

FACTORS AFFECTING THE OPERATIONAL CHARACTERISTICS OF SPECIAL CLOTHING

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Abstract. *This article examines the key factors influencing the operational performance of special clothing, with a particular focus on seam construction and its role in ensuring safety and durability. Protective garments are designed for use in hazardous environments involving thermal, chemical, biological, and mechanical risks. In addition to fabric composition, structure, and finishing treatments, seam type, stitch density, thread properties, and seam-sealing technologies significantly affect garment performance. The study highlights advanced construction methods, including taped and ultrasonic welded seams, which enhance barrier properties and improve garment longevity. Findings demonstrate that seam integrity is a critical factor in maintaining protective efficiency and extending service life, emphasizing the importance of proper seam selection and engineering in protective apparel design.*

Keywords: *special clothing, seam construction, stitch density, seam sealing, ultrasonic welded seams, durability, barrier performance, technical textiles, safety apparel, industrial protection*

Special clothing plays a vital role in safeguarding individuals working in hazardous environments, including thermal, chemical, biological, and mechanical risk zones. While material properties (fiber type, fabric construction, finishing treatments) significantly influence the performance of protective garments, seam construction remains an equally critical yet often under-examined element. Seam type, stitching density, thread characteristics, and post-seam sealing methods directly affect the garment's durability, barrier efficiency, and overall comfort during use. This article reviews the primary factors affecting protective apparel performance, emphasizing correct seam selection and design strategies to ensure optimal protection and functional longevity.

Special clothing is designed to provide a physical barrier against hazardous environments. Performance requirements vary depending on the exposure type-heat and flame, chemical splash, cold environments, medical biohazards, or mechanical hazards. Studies emphasize that even garments made with high-performance fabrics may fail if seam integrity is compromised, as friction, fluid penetration, and mechanical stress often initiate at seam lines [1]. Therefore, seam construction must be strategically engineered to maintain protection throughout the product life cycle.

Key properties influencing garment durability include fiber composition (e.g., aramid, polyester, cotton), fabric weave, thickness, and finishing treatments. High-performance fibers provide flame resistance, chemical repellency, and mechanical strength, yet seams remain potential weak zones if not designed correctly [2].

Exposure to chemicals, UV radiation, abrasion, extreme temperatures, and moisture can degrade both fabrics and seams. Dust, particulate matter, and thermal cycling accelerate aging of seam threads and tapes [3].

Improper donning/doffing, ill-fitting garments, and neglecting care guidelines lead to premature seam failure. Frequent laundering also affects seam adhesives and thread strength.

Seams join garment components and must withstand mechanical stress, movement, chemical exposure, and thermal loads.

Special clothing incorporate several specialized seam constructions, each tailored to particular hazard conditions and functional needs. The basic superimposed seam, often created through conventional stitching, is commonly used when only general-purpose protection is required and the risk of liquid penetration is minimal. For environments where moderate liquid resistance and increased durability are necessary, a bound seam is preferred; this design encloses the raw edges with an additional fabric strip, providing improved strength and barrier performance. When flexibility and wearer comfort are prioritized, as in highly mobile occupational settings, flat or overlock seams are implemented due to their low bulk and ability to stretch. In high-hazard chemical or biological workplaces, stitched seams that are subsequently taped are the standard solution, ensuring that stitch perforations are sealed and fluid ingress is prevented. The highest level of protection is achieved through ultrasonically welded seams, which bond fabric layers without needle punctures, delivering superior impermeability and strength for critical protective clothing applications.

Studies show stitched-and-taped and ultrasonically welded seams provide the highest barrier protection against chemicals and biological hazards [4].

ISO standards ISO 4915 [5] and ISO 4916 [6] provide technical frameworks for correct selection and classification.

Testing shows seam failure is commonly caused by:

- needle perforation pathways for liquid penetration
- thread degradation due to chemicals/heat
- abrasion at high-movement zones (knees, elbows, crotch)
- aging of adhesives and seam tapes after repeated laundering

A study comparing taped vs. untaped seams found 50-60% higher resistance to liquid permeation in taped seams [7].

In addition, ergonomic requirements play a significant role in improving the functional properties of protective clothing. The garment structure must correspond to human body movements, provide freedom of motion during work, and ensure long-term comfort. Research shows that improperly designed clothing may lead to fatigue, restricted mobility, and an increased likelihood of industrial incidents. Therefore, modern manufacturers develop functional design solutions incorporating anthropometric data, elastic zones, and ventilation systems [8].

The fibers and fabrics used in protective clothing are also advancing with scientific and technological progress. For instance, aramid fibers, polybenzimidazole (PBI) materials, and silicone-coated fabrics are distinguished by high heat resistance and mechanical durability. Additionally, the use of nanostructured coatings to impart water, oil, and chemical resistance has become increasingly common. These innovations extend the service life of protective garments and enhance safety for workers operating in hazardous environments [9].

Digital technologies also play a vital role in modern protective garment development. 3D modeling systems, virtual fitting tools, and stitch-stress analysis software help predict pressure and strain distribution along seam lines. This approach reduces deformation, friction, and material fatigue, allowing designers to reinforce critical stress points and optimize seam placement [10].

Furthermore, the concept of “smart textiles” continues to evolve in order to expand the functionality of protective clothing. Research developments include temperature-monitoring sensors, fibers capable of detecting toxic gases or chemical exposure, and micro-sensors for emergency signaling. Such embedded technologies significantly increase workplace safety and minimize human error in hazardous environments [11].

Seams play a crucial role in determining the protective effectiveness and service life of special clothing. Proper seam selection-supported by suitable thread materials, appropriate stitch density, and advanced sealing techniques-ensures that protective garments provide consistent and reliable performance. Future developments in nanocoatings, smart seam monitoring, and automated seam welding technologies will further enhance seam integrity and worker safety.

In summary, the development of protective garments must integrate proper material selection, seam engineering, ergonomic design, standardization, and modern technological innovations. Only through rigorous quality control, laboratory testing, and compliance with international standards can manufacturers ensure high protective performance. Ultimately, these improvements contribute to enhanced industrial safety, reduced workplace injuries, and preservation of worker health in demanding operational settings.

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