontal flammability test does not show any significant dependence. This is caused by used method of horizontal test. Because of the fiber materials which are made of thermoplastic fibers only, the significant dripping of melted polymer occurred. It caused that the flame dripped out with melted fibers and the sample itself stopped burning. Therefore, there is no reliable data from this test.

11.4 BURN RATE MEASUREMENT FROM VERTICAL TEST

The below table provides us the corresponding burn rates with respect to the various thickness of the samples. The provided data is for burn rates from vertical test given in millimeters/minute.

	5mm	10mm	15mm	20mm
SAMPLE 1	0			
SAMPLE 2		0		
SAMPLE 3			0	
SAMPLE 4				0
SAMPLE 5	0			
SAMPLE 6		0		
SAMPLE 7			0	
SAMPLE 8				0
SAMPLE 9	645			
SAMPLE 10		862.5		
SAMPLE 11			500	
SAMPLE 12				0
SAMPLE 13	864			
SAMPLE 14		1164		
SAMPLE 15			948	
SAMPLE 16				918

Table 9. Burn rate from vertical test.

11.5 BURN RATE FROM VERTICAL TEST RESULTS

The below graph shows us the results of burn rate obtained for the 16 samples under vertical flame test.

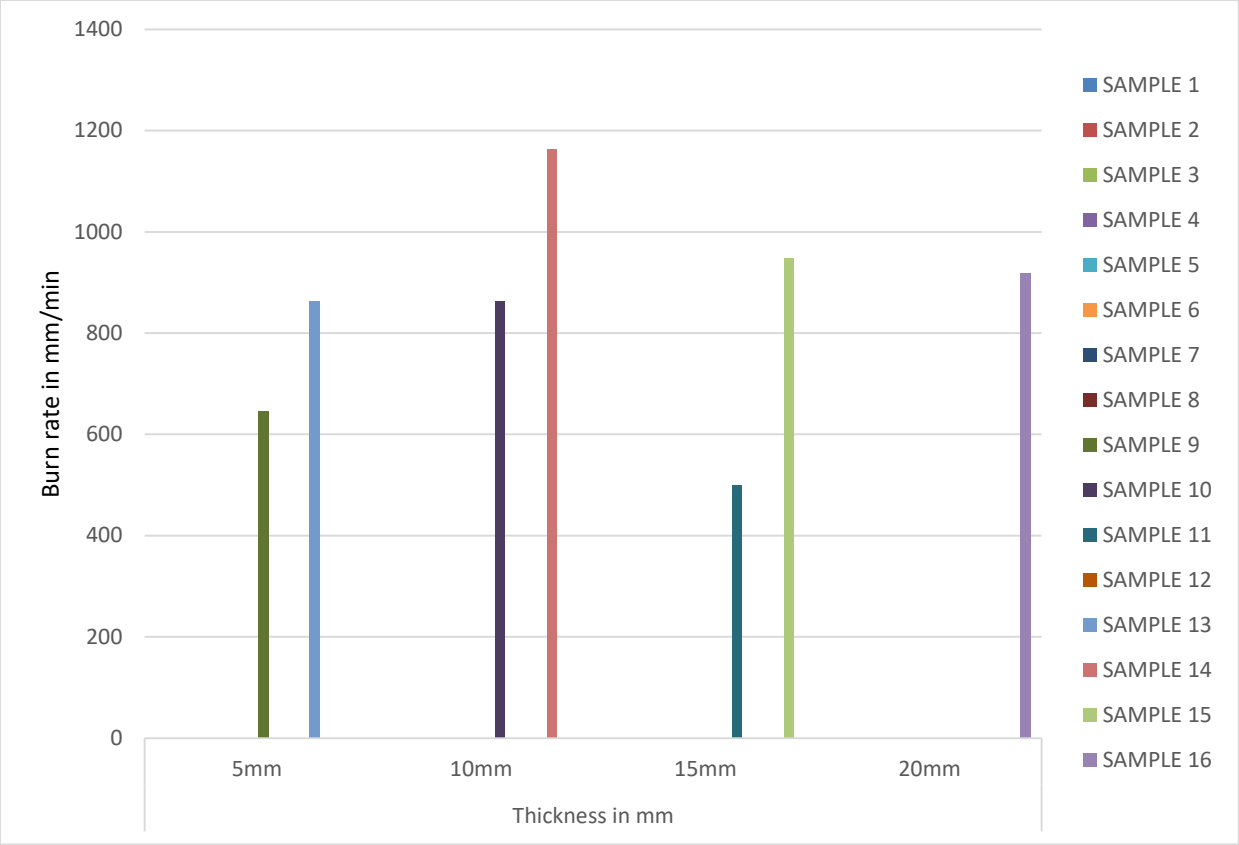

Figure 24. Thickness vs Burn rate results from vertical test.

11.6 INFERENCE

Based on the above graph we can see the various effects of burn test on the samples with respect to vertical test. As we can infer from Figure 24, the results from vertical flammability test does not show any significant dependence. As far as this test is concerned we can see from the figure (Fig 18), that some of the samples were completely burnt and hence the values cannot be included and hence turned out inconclusive.

12. HORIZONTAL TEST FINENESS AND BURN TIME TABULATION

The below table (Table 10) shows us the burn time in seconds with respect to the fineness of the fibers used. The values tabulated are with respect to horizontal flame testing method.

Bulk density (Kg/m^3)	3.3 dTex	6 dTex	11 dTex	3.3/11 dTex
14	4	51	0	24
18	6	12	0	49
26	35	11	0	28
42	0	17	0	59

Table 10. Table for individual bulk densities in horizontal test. Time is in seconds.

12.1 HORIZONTAL TEST RESULTS WITH RESPECT TO FINENESS AND BURN TIME

The below graph shows us the results of burn time obtained for the 16 samples under horizontal flame test.

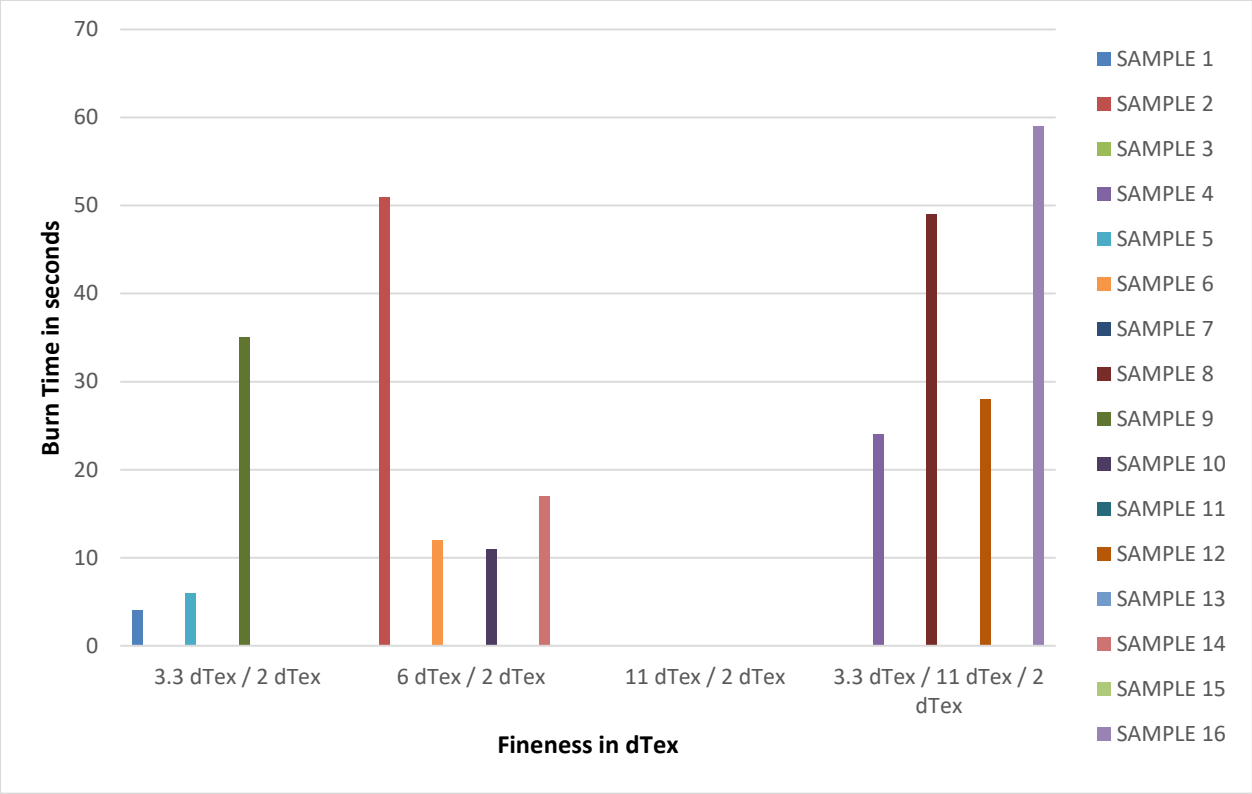

Figure 25. Fineness vs Burn time results from horizontal test.

12.2 INFERENCE

As we can infer from the graph (Figure 25) the values are minimum for 11 dTex fibres which is due to the dropping of the fibres due to the thermoplastic nature and fibers of 3.3 dTex and 11 dTex blend shows significantly higher values compared to those of other samples tested.

12.3 VERTICAL TEST FINENESS AND BURN TIME TABULATION

The below table (Table 11) shows us the burn time in seconds with respect to the fineness of the fibers used. The values tabulated are with respect to vertical flame testing method.

Kg/m^3	3,3 dtex	6 dtex	11dtex	3,3/11 dtex
14	0	0	0	10
18	0	36	0	10
26	0	8	0	10
42	0	8	0	10

Table 11. Table for individual bulk densities with respect to vertical test. Time is in seconds.

12.4 VERTICAL TEST RESULTS WITH RESPECT TO FINENESS AND BURN TIME

The below graph shows us the results of burn time obtained for the 16 samples under vertical flame test.

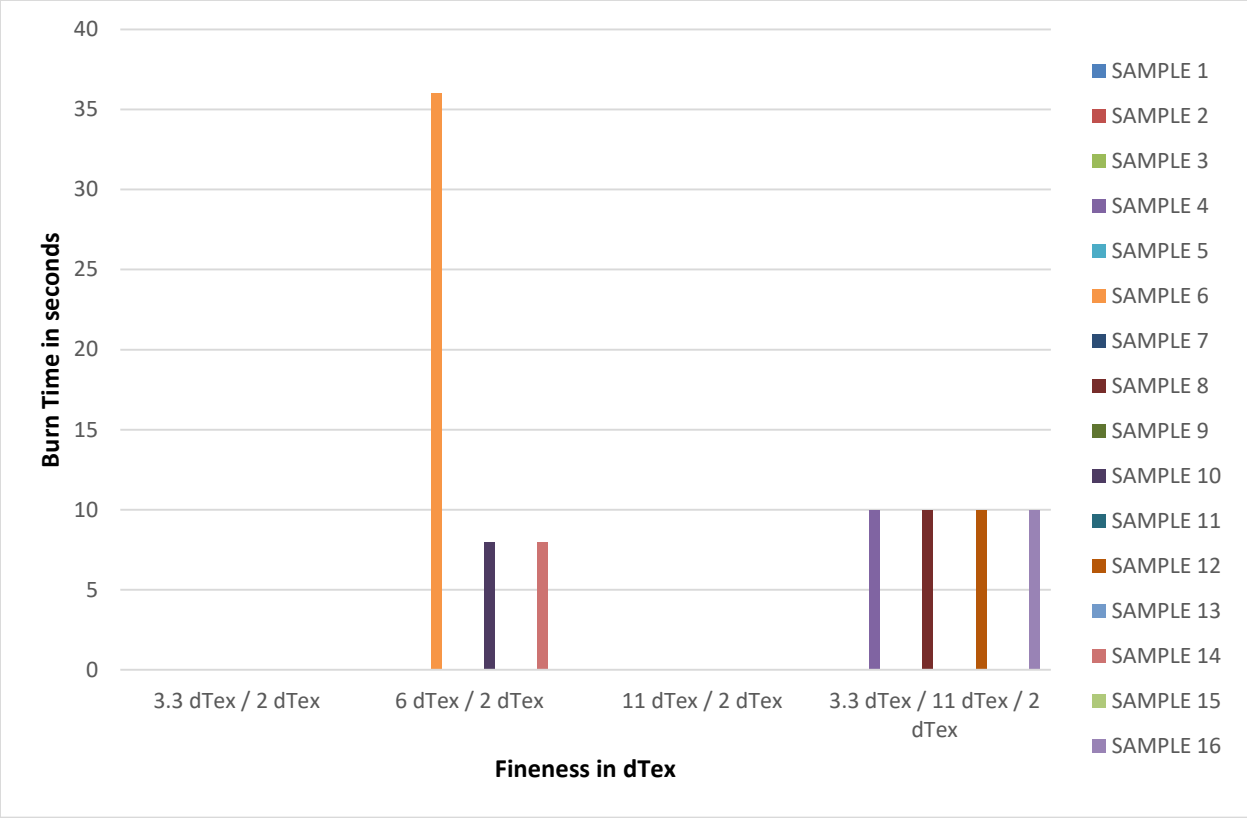

Figure 26. Fineness vs Burn time results from vertical test.

12.5 INFERENCE

As we can infer from the graph (Figure 26) the values are unusual and is completely burnt for the samples of fineness 3.3 dTex and 11 dTex whereas the samples of fineness 6 dTex and 3.3 dTex/11 dTex showed reactivity to the flame and the burn reactivity for 3.3 dTex / 11 dTex samples were uniform.

12.6 HORIZONTAL TEST FINENESS AND BURN LENGTH TABULATION

The below table (Table 12) shows us the burn length in centimeters with respect to the fineness of the fibers used. The values tabulated are with respect to horizontal flame testing method.

Kg/m^3	3,3 dtex	6 dtex	11dtex	3,3/11 dtex
14	6.8	13.6	1.7	8
18	7.8	7.2	1.9	16.8
26	15.2	12.8	1.5	9.3
42	5.2	3.1	5.3	27.9

Table 12. Table for individual bulk densities with respect to horizontal test. Length is in cms.

12.7 HORIZONTAL TEST RESULTS WITH RESPECT TO FINENESS AND BURN LENGTH

The below graph shows us the results of burn length obtained for the 16 samples under horizontal flame test.

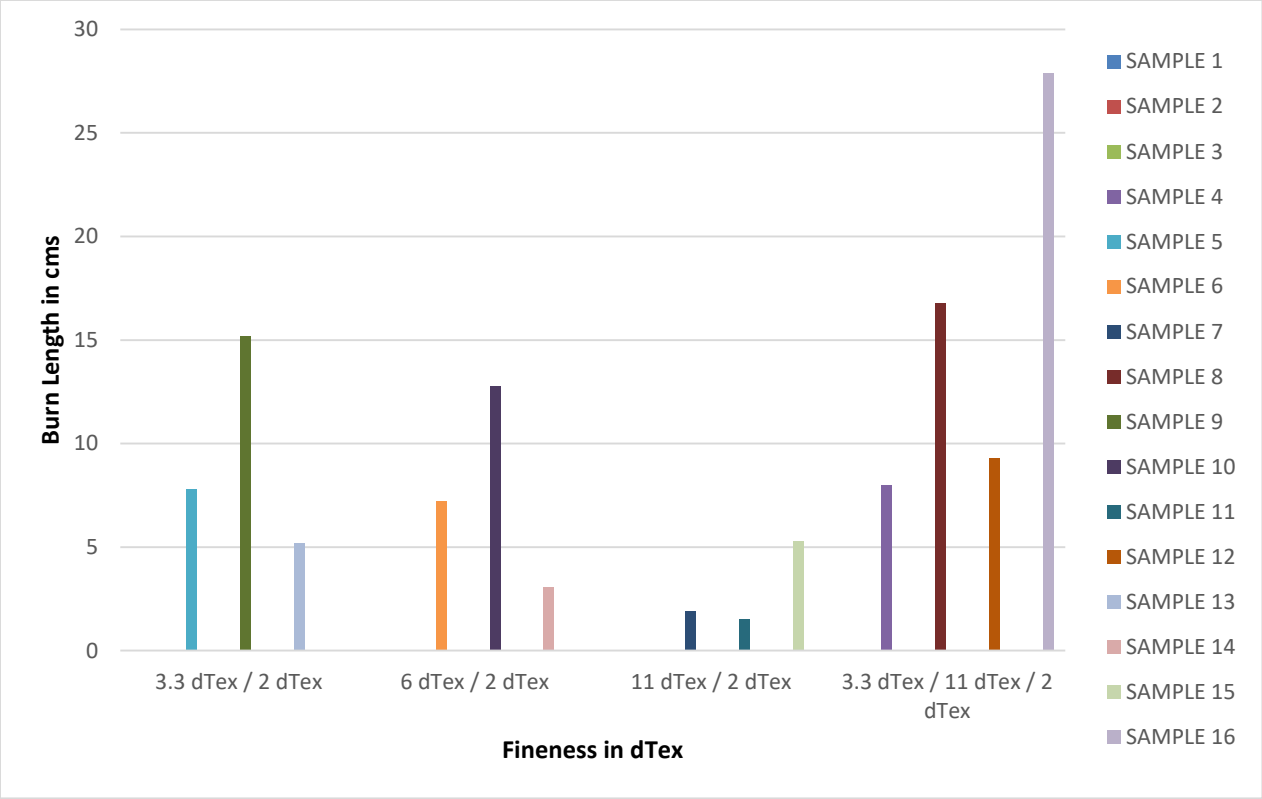

Figure 27. Fineness vs Burn length results from horizontal test.

12.8 INFERENCE

As we can infer from the graph (Figure 27) the values of burn length for the samples of various fineness are plotted. We can conclude that the samples of fineness 11 dTex showed the lowest burn length values among all the samples due to the dropping of the burnt sample thus stopping further burning process. On the other hand, samples of fineness 3.3 dTex / 11 dTex showed slightly higher values of burn length compared to other samples.

12.9 VERTICAL TEST FINENESS AND BURN LENGTH TABULATION

The below table (Table 13) shows us the burn length in centimeters with respect to the fineness of the fibers used. The values tabulated are with respect to vertical flame testing method.

Kg/m^3	3.3 dtex	6 dtex	11dtex	3.3/11 dtex
14	14.2	23.5	14.2	15.3
18	16.2	30	19.9	15.8
26	14	11.5	19.7	19.4
42	9.2	8.6	19.3	14.4

Table 13. Table for individual bulk densities with respect to vertical test. Length is in cms.

12.10 VERTICAL TEST RESULTS WITH RESPECT TO FINENESS AND BURN LENGTH

The below graph shows us the results of burn length obtained for the 16 samples under vertical flame test.

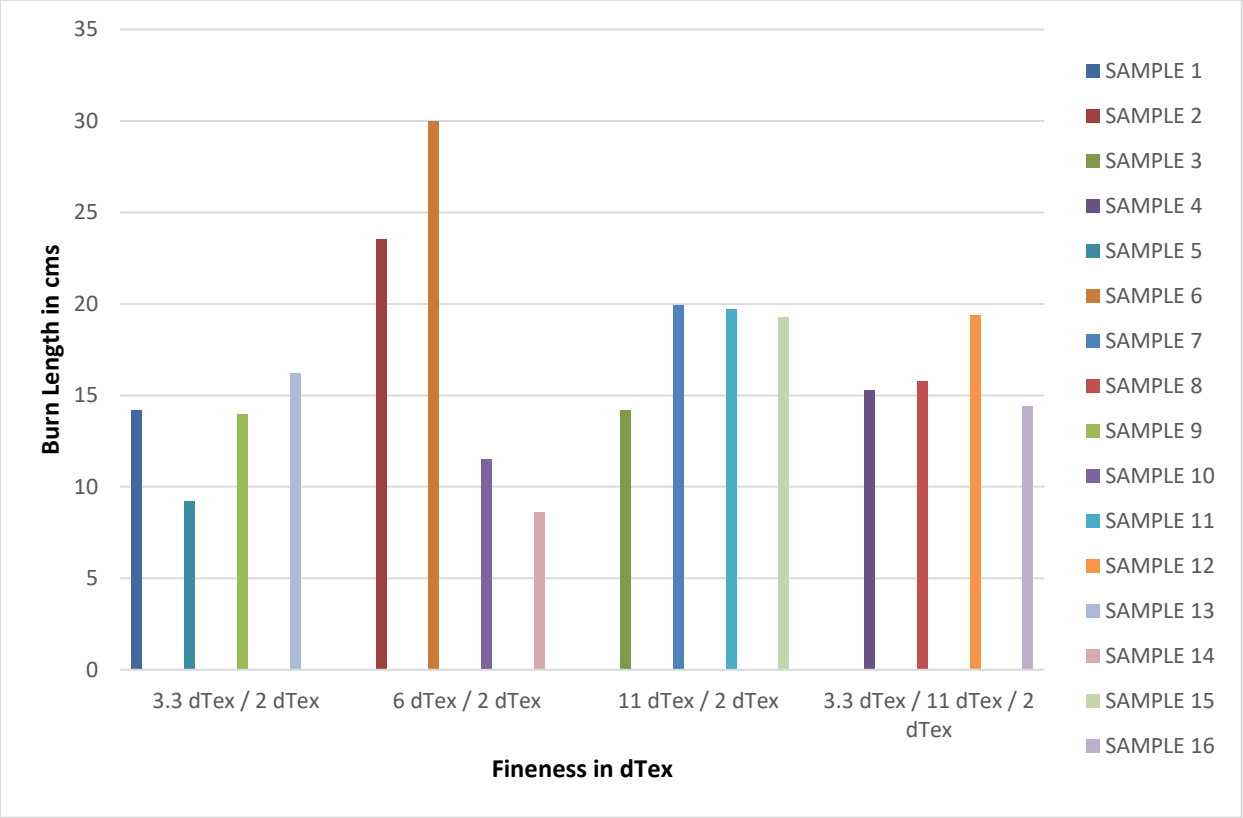

Figure 28. Fineness vs Burn time results from horizontal test.

12.11 INFERENCE

As we can infer from the graph (Figure 28) the values of burn length for various fineness are plotted. All samples showed respective burn lengths with respect to the flame test.

13. CONCLUSION

From the overall experimental work involving various thermoplastic fibers we can conclude the following points.

Based on the composition of fibers taken, thickness, fineness of different values the following conclusions are achieved.

- The whole experiment was carried out with the view of study on the flame retardant properties of low cost available fibers by varying the thickness and fineness of the samples.
- The samples were prepared using carding technique and also the usage of hot press thermal bonding techniques with varied thickness.
- The samples were introduced to flame test as per standard ISO 3795 and the results were computed for burn time, burn length and burn rates.
- As we can infer from the results obtained we can conclude that due to the lack of a uniform trend of the behavior of the samples to the flame retardant test, and hence the results turned out to be inconclusive.
- Further to test materials of this kind, usage of bigger scale tests such as SBI can be undertaken for better results.

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