

Comprehensive review of parametric study on testing advance textile materials for parachute system

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Abstract -This study conducts a comprehensive parametric analysis of advanced textile materials used in parachute systems, focusing on their performance under varying conditions. By examining key parameters such as tensile strength, weight-to-strength ratio, and durability under extreme environmental conditions, the research aims to identify optimal material configurations that enhance the functionality and safety of parachute systems. The investigation incorporates various advanced textiles, including aramid fibers and ultra-high molecular weight polyethylene (UHMWPE), assessing their properties through standardized testing methods to establish performance benchmarks. The findings underscore the critical role of material selection in parachute design, revealing that specific textile characteristics significantly impact deployment reliability and descent stability. Through a systematic comparison of the materials tested, the study concludes that while advanced textiles offer superior performance metrics, their application must be tailored to the intended use-case scenarios of parachute systems. The results not only contribute to the ongoing development of safer and more efficient parachute technologies but also provide valuable insights for future research and material innovation in aerospace applications.

Keywords: - Advanced textile materials, Parachute systems, Tensile strength, Deployment reliability, ultrahigh molecular weight polyethylene (UHMWPE)

INTRODUCTION

The ongoing advancement of textile materials has been crucial in enhancing creativity, performance and safety of parachute system across various applications. Parachutes are used in military, aerospace sectors but by the help of modern material science (MS) which enables them to perform more reliably (Favini et al., 2012). This review brings together insights from various research studies, focusing on the detailed analyses of advanced textile materials and how they affect the design and performance of parachutes. By examining these studies, we can better understand the ways these new materials improve parachute reliability, safety, and

adaptability in different conditions. The physical properties of canopy fabrics like porosity significantly affect the performance of parachute affecting drag and lift characteristics during descent (Favini et al., 2010). Smart materials allow for dynamic adjustments in parachute characteristics during flight, enhancing portability and safety (Favini et al., 2010).

Textile materials in the parachute system include nylon and Kevlar, utilized for their high strength-to-weight ratio. The CPAS system primarily features textile components, with only three metallic parts, enhancing packing efficiency and overall system mass savings. NASA Orion Capsule (NOC) Parachute Assembly System development completed in 2018. Lessons learned include textile design, joint testing and material challenges (a) Joint testing for determining joint efficiencies (b) Fault tree analysis for failure cause investigation. (Anderson et al., n.d.). The textile materials used in the Capsule Parachute Assembly System (CPAS) include Kevlar cord and webbing, Nylon broadcloth and webbing, and Vectran cord, which are essential structural elements for the NASA Orion Crew Module parachute system. Parachute textiles face contamination throughout their lifecycle. Strength degradation from contaminants and cleaning agents is examined. (Mollmann, n.d.)

The paper discusses the use of flexible composites and high strength-to-weight ratio fibers in parachute systems. These advanced materials enhance performance by minimizing weight while improving strength, making them suitable for various aerospace applications, including parachutes and parafoils. (a) Development of flexible composites using high-performance materials (b) Use of high strength-to-weight ratio fibers and fabrics (Senthil Kumar, 2018). The study focuses on 100% nylon plain fabrics used in parachute systems. The air permeability of these fabrics is influenced by factors such as yarn count, density, and fabric construction, which are critical for

parachute performance. (a)Theoretical model for predicting air permeability. (b)Linear Regression model to improve predictions. The parachute fabrics tested in the study were PIA-C-7020D Type I and PIA-C-44378D Type I, both woven from nylon fibers, as specified by the Parachute Industry Association (PIA) specifications. (a)Testing permeability of parachute fabrics at varying differential pressures. (b)Calculating effective porosity and total porosity for parachutes.(Cruz et al., n.d.).The textile materials used in the parachute system include 10-oz plain weave Kevlar cloth for the inner sleeve, Teflon cloth for the middle lubricating sleeve, and 10,000-lb Kevlar tubing for the outer rolling sleeve. (a)Knockdown analysis for strength testing of risers. (b)Abrasion testing using Instron 8800 machine.(Hennings et al., n.d.)

The introduction of this study highlights the importance of parachute performance in terms of lift, drag, and stability, which depend on the physical properties of the parachute canopy, such as porosity and geometry. To enhance parachute functionality and adaptability, researchers have explored the use of intelligent sensors embedded within parachute materials. These sensors can provide real-time data on strain, load, and pressure, which could enable adjustments to parachute characteristics mid-flight, thereby increasing control and safety.(Favini et al., 2012). Sensing capabilities of parachute fabrics and suspension lines that are coated with conductive polymers like polyaniline (PANI), polypyrrole (PPY), and carbon nanotubes (CNTs). By leveraging the inherent strength of these coatings and their ability to bond with fabric surfaces, researchers aimed to create "smart" fabrics that can detect deformation and load changes through electrical resistance variations. These innovations hold potential for advanced applications in parachute systems by monitoring structural health and ensuring parachute integrity during deployment.(Favini et al., 2012)

Tensile test device designed for measuring the tensile properties of fabrics, comparing its performance with the Instron 4301. This device can be utilized for testing fabric strength in parachute systems. (a)Mechanical imperfections causing deviations in test results.(b)Need for increased rigidity of movable clamp unit.(Hasçelik & Eren, n.d.). The machines used for checking the strength of fabric materials in the parachute system include the 5k Tinius Olsen and 30k Tinius Olsen, equipped with Sedam grip test

fixtures to apply tension and measure breaking strength during testing.(a)Loss of material strength at joints affects reliability.(b)Ensuring adequate margins for parachute components under peak loads.(Mollmann, n.d.-a). The use of trellis frame shear tests and photogrammetry systems to measure the structural response of fabrics, specifically focusing on the static stress-strain response of candidate fabrics for entry, descent, and landing applications.(a)Limited characterization of fabric material properties.(b)Difficulty in measuring fabric deformation accurately.(Zilliac et al., 2012)

The tensile strength and elongation at break of the fabric samples were determined using a testing machine, which is essential for evaluating the mechanical properties of materials used in parachute systems, including paraglider.(a)Complex structural geometry of paraglider wing.(b)Variable flight conditions affecting performance analysis.(Maślanka et al., 2022). Micro-mechanics of parachute fabrics under tensile stress using in situ X-ray micro-tomography. It focuses on two nylon textiles (MIL-C-7020H Type III and MIL-C-44378 Type II), examining how they respond to incremental tension. Through high-resolution imaging, the study captures detailed structural changes in the fibers, helping to identify how fabric architecture impacts strain and porosity under load. The findings offer insights into the relationship between textile design and mechanical behavior, contributing to more efficient parachute designs by linking fabric structure to performance under stress.(Phillippe et al., 2024)

Computational modeling and simulation to assess textile seams and joints in parachute designs. Traditionally, parachute joint strength is tested through destructive tensile testing, which is resource-intensive. The study introduces an alternative approach by using an LS-DYNA model to simulate various stitch patterns and joint failures, providing a potentially cost-effective and efficient tool for evaluating joint durability and optimizing designs without physical testing. Results indicate that simulation can predict joint failure within a reasonable margin of accuracy, supporting its utility in parachute engineering(Janda et al., 2015). An overview of the role of statistical quality control (SQC) in textile manufacturing. It outlines how statistical tools, such as control charts, hypothesis testing, and sampling, are applied to assess and maintain quality in fiber, yarn, and fabric production. By using methods like acceptance sampling,

manufacturers can evaluate large batches while avoiding the impracticality of testing every item. The chapter emphasizes the need for quality management and monitoring to enhance product consistency, reduce defects, and meet the fast-paced demands of the textile industry.(Das, 2012)

Heat sealing Machine

Stitching is not suitable for the PVC coated nylon because stitching can introduce weak points and might not hold up under the extreme pressure of a high-fall impact air are not trapped in the cushion. So, we preferred the heat sealing for the cushion. Heat sealing provides a more reliable and consistent bond compared to stitching. Heat sealing ensures a completely airtight construction. The cushions are often constructed using a process called heat sealing.

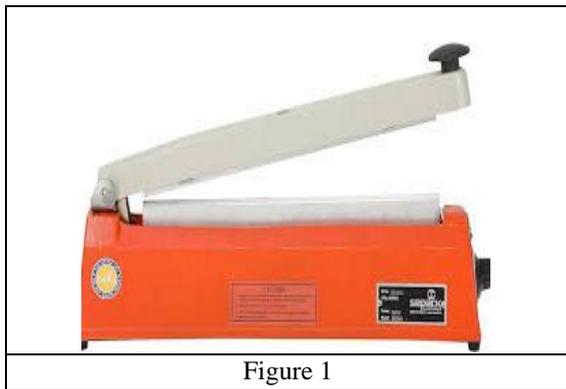


Figure 1

Laser seaming is an innovative approach for joining fabrics, offering speed, precision, and automation potential. It utilizes controlled heat and pressure for welding textiles without compromising flexibility or external aesthetics. Key processes include direct laser welding using CO₂ lasers and through-transmission laser welding (TTLW). Parameters like power density, welding speed, and absorber material play a crucial role in seam quality. Advantages include non-contact operation, cleanliness, and suitability for thermoplastic fabrics, though color independence remains challenging. Future trends emphasize automation and cost-effective equipment adaptation(Jones & Patil, 2013). Ultrasonic sealing offers a needle-free method to bond thermoplastic fabrics, reducing costs and enhancing environmental impermeability. This technique uses mechanical vibrations to generate heat, bonding fibers at the interface. The study investigates factors like weld pressure, time, and thermal properties of polyethylene terephthalate (PET) and spectra fabrics, highlighting seam strength variations based on processing conditions. Findings reveal that higher

weld times and optimal pressure yield superior bonds, but excessive energy or pressure may degrade material strength. This method is pivotal for applications in technical textiles where seamless integrity is essential(Yang et al., 2010)

Protective clothing demands seam constructions that ensure durability and environmental resistance. The document categorizes seam types for applications in chemical, biological, and cold-weather protection. Techniques such as serged, bound, glued, and heat-sealed seams address specific needs, with ultrasonic and hot air welding providing adhesive-free options for impermeable seams. Innovations include heat-sealed tape for chemical suits and ultrasonic bonding for nonwoven medical garments. These technologies ensure enhanced safety and performance, particularly under extreme conditions(Radhakrishnan & Kumari, 2017). The temperature at which a heat sealing machine is used to seal air rescue cushions typically depends on the type of material being sealed. Most air rescue cushions are made from durable synthetic materials like PVC (polyvinyl chloride) or TPU (thermoplastic polyurethane). For PVC materials, the heat sealing temperature generally ranges from 120°C to 180°C. For Thermoplastic materials, the temperature range is usually between 140°C to 210°C.(Aithani et al., 2006)

Tensile properties in fabric performance

The tensile properties of fabrics is crucial for ensuring their performance across diverse applications. These properties, including tensile strength and elongation, significantly affect how textiles behave under stress, impacting their durability and usability in products like car seats and electronic textiles. For instance, fabrics used in automotive interiors must withstand various environmental challenges, including abrasion and UV exposure, while maintaining structural integrity under load (Kovačević et al., 2017)

The innovation of the new test device for measuring the tensile properties of fabrics lies in its combination of advanced materials and responsive technology, enhancing both performance and usability. One of the key features is the integration of strain rate sensitive materials, which adapt their behavior based on the speed and force of the applied stress, thereby providing more accurate measurements across various conditions. (Plant, 2014) offering valuable insights into the optimization of such materials for practical applications. Additionally, the development

of textile-based sensors utilizing PEDOT:PSS(Mater & Università, 2016)

It emphasizes the increasing use of textile reinforcements in composite materials due to their lightweight, high strength, and design versatility. These materials are extensively employed in aerospace, automotive, and civil engineering applications. Their mechanical performance, especially under complex loading scenarios, is critical for the structural integrity and reliability of composite structures. The study contributes to a deeper understanding of the mechanical behavior of textile reinforcements by providing detailed strain field data. (Willems et al., 2008) The goal of the project is to develop a dependable and effective tool for assessing the bending characteristics of technical textiles, which are essential for their use in a variety of industries, including protective apparel, parachutes, and geotextile.(Sengupta et al., 2016)

Advanced textile materials

The essential characteristics of textile materials used in parachute manufacturing, aiming to identify the most suitable fabric for various applications. The study evaluates key physical and mechanical properties, such as mass per unit area(MPU), breaking strength(BS), elongation, tear resistance(ETR), and air permeability(AR). They are critical for ensuring the durability, safety, and performance of parachute systems under diverse operational conditions. The tests conducted include evaluations of yarn and fabric breaking strength, elongation, tear strength, and air permeability. Measurements were made using standardized methods and specialized equipment like the Tinius Olsen Dynamometer(TOD) H5KT.(Adrian SALISTEAN et al., 2018) The parachute was designed with a combination of nylon and Kevlar materials. Nylon was used for the canopy and suspension lines, while Kevlar was used for the load-bearing ringslots.(Kumar et al., 2014)

The parachute was tested in a subsonic wind tunnel to measure its drag coefficient and stability characteristics. The tests were conducted at different angles of attack and dynamic pressures. The parachute exhibited a high drag coefficient of around 0.85, which is typical for ringslot parachute designs. The drag coefficient remained relatively constant over the tested range of angles of attack.(Kumar et al., 2014)

The effect of fabric stiffness on solid-cloth parachute performance, with an emphasis on how it affects structural behavior, inflation, and deployment. The authors created stiffness scaling rules to forecast parachute performance over a range of sizes and materials using theoretical modeling and experimental testing. They discovered that while more rigidity improves structural resistance, it may also reduce deployment effectiveness, which would impact drag performance. These findings are vital for refining parachute design in high-performance applications like space exploration and military use, enabling a cost-effective approach to development and testing.(Johari & Desabrais, 2003). The development of a predictive model for assessing the air permeability of nylon textiles used in parachutes is the main goal of the study Predicting Air Permeability of Nylon Parachute Fabrics by a crucial factor in parachute performance, air permeability influences inflation, drag production, and stability when descending. To examine the connections between fabric structural characteristics including weave, thread density, and yarn count and air permeability, the researchers used statistical modeling and empirical testing. With the help of the suggested model's precise forecasts, designers can choose fabrics and streamline production procedures to satisfy particular performance standards. Technical textile engineering for aerospace and Defense application(Al-Ebiary et al., 2017)



Figure 2

Textile Wing Fabric for Emergency Response UAS focuses on the creation and evaluation of textile materials for usage in emergency response-specific unmanned aerial systems (UAS). Critical characteristics such as low fabric mass, high axial breaking strength, elongation, rip resistance, and air permeability are highlighted in the study's evaluation of a number of parachutist and paraglider materials. These qualities are necessary to guarantee mechanical dependability and lightweight design.

Property	Kevlar® Fabric	Nylon Fabric
Tensile Strength (MPa)	3,600–4,000	900–1,000
Density (g/cm³)	1.44	1.14
Thermal Stability (°C)	Up to 400	120–150
Abrasion Resistance	Excellent	Good
Chemical Resistance	Excellent (resistant to acids, bases)	Moderate (prone to chemical degradation)
Weight	Lighter (higher strength-to-weight ratio)	Heavier for equivalent strength
Durability in Extreme Conditions	Superior	Moderate

Table: Comparison of Kevlar® and Nylon Fabrics for Parachutes

The results aid in the development of a new inflatable wing with strengthened seams for increased stability and a single-skin construction. The experimental findings, which have been verified by international testing standards, identify the best fabric variation for these uses and show promise in emergency situations where dependable and effective UAS are needed.(Săliștean & Mihai, 2020)

High-strength, lightweight ripstop nylon is a common material for parachute canopies. To stop tears from spreading, it has a unique weave that includes stronger strands at regular intervals. Depending on the needs for air permeability, variations include low-porosity and zero-porosity (silicone-coated) textiles.(Cruz et al., 2018)Some

parachutes employ polyester materials because they are less likely to absorb moisture than nylon, have structural stability, and are resistant to UV rays. Because of their stability in a range of climatic circumstances, these textiles are frequently chosen for reserve canopies and static line parachutes.(Phillippe et al., 2024) High-modulus fibers such as Kevlar (an aramid fiber) and Vectran (a liquid crystal polymer) are utilized in high-performance parachute designs, particularly for aerospace applications. Superior strength-to-weight ratios and resistance to chemical and thermal deterioration are provided by these materials.(Anderson et al., n.d.)

The study emphasizes Kevlar®'s special qualities, such as its remarkable tensile strength, excellent thermal stability, resistance to abrasion, and resistance to chemical deterioration. It is also lightweight. Because of these qualities, it is a perfect fit for cutting-edge parachute systems, especially those used in aerospace and military settings.The engineering difficulties in creating parachute textiles that satisfy exacting performance standards while lowering total weight are covered in the article. Additionally, it compares Kevlar® fabrics to conventional nylon-based materials, demonstrating their better load-bearing capacity and durability. The study highlights how Kevlar® might improve parachutists' dependability and effectiveness in harsh environments, thereby establishing new benchmarks for parachute material technology.(Nemours, 1989)

Under a microscope, the warp threads in the fabric core are uniformly spaced at the edges and regularly paired, with large spaces between pairs. Figure 3 depicts this irregular spacing.

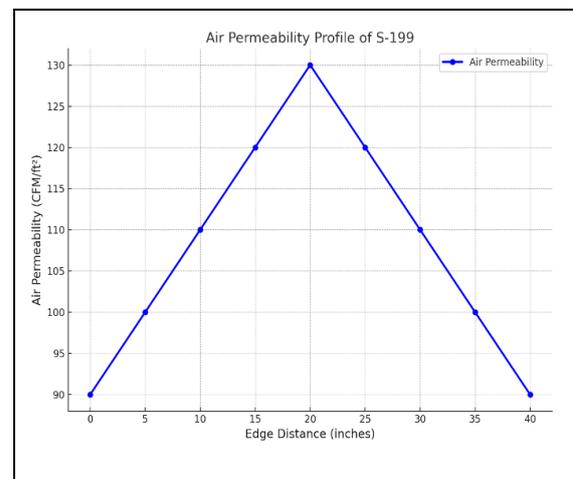


Figure 3

The negative impact of high weave crimp on Kevlar's tensile qualities results in an intolerable loss of warp yarn strength in this tight design. This is particularly noticeable at the fabric's margins, where higher weaving tensions cause warp yarn abrasion.

Figure 4 provides a summary of the tensile results.

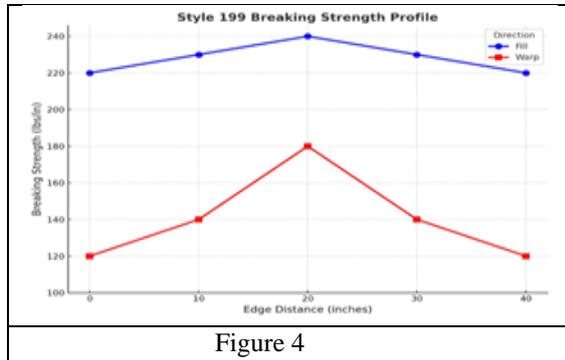


Figure 4

Figure 5 shows that while the strength translation of the looser 4- and 8-harness satin weaves is much higher than that of the plain weave, the air permeability increases noticeably.

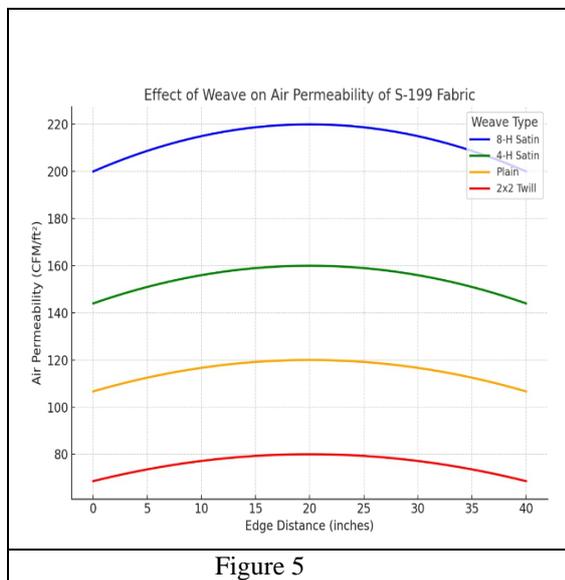


Figure 5

Based mostly on weaveability considerations, S-199 was first created using 55 denier yarn and a twist level of 3 tpi. Even while 3 tpi is a rather low twist number for a yarn as fine as 55 denier, better cover and flattening of the yarn should result in less air permeability. 94x94 plain weave fabrics were woven using the matching twist in the filling yarn after two new 94 end/in warps with zero twist and 1.5 tpi were created. Figure 4 shows the striking impact of twist on air permeability throughout the comparatively narrow range of 0 to 3 tpi.

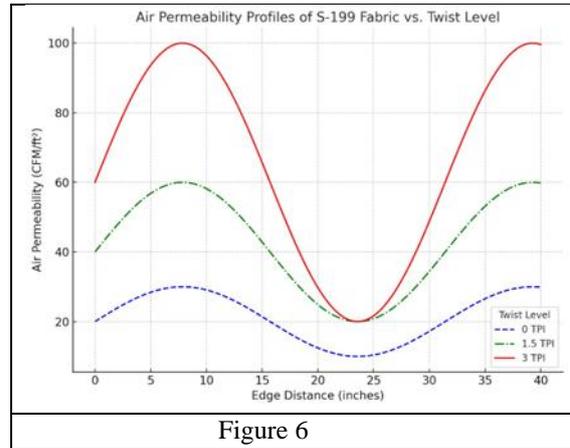


Figure 6

COMPARISON OF NYLON AND KEVLAR® PARACHUTE FABRICS

Property	Nylon	Kevlar®
Denier/Filaments	30/10	55/20
Style ID	7020G, Type I	S-172
Weight, oz/yd ²	1.1	1.1
Weave	plain, ripstop	2X2 twill
Count, ends x picks	120X120	72X72
Tensile Strength, lbs/in	50X50	150X150
Elongation, %	20	4
Tear Strength, lbs	8X8	32X32
Thickness, mils	2.9	2.6
Air Permeability, CFM/FT ²	100 ± 20	100 ± 20
Melting Point, °C	260	---

Methods to improve ultrahigh molecular weight polyethylene (UHMWPE) fibers—which are renowned for their high strength, low density, and resistance to wear—are reviewed in "Research Progress on Surface Modification and Application Status of UHMWPE Fiber." Applications in sports, ocean engineering, aircraft, and protective materials are made possible by surface modification techniques like coatings, oxidation, plasma treatment, and chemical grafting, which enhance adhesion with polymer matrices. Future developments must still address issues like creep resistance and reducing harm from modifications. (Wang & Hou, 2022)



Figure 7

There are two types of surface treatment effects of plasma on high-performance fiber polymers: etching and activation. In addition to greatly increasing surface roughness, plasma treatment can provide polar functional groups to the surface of UHMWPE fibers, which will boost interfacial adhesion. There is rivalry between activation and etching (Wang & Hou, 2022)

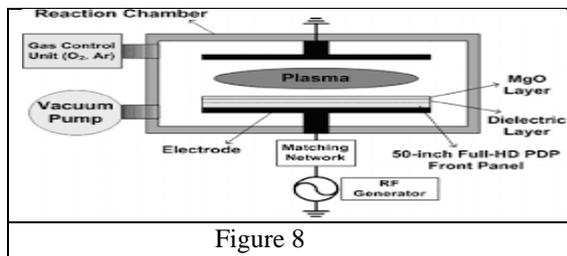


Figure 8

CONCLUSION

The performance and crucial characteristics of cutting-edge textiles such as nylon, Kevlar, and UHMWPE fibers used in parachute applications are examined in "Materials for Parachute Systems." It emphasizes how crucial air permeability, porosity, and tensile strength are to maximizing descent stability and deployment dependability. The superiority of high-performance fibers in terms of strength-to-weight ratios, abrasion resistance, and durability in harsh environments are among the main conclusions. Advanced testing procedures, joint and seam computational modeling, and cutting-edge technologies to improve material properties—such as plasma treatment and smart coatings—are all included in the study. The versatility of these materials is demonstrated by their use in emergency response systems, the military, and aerospace. The study highlights a multidisciplinary strategy to enhancing performance, safety, and reliability in demanding situations and concludes that material

innovations and testing frameworks are essential for future parachute developments.

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