Evaluation of Functionality and Mechanical Performance in Transformable Textile Systems Developed Through a Sustainable Design Approach

Asude Eda Bak[1], Damla Erdem[1], Özge Ural[2], Emine Dilara KOÇAK[2]

[1]Mudo Giyim A.Ş. Design Center, Istanbul, Türkiye

[2]Textile Engineering Department, Technology Faculty, Marmara University, Istanbul, Türkiye.

DOI: https://doi.org/10.51244/IJRSI.2026.1306000418

Received: 28 June 2026; Accepted: 03 July 2026; Published: 15 July 2026

ABSTRACT

In the context of sustainable product design, the ability of a single product to fulfill multiple usage functions is of critical importance in reducing resource consumption. In this study, a multifunctional transformable textile product was developed from PU-coated ripstop polyester fabric, which can be used as a raincoat, backpack, and seating mat. The performance of the product was evaluated through water resistance, tear strength, and load-bearing capacity tests. The results indicated that, although there were some statistical differences between usage modes, the mechanical performance was largely maintained. In backpack mode, the product demonstrated an average load-bearing capacity of 12.9 ± 0.3 kg, and no structural damage was observed during the tests. Furthermore, effective waterproof performance was achieved across all usage modes. The findings demonstrate that the developed transformable textile product maintains its functional and mechanical properties, making it suitable for sustainable and multifunctional use.

Keywords: Transformable textile, sustainable design, multifunctional product, ripstop polyester, mechanical performance.

INTRODUCTION

Rapidly increasing urbanization, changing lifestyles, and sustainability-oriented consumption patterns have significantly altered users' expectations from everyday products. In particular, individuals in metropolitan life are exposed to varying environmental conditions throughout the day, spend extended periods outdoors, and are required to carry multiple pieces of equipment simultaneously. Products such as raincoats, backpacks, portable energy sources, and seating equipment are among the most commonly used items in this context. However, meeting each need with a separate product not only reduces ergonomic efficiency but also increases material consumption due to the growing number of products. Circular economy principles and sustainable design approaches encourage the development of systems in which a single product can perform multiple functions (Niinimäki, 2020; Nemeša et al., 2024).

Technical textiles play a crucial role in addressing this need. Technical textiles are defined as engineered products developed to meet specific performance requirements. Textile products used in outdoor applications are expected to provide high water resistance, breathability, mechanical durability, low weight, and long-term performance. In recent years, waterproof and breathable textile systems have achieved the ability to combine high hydrostatic pressure resistance with user comfort through polyurethane-based coatings and membrane technologies (Chang et al., 2023; Ghezal et al., 2024). However, product performance is not solely dependent on fabric structure. The sealing performance of seam regions, the durability of fastening components, and the preservation of structural integrity after repeated folding processes also directly affect the success of technical outdoor textile products (Pankevich & Burkin, 2022).

One of the emerging research areas in textile engineering is functional and smart textiles. Studies on smart textile systems have demonstrated that textile products are not limited to protective functions but can also provide

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

energy storage, electronic integration, communication, and user-assistive functionalities (Ruckdashel et al., 2022; Younes et al., 2023). These developments have paved the way for transforming conventional textile products into multifunctional systems and have accelerated user-centered product development approaches.

In parallel with advancements in functional textiles, transformable clothing and product systems have recently become an important research topic. The transformable design approach enables a single product to adapt to different usage forms, thereby extending product lifespan and reducing material consumption. Nemeša et al. (2024) state that transformable garments represent an effective design strategy for reducing both production- and consumption-related textile waste. However, a review of existing literature shows that the majority of studies on transformable systems focus on fashion design and aesthetic use scenarios. Research on transformable systems for outdoor products requiring technical performance remains quite limited.

Although there is a substantial body of literature on waterproof technical textiles, functional textiles, and transformable garments, these studies have generally been conducted in separate domains. While high-performance waterproof fabrics are being developed on one hand, transformable design studies have mainly progressed within the fashion context. Similarly, research on smart textiles has largely focused on energy storage and electronic integration. However, studies integrating waterproof technical fabrics, transformable design principles, and functional user requirements within a single system remain scarce. In particular, no study has been found in the literature that combines raincoat, backpack, and seating mat functions (for outdoor social activities such as excursions, festivals, and concerts) within a single technical textile system and experimentally evaluates the engineering performance of such a system.

In this study, a multifunctional technical textile product made from PU-coated ripstop polyester fabric was developed. The designed system can be used as a raincoat, backpack, and seating mat; it also incorporates a portable battery compartment, a mobile phone charging pocket, reflective safety elements, and emergency equipment storage areas. The main objective of the study is to evaluate the waterproof performance, seam strength, and transformable structural properties of the developed product. The original contribution of this study lies in transforming a waterproof textile structure that meets technical performance requirements into a modular system capable of functioning in three different usage scenarios and experimentally investigating this system from a textile engineering perspective.

MATERIALS AND METHODS

Main Fabric

In this study, a plain weave ripstop fabric made of 100% polyester fibers was used as the main material. The fabric has a mass per unit area of 210 ± 5 g/m² and a width of 150 cm. The warp density was determined as 48 threads/cm, while the weft density was 42 threads/cm. The technical properties of the fabric are presented in Table 1.

Table 1. Technical Properties of the Fabric

Property	Value
Warp yarn count	300D
Weft yarn count	300D
Warp tensile strength	1280 N
Weft tensile strength	1145 N
Coating type	Poliüretan (PU)
Water resistance	>10.000 mmH_2O
Water vapor permeability	5200 g/m²/24 h

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Sewing Thread

A high-strength continuous filament polyester sewing thread was used in the sewing processes. The thread has a linear density of 70 tex and a breaking strength of 5.8 kgf.

Zippers and Connection Elements

In this study, waterproof PU-coated zippers were used to enable transformation between raincoat, backpack, and seating mat modes. For carrying and connection systems, 25 mm wide polyester webbing straps were preferred, while aluminum alloy carabiners and stainless-steel D-rings were used in load-bearing regions. Modular connection points included stainless-metal snap fasteners and POM-based plastic buckles. These components are characterized by low weight, high mechanical strength, corrosion resistance, and suitability for repeated use.

Power and Lighting System

To enhance the functionality of the product, a portable battery system (Table 2) and an LED lighting unit (Table 3) were incorporated.

Table 2. Battery Specifications

Property	Value
Battery type	Li-ion
Capacity	10.0 h
Output voltage	5 V
USB output	USB-A / USB-C
Weight	185 g

Table 3. LED System Features

Property	Value
LED type	SMD LED
Power	0.5 W
Light color	White
Visibility distance	80 m

The 10,000 mAh Li-ion battery used as the energy source in the product provides sufficient energy storage capacity for portable use. The theoretical energy capacity of the battery is approximately 37 Wh, and when evaluated in conjunction with the 0.5 W SMD LED system, the LED lighting operates continuously for approximately 70–75 hours. Thanks to its USB-A and USB-C outputs, the system also enables charging of mobile devices.

The 0.5 W SMD LED used as the lighting system offers low energy consumption and a visibility distance of approximately 80 m, thereby contributing to user safety, particularly in camping, hiking, and emergency conditions. Due to its low power consumption, the impact of the LED system on the overall energy demand of the product remains limited, supporting an extended battery life. These features indicate that the developed transformable textile product is suitable not only in mechanical and functional terms but also in terms of energy efficiency for outdoor use.

Reflective and Auxiliary Components

Microprismatic reflective tapes were used to enhance user safety. In addition, auxiliary storage compartments were incorporated into the product, including a phone pocket, a first-aid compartment, and various spaces designed to carry emergency equipment (Table 4).

Table 4. Reflective and Auxiliary Materials

Component	Property
Reflective tape	Microprismatic

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Tape width	25 mm
Phone pocket	TPU coated
Inner lining	70D polyester
First aid pocket	Su geçirmez
Seat mat padding	3 mm EVA foam
Emergency whistle	ABS plastic

Method

Product Design and Manufacturing Method

The product developed in this study was designed to function as a raincoat, backpack, and seating mat, featuring three different usage modes. The functional properties of the product are presented in Figure 1. During the design process, the primary focus was to define the geometry of the product in its fully unfolded state, with the aim of achieving all functionalities from a single textile surface. For this purpose, a main panel measuring 220 cm × 120 cm was prepared from a 150 cm-wide fabric. Folding axes, connection points, and transformation zones on the main panel were created using computer-aided design (CAD) software.

For the outer surface of the product, PU-coated ripstop polyester fabric was used, while 70D polyester lining was selected for the inner sections to enhance user comfort. In order to provide back support in backpack mode and seating comfort in mat mode, 3 mm EVA foam was placed in designated areas. The EVA layer was laminated between the outer fabric and the lining to form a multilayer composite structure.

In the production process, fabric components were prepared using the Gerber AccuMark + Paragon cutting system, and all components were cut according to technical patterns. The cut parts were assembled using an industrial lockstitch machine with stitch type 301 in accordance with ISO 4915 standards. An average stitch density of 4 stitches/cm was applied. To maintain water resistance performance, polyurethane-based seam sealing tapes were applied to critical seam areas using the hot-air method.

Figure 1. Functional Product Design

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

To enable the transformable structure of the product, waterproof zippers, D-rings, carabiners, POM buckles, and elastic connectors were used. These components allow the product to be converted into different usage modes. In raincoat mode, the front closure system is provided by a waterproof zipper, while in backpack mode, the folded panels are secured using zippers and buckles. In seating mat mode, all panels are fully unfolded to obtain a flat surface.

To enhance the functionality of the product, a portable 10,000 mAh battery system was integrated. The power unit is located in a waterproof inner pocket. The battery system supplies energy to USB output ports, LED lighting units, and a mini flashlight. LED strips were placed on the front and back panels to increase visibility in raincoat and backpack modes.

To improve user safety, microprismatic reflective tapes were used on the shoulder, arm, back, and side panels of the product. The reflective tapes were designed to maintain visibility across all usage modes. Thus, the product ensures safe use under both daytime and nighttime conditions. The final product dimensions and usage modes are presented in Table 5**.**

Usage Mode	**Dimensions (cm)**	**Function**
Raincoat	110 × 64	Rain protection
Backpack	48 × 32 × 18	Carrying system
Seating Mat	100 × 60	Thermal and moisture insulation

Table 5. Final Product Dimensions and Usage Modes

Experimental Studies and Test Methods

In order to evaluate the technical performance of the developed multifunctional textile product, various tests were conducted on fabric, seams, and overall product functionality. In this context, hydrostatic pressure and seam waterproofness tests were performed to determine water resistance performance, while seam strength and tear strength tests were applied to assess mechanical performance. Additionally, transformation cycle and bag carrying capacity tests were carried out to evaluate the usability performance of the product’s multifunctional structure. The applied test methods and corresponding standards are presented in Table 6.

Table 6. Applied Tests and Relevant Standards

Test	**Standard**
Hydrostatic Pressure	ISO 811
Seam Strength	ISO 13935-2
Seam Waterproofness	AATCC 127
Tear Strength	ISO 13937-2
Transformation Cycle	Method developed by the researcher
Bag Carrying Capacity	Based on ASTM D6775

Statistical Analysis

All experimental results were obtained from five repetitions and reported as mean ± standard deviation. One-way analysis of variance (One-Way ANOVA) was applied to evaluate the homogeneity of the measurement

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

results. The analyses were performed at a 95% confidence level, and a p-value of < 0.05 was considered the threshold for statistical significance.

RESULTS

Hydrostatic Pressure Results

In the hydrostatic pressure tests presented in Table 7, the average water resistance value was determined as 10968 ± 125 mmH_2O. The ANOVA results indicated that there was no statistically significant difference between the test groups ($p > 0.05$). The low standard deviation values indicate that the coating and production processes were carried out homogeneously.

Table 7. Hydrostatic Pressure Results

Group	**Mean (mmH_2O)**	**SD**
Base Fabric	10968	125
Raincoat Mode	10628	75
Seam-Taped Region	9752	98
Seat Mat Mode	10221	77

The highest hydrostatic pressure value was obtained in the main fabric group, while the lowest value was determined in the taped seam regions. However, all measured values in all groups were above 9500 mmH_2O, indicating that the product can provide an effective water barrier in raincoat and seating mat modes.

In a similar study conducted by Sfameni (2023), it was reported that PU-coated polyester ripstop fabric exhibited high hydrostatic pressure performance, supporting the usability of coated products in rainy environmental conditions. Akgün (2022) stated that surface modifications of polyester fabrics directly affect liquid transfer properties. Therefore, the high hydrostatic pressure values obtained in raincoat and seating mat modes are attributed not only to the fabric structure but also to the applied coating system.

As a result, the developed three-functional textile product demonstrated high water resistance performance across all usage modes and was found suitable for outdoor applications.

Seam Strength Results

The seam strength values are presented in Table 8. In the seam strength tests, the highest average value was obtained in the basic seam group (698 ± 9.6 N), while the lowest value was observed in the backpack mode (684 ± 8.9 N). Although certain differences were observed between usage modes, the One-Way ANOVA results indicated that these differences were not statistically significant ($F = 2.18$, $p = 0.108 > 0.05$).

Table 8. Seam Strength Results

Test Group	**Seam Strength (N) Mean**	**± SD**
Base Seam	698	9.6
Raincoat Mode	692	8.9
Backpack Mode	684	8.9
Seat Mat Mode	689	8.4

The low standard deviation values indicate that the sewing processes were performed homogeneously and that the product exhibits similar mechanical performance across different usage modes. In particular, values exceeding 680 N in the backpack and seating mat modes demonstrate that the polyester sewing thread and seam construction used provide sufficient strength under multifunctional usage conditions.

Seam Waterproofness Results

The waterproof performance of PU tape-applied seam regions is presented in Table 9. The study was conducted across five groups by considering critical seam areas in different usage modes of the product. Five repetitions were performed for each group, and the results are reported as mean ± standard deviation.

Table 9. Seam Waterproofness Results According to Usage Modes

Test Group	**(mmH_2O)**	**± SD**
Raincoat Seams	9752	92
Backpack Seams	9691	81
Seat Mat Seams	9615	79
High-Stress Connection Seams	9496	82

One-way ANOVA results indicated that there were statistically significant differences between the test groups ($F = 6.87$, $p = 0.001 < 0.05$). The highest seam waterproofness value was obtained in the raincoat seam regions, while the lowest value was observed in high-stress connection seams. This difference is attributed to localized stress concentrations occurring around seam lines, tapes, and connection elements in areas that are subjected to the greatest mechanical loads during product transformation.

Nevertheless, all measured values across all groups were above 9000 mmH_2O, demonstrating that the PU seam sealing process is effective. In particular, since seam areas are critical in terms of water penetration in raincoat mode, the obtained values indicate that the product can provide sufficient waterproof performance under rainy outdoor conditions.

Boz et al. (2024) reported that in softshell and ripstop softshell fabrics, conventional seaming, taped seaming, and ultrasonic joining methods affect waterproof performance, and that seam sealing plays a significant role in reducing water penetration at seam regions. The findings of this study are consistent with the high waterproof values obtained in PU tape-applied seam regions. In addition, Table 10 demonstrates that the developed transformable textile system integrates three different functional uses within a single product structure, providing a versatile solution to user needs and maintaining its technical performance after functional transitions.

Tear Strength Results

Tear strength was evaluated in both warp and weft directions across different usage modes of the product.

Table 10. Tear Strength Results According to Usage Modes

Test Group	**Warp Direction (N)**	**SD**	**Weft Direction (N)**	**SD**
Main Fabric	44.6	0.7	40.6	0.5
Raincoat Mode	44.0	0.5	40.1	0.4
Backpack Mode	43.5	0.5	39.8	0.5
Seating Mat Mode	42.8	0.5	39.2	0.4

One-Way ANOVA results indicated statistically significant differences between the groups in both warp direction ($F = 12.17$, $p = 0.002$) and weft direction ($F = 10.84$, $p = 0.003$). Although the usage areas differ, the similarity of tear strength values suggests that the transformation processes do not adversely affect the mechanical performance of the fabric.

In general, the warp direction tear strength, which reflects the structural strength characteristics of woven fabrics, was found to be higher than that of the weft direction. This is associated with the higher warp density (48 threads/cm) compared to the weft density (42 threads/cm). While the highest values were obtained in the main fabric group, the slight decreases observed after transformation are attributed to deformation caused by folding, tension, and usage-related mechanical loads. Although the lowest values were recorded in backpack mode, the strength loss remained at approximately 5%.

The ripstop reinforcement yarns in the fabric structure, selected to maintain functional properties, limited tear propagation and improved load distribution, thereby ensuring the preservation of high tear resistance across all usage modes (Srivastava et al., 2026). These results demonstrate that PU-coated ripstop polyester fabric maintains its mechanical integrity despite being transformed into different functional forms such as raincoat, backpack, and seating mat, confirming its suitability for transformable textile applications.

Transformation Cycle Results

After 50 transformation cycles performed on the product, no functional degradation was observed in any of the samples. Zippers, carabiners, D-rings, buckles, and seam regions maintained their structural integrity. Since no performance differences were observed between samples, ANOVA analysis was not required. The results indicate that the product can be safely used through repeated transitions between raincoat, backpack, and seating mat modes.

Bag Load Capacity Results

In load tests conducted in backpack mode, the maximum safe carrying capacity was determined as 12.9 ± 0.3 kg. The low standard deviation indicates high repeatability and homogeneous load-bearing performance among samples. One-way ANOVA results showed no statistically significant difference between groups ($p = 0.284$), indicating consistent load-carrying capacity across samples.

During testing, no damage or permanent deformation was observed in shoulder straps, connection elements, or seam regions. This demonstrates that the load-bearing system effectively distributes applied forces and maintains structural integrity. The findings confirm that the transformable textile product retains its mechanical durability after functional transformation and provides sufficient load capacity for everyday use conditions.

CONCLUSİONS

In this study, a transformable textile product based on PU-coated ripstop polyester fabric was developed and evaluated in three different functional modes: raincoat, backpack, and seating mat.

- The physical and mechanical properties of the fabric were largely preserved after transformation processes, and structural integrity was maintained across all usage modes.
- Waterproofing tests demonstrated that the PU-coated ripstop polyester fabric provides an effective barrier performance in all usage modes and sufficient protection against outdoor environmental conditions.
- Although statistically significant differences were observed in tear strength results in both warp and weft directions, the values across all usage modes remained close, indicating that mechanical performance loss was limited.
- Higher warp-direction tear strength compared to weft direction was attributed to higher warp density and the contribution of ripstop reinforcement yarns to load distribution.

- Load tests in backpack mode showed an average carrying capacity of 12.9 ± 0.3 kg, and no statistically significant differences were found between samples ($p > 0.05$).

- No damage or deformation was observed in shoulder straps, connection elements, or seam regions during loading tests, confirming the structural durability of the product.

- The combination of ripstop structure and PU coating enabled high strength, low performance loss, and long-term usability across different usage scenarios.

Overall, the study demonstrates that a single textile surface can be successfully transformed into three different functional applications while maintaining its mechanical performance. The results highlight that multifunctionality and durability can be achieved simultaneously in transformable textile products.

The developed system offers significant potential within sustainable product design approaches by reducing material consumption, extending product life cycle, and enabling innovative textile products adaptable to user needs.

REFERANSLAR

1. Akgun, M., Kanik, M., Seçmen, S., Macit, M., & Gülşen, E. (2022). Research on the method for controlling the liquid absorptivity behavior of polyester textile materials. AATCC Journal of Research, 9(3), 143-151. https://doi.org/10.1177/2472344422108439
2. Boz, S., Oral, O., & Dirgar, E. (2025). Evaluation Of Alternative Joining Methods In Softshell FabricTypes. TextileResearchJournal, 95(9-10,975-987. https://doi.org/10.1177/00405175241273007
3. Chang, Y., Li, Y., & Wang, J. (2023). Review Of Waterproof Breathable Membranes For Functional Textiles. Polymers, 15(16), 3456. https://doi.org/10.3390/polym15163456
4. Ghezal, I., Moussa, A., Marzoug, I. B., El-Achari, A., Campagne, C., & Sakli, F. (2024). Development Of A Multi-Layered, Waterproof, Breathable Fabric For Full-Weather Apparel: Original scientific paper. Chemical Industry & Chemical Engineering Quarterly, 30(3), 265-273. https://doi.org/10.2298/CICEQ230407029G
5. Nemeša, I., Pešić, M., Bukhonka, N. P., Bozoki, V., & Šušćević, J. (2024). Transformable clothing to reduce pre and post consumer textile waste. Contemporary Trends and Innovations in Textile Industry. https://doi.org/10.5937/CT_ITI24055N
6. Pankevich, D. K., & Burkin, A. N. (2022). Methodology for evaluating the properties of waterproof clothing materials. Technologies & Quality, 56(2), 5–10. https://doi.org/10.34216/2587-6147-2022-2-56-5-10
7. Ruckdashel, R. R., Khadse, N., & Park, J. H. (2022). Smart e-textiles: Overview of components and outlook. Micromachines, 13(9), 1398. https://doi.org/10.3390/mi13091398
8. Sajovic, I., Geršak, J., & Rudolf, A. (2023). Smart textiles: A review and bibliometric mapping. Applied Sciences, 13(18), 10489. https://doi.org/10.3390/app131810489
9. Sfameni, S., Lawnick, T., Rando, G., Visco, A., Textor, T., & Plutino, M. R. (2023). Super-hydrophobicity of polyester fabrics driven by functional sustainable fluorine-free silane-based coatings. Gels, 9(2), 109. **https://doi.org/10.3390/gels9020109**
10. Srivastava, A., Maity, S., & Das, B. R. (2026). Creep and Anti-Sag Behavior of Polyester Outer Shell Fabric for Bulletproof Jacket. Polymer Engineering & Science, 66(3), 1992-2007. **https://doi.org/10.1002/pen.70323**
11. Thorisdottir, T. S., Johannsdottir, L., Pedersen, E. R. G., & Niinimäki, K. (2025). A boundary perspective on sustainable business models: insights from the Nordic fashion industry. Journal of Fashion Marketing and Management: An International Journal, 29(8), 1431-1454.https://doi.org/10.1108/JFMM-05-2024-0190
12. Younes, B. (2024). Textronics: A review of their technological aspects and applications. Textile Progress. https://doi.org/10.1080/00405000.2023.2236320
13. Younes, B., Bouhjar, F., & Koncar, V. (2023). Smart e-textiles: A review of their aspects and applications. Journal of Industrial Textiles, 53. https://doi.org/10.1177/15280837231215493