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Investigation of thermal and mechanical protection performance of polymer-coated aramid blends

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Effective thermal protection is essential for worker safety in industrial settings with high heat. Designing comfortable, affordable, and efficient protective wear is a significant challenge for the textile industry, underscoring the need for cost-effective heat-resistant fabric. Fire-retardant (FR) cotton, viscose, para-aramid (P-aramid), meta-aramid (M-aramid), modacrylic, and fibreglass are the most commonly used fabrics for thermal protection in industries. Polyamide fibres (P-aramid and M-aramid) are blended with other fibres to develop cost-effective, high-performance protective clothing. Polymer-coated fabrics (PCF) are widely used in industry to protect against thermal hazards. In this research, seven fabrics (five woven and two knitted) coated with polymer (neoprene) are selected to investigate their thermal and mechanical protective performance as per EN ISO 11612:2015. Fabrics containing a high percentage of aramid fibres in their blend performed exceptionally well in thermal protection and exhibited high tensile and tear resistance. The performance of FR cotton fabric was moderate in thermal protection but exhibited low tear and tensile strength. Knitted fabrics exhibited low tensile strength and exceptionally high elongation during the tensile strength test.

Keywords: Aramid fibres, Neoprene coating, Polymer-coated fabrics, Protective clothing

1 Introduction

Industrial workers perform their duties in the presence of various hazards (Thermal, mechanical, physical, biological, chemical, and radiation). Thermal exposure, often from hot liquids, steam, and/or hot solids transmitted through conduction, convection, and/or radiation, is a primary thermal hazard for industrial workers. Various environmental and physical factors influence the properties of thermal hazards. These factors can be grouped into three categories based on their ecological impacts: general, dangerous, and emergency[1,2]. To mitigate these hazards, Flame-retardant (FR) treatment plays a crucial role in thermal protective textiles, particularly in fire-safe applications.

Researchers are continually working to develop more effective protective clothing and improve the performance of existing fabrics. Coating is one way to improve the fabric's thermal protective performance. Coated fabrics exhibit improved strength, durability, fire-retardant properties, etc. Cotton fabrics coated with Silica nanoparticles exhibit excellent flame retardancy and zero burning rate compared to untreated ones[3]. Pure cotton coated with silica and zinc oxide-based coating exhibits enhanced flame retardancy and high comfort properties[4]. The thermal performance of neoprene-coated 100% Para-aramid composite fabric is better than its blends[5]. The graphene coating on cotton fabric enhances its thermal protective performance[6]. Flame retardancy and water repellence properties of pure cotton fabric are enhanced by TiO_2–boron–based coating[7]. The boron–nitrogen polymer coating on the pure cotton fabric enhances its flame retardancy by improving char formation[8]. The Coating of Titanium silicide on blended fabrics, Proton (Para-amide 58%, PBI 40%, antistatic 2%), and Nathan (Nomex 75%, Kevlar 23%, P140 2% (carbon fibre) results in a slight reduction in heat radiation in comparison to coated fabric[9]. The results of Thermoplastic polyurethane (TPU) and polyvinyl chloride (PVC) coating on Polyester fabric show higher abrasion and tear resistance in TPU-coated fabrics, while PVC-coated fabrics exhibit higher flexural rigidity[10]. The investigation of the thermal protective performance of neoprene-coated woven 100% P-aramid, FR cotton, and knitted savesplash® (Viscose 65%, P-aramid 25%,

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PVC 10%) fabric indicated that the thermal resistance of savesplash® is better than that of 100% P-aramid. In contrast, in low-pressure steam protection, 100% P-aramid outperforms savesplash®[11]. The mechanical strength and thermal resistance of yarn and thus the fabrics increase with an increase in aramid content (especially p-aramid) in the textile blend, and subsequently decrease with an increase in FR viscose content[12]. The investigation of the flame-retardant properties of inherent flame-retardant P-aramid fabric coated with barrier chemicals demonstrated the excellent flame-retardant properties of neoprene coating[12].

The Previous literature highlights that fire-retardant (FR) cotton is primarily used in producing thermal protective fabrics because of its durability, comfort, and affordability[13]. There is considerable scope for investigating the thermal and mechanical protective performance of woven and knitted fabrics coated with polymer coatings. Current research explores the thermal protective performance of polymer-coated FR cotton and aramid fibre blends under different heat exposures.

2 Materials and Methods

2.1 Materials

The fabrics for the current study were selected based on their utilisation in fire-hazard environments. Woven aramid blends are widely used as the outer layer of firefighters' clothing. FR cotton is widely used for thermal protective wear due to its low cost. Knitted fabric is ideally suited as inner thermal liners. In the current study, seven fabrics were chosen: six are blends of aramid with other fibres, and one is FR cotton. The woven and knitted versions of high-shrink fabrics were developed to evaluate their performance against commonly used blended fabrics in thermal protective clothing. The composition, physical characteristics, and pictorial representation of the selected and developed fabrics are presented in Tables 1 and 2 and Fig. 1, respectively.

2.2 Development of Coating for Fabric

Depending on the intended application, a unique coating formulation was designed. The unique formulation was designed around the base polymer, which was Neoprene in this case. Rubber-coated fabrics are widely used in the manufacture of pneumatic structures, hoses, inflatable architectural membrane structures, protective textiles, and other applications. Their popularity stems from their high extensibility, low permeability, and resistance to oil and weather conditions[14]. Neoprene rubber (Grade Baypren 210 or Equivalent) is used for this study, as this polymer has some inherent characteristics against flame retardancy and temperature resistance[15]. Neoprene was chosen over alternatives such as silicone or polyurethane because of its cost-effectiveness, durability, and inherent fire resistance, making it a practical choice for protective textile

Table 1 — Selected fabrics and their composition

Fabric code	Fabric name	Type of weave	Composition
W1	FR cotton	Plain	100 % Cotton
W2	M-aramid (93/5/2)	Twill	93% M-aramid, 5% P-aramid and 2% antistatic
W3	Modacrylic/M-aramid/P-aramid/Antistatic	Twill	66% modacrylic, 22% M-aramid, 10% P-aramid and 2% Antistatic
W4	P-aramid, green modacrylic with 50 microns SS wire	Twill	67% P-aramid, 15% modacrylic and 18% SS wire
W5	FR high shrink (woven)	Twill	65% viscose, 25% P-aramid and 10% PVC fibre
K1	FR high shrink*	Knitted	65% viscose, 25% P-aramid and 10% PVC fibre
K2	Non-FR high shrink*	Knitted	65% viscose, 25% P-aramid and 10% PVC fibre

Table 2 — Physical characteristics of fabrics used in this study

Fabric code	Thickness, mm	Areal density, g/m^2	Weft count, Thread/cm	Warp count, Thread/cm	Thickness, Coated fabric, mm	Arealdensity, Coated fabric, g/m^2
W1	0.58	253	40	25	0.63	403
W2	0.58	276	25	18	0.93	426
W3	0.53	220	34	18	0.63	370
W4	1.08	262	25	15	1.23	412
W5	0.6	190.5	25	25	0.73	341
K1	0.87	273	-	-	0.92	423
K2	0.97	260	-	-	1.01	410

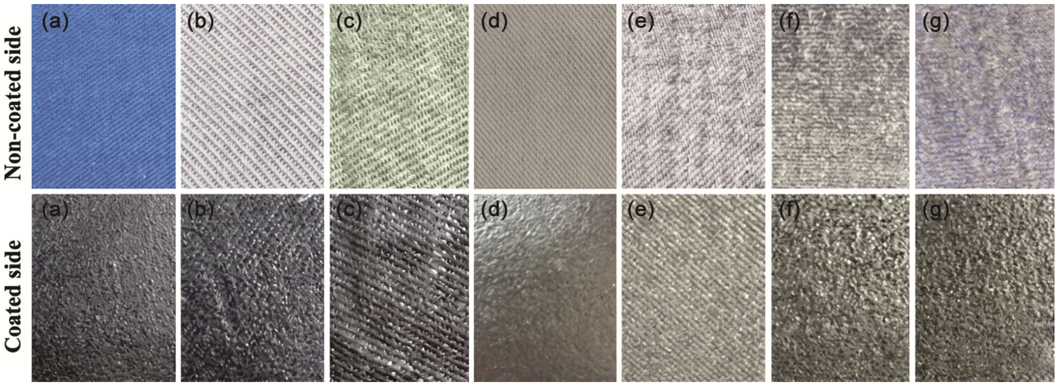

Fig. 1 — Neoprene-coated fabrics, (a) FR cotton, (b) M-aramid (93/5/2), (c) Modacrylic/M-aramid/P-aramid/Antistatic, (d) P-aramid, green modacrylic with 50 microns SS wire, (e) FR high shrink (woven), (f) FR high shrink (knitted), and (g) non-FR high shrink (knitted)

Table 3 — Formulation of neoprene used in this study

S. No	Ingredients	Parts per hundred
1	Neoprene Rubber (Baypren210)	100
2	Stearic Acid	1
3	Zinc Oxide	4.8
4	Magnesium Oxide	2.1
5	Calcium Carbonate	29.7
6	Brown Factice	2.9
7	Antioxidant 4020	1.9
8	DOP	4.1
9	ETU	0.5
10	TMT	0.5
11	Carbon N 220	5.5

applications. Additionally, Neoprene coating enhances the fabric’s resistance to conductive, convective, and radiant heat through its insulating foam structure. Because of chlorine atoms in the polymeric chain, neoprene resists flame propagation through the vapour-phase radical mechanism by interrupting exothermic reactions by suppressing combustion[16]. The neoprene formulation used to coat the selected fabrics in this study is listed in Table 3.

There are multiple grades available for the polymer, so selecting the specific grade becomes very important, as it will have the dominant impact on the final properties of the coating. Various chemicals are then infused with the base polymer, which includes specific chemicals to impart the properties required for the specified application. The compound is then dissolved in a solvent to make a paste of the intended viscosity, which again depends on the dry polymer add-on required on the fabric. At present, various coating processes are used, including Spread Coating, Calendar Coating, Dip Coating, Melt Coating, Foam Coating and Lamination[10].In this study, the spread coating method, also known as Knife-over-roll coating, is used. It is a blade-coating technique in which a knife blade is suspended over the roller, and a liquid or paste coating material is applied to a moving substrate, then spread into a uniform layer by the sharp blade. The coating thickness is controlled by the gap between the substrate and the knife, and the viscosity of the compound paste controls the weight[17]. The coated fabrics serve as protective barriers for many standard applications because the neoprene coating is resistant to chemicals, water, heat, flames, oxygen, and ozone. Further, the compound is formulated to provide excellent abrasion resistance and good flex-cracking properties. Fig. 2 shows the schematic diagram of blade over roll coating process used in current study.

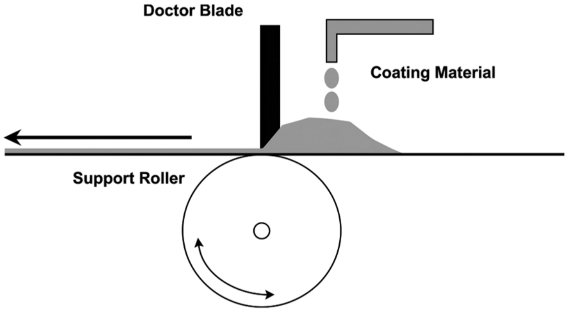

Fig. 2 — Schematic diagram of blade over-roll coating

2.3 Methods

Initially, the fundamental parameters of the selected and developed fabrics, such as thickness, weight, and fibre counts in the weft and warp directions, were measured. Subsequently, all the fabrics were coated with a polymer (neoprene) using the knife-over-roll coating process. The thickness and weight of the polymer-coated fabrics were measured and summarised in Table 2. Then, the fabrics were

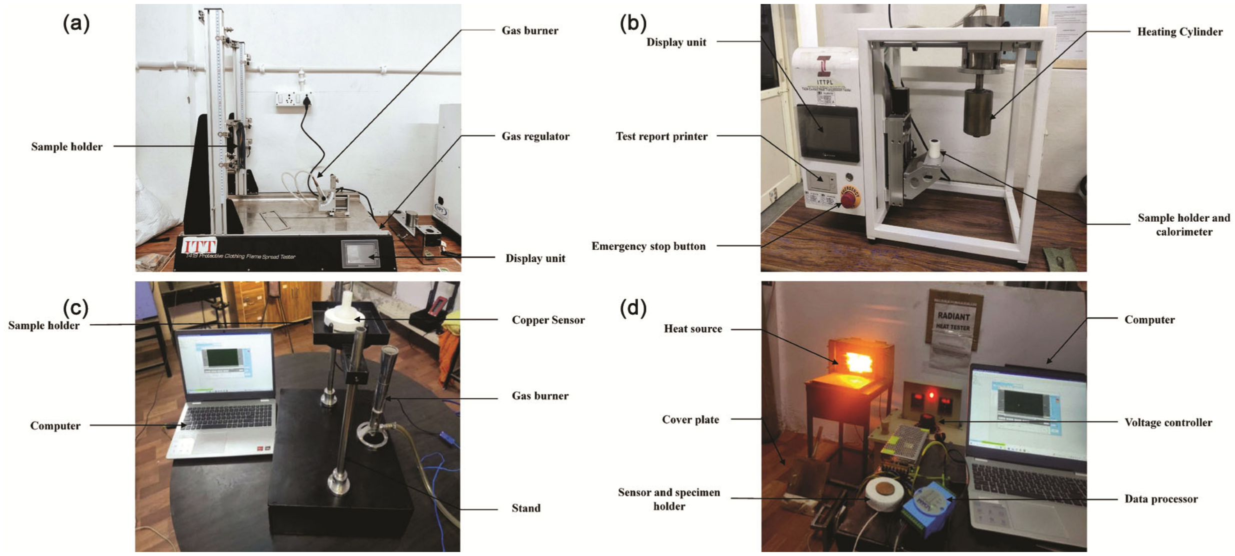

Fig. 3 — Thermal performance test devices, (a) T419 Protective clothing flame spread tester, (b) T424 Contact heat transmission testing machine, (c) ITT/CVHTT convective heat tester, and (d) ITT/RHTT Radiant heat tester

exposed to different thermal hazards, such as conductive, convective, and radiant heat exposures, before and after coating, to assess their thermal protective performance using the test equipment shown in Fig. 3. Flame-retardant properties of polymer-coated fabrics were also tested, as the flame spread test is essential for fabrics employed in thermal protective garments to determine their burning tendency after removal of the source of heat from them. Thermal protective performance tests were conducted in accordance with EN ISO 11612:2015[18]. The flame spread test was performed using the protective clothing flame spread tester (T419) illustrated in Fig. 3(a). During the test, ignition was initiated at the bottom edge of the fabric, and key parameters such as after-flame duration, afterglow time, and char length were recorded[19].

The contact heat transfer test of fabrics was conducted to determine the extent of heat transfer through the fabric when it comes in contact with a heated solid object. The contact heat transmission test was performed using a contact heat transmission testing machine (T424), as shown in Fig. 3(b), in accordance with ISO 12127-1:2015[20]. In this test, the specimen was placed on a sample holder (copper calorimeter), and a heated cylinder at 250°C was brought in contact with it. The time required to raise the specimen's temperature by 10 °C (threshold time) was calculated to evaluate the specimen's performance [21].

The performance of the fabrics against convective heat was tested according to ISO 9151:2016[22] using the convective heat tester (ITT/CVHTT)shown in Fig. 3(c). In this test, the samples were exposed to a direct flame, and their performance was assessed by measuring the heat transfer index (HTI). HTI[23] is used to rank clothing's ability to delay heat transfer from a flame and is defined as the mean time required for a sample to undergo a temperature rise of 24±0.2°C in a copper calorimeter. During the test, the specimen was placed horizontally on the specimen holder, and a heat flux of 80±2 kW/m^2 was provided by adjusting the gas flow. The heat flux was generated by placing a burner below the test specimen, and the copper calorimeter at the top of the specimen measures the HTI[11].

A radiant heat test evaluates the temperature variation with time for the fabric exposed to a radiant heat source. Resistance to thermal radiation was tested per ISO 6492:2022 using a radiant heat tester (ITT/RHTT) shown in Fig. 3(d). In this test, the specimen was placed on the face of a copper calorimeter and exposed to a thermal radiation density of 20 kW/m^2. The time taken for a temperature rise of 24±0.2°C in the calorimeter behind the sample was recorded and expressed as relative heat transfer index RHTl_{24}. RHTl_{24} is the primary protective parameter. In addition, the transmission factor (TF) was calculated as the ratio of the heat flux density passing through the fabric to the incident heat flux density on the fabric.[23,24] The transmitted heat flux density value was calculated using Equation (1).

$$\mathrm{Qc} = \frac{\mathrm{M.Cp.12}}{\mathrm{A.(t_{24}-t_{12})}} \qquad \ldots(1)$$

where M is the mass of the copper plate (0.036 kg); Cp, specific heat of copper (0.385 kJ/kg °C); A, area of the copper plate (0.0025 m^2); t_{12} and t_{24}, time required for a temperature rise of 12°C and 24°C, respectively.

TF was calculated according to equation (2).

$$\mathrm{TFQ_0} = \frac{\mathrm{Q_C}}{\mathrm{Q_0}} \qquad \ldots(2)$$

where, Q_c is the heat flux density leaked through the sample to the calorimeter (kW/m^2); Q_0, flux density of the radiant heat source (kW/m^2)

A high TFQ_0 value indicates lower thermal insulation, while a low TFQ0 value indicates better thermal insulation performance of the fabrics.

Tensile and tear strength tests are essential for industrial fabrics because they help determine their durability and quality. The tensile and tear strengths of polymer-coated fabrics were tested according to ISO 13934-1:2013 and ISO 13937-2:2000, respectively, using a universal testing machine (T364).

3 Results and Discussion

3.1 Thermal Analysis

3.1.1 Flammability Test

The flame spread resistance test results are shown in Table 4. The after-flame and afterglow durations were recorded with a stopwatch, while char length was determined by visual inspection and measured with a steel ruler. Fabric samples were examined under an optical microscope before and after the flame spread test to assess the extent of damage caused by flame exposure. These microscopic images reveal changes in the fabric structure due to burning (Fig. 4).

Table 4 — Results of flammability test on polymer (neoprene) coated fabrics

Fabric code	After flame, s	Afterglow, s	Char length, cm
W1	2	0	7.0
W2	0	0	4.0
W3	0	0	9.5
W4	0	0	4.5
W5	0	0	6.0
K1	0	0	7.0
K2	0	0	9.0

The fabrics were blended to achieve desirable

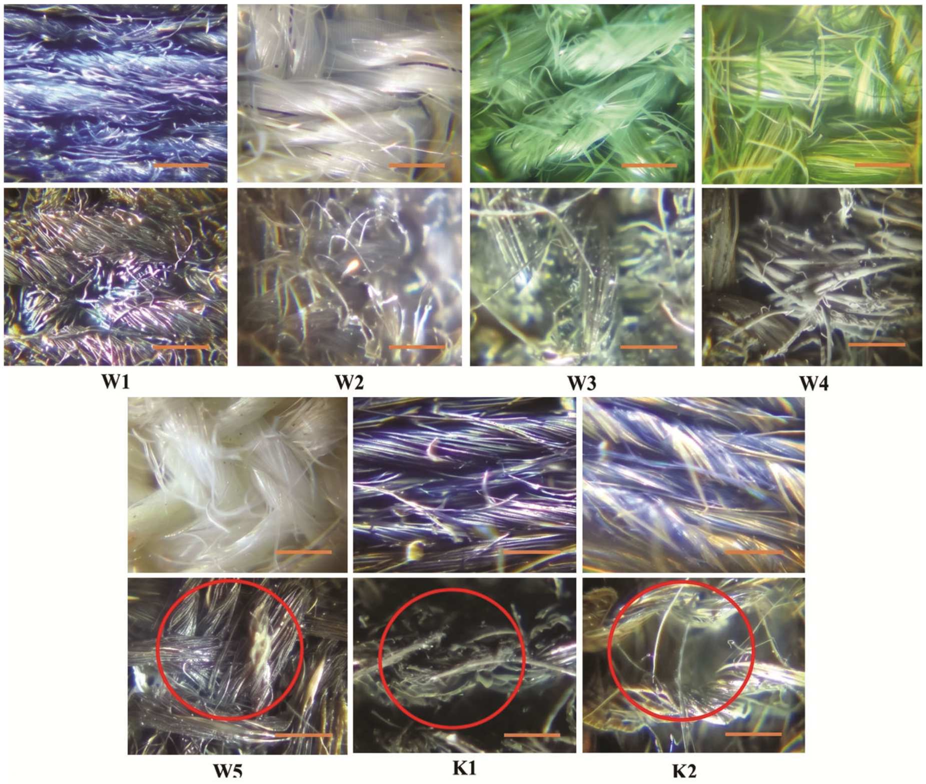

Fig. 4 —Microscopic images of coated fabrics before and after exposure to direct flame (For fabric codes W1–W5 and K1, K2, respectively. (Scale bar (in orange) =200µm)

properties cost-effectively, without compromising their protective performance. The flame-retardancy of blended fibres can be improved by understanding the mutual interactions between the constituent fibres under a heat source. All fabrics with aramid fibre in their blend exhibited excellent fire-retardant properties with no after-flame or afterglow due to their self-extinguishing properties and high limiting oxygen index (LOI)[25]. Aramid fibres are resistant to heat and flame due to their bonds and molecular structure, and they retain these features at high temperatures[26,27].In contrast, FR cotton (FabricW1) exhibited an after-flame time of 2 sec, indicating inferior fire resistance compared to aramid-rich fabrics due to the cellulosic fibre's lack of inherent flame retardancy and its low LOI[27]. Among the developed high-shrink fabrics, fabric K1 demonstrated shorter char length than fabrics K2 and W5. This indicates that the knitted FR high-shrink fabric outperforms the knitted non-FR high-shrink and woven high-shrink fabric of the same composition in the vertical flammability test. This enhanced performance of FR knitted fabric is due to its flame-retardant property and higher thermal resistance than that of woven fabrics of the same composition[24]. As observed in the microscopic images of fabrics (Fig.4), the high-shrink woven and knitted fabrics (fabrics W5, K1, and K2) exhibited greater damage (indicated by a red circle) than FR cotton and aramid blends after exposure to the flame.

3.1.2 Resistance to Contact Heat Transmission

The contact heat test results for fabrics before and after neoprene coating are presented in Fig. 5(a). The threshold times for resistance to contact heat before coating ranged between 4.1 and 5.7 sec, highlighting a moderate level of heat resistance across all fabrics. Fabrics containing a high percentage of inherent flame-retardant fibres (M-aramid, P-aramid, and Modacrylic) exhibited superior contact heat resistance in comparison to FR cotton and viscose fibre blends, due to the highly oriented rigid molecular structure of aramid and the halogenated long-chain structure of modacrylic fibre[28]. The fabric K2 exhibited the lowest threshold time (4.1 s), indicating lower initial heat resistance than other fabrics due to its knitted structure, low areal density, and absence of FR treatment, as insulation from conductive heat primarily depends on insulative properties and thickness.[1]Neoprene significantly increases the contact heat resistance of fabrics by enhancing thermal insulation and providing a protective barrier. After coating, the threshold times improved notably for most fabrics, as the added neoprene increases thickness and areal density. The most significant improvement in the threshold time was observed in fabric W2, and the FR cotton (fabric W1) showed the least increase in the threshold time, due to the low thermal resistance of natural fibres compared to blends of aramid fibres. Consistent with flammability test outcomes, fabrics with a higher proportion of aramid fibres demonstrate a greater improvement in contact heat threshold time than blends with lower aramid content. Furthermore, the knitted high-shrink fabrics K1 and K2 exhibited superior contact heat resistance after coating compared to the woven high-shrink fabric W5, due to their higher thickness and areal density.

3.1.3 Resistance to Convective Heat Transmission

The result of the convective heat test of uncoated and polymer-coated fabrics is shown in Fig. 5(b). For uncoated fabrics, the observed HTI24 value is highest for fabric W4 and lowest for fabric W3, due to its

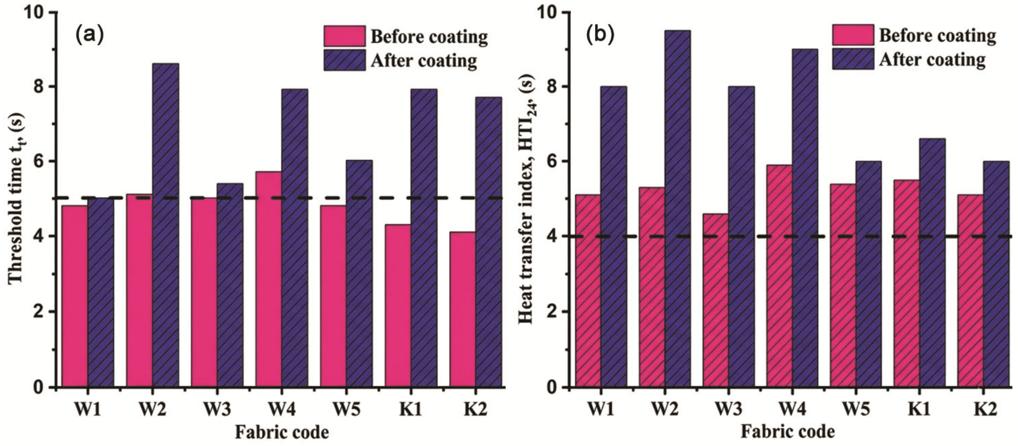

Fig. 5 — Variation in performance of uncoated and polymer-coated fabrics in (a) Contact heat test, and (b) Convective heat test

high thickness and areal density, as well as the high percentage of P-aramid fibre in its blend, as aramid fibres (M-aramid and P-aramid) are highly resistant to heat[29]. Polymer coating on fabrics has shown considerable improvement in convective heat resistance. Among the polymer-coated fabrics, fabric W2 provides the highest protection due to the combined effect of the neoprene coating and the high percentage of M-aramid fibre in its blend; however, it exhibits considerable shrinkage after convective heat exposure. Results of the convective test on polymer-coated fabrics also demonstrated the high performance of aramid-based fibres compared to FR cotton or viscose-based fibres, due to the presence of amide linkages with aromatic rings, which confer higher fire resistance. The aramid fibres are blended with viscose fibres to make the fabric comfortable and improve physiological performance[30]. Among the developed polymer-coated high-shrink fabrics, knitted fabrics K1 and K2 performed better compared to the similar composition of woven fabric W5, due to their higher thickness and weight. Visible damage was observed in the developed high-shrink woven fabric W5 after exposure to a convective heat source, due to its lowest areal density and low thermal resistance, resulting from its FR viscose fibre content.

3.1.4 Resistance to Radiant Heat Transmission

The results of the radiant heat test for both non-coated and polymer-coated fabrics are presented in Fig. 6(a). From the standpoint of radiant heat resistance, a fabric is considered more effective if it takes longer to raise the calorimeter's temperature to (24 ± 0.2) °C. Among the woven fabrics, the highest RHTI_{24} was observed for fabric W2, due to the high thermal resistance of the M-aramid fibres. The RHTI_{24} of FR cotton fabric exhibited slightly better protection against radiant heat than high P-aramid (W4) and Modacrylic blends after coating. The woven high shrink fabric W5 exhibited the lowest protection Fig. 6(a) against radiant heat exposure compared to the similar composition of Knitted fabrics K1 and K2, due to its lower porosity, thickness and are al density. As in the convective heat test, the fabric W2 also showed high shrinkage during thermal exposure in the radiant heat test. This high shrinkage in the fabric is due to the high M-aramid content (93 %), as M-aramid fibres tend to shrink on thermal exposure. The time taken to increase the calorimeter temperature to 12°C and 24°C is presented in Fig. 6(b). The fabrics with a high aramid fibre content exhibited high initial resistance and maintained good performance after coating. Fabrics with viscose content showed varying responses, depending on whether they are woven or knitted. The comparative result of the fabric performance with the value of the transmission factor TF is illustrated in Fig. 6(b). It can be observed that the TF is the lowest for fabric W2 and the highest for fabric K1. This indicates that among the selected fabrics, fabric W2 exhibited the best insulation, while fabric K1 showed the least insulation in the radiant heat test. The low insulation performance of the fabric K1 is due to its knitted structure and high percentage of viscose fibre in its blend. The TF of the W1 and W4 is 64% as W4 contains considerable content of SS wire in its blend.

3.2 Mechanical Performance Analysis

Work wear fabrics must protect against workplace hazards. However, without durability, their protective effectiveness diminishes. Aramid fibres offer outstanding thermal and flame protection, as well as high mechanical strength. Among them, P-aramid fibres provide exceptional mechanical strength and

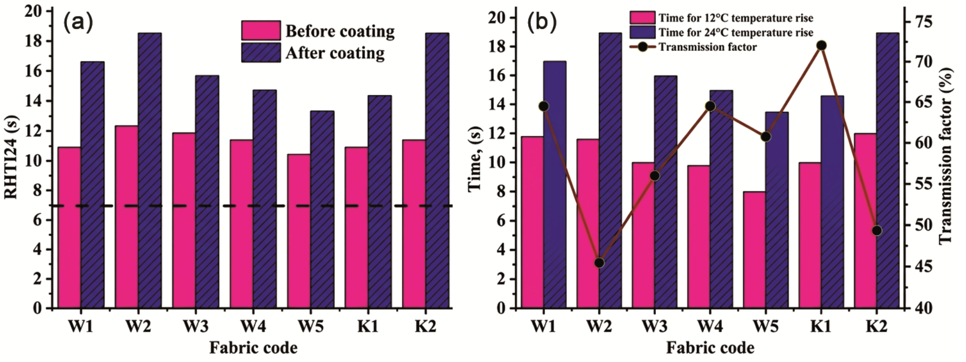

Fig. 6 — The radiant heat test result of (a) uncoated and polymer-coated fabrics, and (b) the calorimeter temperature rise by 12°C and 24°C with a heat flux density of 20 kW/m^2 and transmission factor (TF) of the fabrics

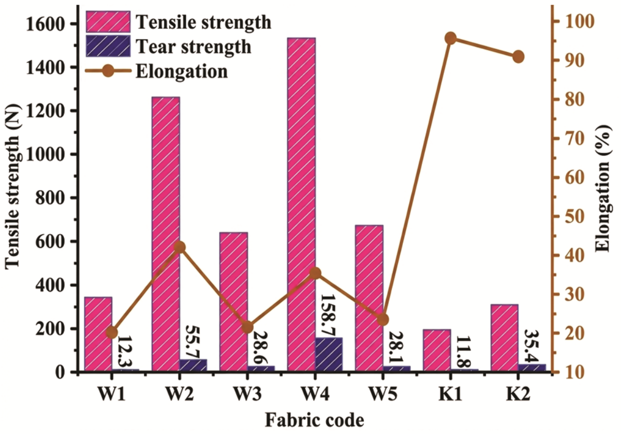

Fig.7 — Results of tensile strength, tear strength and % elongation of coated fabrics before break

low thermal shrinkage, whereas M-aramid fibres excel in flame and thermal resistance but exhibit high thermal shrinkage[31].The measured value of mechanical strength and elongation of fabrics is illustrated in Fig. 7. The highest tensile strength was observed with Fabric W4 due to the presence of a high content of P-aramid fibres in its blend and stainless-steel wire, as the strength of P-aramid fibres is inherently high. The breaking strength of M-aramid is also considerably higher than that of FR cotton and modacrylic blends due to the significantly higher tenacity of M-aramid fibre. Among the woven structures, the lowest tensile strength was observed with fabric W5 due to a high percentage of viscose fibre in its blends, as the strength of viscose fibres is considerably low[32]. The knitted fabrics (K1 and K2) exhibited the lowest tensile strength and substantially higher elongation, as the knitted structures are highly flexible but weaker. Despite its high tensile strength, the elongation of M-aramid (93/5/2) fabric W2 was relatively high (42.2 %) among all the woven fabrics due to its high % of M-aramid fibre in its blend[33]. The FR cotton fabric had the lowest elongation (20.3%), which indicated the low stretch ability of the Cotton fabric[34,35]. Fabrics containing antistatic fibres W2 and W4 had decent tensile strength (above 600 N), suggesting that including antistatic fibres does not significantly weaken the fabric.

The tearing behaviour of materials is an essential aspect of their mechanical performance. This is especially crucial for protective materials, where tear resistance is a key requirement. For instance, protective gloves and firefighter suits must be designed to withstand tearing to ensure safety and durability[36]. The result of the tear strength of fabrics is indicated in Fig. 7. The highest tear strength was observed in fabric W4, indicating excellent resistance from P-aramid and stainless-steel wire. The tear strength of fabrics with a high percentage of modacrylic (W3) and FR viscose (W5) is considerably lower than that of fabrics containing a high percentage of aramid fibres in their blends. The FR cotton (W1) exhibited the lowest tear strength among the woven fabrics, confirming that natural fibres are weaker than aramid and synthetic fibre blends. The lowest tear strength was observed for the developed FR high-shrink fabric K1, suggesting that the knitted structure is weaker in resisting tears than woven fabrics. Fabrics containing antistatic fibres (e.g., Fabrics W2 and W3) maintained a moderate tear strength (above 28 N), suggesting that antistatic fibres do not significantly weaken tear resistance.

4 Conclusion

The Performance of heat-protective textiles is significant for the safety of people working in hazardous environments. For this reason, this study aimed to investigate the thermal protective performance of various fabrics coated with polymer (neoprene) under different thermal exposures as per EN ISO 11612:2015. The fabrics containing a high percentage of aramid fibres in their blend exhibited higher thermal insulation properties and high tensile and tear strength. The presence of 50-micron SS wire in the fibre of fabric W4 increased the strength considerably but made it unsuitable for use in electrical environments. All fabrics, except FR cotton, exhibited immediate self-extinguishing characteristics. The FR cotton's 2-second after-flame indicates that, while treated, it still sustains a brief burn. Fabrics with a high aramid content exhibited shorter char lengths, indicating enhanced flame resistance. The blend containing a high percentage (66%) of modacrylic resulted in a significantly higher char length, suggesting that modacrylic may compromise the overall flame-retardant performance even in the presence of aramids. The FR high-shrink fabrics showed shorter char lengths than the non-FR high-shrink fabric, underscoring the efficacy of flame-retardant treatments. Additionally, the woven FR high-shrink fabric exhibited a lower char length than its knitted counterpart, indicating that fabric construction affects flammability performance. All the fabrics (woven and knitted) have shown considerable improvement in thermal resistance after coating due to char formation, providing an extra layer of protection between the heat source and fabric. M-aramid fibres possess an inherent shrinkage property on thermal exposure, and a similar trend was evident in the flammability, convective and radiant heat tests on M-aramid (93/5/2) fabric W2. During the radiant heat test, the m-aramid (93/5/2) fabric W2 provides the highest insulation, while the FR high-shrink fabric K1 provides the lowest insulation, as indicated by the calculated TF value.

The tensile strength test results indicated high tensile strength and low elongation for aramid-based fabrics, making them suitable for high-strength applications. The Knitted fabrics have significantly higher elongation but lower tensile strength, making them more flexible and stretchable. FR cotton has the weakest tensile strength and lowest elongation among woven fabrics, making it the least durable. Blended fabrics (modacrylic/aramid) balance strength and flexibility, making them versatile. In the tear strength test, the highest tear strength was observed with P-aramid-based fabrics, which made them ideal for high-performance applications. Woven fabrics have better tear resistance than knitted fabrics. FR cotton has demonstrated poor tear resistance, limiting its use in heavy-duty applications. Blended fabrics (modacrylic/aramid) balance tear resistance and flexibility. Due to the presence of a series of connected loops in knitted fabrics, they are more stretchable but less durable than woven fabrics. Non-FR high-shrink fabric performs exceptionally well post-coating despite lacking inherent flame resistance, making it a viable alternative. The study demonstrates that fabric composition and structure are crucial in heat resistance. Aramid fibres (M-aramid and P-aramid) significantly enhance heat protection, while coating further improves performance. The main criteria for real-world Personal Protective Equipment (PPE) application for thermal protection are protective performance, strength, durability, cost and comfort. The fabrics with high aramid content offer better thermal protection, strength, and durability, but lack comfort and are costly. Viscose provides better comfort and low cost, but is inferior in performance and durability. Knitted fabrics are more comfortable but weaker. The selection of PPE fabrics primarily depends on the intended application. For industries where comfort is a primary requirement, fabrics such as FR cotton and knitted and woven blends of FR viscose with aramid fibres will be ideal. In high-temperature settings and high-strength applications, fabrics with a high inherent flame-retardant content, such as M-aramid, P-aramid, and modacrylic, will be feasible.

This study is limited to a specific blend ratio of different fibres in the fabric and to a single polymer coating, i.e., neoprene. To conduct a more detailed study on the impact of aramid fibres and polymer coating on the thermo-mechanical performance of protective clothing, the study can be continued by varying fibre content and investigating the effects of other available coating materials, such as silicon, nitrile, and polyurethane. This approach would systematically investigate how different percentages of aramid fibres affect the clothing's properties. The results provide essential insights for selecting appropriate fabrics for high-thermal-protection applications.

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