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Research Article

Evaluation of Protective Clothing against Chemical and Fire Hazards

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Abstract: Workplace accidents are very unpredictable. Protection against these risks and hazards is of utmost importance in every profession. Clothing has always been considered one of the integral parts of personal protective equipment. The present study aims at manufacturing and evaluating protective clothing materials used by chemical workers. It was experimental. Two important resistance characteristics; chemical and fire were assessed against international performance standards. The results highlighted the fact that the right selection of construction parameters was able to make a safe fabric against such hazards. The resultant fabric was evaluated at various washing intervals and was found to be resistant to four selected chemicals through penetration and repellency index. It was also able to resist fire by passing the standard after flame and char length tests. Very little research work has been done in Pakistan regarding the manufacturing and physical assessment of clothing materials used by chemical workers. This study aimed to approach the target area where the protection and safety of the worker should be a priority.

Keywords: After Flame, Aramid, Char Length, Permeation, Repellency, Lamination, Weave, Washing

1. INTRODUCTION

Protective clothing is one of the important fields in technical textiles. It refers to any apparel that is used to protect against environmental hazards such as biological, chemical, or physical [1]. Chemical industry is one of the essential key holders to contribute to the economic growth and development of any country [2]. A wide variety of chemicals such as Sulfuric acid, Ammonia, Sodium hydroxide or Nitric acid, etc. having multiple characteristics are used in this sector for manufacturing different products. These chemicals may pose a great risk to the person dealing with them. The type of danger differs from chemical to chemical depending upon its nature. For example, some chemicals can create skin irritation, others may burn the body. So, it is always needed for the worker to wear a protective ensemble such as coveralls, gloves, and masks for safety purposes [3, 4].

Unfortunately, there is a lack of awareness among the staff and management to wear adequate protective clothing items [1]. It must be worn by personnel working with toxic substances at the workplace [5, 6]. Safety at work is a fundamental right of every employee which should not be ignored by higher authorities [7, 8]. To provide safety to the workers, it is necessary to manufacture an appropriate type of protective clothing against certain hazards. The right selection of textile materials should be made for making such clothing items, as these materials are supposed to offer great protection [9]. This type of clothing serves as a second skin for the wearer against many risks like fire, cuts, abrasives, hazardous liquids, or toxic substances [10]. There is always a margin for improvement in every sphere of business. The performance behaviour of such materials should always be assessed before use and requires innovation in the production of fibers, yarns, fabrics and finishes for better results [11].

Designing personal protective clothing should follow easy-to-care instructions for an end user to reduce the hazards related to self-contamination. This should be effective in terms of performance during the working hours of the wearer to give him/her protection against many hazards [12]. Quality

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of clothing material used for making protective coveralls also plays an important role in providing safety. It was found that poor-quality fabric worn out easily during wear and resulted in rips and holes at various areas of the coverall thus, was unable to protect the end user [13]. In another study, it was investigated that nine tested gowns out of twenty-two did not meet the international performance standards against liquid/fluid penetration. Many studies pointed out the fact that pre-marketing evaluation and post-market survey from the end user should be made for better protection [14]. A lot of research is needed to manufacture PPE which is breathable, comfortable yet functional that does not hinder the activities of workers at work place.

Chemical protective clothing must be taken as a protective measure and the last safety line for workers dealing with toxic substances and chemicals. Although protective gowns and other equipment cannot provide a hundred percent against all types of chemicals, as they vary in nature, severity, and toxicity [15]. It depends on the total amount of chemical penetration, permeation, repellency and breakthrough time. Thus, various kinds of polymers are being tried to bring the best suitable product to the ultimate consumer. There are generally four ways in which interaction can be made between a chemical and a protective ensemble. Firstly, in the process of chemical degradation where a breakdown of the substrate is made. Secondly in the form of penetration of specific chemicals where a chemical flow is being made through wicking or wetting action. Thirdly, permeation of chemicals in the form of molecular flow and fourthly in the form of vapours where a chemical reaches the garment [16,17].

There is very little research done on protective clothing used by chemical workers in Pakistan. This study aims at the manufacturing of clothing materials through a combination of natural and synthetic fibers. It also evaluates the efficiency of protection in terms of chemical and fire resistance after various washing intervals.

2. MATERIALS AND METHODS

The study was experimental in nature and completed in two sections. In the first phase, an experimental clothing material was manufactured and in the second phase, the performance behavior of manufactured fabric was assessed by following international standards.

Opening and cleaning was the first operation in the spinning process. The fibers were blown out through the ducts in a blow room where they were free from any residual dirt and dust. Then these fibers were straightened out to convert them into a sliver. The alignment of fibers was made in the combing stage. Short fibers were separated from long fibers and became parallelized. The twist was inserted into the yarn to make it strong and even. The rovings were stretched out to induce thickness to the prepared yarns. Finally, they were wound onto the bobbins.

Yarns were manufactured through ring spinning to weave a fabric. It consisted of two layers. An inner layer was made of a combination of polyester and cotton with a ratio of 60 / 40. It is the most common blend percentage used in making comfortable and breathable fabrics. This blend was chosen as cotton was a locally produced fiber and was the best choice to provide comfort to the wearer due to its inherent ability to breathe. Polyester content was used to add strength to the material. This blending ratio also helps to make the fabric wrinkle-resistant. The linear density was 17.653 in the tex system for warp and weft directions. The outer layer was composed of an Aramid fiber that has the inherent ability to resist fire. The two ingredients such as m-phenylenediamine and m-isophthalic acid were used to manufacture Meta Aramid fibers. The polymers were extruded through a spinneret at 120 °C. The obtained fibers were then washed, dried, and presented in highly crystalline form with a high modulus. The linear density was set at 15.023 in the tex system for warp and weft directions. Transol FL-20 chemical protector was applied over the surface of the prepared fabric to avoid chemical leakage through padding [18]. Liquid pick-up was 30-70 %. pH was between 4-8. The fabric was dipped in the solution and then squeezed completely. It was then dried for a few seconds at 120 °C. Curing was done for a minute at 155 °C. Plain weave structure was adopted in which each warp yarn was passed alternately above and under one weft yarn. Fabric density was 73 ends and 65 picks per inch. Fabric weight was 127 GSM. The length of the prepared fabric was 7 meters and the width was set at

19 inches in accordance with the width of the loom. It was desized and scoured to make it impurity free. Waxes and pectins were removed by using caustic soda. It was bleached to remove stains and to obtain better results.

In the second part of the study, the newly manufactured fabric was evaluated for its chemical and fire resistance properties after multiple washing intervals.

Resistance against chemicals was evaluated by following ISO 6530:2005 test method to know the rate of penetration and repellency of selected chemicals [19]. According to the standard, the fabric was tested against four chemicals i.e. Sulphuric Acid (diluted 30-aqueous), Sodium Hydroxide (diluted 30-aqueous), Xylene (concentrated), and Butanol (concentrated). In order to perform the test, (Fig 1) the test specimen was cut from the fabric with the dimensions of 360 mm / 235 mm. An absorbent sheet with the same dimensions was also cut. Both layers were weighed and turned a little bit along their length before placing them on a collector sheet. They were clipped to the gutter inclined diagonally at 45° where a beaker was put at its bottom to collect the liquid spilled from the test sheets. A dropper was filled with 10 ml of each liquid one by one and poured out at 100 mm for 8-10 seconds on the upper surface of a test sheet. Poured chemical that was not absorbed by the test sheets was dripped in a beaker. After a minute, both layers were separated and weighted. The amount of chemical solution that remained in the test solution was considered as the rate of retention. The amount of chemical retained by the collector sheet was considered as the rate of penetration and the amount of chemical collected in a beaker was the rate of repellency.

The rate of penetration was measured as the amount of chemical on an absorbent sheet divided by the amount of chemical retained by the test specimen and expressed as a percentage. The rate of repellency was evaluated as the amount of chemical in a beaker divided by the amount of chemical retained by the test specimen and expressed as a percentage.

Resistance against flame was determined by following ASTM D 6413-99 known as the Vertical Flame Test [20]. In order to perform this test, five test specimens were cut with dimensions of 3 x 12 inches. Care was taken to avoid any selvedge, creased or wrinkled areas. The samples were conditioned by following instructions stated in ASTM-D1776 [21]. The test specimen was fitted to a holder to maintain its position and exposed to the fire area. The distance between the burner and the specimen was kept at 19 mm. A stopwatch was set to note the time. The specimen was exposed for 10-12 seconds to the burner. The behavior was noted in terms of melting or dripping. The specimen was removed from the fire area. An after-flame time was

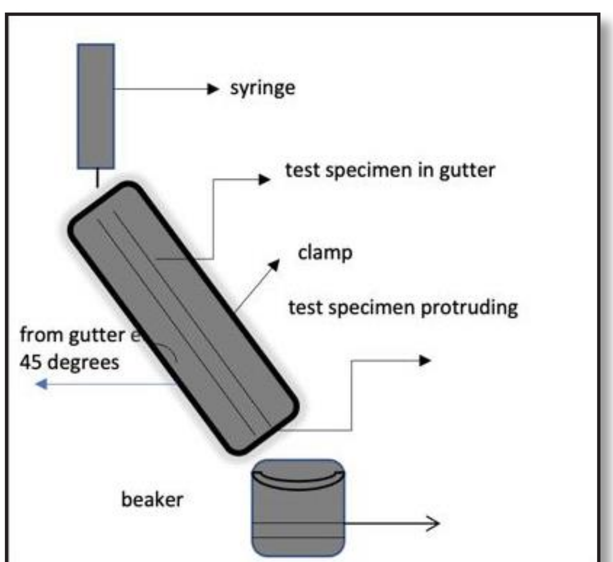

Fig 1. Determination of chemical resistance

recorded and char length was measured.

Washing of specimens was conducted by following Monograph M6 [22]. Front-load automatic machine was used with an agitation speed of 45 rpm. The temperature was maintained at 50-60 °C for 12 minutes. 0.1g/liter AATCC washing detergent was added to the washing cycle. Two rinsing cycles were given, and a final drying was made in tumble form at 65 °C for one and a half hours. The specimens were given a total of 9 washing cycles and evaluated after every 3 cycles.

3. RESULTS AND DISCUSSION

The collected data was recorded and analyzed through SPSS version 25. Mean values along with standard deviation were calculated. ANOVA was applied to analyze the variance at various washing intervals for chemical and fire resistance characteristics of the experimental fabric. P-value ≤ 0.05 was taken as significant.

Table 1 explains the chemical behaviour of fabric in terms of repellency and penetration index. It was observed that all tested chemicals penetrated between 0.00 % to 0.003 % through the test specimens at different washing intervals. Whereas the rate of repellency was more than 95% in each tested chemical at each interval of washing. Repellency rate of 95 % or more and a penetration rate of less than 5 % were considered acceptable criteria as per the guidelines of a test procedure.

Risks associated with chemicals are acute to chronic, depending on the toxicity and duration of exposure. To evaluate their resistance clothing materials must be assessed with the rate of penetration, permeation and repellency [6].

Table 2 describes the difference among each chemical after various washing intervals. The p-value stated as 0.003, 0.001, 0.001 and 0.000 respectively for each liquid chemical. It shows that there is no statistical difference among all tested chemicals after each washing interval against the criterion. The fabric remained stable up to 9 washes. One of the possible reasons is the right selection of polymer to resist chemical penetration through the fabric surface. George and Thomas [23] investigated in their study how kind of polymer can impact the permeation properties of an end product. Selection and ratio of blending fibers greatly affect the molecules to behave against certain hazardous substances and solutions [18]. Aramid fiber showed greater resistance against liquid chemicals. Meta and para-aramid are good options to respond against thermal hazards due to their strong structure. They can be used as the upper layer in protective clothing materials for various industries [24, 25]. Another reason is the application of an effective chemical finish that helped to retain up to 9 washes. Lamination and coating add good protection against chemicals, liquids, and fluids [26]. Good quality lamination or coating adheres to the surface of the material in a uniform way to avoid any leakage, on the other side poor finishing treatments crack away easily to permeate liquids through the surface [27]. Light weight clothing is a better option as compared to thick and heavy fabric. The physical burden adds to the weight of the fabric. It also decreases the effectiveness of clothing items and the performance of a worker [28].

An experimental fabric comprised of an inner and outer layer with the addition of lamination to provide better protection and safety to the worker against toxic liquids/chemicals. This fact is also highlighted by many researchers that multilayered

Table 1. Chemical penetration and repellency

Washing Interval	Sulphuric Acid		Sodium Hydroxide		Xylene		Butanol	
	P(%)	R(%)	P(%)	R(%)	P(%)	R(%)	P(%)	R(%)
0	0.02	96.35	0.02	97.28	0.00	98.25	0.00	97.63
3	0.02	96.12	0.02	97.11	0.00	98.11	0.00	97.01
6	0.03	95.33	0.02	96.98	0.01	97.15	0.01	96.51
9	0.03	95.01	0.03	96.15	0.01	97.12	0.01	95.89

Table 2. Tests of within-subjects contrasts for various chemicals

Source	Sulphuric Acid	Sodium Hydroxide	Xylene	Butanol
Washes	Linear	Linear	Linear	Linear
Mean Square	0.138	0.121	0.151	0.231
Frequency	17.897	45.754	74.321	22.781
p-value	0.003	0.001	0.001	0.000

materials are a better option for protective clothing as thick fabrics resist chemical permeation through its surface for a longer time as compared to single-layered or thin clothing materials [29-31]. Now-a-days multilayered materials are used for making protective clothing items. The textile layers with different functions/benefits are used against various types of hazards such as environmental, physical, thermal, or ballistic, etc. The added layers are also used to release the heat stress for physio thermal comfort [17].

Openness and closeness of the weave structure are also important factors to consider against the permeation behaviour of materials [32]. An increased number of open areas in the fabric structure presents a high rate of penetration and low rate of repellency. An inadequate manufacturing process can open the pores with each washing cycle and let the liquid pass through more readily [33]. Insertion of high twist in a material has a twofold function, inducing strength and making a compact structure. So, another important aspect to consider while making protective clothing [34]. The time of exposure to a chemical with a particular fabric structure and the nature of the chemical itself can either increase or decrease the associated risks [35].

Table 3 explains the rate of fire resistance in terms of after flame measured in seconds and char length measured in inches. According to the test method, the time for after flame should not exceed 2 seconds. One possible reason is the compact structure that supports less exposure to oxygen [36]. Aramid fiber has an inherent ability to resist fire as the polymer plays an important role in determining performance behaviour [37].

Some fibers such as nylon drip and melts upon exposure to flame and can cause severe dangers. It is a synthetic fiber made of petroleum as a major ingredient. It rapidly burns and shrinks away from fire. It produces black smoke and hazardous fumes around the environment. Aramid becomes swollen when interacting with fire and becomes thicker in its mass, thus providing resistance against fire hazards [1]. Char length should not exceed 4 inches; the obtained results fall within the acceptable range.

Chemical protective clothing should provide complete protection against flame, as it needs to provide at least a few precious seconds of escape to the wearer. Repeated washing must not affect the fire resistance characteristics of tested fabrics [38]. P-value 0.002 was recorded for after flame and 0.001 for char length which clearly explains that there is statistically an insignificant difference between experimental fabric and the standard criterion (Table 4).

Aramid fiber helps in minimizing the burning process and even laundering did not affect much

Table 3. Fire resistance of tested fabrics

	After flame (sec)		Char length (inches)	
Washing cycle	Mean	S.D	Mean	S.D
0	0.12	0.02	0.56	0.01
3	0.13	0.01	0.66	0.02
6	0.23	0.02	0.79	0.02
9	0.35	0.03	0.85	0.04

Table 4. Tests of within-subject contrasts for fire resistance

Source	After flame	Char length
Washes	Linear	Linear
Mean Square	0.024	0.213
Frequency	5.765	9.546
p-value	0.002	0.001

of their durability [37]. Multilayered fabric poses better protection against many mechanical and thermal hazards by proving self-extinguishing properties [25]. Lamination and coating on the surface of yarns and fabrics are better able to provide protection and safety to the wearer in response to many physical and chemical hazards. The fact was also supported by another research that the best coating of fibers plays an important role in presenting 100 % accuracy against fire hazards [39, 40].

In this world of technological advancements, aramid fibers (meta and para) are used in technical textiles for providing thermal protective clothing materials along with stable mechanical properties [41]. It is necessary to produce an outer layer of protective clothing with aramid fiber to protect against flames that may encounter the worker at the workplace. The aramid fiber is an inherently fireproof material that helps to protect the inner layer of fabric and save the skin of the wearer [42]. The structural behavior of fabrics has a strong impact on mechanical characteristics such as fabric mass, thickness, flexibility, elasticity, linear density, porosity, penetration, and permeation through them. Protective clothing materials are usually multilayered. Woven structures are followed by usual interlacing patterns such as plain, twill, satin, or sateen weaves along with a combination of non-woven layers. lamination and coating should be applied to give maximum protection against thermal, physical, biological, or chemical hazards [43, 44]. The composition of different blends makes the breathable and protective against thermal effects.

It can be said that additional layers give better protection against fire, chemicals, and certain other hazards. Weaving as a fabric construction technique not only provides a clothing material with protection against risks but also gives comfort to the wearer [45].

4. CONCLUSION

Workplace safety and protection are directly associated with the health and well-being of an employee. So, it should not be ignored. It is concluded from the current study that an appropriate type of clothing material can be able to protect against chemical and fire hazards. The results depicted that an experimental fabric made with multiple layers of cotton, polyester, Aramid, and lamination can assist in passing the required international standards against such risks. The construction parameters used for manufacturing the material were able to serve as a safety measure. The statistical analysis clearly explains that manufactured fabric passed the internationally accepted criterion against all tested four liquid chemicals. Moreover, the char length and after flame depicted that the experimental fabric can able to provide adequate safety against fire hazards. This research can assist textile manufacturers and technologists to alter their key indicators for manufacturing chemical protective clothing materials. Follow-up studies can focus on the evaluation of mechanical and resistance characteristics of clothing materials used for making chemical protective clothing. Moreover, future studies can be made to evaluate the performance behavior of protective items such as headgear, footwear, masks, or gloves.

5. CONFLICT OF INTEREST

There is no conflict of interest.

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