STUDIES ON ELECTROMAGNETIC SHIELDING BEHAVIOUR OF TEXTILE FABRICS AND THEIR COMPOSITES

KRISHNASAMY JAGATHEESAN

DEPARTMENT OF TEXTILE TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY DELHI
NEW DELHI-110016, INDIA

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KRISHNASAMY JAGATHEESAN

Department of Textile Technology

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DEDICATED

TO

MY PARENTS

CERTIFICATE

This is to certify that the thesis entitled "**Studies on Electromagnetic Shielding Behaviour of Textile Fabrics and their Composites**" submitted by **Mr. Krishnasamy Jagatheesan** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy**, in the Department of Textile Technology, is a record of bonafide research work carried out by him. Mr. Krishnasamy Jagatheesan has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis.

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

(Dr. Apurba Das)

Professor

Department of Textile Technology

Indian Institute of Technology Delhi

Hauz Khas, New Delhi-110016

(Dr. R. Alagirusamy)

Professor

Department of Textile Technology

Indian Institute of Technology Delhi

Hauz Khas, New Delhi-110016

(Dr. Ananjan Basu)

Professor

Centre for Applied Research in Electronics

Indian Institute of Technology Delhi

Hauz Khas, New Delhi-110016

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ABSTRACT

The electromagnetic shielding behaviour of materials is undoubtedly dependent on the material, conductivity, incident frequency, permeability, thickness and openness present in the shield. Textile material, being flexible and light weight, can be used as shields in wide range of frequencies. Essentially, shielding occurs by means of reflection, absorption and multiple reflection of waves. To develop an effective shield for arresting wide range of frequencies (includes low frequency and C band), carbon/stainless steel/polypropylene hybrid yarn based fabrics were prepared in this study. As the structural parameters, thread density, metal content, fibre arrangement and cover factor of fabric decide the shielding efficiency, all these parameters are taken for study. The present thesis addresses these variables by studying in fabric and composite forms in wide frequency range. Different hybrid yarns such as C/PP, SS/PP, basalt/PP, C/SS/PP, carbon helical yarn and carbon helical yarn with SS core were prepared and they were investigated for EM absorption and reflection behaviour in fabric and composite stages.

As the fabric structure and fibre arrangement were crucial factors in deciding the shielding effectiveness, different woven and knitted fabrics were prepared. The openness of woven grid fabrics was varied in warp and weft directions. The increase in openness of fabric highly influences the overall shielding effectiveness of grid fabrics. The shielding behaviour of carbon, SS and C/SS/PP hybrid yarn grid fabrics were compared in low frequency range. The grid fabric having hybrid yarns with lower aperture ratio showed larger shielding effectiveness compared to other grid fabrics. In the knitted structures, effect of testing direction on the shielding behaviour was also analyzed. The rib knitted fabric having conductive loop and inlaid yarns demonstrated higher attenuation level than

conductive loop fabrics as well as inlaid knit fabrics. When the fabric was tested in course direction, a higher SE was observed compared to wale direction. The similar behaviour was observed for composite also. But the shielding characteristics were different for the fabrics in low frequency as well as in C band region. In order to develop an electromagnetic absorbing structure, carbon helical yarn was prepared. The EM absorption behaviour of plain knit carbon helical yarn fabrics and woven helical yarn fabrics were compared. In addition, effects of helical yarn density, number of core SS filaments and fabric layers on absorption behaviour of fabrics were investigated. However, the absorption behaviour of composite was totally different compared to fabric form in C band region. The helical yarn fabric composite exhibited good bending rigidity and impact resistance. For improving the EM absorption of composite, ferrite particles were loaded in the PP matrix. The conductivity, dielectric permittivity, magnetic permeability and SE of the films were characterized. The particle dispersion in the film was observed using scanning electron microscopic images. The absorption coefficients of PP based fabric composite and ferrite loaded fabric composite were compared. In this thesis, all the developed hybrid yarns were investigated for shielding behaviour in woven and knitted fabric forms. The shielding behaviours of fabrics and their composites were compared in different frequency ranges. The absorption and reflection coefficients of helical yarn fabric and composite structures and ferrite loaded composite structures were investigated in C band region. The findings on various woven and knitted structures for attenuating the EM filed in low frequency and C band region are reported in the thesis.

ABSTRACT

सामग्रियों के विद्युत चुम्बकीय परिरक्षण व्यवहार निस्संदेह ढाल में उपस्थित सामग्री, चालकता, घटना की आवृत्ति, पारगम्यता, मोटाई और खुलेपन पर निर्भर है।. लचीला और हल्के वजन वाले कपड़ा सामग्री के रूप में, इसे व्यापक श्रेणी के आवृत्तियों में ढाल के रूप में इस्तेमाल किया जा सकता है। मूलतः, परिरक्षण प्रतिबिंब, अवशोषण और तरंगों के कई प्रतिबिंब के माध्यम से होता है। इस अध्ययन में विस्तृत श्रेणी की आवृत्तियों (कम आवृत्ति और सी बैंड शामिल) को गिरफ्तार करने के लिए एक प्रभावी ढाल विकसित करने के लिए, कार्बन / स्टेनलेस स्टील / पॉलीप्रॉपिलिन हाइब्रिड यार्न आधारित कपड़े तैयार किए गए थे। जैसा कि संरचना, धागा घनत्व, धातु सामग्री, फाइबर व्यवस्था और कपड़े का कवर कारक परिरक्षण दक्षता का फैसला करता है, इन सभी मापदंडों को अध्ययन के लिए लिया जाता है।. वर्तमान थीसिस इन आवृत्तियों को व्यापक आवृत्ति रेंज में फैब्रिक और संमिश्र रूपों में पढ़कर संबोधित करते हैं। सी / पीपी, एसएस / पीपी, बेसाल्ट / पीपी, सी / एसएस / पीपी, कार्बन पेचदार धागे और एसएस कोर के साथ कार्बन पेचदार धागे जैसे विभिन्न संकर यार्न तैयार किए गए थे और उन्हें कपड़े और समग्र चरणों में ईएम अवशोषण और प्रतिबिंब व्यवहार के लिए जांच की गई थी। ।.

जैसा कि कपड़ा संरचना और फाइबर व्यवस्था परिरक्षण प्रभावशीलता के निर्णय में महत्वपूर्ण कारक थी, अलग बुना और बुना हुआ कपड़ा तैयार किए गए थे। बुना ग्रिड कपड़ों की खुलीपन ताने और बाने हुए दिशाओं में भिन्न थी। कपड़े के खुलेपन में वृद्धि से ग्रिड वस्त्रों की समग्र परिरक्षण प्रभावशीलता प्रभावित होती है। कार्बन, एसएस और सी / एसएस / पीपी हाइब्रिड धागा ग्रिड कपड़ों के परिरक्षण व्यवहार की तुलना कम आवृत्ति रेंज में की गई थी। ग्रिड कपड़े वाले हाइब्रिड यार्न कम एपर्चर अनुपात के साथ अन्य ग्रिड वस्त्रों की तुलना में बड़े परिरक्षण प्रभाव दिखाते हैं। बुना हुआ संरचनाओं में, परिरक्षण व्यवहार पर परीक्षण की दिशा का प्रभाव भी विश्लेषण किया गया था। प्रवाहकीय लूप और जड़ी हुई यार्न वाले रिब बुना हुआ कपड़े ने प्रवाहकीय लूप कपड़ों के साथ-साथ ब्लेड बुनना कपड़ों की तुलना में अधिक क्षीणन स्तर का प्रदर्शन किया। जब कपड़ों को बिल्कुल दिशा में परीक्षण किया गया था, तो एक उच्च एसई को दांत दिशा की तुलना में देखा गया था। इसी तरह के व्यवहार को समग्र के लिए भी देखा गया था। लेकिन कम आवृत्ति के साथ-साथ सी बैंड क्षेत्र में परिधान विशेषताओं के लिए अलग-अलग थे। एक विद्युत चुम्बकीय अवशोषित संरचना को विकसित करने के लिए, कार्बन पेचदार यार्न तैयार किया गया था। सादे बुनना कार्बन पेचदार यार्न के कपड़े और बुना पेचदार यार्न कपड़ों के ईएम अवशोषण व्यवहार की तुलना में थे। इसके अलावा, पेचदार धागे घनत्व के प्रभाव, कोर एसएस filaments की संख्या और कपड़ों की अवशोषण व्यवहार पर कपड़े परतों की जांच की गई। हालांकि, सी बैंड क्षेत्र में फैब्रिक फॉर्म की तुलना में सम्मिश्र का अवशोषण व्यवहार बिल्कुल अलग था। पेचदार यार्न कपड़े संमिश्र अच्छा झुकने कठोरता और प्रभाव प्रतिरोध का प्रदर्शन किया। कम्पोजिट के ईएम अवशोषण में सुधार के लिए, फेराइट कणों को पीपी मैट्रिक्स में लोड किया गया था। चालकता, ढांकता हुआ

permittivity, चुंबकीय पारगम्यता और फिल्मों के एसई की विशेषता थी। फिल्म में कण फैलाव स्कैनिंग इलेक्ट्रॉन सूक्ष्म चित्रों का उपयोग करते हुए देखा गया था। पीपी आधारित कपड़ा संमिश्र और फेराइट लोड किए गए कपड़े संमिश्र के अवशोषण गुणांक तुलना किए गए थे। इस शोध में, सभी विकसित हाइब्रिड यार्नों की बुना और बुना हुआ कपड़ा रूपों में व्यवहार को बचाने के लिए जांच की गई थी। कपड़े और उनके कंपोजिट के परिरक्षण व्यवहार की तुलना अलग-अलग फ्रीक्वेंसी रेंज में की गई थी। सी बैंड क्षेत्र में पेचदार यार्न कपड़े और समग्र संरचनाओं और फेराइट लोड किए गए समग्र संरचनाओं के अवशोषण और प्रतिबिंब के गुणांक की जांच की गई। निचला आवृत्ति और सी बैंड क्षेत्र में दायर ईएम को हटाने के लिए विभिन्न बुना और बुना हुआ संरचनाओं पर निष्कर्षों की थीसिस में सूचना दी गई है।.

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Abbreviations

EM	-	Electromagnetic
EMI	-	Electromagnetic interference
ICP	-	Intrinsically conductive polymer
SS	-	Stainless steel
L/D	-	Length to diameter
ASTM	-	American society for testing and materials
s	-	Second
m	-	Meter
Hz	-	Hertz
GHz	-	Giga-Hertz
MHz	-	Mega-Hertz
UD	-	Unidirectional
SE	-	Shielding effectiveness
Mn	-	Manganese
Zn	-	Zinc
EMF	-	Electromagnetic field
ELF	-	Extremely low frequency
IARC	-	International Agency for Research on Cancer
AGNIR	-	Advisory Group on Non-ionising Radiation
AAEM	-	American Academy of Environmental Medicine Calls
RF	-	Radio frequency
MRI	-	Magnetic Resonance Imaging
RAS	-	Radar absorbing structure
EMSE	-	Electromagnetic shielding effectiveness
dB	-	Decibel
TEM	-	Transverse electromagnetic
FDTD	-	Finite difference time domain
MoM	-	Method of moments
FEM	-	Finite element method
ε	-	Electric permittivity

ε_r	-	Relative Permittivity
ε_o	-	Vacuum permittivity
μ	-	Magnetic permeability
μ_r	-	Relative permeability
μ_o	-	Magnetic permeability in free space
kPa	-	kilo-pascal
g/d	-	grams/denier
J	-	Joules
FID	-	Ratio of diameter of lens to focal distance
Δf	-	Frequency of resonance
PET	-	Polyester
PP	-	Polypropylene
Ni	-	Nickel
Cu	-	Copper
XPS	-	X-ray photoelectron spectroscopy
PTH	-	Polythiophene
PPV	-	poly(p-phenylene-vinylene)
CB	-	Carbon black
SCF	-	Short carbon fibre
EVA	-	Ethylene vinyl acetate
NR	-	Natural rubber
ABS	-	Acrylonitrile butadiene styrene
TEM	-	Tunneling electron microscope
EPDM	-	Ethylene-propylene-diene monomer
CNT	-	Carbon nano-tube
MWCNT	-	Multi-walled carbon nano-tube
CVD	-	Chemical vapor deposition
NCGF	-	Nickel coated glass fibre
ESD	-	Electrostatic discharge
F-SS	-	Ferritic stainless steel
SSF	-	Stainless steel fibre
PPNS	-	Polypropylene nonwoven selvedge
PVC	-	Polyvinyl chloride

C/SS/PP	-	Carbon/stainless steel/polypropylene
PVB	-	Polyvinyl butyral
CCF	-	Continuous carbon fibre
CFC	-	Carbon fibre composite
FSFC	-	Frequency selective fabric composite
FSS	-	Frequency selective surface
CWKF	-	Co-weaving-knitting fabric
CMC	-	Carbon micro-coil
CCNT	-	Coiled carbon nano-tube
SWCNT	-	Single walled carbon nano-tube
OFCY	-	Open end core friction spun yarn
ppcm	-	Picks per centimeter
epcm	-	Ends per centimeter
EPI	-	Ends per inch
PPI	-	Picks per inch
DSC	-	Differential scanning calorimetric
ANOVA	-	Analysis of Variance
PAN	-	Poly acrylonitrile
3k, 6k	-	3000, 6000 fibres/tow
TPM	-	Turns/meter
SJ	-	Single jersey
VNA	-	Vector network analyzer
EMF	-	Electromotive force
XRD	-	X-ray diffraction
TGA	-	Thermogravimetric analysis
EDX	-	Energy dispersive X-ray spectrometry