

**STUDIES ON DURABLE ANTIBACTERIAL
FABRICS USING NANO-SILVER EMBEDDED
POLYESTER FIBRES**

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NANO-SILVER EMBEDDED POLYESTER FIBRES**

by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



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Dedicated to my father

CERTIFICATE

This is to certify that the thesis titled '**Studies on Durable Antibacterial Fabrics using Nano-Silver Embedded Polyester Fibres**', being submitted by Mr. Prakash Arun Khude to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute.

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

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ABSTRACT

In the modern era, consumer's attitude towards active healthcare and hygiene has created an increasing demand for the textile fabric functionalised with antibacterial properties. Textile fabric plays an important role in acquisition and transmission of pathogens in the hospitals as well as domestic use. Textile have long been recognised as media to support the growth of bacteria and fungi as it acts as a source of nutrients as well as shelter for bacteria. The growth of microbes on textiles during use and storage negatively affects the wearer as well as the textile itself. For these reasons, it is highly desirable that the growth of microbes on textiles be minimized by use of durable antibacterial textiles by incorporating the antibacterial agent into synthetic fibres during fibre formation. Out of many antibacterial agents, silver is one of the most widely used antibacterial agents since the evolution of the mankind. It is known that silver is one of the safest antibacterial agents as compared to organic compounds. Silver has been medically proven to kill over 650 disease-causing organisms.

While most of the research efforts have revolved around application of silver nanoparticles on textile substrates through finishing route, only limited efforts have been made to incorporate silver nanoparticles in fibres at melt spinning stage. Besides, most of the studies on antibacterial nanocomposite fibres are limited to fibre development and their characterisation only. It has been known that incorporation of silver nanoparticles in the fibres during the melt spinning stage leads to formation of fibres with much more durable antibacterial activity as compared to those where silver is applied topically through finishing route.

There is a void in development of antibacterial fabrics (woven or knitted) using fibres embedded with silver nanoparticles (nanocomposite fibres) and understanding the role of yarn and fabric parameters on antibacterial activity. Thus, in this research work, an attempt has been

made to impart antibacterial functionality to woven and knitted polyester fabrics by blending normal polyester fibres with polyester-silver nanocomposite fibres at various blend proportions and to study the effect of yarn and fabric construction parameters on antibacterial efficacy of such fabrics. It has been observed that woven and knitted fabrics prepared by polyester yarns containing small proportion (10-30%) of polyester-silver nanocomposite fibres demonstrate very good (63.20-98.89%) antibacterial activity against both Gram-positive (*S. aureus*) and Gram-negative (*E. coli*) bacteria. Blend proportion of nanocomposite fibres is found to be the most dominant factor in influencing the antibacterial activity of woven and knitted fabrics.

For healthcare applications, it is important to know the exact antibacterial activity of the textile materials. As this activity depends on various factors, it becomes an arduous task to predict its value in advance before the manufacturing of textile materials. For this reason, modelling, and prediction of antibacterial properties of knitted fabrics has been carried out using soft computing techniques such as ANN and ANFIS. The optimisation of the antibacterial and comfort properties of knitted fabric has been evaluated using desirability function. Further, some selected woven fabrics have been evaluated for antibacterial activity against multivariate bacteria. All these fabric show more than 93% antibacterial activity against multivariate bacteria. Further, 100% polyester woven samples which exhibited very good antibacterial activity were dyed with shade depth of 0.5% and 2.5% with a disperse dye. The effect of dyeing of woven fabrics on their antibacterial properties was determined. It was observed that the dyeing performance of polyester fabrics containing polyester-silver nanocomposite fibres in terms of K/S value was almost similar to neat polyester fabric. The wash and light fastness of such fabrics was very good and comparable to neat polyester fabrics. After dyeing, a marginal reduction (<2%) in antibacterial activity was noticed.

सार

आधुनिक युग में, सक्रिय स्वास्थ्य देखभाल और स्वच्छता के प्रति उपभोक्ता के दृष्टिकोण ने जीवाणुरोधी गुणों के साथ कार्यात्मक कपड़ों की बढ़ती मांग पैदा की है। कपड़ा अस्पतालों में रोगजनकों के अधिग्रहण और संचरण के साथसाथ घरेलू उपयोग में भी महत्वपूर्ण भूमिका निभाता है। कपड़ा लंबे समय से जीवाणु और कवक के विकास का समर्थन करने के लिए माध्यम के रूप में मान्यता प्राप्त है क्योंकि यह पोषक तत्वों के स्रोतके साथसाथ जीवाणु के लिए भी आश्रय के रूप में कार्य करता है। उपयोग और भंडारण के दौरान वस्त्रों पर रोगाणुओं की वृद्धि पहनने वाले के साथसाथ वस्त्र को भी नकारात्मक रूप से प्रभावित करती है। इन कारणों से, यह अत्यधिक वांछनीय है कि रेशा निर्माण के दौरान कृत्रिम रेशा में जीवाणुरोधी कारकों को शामिल करके टिकाऊ जीवाणुरोधी वस्त्रों के उपयोग से वस्त्रों पर रोगाणुओं की वृद्धि को कम किया जाए। कई जीवाणुरोधी कारकों में से, चांदी मानव जाति के विकास के बाद से सबसे व्यापक रूप से उपयोग किए जाने वाले जीवाणुरोधी कारकों में से एक है। ज्ञातव्य है कि कार्बनिक यौगिकों की तुलना में चांदी सबसे सुरक्षित जीवाणुरोधी कारकों में से एक है। चांदी 650 से अधिक रोग पैदा करने वाले सूक्ष्म-जीवों को मारने के लिए चिकित्सकीय रूप से उपयोगी साबित हुई है।

हालांकि अधिकांश अनुसंधान प्रयास परिष्करण मार्ग के माध्यम से कपड़े पर चांदी के नैनोकणों के अनुप्रयोग के आसपास घूम रहे हैं, मेल्ट स्पिनिंग चरण में रेशे में चांदी के नैनोकणों को शामिल करने के लिए केवल सीमित प्रयास किए गए हैं। इसके अलावा, जीवाणुरोधी नैनोकंपोजिट रेशा पर अधिकांश अध्ययन केवल रेशा विकास और उनके लक्षण वर्णन तक ही

सीमित हैं। यह ज्ञात है कि मेल्ट स्पिनिंग चरण के दौरान रेशों में चांदी के नैनोकणों को शामिल करने से जिस रेशों का निर्माण होता है, उनकी जीवाणुरोधी गतिविधि अधिक टिकाऊ होती है।

चांदी के नैनोकणों के साथ अंतर्निहित रेशों का (नैनोकम्पोजिट रेशा) उपयोग करके जीवाणुरोधी कपड़े (वोवेन और निटेड)के विकास का अध्ययन अपर्याप्त है। इस तरह, इस शोध कार्य में, विभिन्न मिश्रण अनुपातों पर सामान्य पॉलिएस्टर रेशा को पॉलिएस्टरसिल्वर नैनोकम्पोजिट रेशों - के साथ मिश्रित करके वोवेन और निटेड पॉलिएस्टर कपड़ों के लिए जीवाणुरोधी कार्यक्षमता प्रदान करने और ऐसे कपड़ों की जीवाणुरोधी प्रभावकारिता पर धागा और कपड़े निर्माण मापदंडों के प्रभाव का अध्ययन करने का प्रयास किया गया है। यह देखा गया है कि पॉलिएस्टरसिल्वर -) नैनोकम्पोजिट रेशों के छोटे अनुपात(10-30%) वाले पॉलिएस्टर के धागे के द्वारा तैयार वोवेन और निटेड कपड़े ग्राम -और ग्राम (एस ऑरियस) पॉजिटिव-नेगेटिव जीवाणु दोनों के (ई कोलाई)) खिलाफ बहुत अच्छी(63.20-98.89%) जीवाणुरोधी गतिविधि प्रदर्शित करते हैं। नैनोकम्पोजिट रेशों का मिश्रण अनुपात वोवेन और निटेड कपड़े की जीवाणुरोधी गतिविधि को प्रभावित करने वाले कारकों में से सबसे प्रमुख पाया गया है।

स्वास्थ्य देखभाल अनुप्रयोगों के लिए, कपड़ा सामग्री की सटीक जीवाणुरोधी गतिविधि को जानना महत्वपूर्ण है। चूंकि यह गतिविधि विभिन्न कारकों पर निर्भर करती है, इसलिए कपड़ा सामग्री के निर्माण से पहले इसके मूल्य की अग्रिम पूर्वानुमान करना एक कठिन कार्य बन जाता है। इस कारण से, एएनएन और एएनएफआईएस जैसी सॉफ्ट कंप्यूटिंग तकनीकों का उपयोग करके निटेड कपड़ों के जीवाणुरोधी गुणों की मॉडलिंग और पूर्वानुमान किया गया है। निटेड कपड़े के जीवाणुरोधी और आराम गुणों के अनुकूलन का मूल्यांकन वांछनीयता फ़ंक्शन का उपयोग करके किया गया है। इसके अलावा, मल्टीवेरिएट जीवाणु के खिलाफ जीवाणुरोधी गतिविधि के लिए कुछ

चयनित बुने हुए (वोवेन) कपड़ों का मूल्यांकन किया गया है। ये सभी कपड़े मल्टीवेरिएट जीवाणु के खिलाफ %93से अधिक जीवाणुरोधी गतिविधि दिखाते हैं। इसके अलावा, %100पॉलिएस्टर बुने हुए (वोवेन) नमूने जो बहुत अच्छी जीवाणुरोधी गतिविधि का प्रदर्शन करते थे, उन्हें %0.5 और %2.5की शेड डेप्थ के साथ डिस्पर्स डाई से रंगे हुए थे। बुने हुए (वोवेन) कपड़ों की रंगाई का प्रभाव उनके जीवाणुरोधी गुणों पर निर्धारित किया गया था। यह देखा गया कि केएस मूल्य के / नैनोकम्पोजिट रेशा वाले पॉलिएस्टर कपड़ों का रंगाई प्रदर्शन लगभग सिल्वर-संदर्भ में पॉलिएस्टर -सुथरे पॉलिएस्टर कपड़े के समान ही था। ऐसे कपड़ों की धुलाई और प्रकाश स्थिरता साफ-साफ सुथरे पॉलिएस्टर कपड़ों की तुलना में बहुत अच्छी थी। रंगाई के बाद, जीवाणुरोधी गतिविधि में मामूली कमी)< (%2देखी गई।

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols / Abbreviations	Meaning
nm	Nanometer
μm	Micrometer
mm	Millimeter
cm	Centimeter
m	Meter
μL	Microliter
ml	Milliliter
L	Liter
ppm	Parts per million
mg	Milligram
g	Gram
Kg	Kilogram
S	Second
min	Minute
h	Hour
Θ	Theta
$^{\circ}$	Degree
$^{\circ}\text{C}$	Degree Celsius
wt%	(Weight/weight) percent concentration
N_M	Number of slivers of master blend
N_N	Number of slivers of normal polyester fibres
T_M	Linear density (tex) of slivers of master blend
T_N	Linear density (tex) of normal polyester fibres
P_M	Proportion (%) of polyester-silver nanocomposite fibre in the master blend
<i>MIC</i>	Micronaire

Symbols / Abbreviations	Meaning
<i>MLR</i>	Material to liquor ratio
<i>kV</i>	Kilovolt
UHML	Upper half mean length
CFU	Colony forming unit
ATCC	American association of textile chemists and colorists
ASTM	American standard for testing machine
Conc.	Concentration
LB	Luria-bertani
PET	Polyester
PVA	Polyvinyl alcohol
PBS	Phosphate- buffered saline
SEM	Scanning electron microscope
TEM	Transmission electron microscope
EDX	Energy dispersive X-ray
XRD	X-ray diffraction
ICP-MS	Inductively coupled plasma mass spectrometry
DMEM	Dulbecco's modified eagle's medium
NP	Nanoparticle
AgNP	Silver nanoparticle
NSP	Nano-silver impregnated polyester
NP	Normal polyester
HTHP	High temperature high pressure
Ne	New English count
df	Degree of freedom
Cor Total	Corrected total sum of squares