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Analyzing Protection Offered by Nomex Against Resistance Characteristics

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Abstract- Nature is unpredictable and so are accidents. Since industrial revolution, history has recorded many industrial disasters. Scientists for decades have studied circumstances leading up to such accidents, they conclude if proper safety mechanisms are installed at industries, life of workers at these industries can be saved in such situations. Man has to expose himself to different environments for various purposes to carry out daily activities of life. Each environment carries distinctive features or elements and each feature requires different expression of protection and safety. For example, protective measures for medical personnel are entirely different from a military officer. Clothes have been integral part of human life since the beginning of time. Humans have not only been using clothes to fulfill their social or emotional needs but also as a mean of protection. The study was experimental in nature. It was aimed at developing Nomex fabric and assessing its resistance characteristics against water, chemical and fire to provide protection to its wearer. The prepared fabric was also evaluated after various washing intervals in order to know its performance behavior. Ring spun yarns were produce to manufacture a Nomex fabric by following certain construction parameters. Plain interlacing pattern was adopted. The resistance characteristics were evaluated by following international safety standards. Water resistance was measured through absorbency test AATCC-79 and vertical wicking test AATCC-197 both in warp and weft directions. Chemical resistance was determined through ISO 6530:2005 by calculating the percentage values of penetration and resistance index. Flame resistance was evaluated by following vertical flame test ASTM D6413 with char length and after flame. The results depicted that Nomex was able to provide adequate protection to its wearer, if manufactured with adequate construction parameters. It has the ability to resist water, chemical and fire that can offer best solution to the one working at industrial station. The manufactured fabric showed complete resistance against water and selected liquid chemicals even after various washing intervals. Moreover, it can also be considered as fire resistant material as char length and after-flame was adequate according to the safety standard.

Keywords- Nomex, Protection, Absorbent Action, Wicking Behaviour, Chemical Resistant, Fire Resistant

I. INTRODUCTION

Safety, health and wellbeing issues are very necessary in every industry, so professionals from various fields such as surgeons, doctors, pharmaceutical staff, chemists, military staff, fire fighters, pesticide handlers, farmers, food handlers and others must protect themselves from surrounding environment through the selection of adequate type of clothing materials. The clothing must provide protection to its wearer from many physical, chemical or biological hazards and should delivers comfort at the same time. There is a lack of awareness among industrial staff regarding appropriate use of clothing [1]. It must be an obligation for a manager or a supervisor to provide protective ensembles to the workers who may be liable to risk at their work place [2].

The right to be protected fundamental human right, that cannot be ignored at any cost. People are supposed to spend a significant amount of time in their daily routine at work area. Since many years, it has been recognized to have safe working conditions and environment [3,4,5]

Accidents at work place can result in dreadful situations [5]. Occupational risks, dangers and injuries are observed at the highest level in our country as many workers exposed themselves to toxic chemicals in their routine work. Adequate steps must be taken into consideration to avoid any damage [6,7,8].

Choice of fiber used for making industrial garments depends on the type of work and surrounding atmosphere. Therefore assessment of certain mechanical and resistance characteristics of any particular material is very much needed. These properties separately and in combination with each other can develop a protective shield against certain hazards [9]. Immediate form of defense for industry personnel is their clothing. Although there is no magical fabric available that can provide safety against all types of hazards [10]. Fabrics and their variants such as fiber or yarn must be evaluated for their performance behavior before use. Because fabrics may changes their physical and chemical properties with the passage of time, which can affect their performance. Therefore, such variations must be observed to make a wise decision [11].

II. MATERIALS AND METHODS

Ring spinning was done in order to produce an Aramid yarn. The polymers of meta aramid were manufactured with m-phenylenediamine and m-isopthalic acid. The polymers were extruded though the spinneret at 100 degree centigrade. The prepared fibers were then washed, neutralized and dried. The resultant fibers were highly crystalline in nature. These fibers were strong and had high modulus. The fabric was manufactured by following plain interlacing pattern on a sample loom. The developed fabric was 7 meters long and 19 inches wide. The fabric density was kept as 50 ends and 44 picks per inch. Linear density was 15.064 in tex system both for warp and weft directions.

Fabric weight was 139 GSM. The color of prepared fabric was white. Transol FL20 was laminated over fabric surface to make it water/chemical/fluid repellent through padding. The newly developed aramid fabric was evaluated for its resistance characteristics after different washing cycles by following international test procedures.

Evaluation of water resistance

Resistance against water was evaluated in terms of water absorbency and wicking action. Absorbency test was performed by following specifications given in AATCC 79-2010[12]. The sample was conditioned in a standard atmosphere where r.h was 65 ± 2% and temperature 21± 1° C. [13] Five specimen (200 mm x 200 mm) were taken from the fabric. Each specimen was mounted over an embroidery frame. It was made sure that all wrinkles were removed after stretching it over the frame. Five drop tests were made. Distance between each drop was set at least 1 inch. The frame was put under burette tip in order to drop a water droplet on the sample. The drop was carefully observed and stop watch was used to note the timings of water droplet to lose its reflectivity. The readings were recorded till 60 seconds.

Wicking action was determined through AATCC 197-2011 Vertical Wicking Test. [14]. The specimen was cut in lengthwise and crosswise directions with the dimensions of 170mm x 25mm. One end of specimen was vertically fastened and the other end was dipped in distilled water till 3mm at a temperature of 21◦C. The travelling of water along the vertical length of the given sample was noted at intervals of 1, 5 and 10 minutes.

Evaluation of chemical resistance

Resistance against liquid chemicals was also identified. [15]. Four chemicals such as Sulfuric acid, Sodium Hydroxide, Xylene and Butanol were used to make solution in order to evaluate penetration and repellency of chemicals through these specimens. Specimen 360 mm x 235 mm was cut to serve as a top layer. A filter paper attached with plastic sheet with similar dimensions was also taken. The both layers were placed over the collector layer. All layers were weighed separately before making the test. The layers were then clipped to the gutter at an angle of 45°. A 10ml of chemical was then poured over the layers for 10 seconds and a beaker was placed under the gutter to collect an excessive chemical. About 10ml of each chemical was poured off for 10 seconds over the specimen with nozzle. Then the layers were separated and weighed again. The weight measured for underneath collector layer was taken as penetration index and an amount of chemical dripped into a beaker was taken as repellency index.

The test standard recommends that material should pass performance grade 3 for repellency and grade 2 for penetration index against at least one of the four liquid chemicals to be considered as protective. (Table I)

TABLE I PERFORMANCE CRITERIA OF CHEMICAL RESISTANCE OF FABRIC

Performance Grade	Repellency (%)	Penetration (%)
3	95	<1
2	90	<5
1	80	<10

Evaluation of flame resistance

Resistance against flame was measured through Vertical Flame Test [16]. Five lengthwise specimens (76mm x 300 mm) were cut. The specimen was placed in a frame where the burner was set 199 mm below the test specimen. Each specimen was exposed to fire for 12 seconds. After flame time was recorded with stop watch and burnt length was measured with template for each tested specimen.

Laundering process

Samples were laundered by following instructions of AATCC Monograph [17]. The agitation speed during washing was 45±10 rpm and temperature was set at 54±2.9°C. 0.1g/liter AATCC detergent was added in each wash cycle for 11±1 minutes. Spinning cycle was made at 1300±150 rpm for 12 minutes. Drying was done at 68±6°C for 1 hour and 30 minutes. Samples were assessed for their resistance against water, chemicals and fire at intervals of 0, 5, 10, 15 and 20 washing cycles.

III. RESULTS AND DISCUSSION

Analysis of the collected data was made through SPSS version 22. Mean ± S.D were presented. Repeated measurement analysis of variance (ANOVA) was used to measure the significance level of various washing intervals on tested resistance characteristics. P-value ≤ 0.05 was considered as significant. Table II explains mean values and SD of drop test performed in this study. Absorbency time was noted upto 60 seconds at 0, 5, 10, 15 and 20 washing cycle. It shows that the fabric was able to resist water till 60 seconds, the maximum value suggested by the standard. The drop remained in the pearl shape for whole 1 minute. The result was same till 20th wash.

TABLE II
EVALUATION OF DROP TEST AT DIFFERENT WASH CYCLES

Wash Cycle	Mean (measured in sec)	S.D
0-Wash	60.00	0.00
5th Wash	60.00	0.00
10th Wash	60.00	0.00
15th Wash	60.00	0.00
20th Wash	60.00	0.00

Laundering did not affect the absorbency behavior of tested fabric. One possible reason behind the specific observation was the use of lamination over the surface of fabric after manufacturing. Microporous films, laminations and coating can serve as a useful tool in making water repellent or breathable clothing materials for various purposes [18]

TABLEIII
WICKING ACTION (WARP) AT DIFFERENT WASH CYCLES

Wash Cycle	Wicking at 1 min		Wicking at 5 min		Wicking at 10 min	
	(Measured in cm)					
	Mean	S.D	Mean	S.D	Mean	S.D
0-Wash	0.10	0.00	0.13	0.05	0.10	0.00
5th Wash	0.10	0.00	0.13	0.05	0.13	0.05
10th Wash	0.20	0.00	0.30	0.00	0.26	0.05
15th Wash	0.20	0.00	0.30	0.10	0.40	0.10
20th Wash	0.26	0.05	0.40	0.10	0.43	0.05

p-value = 0.345 (Insignificant: p-value>0.05)

Table III shows wicking behavior of Nomex in warp direction, observed during this study at 1,5 and 10 minutes. It remained almost stable till 5 wash then a slight increase in wicking was observed at 20 wash. The p-value 0.345 suggested an insignificant difference among all washing intervals. Figure 1 shows that Nomex performed well till the last tested wash cycle.

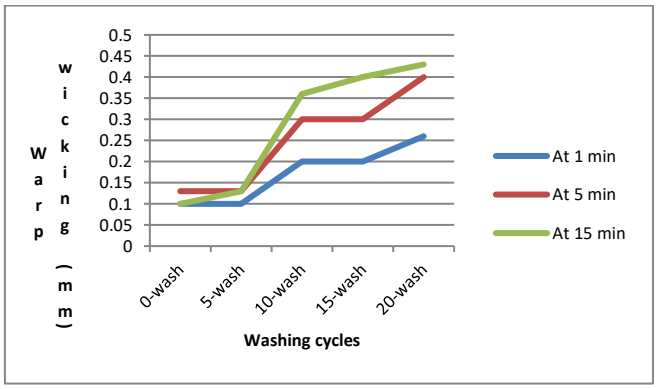

Fig. 1. Wicking action in warp direction

Different types of fibers produce various effects on finished fabric towards moisture transmission in water or vapour form. Less resistance against water can be observed in hygroscopic fibers where fibers led the increase of water transfer [19]. Tortora and Collier [20] also emphasized that various kinds of polymers had varied effects of water on their performance behavior, as the moisture can well absorbed by fibers and able to transport through the fabric structure which then desorbs to the surrounding atmosphere. Li [21] studied that laminated or coated clothing materials had lesser values for wicking than unfinished materials. So, these type of fabrics are safe to be used by industrial workers as they do not create discomfort for the wearer by wetting him/her skin.(Fig 2)

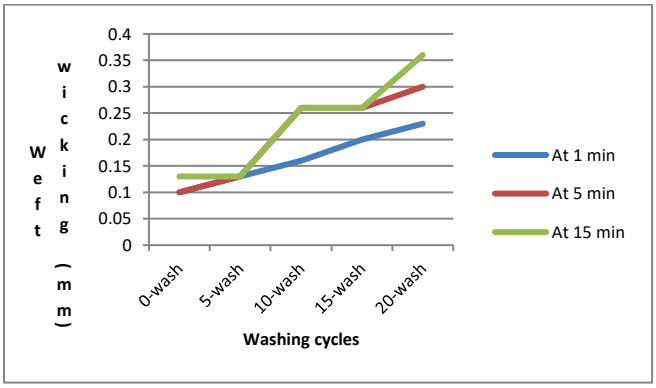

Fig.2. Wicking action weft direction

TABLE IV
WICKING ACTION (WEFT) AT DIFFERENT WASH CYCLES

Wash Cycle	Wicking at 1 min		Wicking at 5 min		Wicking at 10 min	
	(Measured in cm)					
	Mean	S.D	Mean	S.D	Mean	S.D
0-Wash	0.10	0.00	0.10	0.00	0.13	0.05
5th Wash	0.13	0.05	0.13	0.05	0.13	0.05
10th Wash	0.16	0.05	0.26	0.05	0.26	0.05
15th Wash	0.20	0.10	0.26	0.05	0.26	0.05
20th Wash	0.23	0.11	0.30	0.10	0.36	0.05

p-value = 0.451 (Insignificant: p-value>0.05)

Table IV shows wicking action in weft direction at various intervals. A slight increase was observed from 0 till 20th wash. The p-value 0.451 also recommended an insignificant difference among all washing intervals.

TABLE V
CHEMICAL PENETRATION OF NOMEX AT DIFFERENT WASH CYCLES

Wash Cycle	Sulphuric acid		Sodium hydroxide		Xylene		Butanol	
	(Measured in percentage)							
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
0-Wash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5th Wash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10th Wash	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15th Wash	0.00	0.00	0.00	0.00	0.03	0.05	0.00	0.00
20th Wash	0.03	0.05	0.03	0.05	0.03	0.05	0.00	0.00

p-value = 0.358 (Insignificant: p-value>0.05)

Table V explains penetration percentage of Nomex at various washing cycles in this study. It did not penetrate Sulfuric acid till 15 wash. A slight but insignificant (p-value 0.358) increase in penetration was observed at 20 wash. Excellent results were observed with Butanol during all washing intervals. It can be said that Nomex can provide protection against such liquid chemical at least up to 20 washes. The test standard suggested minimum performance grade No 2 for (<5 penetration index) was needed to pass by at least one of the four chemicals. George and Thomas [22] highlighted the need of adequate type of fiber to present permeation characteristics. Nomex had passed grade No 3 for penetration even after 20 wash. The reason can be due to the inherent properties of fiber to resist chemicals at some extent [23,24]

TABLE VI CHEMICAL REPELLENCY OF AT DIFFERENT WASH CYCLES

Wash Cycle	Sulphuric acid		Sodium hydroxide		Xylene		Butanol	
	(Measured in percentage)							
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
0-Wash	98.63	0.05	98.40	0.20	95.76	0.15	94.23	0.05
5th Wash	98.60	0.30	98.20	0.36	95.73	0.11	94.20	0.10
10th Wash	98.46	0.25	98.16	0.30	95.63	0.25	94.20	0.10
15th Wash	98.36	0.11	97.90	0.70	95.60	0.36	94.20	0.30
20th Wash	98.23	0.35	97.56	1.80	95.40	0.43	94.16	0.30

p-value = 0.397 (Insignificant: p-value>0.05)

Table VI presents repellency percentage at various washing cycles. it was better able to repel all four tested chemicals till 20th was. The p-value (0.397) also gives the impression of higher repellency index of Nomex throughout washing cycles. The test standard recommended performance grade No 3 for (95% repellency index) was needed to pass by at least one of the four chemicals. Nomex had passed the required criteria for three liquid chemicals till 20th wash. It is also observed [25] that finished fabrics presents good repellency against liquid chemicals and can able to protect the wearer. Aramid based fibers can resist certain acids but strong concentrations and long exposure may result in its discoloration [26] Surface modification of aramid fibers in terms of physical or chemical action is made in order to inculcate innovative features in the final product. So, many finishing treatments can be applied over the surface of fabrics to provide protection and safety against certain hazards [27]. One of the possible reasons of polymers to resist the attack of liquid chemicals is their crystalline structure as amorphous regions are more prone to be damaged by acids and alkalis [28].

Table VII
FLAME RESISTANCE OF NOMEX AT DIFFERENT WASH CYCLES

Wash Cycle	After flame (sec)		Burnt length (inches)	
	Mean	S.D	Mean	S.D
0-Wash	0.10	0.00	0.13	0.05
5th Wash	0.10	0.00	0.16	0.05
10th Wash	0.10	0.00	0.16	0.05
15th Wash	0.13	0.05	0.20	0.10
20th Wash	0.16	0.05	0.20	0.10

p-value = 0.312 (Insignificant: p-value>0.05)

Table VII depicts after flame and burnt length of tested sample in this study. An insignificant increase (p-value: 0.312) was observed from 0 till 20 wash. After flame time was stable till 10 wash. (Fig 3).

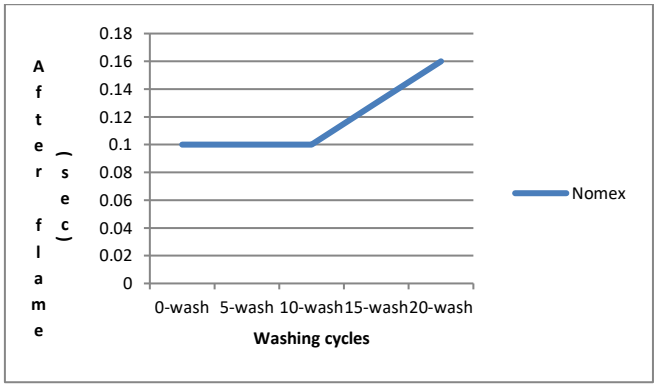

Fig.3. After flame at various washing intervals

This stability was also observed in char length between 5 and 10 wash as well as 15 and 20 wash. The test procedure defined that after-flame time should not be more than 2 seconds. Nomex presented less than 2 seconds for after flame even at the last wash cycle. It was due to the inherent ability of the fiber. A lot of attention has been given to the development of fire retardant materials in the recent years. A layered fabric is usually recommended for better results, which is composed of shell layer, thermal liner and a liquid/moisture barrier in the form of lamination of coatings [29]. NPCS [30] concluded that repeated launderings and tumble drying of flame retardant materials did not affect their resistance against flame. The test standard defined that char length must not be more than 4 inches.

The result showed less consumption of char length till last washing cycle. (Fig 4) Nomex made with Aramid was able to provide better protection. Single layer of aramid fiber added with a layer of coated fabric was effective to use in manufacturing flame resistance materials [31]. Fire retardants have a significant effect on the thermal stability of treated fabrics in the presence of nitrogen and resultantly effects their resistance against fire [32]. Protective clothing made from either meta Aramid or para Aramid fibers are better able to provide great protection against thermal as well as mechanical risks. A strong chemical structure of Aramid is the prime reason of its excellent performance in terms of its physio-mechanical behavior. It can be used as a base material for layered fabrics in various items of protective ensemble [33]. Sellers and Carr [34] also found

out that aramid help in stopping burning process. Nomex and Nomex blended fibers showed high resistance against flame as well as presented high laundering durability [35]. Fibers treated with Nano-Hydroxyapatite helped to improve their resistance against fire by inducing self-extinguishing characteristics and zero burn rate [36]. It was also investigated in another study that fabrics made with Nomex yarns showed better flame retardancy behavior as compared to some virgin fabrics in vertical flame test. Moreover, they also showed somewhat excellent thermal stability [37, 38].

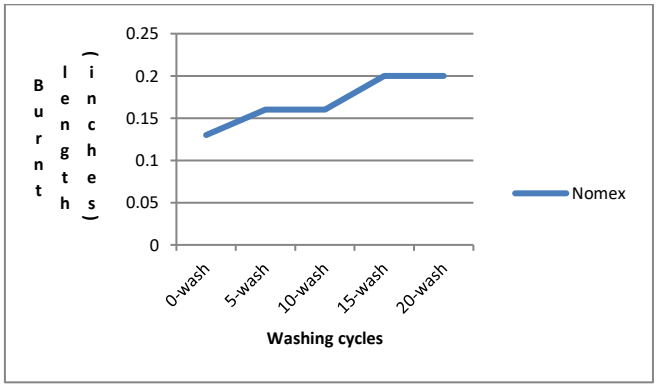

Fig.4. Burnt length at various washing intervals

Bio composites burnt more easily as compared to traditional forms of composites. Therefore, such materials are not recommended to use in industries where risks of flame exposure is high [39]

IV. CONCLUSION

Occupational investigation with reference health and safety issues in our country has not yet received due importance There is an urgent need to create awareness among management staff and workers regarding protective measures. It is concluded that Nomex yarn can serve as a useful tool in providing protection against hazards created with excessive amount of water, chemicals and fire. The results showed that the developed fabric was able to resist absorbency of liquids such as water and chemicals. It was also able to resist fire according to the test procedure. The results remained statistically stable throughout laundering cycles. It was concluded that Nomex fiber can be used as a safety measure against these hazards. The construction parameters and lamination applied over the surface of fabric made it perform well against tested resistance characteristics. This study can serve as a beneficial tool for the textile producers to modify their manufacturing specifications and help them make wise decision to select an adequate kind of polymer for their end products. It can provide a framework for developing safety standards for various items of protective clothing.

REFERENCES

[1] M.J. Stellman, (2018, May).“Encyclopedia of occupational health and safety”. [online] Available: http://www.ilo.org/oshenc/part iv/personal-protection/item/691.

[2] Occupational Safety and Health Administration. Personal protective equipment, Technical Manual, 2003.

[3] K. Amponsah-Tawiah, K. Dartey-Baa, “Occupational health and safety: key issues and concerns in Ghana”, International Journal of Business and Social Science. vol.2, no.14, 2011.

[4] M. Pagell, D. Johnston, A. Veltri, R. Klassen, M. Biehl, “Is safe production an oxymoron?” Production and Operations Management. vol.23, no.07, pp.1161-75, 2014.

[5] A.C. Waddimba, H.B. Beckman, T.L.Mahoney, J.J. Burgess, “The Moderating Effect of Job Satisfaction on Physicians’ Motivation to Adhere to Financially Incentivized Clinical Practice Guidelines”, Medical Care Research and Review. Vol. 74, no.02, pp. 148-177, 2017.

[6] M.R. Ahasan, T. Partanen, “Occupational health and safety in the least developed countries-a simple case of neglect”, Journal of epidemiology, vol.11, no2,pp.74-80, 2001.

[7] A. Kamal, M. Qayyum, I.U. Cheema, A. Rashid, “Biological monitoring of blood naphthalene levels as a marker of occupational exposure to PAHs among auto-mechanics and spray painters in Rawalpindi”, BMC Public Health. vol. 11, no.1. pp.467-475, 2011.

[8] N. Malik, A.A. Maan, T.S. Pasha, S. Akhtar, T. Ali, “Role of hazard control measures in occupational health and safety in the textile industry of Pakistan”, Pakistan Journal of Agricultural Sciences. vol. 47 no.1 pp. 72-76, 2010.

[9] J.W. Hearle, W.E. Morton, Physical properties of textile fibres. Elsevier, 2008.

[10] A. Di Giovanni, “Technology Today: Fire Protective Clothing: As Complex as any other PPE”, Fire Engineering. vol. 15 no.9 pp. 126-128, 2006.

[11] R.M. Rossi, W. Bolli, R. Stämpfli, “Performance of firefighters’ protective clothing after heat exposure”, International journal of occupational safety and ergonomics, vol. 14 no.1 pp. 55-60, 2008.

[12] Absorbency of Textiles. American Association of Textile Chemists and Colorists. AATCC 79-2010.

[13] Standard practice for conditioning and testing textiles, ASTM D1776, 2015.

[14] Vertical wicking of Textiles. American Association of Textile Chemists and Colorists. AATCC 197-11.
[15] Resistance of materials to penetration by liquids. ISO 6530:2005.
[16] Standard test method for flame resistance of textiles (vertical test). ASTM D6413.
[17] Standardization of home laundry test conditions, AATCC Monograph M6, 2013.
[18] D.A. Holmes, Textiles for survival. Handbook of technical textiles, 2000
[19] J. Guo, "The effects of household fabric softeners on the thermal comfort and flammability of cotton and polyester fabric" Doctoral dissertation, Virginia Tech.
[20] P.G. Tortora, B.J.Collier, Understanding textile,. 1997.
[21] Y.C Li, (2011). "Environmentally Benign Flame Retardant Nanocoatings for Fabric"Doctoral dissertation, Texas A&M University.
[22] S.C. George, S. Thomas, "Transport phenomena through polymeric systems", Progress in Polymer science. vol. 26 no.6 pp. 985-1017, 2001
[23] S. Krzeminskaa, W.M. Rzymski, "Thermodynamic Affinity of Elastomer-Solvent System and Barrier Properties of Elastomer Materials", Acta Physica Polonica, vol. 12 no.1, 2013.
[24] Environmental Health and Safety. Personal protective equipment selection guide. Stony Brook University, 2008.
[25] H. Laamanen, H. Meinander, Protective clothing in transport of liquid chemicals, 1996.
[26] F. Mohi "Experimental investigation on mechanical properties of kevlar fibre" International Research Journal of Engineering and Technology, vol. 4 no.7 pp. 3466-3473, 2017.
[27] Z. Lu, Y.Zhao, Z.Su, M.Zhang, B.Yang "The effect of phosphoric acid functionalization of para-aramid fiber on the mechanical property of para-aramid sheet". Journal of Engineered Fibers and Fabrics, vol. 10, no.3, pp. 14-22, 2018.
[28] B.A. Morris, "The science and technology of flexible packaging: multilayer films from resin and process to end use", William Andrew, 2016.
[29] G. Song, S. Mandal, R.Rossi " Development of high performance thermal protective clothing", in Thermal protective clothing for fire fighters, Woodhead publishing, 2017, pp. 27-55
[30] Niir Project Consultancy Services. Handbook on textile auxiliaries, dyes and dye intermediates technology, Delhi: Asia pacific business press, 2000
[31] M.W. King, X. Li, B.E. Doupe, J.A. Mellish, "Thermal Protective Performance of Single-Layer and Multiple-Layer Fabrics Exposed to Electrical Flashovers", InPerformance of Protective Clothing: Second Symposium. ASTM International.1988.
[32] R. Atakan, A. Bical, E., Celebi, G. Ozcan, N. Soydan, A.S. Sarac, "Development of a flame retardant chemical for finishing of cotton, polyester, and CO/PET blends", Journal of Industrial Textiles, 2018.
[33] C. Arvinte, A.V.Sandu, D.D. Burduhos-Nergis, M.B. Sava, C. Bejinariu "Technical requirements and materials used in firefighters gloves manufacturing". In Conference Series: Materials Science and Engineering, 2019
[34] R.D. Sellers, Jr. Carr, VJ, "Performance of Nomex Military Uniforms in Attacks by Flame Field Expedient Weapons-A", Applied research associates Inc Tyndall Afb Fl, 2007.
[35] C. Yang, Q.Chen "Heat Release Property and Fire Performance of the Nomex/Cotton Blend Fabric Treated with a Nonformaldehyde Organophosphorus System". Polymers, vol. 8, n0.9, pp. 327-329, 2016.
[36] P. Khalili, X. Liu, X. Zhao, B. Blinzler, "fully biodegradable composites: thermal, flammability, moisture absorption and mechanical properties of natural fibre-reinforced composites with nano-hydroxyapatite", Materials, vol. 12 no. 7, pp. 1145-1150, 2019.
[37] Q.Feng, F.L. Zhu, J.Hu "Estimation of the radiant performance of flame-retardant fabrics considering thermal degradation effect". Journal of Engineered Fibers and Fabrics, vol. 14, no.1, pp.1-10, 2019
[38] X. Zhang, X.Tang, R.Wang, X.Yan, M.Shi "The fire retardant properties and pyrolysis mechanism of polysulfonamide (PSA) fibers". Textile Research Journal, vol.88, no.11, pp.1299-1307, 2018
[39] P. Khalili, K.Y. Tshai, I.Kong, "Natural fiber reinforced expandable graphite filled composites: evaluation of the flame retardancy, thermal and mechanical performances", Composites part A: applied science and manufacturing, vol. 100,pp. 194-205, 2017.