

**STUDIES ON INNER AND OUTER LAYERS OF
EXTREME COLD WEATHER CLOTHING FOR
DEFENSE PERSONNEL**

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EXTREME COLD WEATHER CLOTHING FOR
DEFENSE PERSONNEL**

by

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to the



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*Dedicated to My Beloved Parents
for their endless love and encouragement*

CERTIFICATE

This is to certify that the thesis entitled “**Studies on inner and outer layers of extreme cold weather clothing for defense personnel**”, being submitted by **Ms. Ranjna Kumari** to the Indian Institute of Technology Delhi, for the award of “**Doctor of Philosophy**” is a record of bonafide research work carried out by her in the Department of Textile and Fibre Engineering, IIT Delhi. She has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis.

To the best of my knowledge, the results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

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ABSTRACT

The extreme cold weather clothing (ECWC) consists of three layers ; inner, middle, and outer layers. The inner layer of the ECWC stays in contact with the skin. The function of the inner layer is to transport sweat from the skin to the next layer so that the skin remains dry. Further, it should have durable antimicrobial and quick sweat absorption properties. The function of the middle layer is to provide thermal insulation, whereas the outer layer protects from wind rain and snow.

In the present work, antimicrobial fabric was developed for potential use as an inner layer in extreme cold climate. The yarn used for skin-contacting inner layer (single jersey) was specifically designed to provide antimicrobial properties and quick liquid moisture transport by selecting an appropriate blend of antimicrobial (1.4 denier) and virgin fibres of different deniers (0.8 and 1.2 denier). Fabrics made from antimicrobial fibres doped with silver nanoparticles demonstrated superior durability of antimicrobial activity even after extensive washing compared to fabrics coated with silver nanoparticles. The inner layer fabric composed of coarser fibres (1.2 denier) exhibited better moisture management properties compared to fabrics made of finer fibres (0.8 denier). The liquid absorption and spreading capability of these fabrics, simulating the skin's sweating phenomenon, showed that fabrics with coarser fibres quickly imbibe microdroplets and spread them over a larger area.

A second garment layer was designed to absorb moisture from the skin-contacting layer and provide insulation. A fleece fabric structure was chosen to meet these functional requirements. Variations in the fleece fabrics were achieved by using filament and spun yarns in the fleece and base parts of the fabrics. The results indicated that fabric with filament yarn on the base side and

spun yarn on the fleece side enhances moisture transport. The use of spun yarn made of coarser fibres in the fleece part further promotes moisture management due to its faster wicking.

A thorough study was carried out on the outer garment (insulating cum environmental protective) consisting of a nonwoven layer sandwiched between the lining and the protective shell. The effect of weave design on the mechanical properties was studied for the lining and the outer shell layer fabrics. The performance of the twill ripstop weave was found to be best due to the presence of ribs consisting of a group of parallel yarns and floats. The fabric is further laminated with different membranes (PU, mono-PTFE, and bi-component PTFE) to be used as an outer shell. The fabric laminated with bi-component PTFE membrane was found to enhance tear strength and provide good vapor transmission.

Thermal bonded nonwovens, made from different denier fibres in various proportions, were analysed to identify the one with maximum vapor transmission. Results showed that evaporative resistance increases as porosity decreases and the average specific surface area of the fibre mixture increases. Fabric thickness significantly affects evaporative resistance: thicker fabrics offer more resistance to vapor transmission.

Three ensembles (composed of single jersey, fleece and insulating jacket and trouser set) were made to investigate their performance on manikin. The variation was introduced by changing the laminated fabric layer. The ensemble with a mono PTFE laminating membrane exhibited the least evaporative resistance, followed by bi-component PTFE and PU laminated ensembles. The evaporative resistance measured on the manikin was always higher than the algebraic sum of the estimated resistance of the component fabrics measured on a sweating-guarded hot plate, due to presence of void space between the fabric layers in the ensemble.

सारांश

अत्यधिक ठंडे मौसम के कपड़े में तीन परतें होती हैं; आंतरिक, मध्य और बाहरी परतें। ईसीडब्ल्यूसी की आंतरिक परत त्वचा के संपर्क में रहती है। अंदरूनी परत का काम पसीने को त्वचा से अगली परत तक पहुंचाना है ताकि त्वचा सूखी रहे। इसके अलावा, इसमें टिकाऊ रोगाणुरोधी और त्वरित पसीना सोखने वाले गुण होने चाहिए। मध्य परत का कार्य थर्मल इन्सुलेशन प्रदान करना है, जबकि बाहरी परत हवा, बारिश और बर्फ से बचाती है।

वर्तमान कार्य में, अत्यधिक ठंडी जलवायु में आंतरिक परत के रूप में संभावित उपयोग के लिए रोगाणुरोधी कपड़े विकसित किए गए थे। त्वचा से संपर्क करने वाली आंतरिक परत (सिंगल जर्सी) के लिए उपयोग किए जाने वाले धागे को विशेष रूप से रोगाणुरोधी (1.4 डेनियर) और विभिन्न डेनियर (0.8 और 1.2 डेनियर) के वर्जिन फाइबर के उचित मिश्रण का चयन करके रोगाणुरोधी गुण और त्वरित तरल नमी परिवहन प्रदान करने के लिए डिज़ाइन किया गया था। चांदी के नैनोकणों से लेपित रोगाणुरोधी फाइबर से बने कपड़ों ने चांदी के नैनोकणों से लेपित कपड़ों की तुलना में व्यापक धुलाई के बाद भी रोगाणुरोधी गतिविधि का बेहतर स्थायित्व प्रदर्शित किया। मोटे रेशों (1.2 डेनियर) से बने आंतरिक परत के कपड़े ने महीन रेशों (0.8 डेनियर) से बने कपड़ों की तुलना में बेहतर नमी प्रबंधन गुण प्रदर्शित किए। त्वचा के पसीने की घटना का अनुकरण करते हुए, इन कपड़ों की तरल अवशोषण और फैलाने की क्षमता से पता चला है कि मोटे फाइबर वाले कपड़े जल्दी से सूक्ष्म बूंदों को अवशोषित करते हैं और उन्हें एक बड़े क्षेत्र में फैलाते हैं।

परिधान की दूसरी परत त्वचा से संपर्क करने वाली परत से नमी को अवशोषित करने और इन्सुलेशन प्रदान करने के लिए डिज़ाइन की गई थी। इन कार्यात्मक आवश्यकताओं को पूरा करने के लिए फ्लीस कपड़े की संरचना को चुना गया था। कपड़ों में विविधता फ्लीस और कपड़ों के आधार भागों में फिलामेंट और काते हुए

धागों का उपयोग करके हासिल की गई थी। परिणामों से संकेत मिलता है कि आधार पक्ष पर फिलामेंट धागा और फ्लीस पक्ष पर काता हुआ सूत वाला कपड़ा नमी परिवहन को बढ़ाता है। ऊनी हिस्से में मोटे रेशों से बने सूत का उपयोग इसके तेजी से सोखने के कारण नमी प्रबंधन को बढ़ावा देता है।

बाहरी परिधान (इंसुलेटिंग सह पर्यावरण सुरक्षात्मक) पर गहन अध्ययन किया गया, जिसमें अस्तर और सुरक्षात्मक आवरण के बीच एक गैर-बुना परत शामिल थी। अस्तर और बाहरी आवरण परत के कपड़ों के यांत्रिक गुणों पर बुनाई डिजाइन के प्रभाव का अध्ययन किया गया था। टवील रिपस्टॉप बुनाई का प्रदर्शन समानांतर और फ्लोट्स के समूह से युक्त रिब्स की उपस्थिति के कारण सबसे अच्छा पाया गया। बाहरी आवरण के रूप में उपयोग करने के लिए कपड़े को विभिन्न झिल्लियों (पीयू, मोनो-पीटीएफई, और द्वि-घटक पीटीएफई) के साथ लेमिनेट किया जाता है। द्वि-घटक पीटीएफई झिल्ली से लेमिनेट किया गया कपड़ा फाइने की शक्ति को बढ़ाता है और अच्छा वाष्प संचरण प्रदान करता है।

विभिन्न अनुपातों में अलग-अलग डेनियर फाइबर से बने थर्मल बॉन्डेड नॉनवॉवन का विश्लेषण अधिकतम वाष्प संचरण वाले एक की पहचान करने के लिए किया गया था। परिणामों से पता चला कि वाष्पीकरण प्रतिरोध सरंध्रता में कमी और फाइबर मिश्रण के औसत विशिष्ट सतह क्षेत्र में वृद्धि के साथ बढ़ता है। कपड़े की मोटाई वाष्पीकरण प्रतिरोध को महत्वपूर्ण रूप से प्रभावित करती है: मोटे कपड़े वाष्प संचरण के लिए अधिक प्रतिरोध प्रदान करते हैं।

मैनिकिन पर उनके प्रदर्शन की जांच करने के लिए तीन पहनावे (सिंगल जर्सी, फ्लीस और इंसुलेटिंग जैकेट और ट्राउजर सेट) बनाए गए थे। लेमिनेटेड कपड़े की परत को बदलकर बदलाव पेश किया गया था। मोनो पीटीएफई लेमिनेटिंग झिल्ली वाले समूह ने सबसे कम बाष्पीकरणीय प्रतिरोध प्रदर्शित किया, इसके बाद द्वि-घटक पीटीएफई और पीयू लेमिनेटेड संयोजन का स्थान रहा। मैनिकिन पर मापा गया बाष्पीकरणीय प्रतिरोध

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