INVESTIGATION OF MECHANICAL AND FUNCTIONAL PROPERTIES OF COATED FABRICS FOR MATERIAL SELECTION IN FALL-PROTECTION AIRBAGS

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ABSTRACT

Falls are a common type of accident among the elderly and represent a major cause of serious injuries. Therefore, wearable smart airbag systems have been developed to mitigate impact forces and protect the human body during fall events. The protective performance of these systems largely depends on the properties of the materials used for airbag fabrication, in which the selected fabrics must meet specific technical requirements. This paper presents the results of a study on the mechanical and functional properties of coated fabrics used in airbag manufacturing through a series of tests, including tensile strength, elongation at break, bursting strength, puncture resistance, water resistance, and air permeability. The results provide a scientific basis for the selection and evaluation of fabric materials in the design and development of wearable smart airbags, contributing to improved protection efficiency for users during fall events.

Keywords: *Bursting strength, puncture resistance, water resistance, air permeability, tensile strength, coated fabrics, airbags.*

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1. INTRODUCTION

Globally, falls are a serious public health issue. It is estimated that approximately 684,000 deaths occur each year due to falls, making them the second leading cause of unintentional injury-related mortality, after road traffic accidents. More than 80% of fall-related deaths occur in low- and middle-income countries, with the Western Pacific and Southeast Asia regions accounting for 60% of these cases. Across all regions worldwide, the highest mortality rates are observed among adults aged over 60 years [1].

In response to this situation, the research and development of solutions aimed at mitigating the consequences of falls have attracted significant attention from scientists worldwide. In addition to fall prevention measures such as improving living environments, using mobility aids, active protection systems, particularly wearable smart airbags are considered a potential approach. These systems can detect a fall and deploy the airbag within a very short time before the body impacts the ground, thereby absorbing and dissipating impact forces, reducing the severity of injuries.

However, the protective performance of smart airbag systems depends not only on sensing technologies and fall detection algorithms but also critically on the materials used in airbag fabrication. The fabrics employed must simultaneously meet stringent requirements, including high tensile strength, excellent bursting strength, puncture resistance, water resistance to maintain internal pressure during deployment, while also ensuring lightweight characteristics and flexibility suitable for wearable applications.

The research group led by M.S. Parvez et al. [2] investigated recent advances in material selection for airbag systems. Automotive airbags play a crucial role in ensuring passenger safety over extended periods. Although the field of airbag technology is rapidly evolving, factors such as airbag components, positioning, coating materials, folding patterns, and sensor activation time are critical determinants of airbag performance. Currently, most airbags are manufactured from Polyamide 6.6. While other Polyamide variants are also available, for instance, Polyamide 6 is softer than

Polyamide 6.6 and can be used to reduce abrasion. On the other hand, Polyamide 6.6 exhibits superior properties compared to other types, including a high strength-to-weight ratio, excellent thermal and chemical stability, favorable elastic behavior, controlled moisture absorption, and appropriate fiber density. Polyamide 6.6 fibers commonly used in airbag applications typically range from 210 to 840 denier. In addition to Polyamide, Polyester is also preferred due to its good dimensional stability, even under humid conditions. However, conventional material configurations still present significant limitations, prompting manufacturers to explore alternative solutions to further enhance airbag safety performance. Airbags may be coated or uncoated and can be constructed from woven or nonwoven fabrics… Regardless of these variations, the base fabric must possess suitable mechanical properties to ensure proper inflation with minimal air leakage while providing effective protection to the human body. The fabric is required to exhibit low air permeability, high flexibility, adequate tensile strength for rapid deployment, and improved energy absorption capacity to protect users from unintended injuries. The preferred fabric weight for airbags typically ranges from 150 to 200g/m^2, with a thickness of less than 0.35mm. To achieve low air permeability, fabric tightness is controlled by adjusting yarn density and fabric structure, as well as by lamination or coating processes. The coating process generally adds an additional weight of approximately 70 - 80g/m^2 to the fabric.

Metwaly et al. [3] investigated the optimal functional properties required to produce automotive airbag fabrics. Airbags have been introduced as standard safety devices in vehicles under legal regulations to protect drivers and passengers in the event of a collision. Airbags operate through an activation device that triggers a chemical explosion when detecting an impending accident at speeds exceeding approximately 35km/h. Upon impact, sensors activate the igniter within the inflator, leading to the combustion of sodium azide pellets and the rapid release of nitrogen gas as the primary inflation medium. Common types of airbags include those made from coated fabrics (primarily used for driver airbags) and uncoated fabrics with minimal air permeability. Coated fabrics offer advantages such as ease of cutting and sewing, reduced fiber fraying, and better control of air permeability. Uncoated fabrics are lighter, less bulky, and more environmentally friendly due to their recyclability. Airbag fabrics are typically woven from high-strength multifilament Polyamide 6.6 yarns, with common linear densities of 210, 420, 840 denier. Polyamide 6.6 is widely used due to its high strength, elongation, favorable thermal properties, and relatively low production cost. Polyester, which exhibits good dimensional stability even under humid environmental conditions and adequate mechanical strength, has also begun to be utilized in airbag applications. Polyamide 6 is used to a lesser extent due to its softer handle, which helps reduce skin abrasion. Airbag fabrics are commonly produced using rapier looms or air-jet looms. These fabrics are typically not dyed but are subjected to heat-setting and cleaning processes to remove impurities that may cause mold growth or other defects.

The primary requirements for airbag fabrics include [3]:

- High mechanical strength (tear strength, tensile strength, elongation at break, bursting strength, and puncture resistance).

- Airtightness.

- Water resistance.

- Good coating adhesion and reliable performance under extreme hot and cold conditions.

- Ability to be compactly folded without damage; for coated fabrics, no sticking between coated layers.

- Thermal stability.

- Good resistance to aging.

- Energy absorption capability.

- High strength.

- Thermal stability.

- Good aging resistance.

- Energy absorption capability.

At present, most studies on airbag materials are focused on automotive applications, while in-depth research on fabric materials for wearable smart airbags designed to protect the human body during falls remains limited. Therefore, the investigation, evaluation, and selection of suitable fabric materials are essential and hold significant scientific and practical importance.

Based on the stringent technical requirements of smart airbag fabrics such as high mechanical strength, airtightness, water resistance, thermal stability, and the ability to operate under harsh environmental conditions the selection of evaluation criteria including tensile strength, elongation at break, bursting strength, puncture resistance, water resistance, and air permeability is both necessary and scientifically justified.

Specifically, tensile strength and elongation at break reflect the material's ability to withstand tensile forces and deformation, ensuring that the fabric does not tear during sudden airbag deployment. Bursting strength represents the fabric's resistance to multidirectional pressure, which is consistent with the working condition of an inflated airbag. Meanwhile, puncture resistance evaluates the material's ability to withstand penetration by sharp objects during real impact scenarios.

In addition, water resistance ensures that the material is not adversely affected by moisture or water, thereby maintaining its durability and long-term stability. Air permeability is directly related to the airtightness of the fabric, determining its ability to retain air and thus influencing the protective performance of the airbag.

The simultaneous selection of these criteria enables a comprehensive evaluation of mechanical properties, physical characteristics, and real-world performance of the material. This provides a solid scientific basis for comparison, selection, and optimization of the most suitable fabric for smart airbag applications.

The research results provide a basis for evaluating, comparing, and selecting suitable materials, thereby contributing to improving the protective performance of smart airbag systems for the elderly in the event of falls.

2. MATERIALS AND METHODS

2.1. Materials

In this study, the materials investigated and selected for airbag fabrication include 23 types of woven fabrics available on the Vietnamese market, all of which are manufactured from polyester (PET) or Polyamide yarns, which are either polymer-coated or calendered to enhance water resistance.

Table 1. Technical specifications of the experimental fabrics

No.	Fabric code	Fabric type	Weave structure	Base material	Coating material	Technical specifications of coated fabrics	
						Fabric weight (g/m^2)	Thickness (mm)
1	M1	BSP-87210T-1	Woven fabric	PET	PU	70	0.086
2	M2	BSP-15VN102	Woven fabric	PET	PU	115,8	0.186
3	M3	BSP-87210T-2	Woven fabric	PET	PU	70	0.095
4	M4	BSP-2225D0185-2L	Woven fabric	PET	TPU	180	0.348
5	M5	BSP-2225D0186-2L	Woven fabric	PET	TPU	170	0.327
6	M6	BSP-2225D0187-2L	Woven fabric	PET	PU	245	0.354
7	M7	BSP-87S30001	Woven fabric	PET	TPU	108	0.246
8	M8	BSP-92ABM821	Woven fabric	PET	PU	131	0.193
9	M9	BSP-87TBS190	Woven fabric	PET	Silver	58	0.078
10	M10	BSP-8794GSM	Woven fabric	PET	TPU	94	0.133
11	M11	BSP-92ABM107	Woven fabric	PET	-	98	0.120
12	M12	BSP-92ABM230	Woven fabric	PA	-	40	0.070
13	M13	BSP-15VNB0-TLNRX400	Woven fabric	PA	-	40	0.050
14	M14	BSP-80MFP001-#22	Woven fabric	PA	-	40	0.050
15	M15	BSP-15VNB0-TLNRX420	Woven fabric	PA	-	42	0.050
16	M16	BSP-80MSR021	Woven fabric	PA	-	43	0.050
17	M17	BSP-80MFP001	Woven fabric	PA	-	38	0.050
18	M18	BSP-62211T	Woven fabric	PET	-	62	0.100
19	M19	BSP-80MSR021	Woven fabric	PA	-	43	0.070
20	M20	BSP-92ABM-NTP01	Woven fabric	PA	-	57	0.090
21	M21	BSP-92ABM0T2	Woven fabric	PET	-	57	0.080
22	M22	BSP-92-325T	Woven fabric	PET	-	48	0.040
23	M23	BSP-80NP073	Woven fabric	PA	-	38	0.050

2.2. Equipment and testing conditions

❖ ***Tensile strength and elongation at break of fabric strips [4]***

- Testing equipment: Tensile testing machine - Serial No.: 122956 - Cometech, Taiwan)

- Standard: ISO 13934-1

- Crosshead speed: 100mm/min

- Gauge length: 200mm

- Preload: 2N

- Environmental conditions: Temperature 21°C, relative humidity 63%

❖ ***Bursting strength [5]***

- Testing equipment: Bursting strength tester GT-C12A-1 - Serial No.: D24032 - Gester, China)

- Standard: ISO 13938-1

- Test area: 7.3cm²

- Environmental conditions: Temperature 21°C, relative humidity 63%

❖ ***Puncture resistance [6]***

- Testing equipment: Puncture resistance tester (76 ONE MEMBER LIMITED LIABILITY COMPANY)

- Standard: Based on EN 388

- Crosshead speed: 100mm/min

- Environmental conditions: Temperature 21°C, relative humidity 63%

❖ ***Water resistance [7]***

- Testing equipment: Water resistance tester GT-C26B-1 - Serial No.: D24032 - Gester, China)

- Standard: ISO 811

- Test surface: Face side of the fabric

- Test area: 100cm²

- Water pressure: Increased at a rate of 60cmH_2O/min

- Water temperature: 20.4°C

- Environmental conditions: Temperature 21°C, relative humidity 63%

❖ ***Air permeability [8]***

- Testing equipment: Air permeability tester

- Standards: TCVN 5092:2009 / ASTM D737:2004

- Pressure: 50Pa

- Test area: 20cm²

- Environmental conditions: Temperature 21°C, relative humidity 63%

2.3. Specimen preparation

❖ ***Tensile strength and elongation at break of fabric strips [4]***

Cut two sets of specimens in the warp and weft directions, with at least five specimens in each set. Do not take specimens within 150mm of the fabric edge and ensure that no two specimens contain the same yarns. The specimen width shall be 50 ± 0,5mm, and the length shall be 200mm (it may be reduced to 100mm if the elongation exceeds 75%). For woven fabrics, cut specimens parallel to the yarn direction and remove yarns along both edges. For low-density fabrics, ensure that each specimen contains at least 20 yarns; if the width differs from 50mm, record the actual width and the number of yarns.

❖ ***Bursting strength [5]***

The specimens shall be taken in accordance with the relevant material standard for the fabric or as agreed between the parties concerned. In the absence of a specific standard, the sampling locations shall be selected in accordance with Annex A. Areas with creases or wrinkles, fabric edges, and non-representative regions shall be avoided. Test positions shall be arranged across the fabric width, approximately 150mm from the edge, and distributed at different locations, avoiding alignment along the same warp or weft lines.

❖ ***Puncture resistance [6]***

Circular specimens with a minimum diameter of 40mm shall be taken such that seams, reinforcements, or regions with greater thickness are located outside the clamping area and the puncture location. If the specimen consists of multiple unbonded layers, these layers shall be stacked together and tested in a single run as one specimen.

❖ ***Water resistance [7]***

After receipt, the fabric shall be handled as little as possible, avoiding sharp creasing and any treatment other than conditioning. At least five test specimens shall be taken from different locations on the fabric such that they do not contain the same yarns and are as representative of the material as possible. The fabric may be tested without cutting specimens. Areas with deep creases or fold marks shall not be tested.

❖ ***Air permeability [8]***

To obtain a lot of sample for acceptance testing, a number of rolls or fabric pieces shall be selected at random in accordance with the material specification or as agreed between the purchaser and the supplier. For acceptance testing, a 1m length of fabric shall be taken from each roll or fabric piece in the lot sample; for rolls, the outer wrapping or the portion wound around the core shall be excluded. From each unit, representative test specimens shall be taken and distributed over both the length and width, preferably along the diagonal and at least one-tenth of the fabric width from the edges. Care shall be taken to ensure that the specimens are free from folds, creases, or wrinkles, and that they are not contaminated with oil, water, or grease during handling.

2.4. Experimental methods

❖ ***Tensile strength and elongation at break of fabric strips [4]***

After conditioning, the fabric strip specimen shall be clamped in a tensile testing machine operating at a constant rate of extension (CRE), with a gauge length of 200mm. The test shall be carried out at a constant crosshead speed of 100mm/min until the specimen breaks. The maximum force recorded at the moment of rupture shall be taken as the breaking force of the fabric strip.

❖ ***Bursting strength [5]***

The specimen shall be conditioned in a relaxed state at (21.0°C, 63%) and tested over an area of 50cm^2. The rate of volume increase shall be set at 100 - 500cm^3/min, or the bursting time shall be (20 ± 5)s. The specimen shall be placed flat, without tension, and securely clamped in the test fixture. The bulging (distension) measuring device shall be positioned and set to zero, and the safety cover shall be secured. Pressure shall then be applied until the fabric bursts. The bursting pressure, height, and/or volume shall be recorded. Specimens that fail within 2mm of the clamping edge shall be discarded. The test should be repeated at least four times at different locations; the number of specimens may be increased if necessary.

❖ ***Puncture resistance [6]***

Clamp the specimen centrally in the holding device with the outer surface facing the probe. Move the probe downward toward the specimen at a speed of 100mm/min until a displacement of 50mm from the specimen surface is reached. Record the force value obtained, even if the specimen is not penetrated. The test shall be conducted on four specimens of the same material. The shape and dimensions of the probe shall comply with the requirements specified for each test. The final result shall be determined as the minimum recorded force value.

❖ ***Water resistance [7]***

Each specimen uses fresh distilled water; the water surface is cleaned by replacement, overflow, or wiping with a paraffin-coated glass plate; the clamping surfaces are dried. The conditioned specimen is clamped with its inner side in contact with the water, ensuring that no water is forced through the specimen prior to testing. The water pressure is gradually increased while observing for penetration. The pressure is recorded when the third droplet appears; very small droplets that do not grow are disregarded; droplets occurring at the same location are counted as one; specimens leaking at the clamp edge are rejected; the test is repeated until reproducible results are obtained.

❖ ***Air permeability [8]***

The specimen shall be conditioned at 21 ± 1°C and 65 ± 2%, then clamped in the test apparatus and tested under a pressure differential. For coated fabrics, the coated side shall face downward to minimize edge leakage. The air flow rate through the specimen shall be measured in cm^3/s/cm^2 (or ft^3/min/ft^2) and reported to three decimal places. Each test unit shall be evaluated using multiple specimens (typically 10, with a minimum of 4). The results may be corrected to determine the effective air permeability by excluding edge leakage.

3. EXPERIMENTAL RESULTS

3.1. Statistical analysis of the experimental air permeability results of 23 selected fabric samples

Based on the experimental results, the data were statistically processed in accordance with TCVN 5784:1994 [9] including the mean value ($\bar{x}$), mean deviation (Δtb), variance (s^2), standard deviation (s), coefficient of variation (CV), and margin of error (m). These indicators serve as the basis for evaluating the stability of the material and are summarized in Table 2.

Based on the statistical results presented in Table 3, a bar chart illustrating the air permeability of the 23 fabric types (Figure 1) was constructed, followed by classification and screening according to the intended application.

Non-conforming group: Several uncoated or calendered samples exhibited significantly higher air permeability; in particular, sample M18 reached 23.73 ± 0.605cm^3/s/cm^2, which is unsuitable for airtight requirements. Samples M11-M23 showed non-zero air permeability values (0.095 ± 0.005 to 1.620 ± 0.045cm^3/s/cm^2), indicating insufficient airtightness and

Table 2. Table of statistical analysis of air permeability test results for fabric types (unit: $cm^3/s/cm^2$)

No.	Fabric code	Calculation content (statistical characteristics)					
		Arithmetic mean ($\bar{x}$)	Mean deviation (Δtb)	Variance (s^2)	Standard deviation (s)	Coefficient of variation CV (%)	Margin of error (m)
1	M1	0.000	0.000	0.000000	0.000	0.000	0.000
2	M2	0.000	0.000	0.000000	0.000	0.000	0.000
3	M3	0.000	0.000	0.000000	0.000	0.000	0.000
4	M4	0.000	0.000	0.000000	0.000	0.000	0.000
5	M5	0.000	0.000	0.000000	0.000	0.000	0.000
6	M6	0.000	0.000	0.000000	0.000	0.000	0.000
7	M7	0.000	0.000	0.000000	0.000	0.000	0.000
8	M8	0.000	0.000	0.000000	0.000	0.000	0.000
9	M9	0.000	0.000	0.000000	0.000	0.000	0.000
10	M10	0.000	0.000	0.000000	0.000	0.000	0.000
11	M11	0.3263	0.0073	0.000074	0.0086	2.6412	0.0101
12	M12	0.3755	0.0253	0.001137	0.0337	8.9799	0.0396
13	M13	0.7173	0.0374	0.002681	0.0518	7.2189	0.0608
14	M14	0.1403	0.0022	0.000011	0.0033	2.3558	0.0039
15	M15	0.9278	0.0548	0.004358	0.0660	7.1153	0.0776
16	M16	0.1628	0.0123	0.000217	0.0147	9.0495	0.0173
17	M17	0.0948	0.0038	0.000030	0.0054	5.7404	0.0064
18	M18	23.7250	0.5250	0.442500	0.6652	2.8038	0.7816
19	M19	0.3335	0.0110	0.000174	0.0132	3.9515	0.0155
20	M20	1.6200	0.0400	0.002467	0.0497	3.0658	0.0584
21	M21	0.1760	0.0035	0.000023	0.0048	2.7051	0.0056
22	M22	0.1123	0.0093	0.000130	0.0114	10.1672	0.0134
23	M23	0.3160	0.0090	0.000115	0.0107	3.3887	0.0126

potential pressure loss. According to M.S. Parvez [2], airbag materials should possess low air permeability to maintain internal pressure and effectively absorb impact energy; therefore, these samples are not prioritized.

Optimal group: Woven fabrics made from PET yarns with PU or TPU coatings (M1-M10) exhibited zero air permeability ($0cm^3/s/cm^2$) and low variability, demonstrating excellent airtightness and compliance with technical requirements.

The results indicate that a woven structure combined with a polymer coating produces materials with high airtightness and good uniformity, providing a sound basis for selection in protective airbag applications for fall protection.

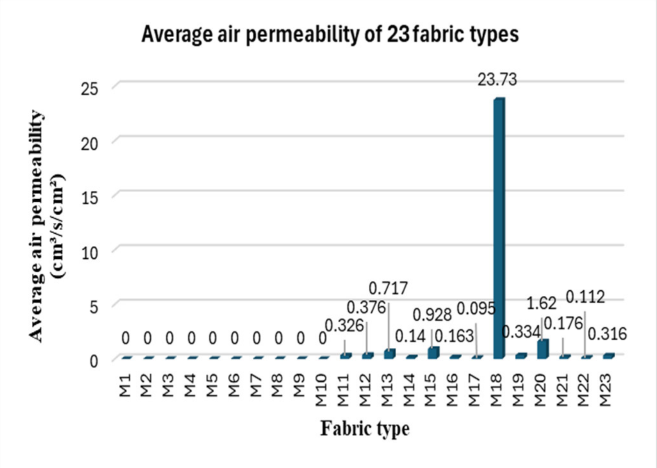

Figure 1. Bar chart showing the average air permeability of 23 fabric types

3.2. Experimental results and statistical analysis of tensile strength of fabric strips, bursting resistance, puncture resistance, and water resistance of the 10 optimal fabric samples

Based on the fabric samples screened through the air permeability criterion, further experiments were conducted to collect data for subsequent selection. The tests included the evaluation of tensile strength, elongation at break, bursting strength, puncture resistance, and water resistance of the materials.

The results obtained from these experiments provide an important basis for analyzing and eliminating fabric samples that do not meet the technical requirements, as well as for identifying the group of materials with properties suitable for protective airbag applications.

From these experimental results, statistical analysis was performed to determine key statistical characteristics. These parameters allow for the assessment of variability and reliability of the test results, and serve as a basis for comparison and material selection. The processed results are summarized and presented in Table 3.

Table 3. Table of statistical analysis of experimental results for tensile strength of fabric strips, bursting strength, puncture resistance, and water resistance of fabric types

No.	Fabric code	Property			Calculation content (statistical characteristics))					
					Arithmetic mean $(\bar{x})$	Mean deviation (Δ_{tb})	Variance (s^2)	Standard deviation (s)	Coefficient of variation, CV (%)	Margin of error (m)
1	M1	Tensile strength of fabric strips	Warp direction	Strength (N)	706.0	6.00	60.50	7.78	1.10	7.41
				Elongation (%)	27.8	0.36	0.27	0.51	1.85	0.49
			Weft direction	Strength (N)	472.0	4.80	35.50	5.96	1.26	5.68
				Elongation (%)	28.7	0.12	0.02	0.16	0.55	0.15
		Bursting strength (kPa)			1198.0	13.20	294.50	17.16	1.43	16.35
		Puncture resistance (N)			38.0	0.30	0.13	0.37	0.96	0.43
		Water resistance (mmH_2O)			> 4000	-	-	-	-	-
2	M2	Tensile strength of fabric strips	Warp direction	Strength (N)	713.0	8.00	106.50	10.32	1.45	9.83
				Elongation (%)	39.6	0.28	0.15	0.38	0.96	0.36
			Weft direction	Strength (N)	529.0	5.20	48.50	6.96	1.32	6.63
				Elongation (%)	25.8	0.32	0.23	0.47	1.84	0.45
		Bursting strength (kPa)			1274.0	21.20	674.00	25.96	2.04	24.73
		Puncture resistance (N)			35.7	0.35	0.21	0.45	1.27	0.53
		Water resistance (mmH_2O)			> 5000	-	-	-	-	-
3	M3	Tensile strength of fabric strips	Warp direction	Strength (N)	530.0	4.80	38.50	6.20	1.17	5.91
				Elongation (%)	18.7	0.40	0.24	0.49	2.62	0.47
			Weft direction	Strength (N)	374.0	3.20	20.00	4.47	1.20	4.26
				Elongation (%)	17.2	0.24	0.09	0.29	1.70	0.28
		Bursting strength (kPa)			1071.0	14.40	327.50	18.10	1.69	17.24
		Puncture resistance (N)			36.4	0.35	0.22	0.47	1.29	0.55
		Water resistance (mmH_2O)			> 4000	-	-	-	-	-
4	M4	Tensile strength of fabric strips	Warp direction	Strength (N)	1080.0	17.20	569.50	23.86	2.21	22.73
				Elongation (%)	27.0	0.44	0.43	0.65	2.41	0.62
			Weft direction	Strength (N)	1061.0	12.80	334.50	18.29	1.72	17.42
				Elongation (%)	38.3	0.28	0.16	0.41	1.06	0.39
		Bursting strength (kPa)			> 2500	-	-	-	-	-
		Puncture resistance (N)			63.9	0.20	0.09	0.29	0.46	0.35
		Water resistance (mmH_2O)			> 4000	-	-	-	-	-

Table 3. Table of statistical analysis of experimental results for tensile strength of fabric strips, bursting strength, puncture resistance, and water resistance of fabric types (continue)

No.	Fabric code	Property			Calculation content (statistical characteristics))					
					Arithmetic mean ($\bar{x}$)	Mean deviation (Δ_{tb})	Variance (s^2)	Standard deviation (s)	Coefficient of variation, CV (%)	Margin of error (m)
5	M5	Tensile strength of fabric strips	Warp direction	Strength (N)	1049.0	15.20	417.50	20.43	1.95	19.46
				Elongation (%)	35.9	0.16	0.05	0.22	0.62	0.21
			Weft direction	Strength (N)	1010.0	8.80	118.50	10.89	0.11	10.37
				Elongation (%)	25.5	0.36	0.30	0.54	2.13	0.52
		Bursting strength (kPa)			> 2500	-	-	-	-	-
		Puncture resistance (N)			75.0	0.35	0.25	0.50	0.66	0.58
		Water resistance (mmH$_2$0)			> 4000	-	-	-	-	-
6	M6	Tensile strength of fabric strips	Warp direction	Strength (N)	1800.0	15.20	421.50	20.53	1.14	19.56
				Elongation (%)	32.5	0.24	0.10	0.32	0.97	0.30
			Weft direction	Strength (N)	1478.0	16.80	458.50	21.41	1.45	20.40
				Elongation (%)	29.1	0.44	0.33	0.57	1.97	0.55
		Bursting strength (kPa)			> 2500	-	-	-	-	-
		Puncture resistance (N)			126.2	0.50	0.49	0.70	0.55	0.82
		Water resistance (mmH$_2$0)			1300.0	6.40	80.00	8.94	0.69	8.52
7	M7	Tensile strength of fabric strips	Warp Direction	Strength (N)	784.0	7.20	74.00	8.60	1.10	8.19
				Elongation (%)	38.9	0.40	0.37	0.60	1.55	0.58
			Weft direction	Strength (N)	571	7.20	89.00	9.43	1.65	8.99
				Elongation (%)	20.1	0.40	0.34	0.58	2.90	0.56
		Bursting strength (kPa)			1133.0	9.20	160.00	12.65	1.12	12.05
		Puncture resistance (N)			35.3	0.40	0.28	0.53	1.50	0.62
		Water resistance (mmH$_2$0)			> 4000	-	-	-	-	-
8	M8	Tensile strength of fabric strips	Warp Direction	Strength (N)	26.5	0.28	0.19	0.43	1.62	0.41
				Elongation (%)	1027.0	10.00	217.50	14.75	1.44	14.05
			Weft direction	Strength (N)	18.1	0.20	0.09	0.29	1.61	0.28
				Elongation (%)	2011.0	19.60	627.50	25.05	1.25	23.86
		Bursting strength (kPa)			2011.0	19.60	627.50	25.05	1.25	23.86
		Puncture resistance (N)			56.0	0.55	0.43	0.66	1.18	0.77
		Water resistance (mmH$_2$0)			> 4000	-	-	-	-	-
9	M9	Tensile strength of fabric strips	Warp Direction	Strength (N)	526.0	5.20	62.50	7.91	1.50	7.53
				Elongation (%)	20.1	0.40	0.26	0.51	2.54	0.49
			Weft direction	Strength (N)	309.0	2.40	11.50	3.39	1.10	3.23
				Elongation (%)	14.0	0.20	0.09	0.29	2.08	0.28
		Bursting strength (kPa)			821.0	13.60	384.00	19.60	2.39	18.67
		Puncture resistance (N)			21.5	0.20	0.07	0.26	1.20	0.30
		Water resistance (mmH$_2$0)			1000.0	13.20	325.00	18.03	1.80	17.17
10	M10	Tensile strength of fabric strips	Warp direction	Strength (N)	670.0	10.40	230.00	15.17	2.26	14.45
				Elongation (%)	28.4	0.50	0.53	0.73	2.55	0.69
			Weft direction	Strength (N)	511.0	5.20	62.50	7.91	1.55	7.53
				Elongation (%)	23.8	0.48	0.40	0.63	2.66	0.60
		Bursting strength (kPa)			1262.0	14.80	405.00	20.12	1.59	19.17
		Puncture resistance (N)			40.2	0.30	0.15	0.39	0.97	0.46
		Water resistance (mmH$_2$0)			> 4000	-	-	-	-	-

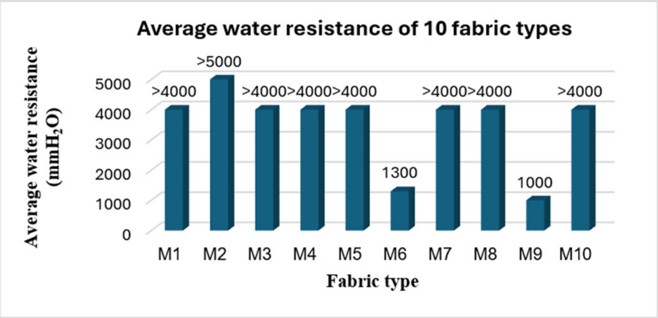

Figure 2. Bar chart showing the average water resistance of 10 fabric samples

Based on the statistical results presented in Table 3, a bar chart (Figure 2) was constructed to evaluate the water resistance of the 10 fabric samples for airbag material selection. Samples with water resistance lower than 4000mmH_2O (M6: 1300 ± 7.621mmH_2O; M9: 1000 ± 17.173mmH_2O) do not meet the requirements due to their low resistance to water penetration. These materials are prone to leakage under low pressure, leading to reduced airtightness, and are therefore excluded. In contrast, samples with water resistance greater than 4000mmH_2O (M1, M2, M3, M4, M5, M7, M8, M10) satisfy the requirements, demonstrating the ability to limit liquid penetration and maintain airtightness. This also reflects the effectiveness of the polymer coatings (PU, TPU) and the material uniformity, ensuring reliability in application. From the selection results, samples M1, M2, M3, M4, M5, M7, M8, and M10 (with water resistance greater than 4000mmH_2O) were chosen for further evaluation of bursting strength to verify their ability to withstand instantaneous pressure.

The experimental results of bursting strength for these seven samples are presented in detail in Figure 4.

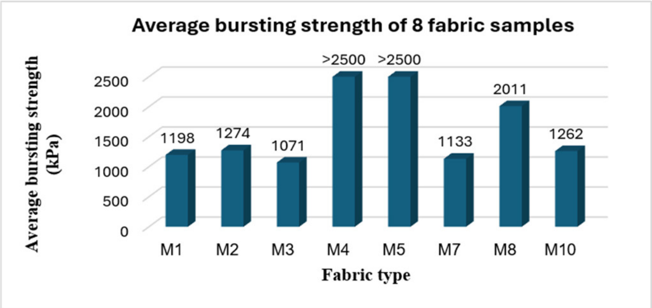

Figure 3. Bar chart showing the average bursting strength of 8 fabric samples

After screening based on the water resistance criterion, seven fabric samples that met the requirements were selected for further evaluation of bursting strength to determine their suitability for protective airbag applications. The results from Table 3 and the bar chart (Figure 3) show a clear difference in bursting strength among the samples. Specifically, among the seven tested samples, only M4 and M5 achieved a maximum bursting strength exceeding 2500kPa. The third-highest value was recorded for sample M8 at 2011 ± 3.665kPa, while the remaining samples exhibited significantly lower values. This indicates that not all materials meeting the water resistance requirement can perform under high-pressure conditions. For airbag applications, the material must not only be water-resistant but also possess high bursting strength to withstand the sudden increase in pressure during activation. Under such pressure, the material is subjected to multidirectional stresses, and a low failure threshold may lead to rupture, resulting in loss of protective function. Conversely, samples with an average bursting strength exceeding 2050kPa demonstrate a high resistance to failure stress, enabling the material to maintain structural integrity and ensure stable airbag performance. Therefore, three samples - M4, M5, and M8 - are identified as fully meeting the mechanical strength requirements, making them suitable for protective airbag applications and selected for further in-depth investigation and evaluation. Following the screening process based on air permeability, water resistance, and bursting strength, the three optimal samples (M4, M5, and M8) were selected for further testing. These evaluations focus on puncture resistance and tensile strength of fabric strips, together with fabric mass and thickness. The experimental results are presented in Figure 4.

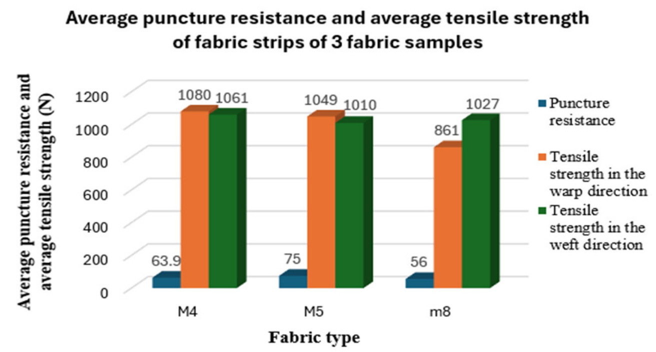

Figure 4. Chart showing the average puncture resistance and average tensile strength of fabric strips for fabric types M4 and M5

Figure 4 illustrates the differences in mechanical properties among the three selected samples, M4, M5, and M8, including puncture resistance and tensile strength in both warp and weft directions. Sample M5 exhibits the highest puncture resistance (75 ± 0.58N), compared to M4 (63.9 ± 0.35N) and M8 (56.0 ± 0.77N). In contrast, M4 shows the highest tensile strength in both warp and weft directions, with values of (1080 ± 22.73N) and (1061 ± 17.42N), respectively, compared to M5 (1049N and 1010N) and M8 (1027 ± 14.05N and 1011 ± 23.86N).

Although the differences in tensile strength among the samples are relatively small, the variation in puncture resistance is more pronounced. Additionally, there are significant differences in fabric mass and thickness: M4 (180g/m^2; 0.348mm), M5 (170g/m^2; 0.327mm), and M8 (131g/m^2; 0.193mm). This indicates that M4 is relatively thick and heavy, which may limit its foldability and flexibility. In contrast, M5 and M8 are lighter and thinner, offering better flexibility.

Therefore, M5 and M8 are considered more suitable for body-protective airbag applications in fall scenarios while still ensuring adequate mechanical strength and functional performance. Notably, M8, despite its significantly lower mass and thickness, still satisfies the required mechanical and functional properties for airbag fabric applications.

4. CONCLUSION

This study conducted a comprehensive evaluation of the mechanical and functional properties of coated fabrics to identify suitable materials for protective airbag applications, through experimental testing combined with statistical analysis in accordance with TCVN 5784:1994. The results show that, among the initial 23 fabric samples, the coated samples (M1-M10) exhibited zero air permeability (0cm^3/s/cm^2), meeting the airtightness requirement necessary to maintain internal pressure during airbag deployment. Based on this, further screening according to water resistance identified seven samples (M2, M3, M4, M5, M7, M8, M10) exceeding the threshold of 4000 mmH$_2$O.

However, when considering bursting strength a parameter reflecting the material's ability to withstand instantaneous pressure only samples M4, M5, and M8 achieved average values greater than 2000 kPa, while the remaining samples showed significantly lower performance. This indicates that materials used for airbags must simultaneously ensure airtightness and the ability to withstand multidirectional loads with a high failure threshold.

The three selected samples, M4, M5, and M8, were further evaluated based on two main groups of properties: puncture resistance and tensile strength in both warp and weft directions. The results show that M5 exhibits the highest puncture resistance (75 ± 0.58N), significantly higher than M4 (63.9 ± 0.35N) and M8 (56.0 ± 0.77N). In contrast, M4 demonstrates superior tensile strength in both directions, with values of (1080 ± 22.73N) in the warp and (1061 ± 17.42N) in the weft, compared to M5 (1049N and 1010N) and M8 (1027 ± 14.05N and 1011 ± 23.86N).

Although the differences in tensile strength among the samples are relatively small, the variation in puncture resistance is more pronounced. In addition, notable differences are observed in fabric mass and thickness: M4 has the highest values (180g/m^2; 0.348mm), followed by M5 (170g/m^2; 0.327mm), while M8 has the lowest (131g/m^2; 0.193mm). This suggests that M4 is relatively thick and heavy, which may limit its foldability and flexibility in practical applications.

In contrast, M5 and M8, with lower mass and thickness, offer better flexibility and are more suitable for integration into body-protective airbag systems for fall scenarios. Therefore, considering both mechanical performance and usability, M5 and M8 are identified as the most suitable materials for airbag applications. In subsequent studies, these two materials will be integrated into a complete airbag model to comprehensively evaluate their operational performance under real-world conditions.

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