

**STUDIES ON NATURAL FIBRE BASED TWIST-LESS HYBRID
YARN REINFORCED THERMOPLASTIC COMPOSITES**

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STUDIES ON NATURAL FIBRE BASED TWIST-LESS HYBRID YARN REINFORCED THERMOPLASTIC COMPOSITES

by

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Submitted

In fulfillment of the requirements for the awards of the degree of Doctor of Philosophy
to the



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Dedicated to my Parents and my
Brother

CERTIFICATE

This is to certify that the thesis entitled “**Studies on Natural Fibre Based Twist-Less Hybrid Yarn Reinforced Thermoplastic Composites**” submitted by **Mr. Mahadev Bar** 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. Mahadev Bar has worked under our guidance and supervision.

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.

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ABSTRACT

Since last few decades, natural fibre reinforced polymer composites (NFRC) are moving towards the forefront in the material community and are finding applications in different areas such as automobile, construction, packaging etc. Experts predict that in near future the market size and the demand for strong NFRC materials will grow exponentially. However, the NFRC materials have some drawbacks such as poor fibre-matrix interaction, non-uniform fibre matrix distribution, random fibre orientation in the composite structure etc. All these above mentioned factors reduce the effective fibre strength utilization in the final composite and ultimately develop a composite with inferior mechanical properties. Hence, the present research aims to develop a NFRC having improved mechanical properties. Two different hybrid yarns i.e DREF yarn and thermally bonded roving have been developed for this purpose and their various properties have been investigated to appraise the preforming ability of these yarns. Further, hybrid yarns are consolidated into unidirectional and woven fabric composite laminates. Finally various properties of these composite samples such as tensile, flexural, impact have been probed and compared with glass-PP composites.

Core-sheath structured DREF yarn has poor weavability as the sheath fibres are wrapped loosely around the core. In the present study, the DREF yarns are subjected to a thermal treatment to improve their weavability. Further, the effect of different process parameters such as core twist, sheath ratio and thermal treatment temperature on hybrid yarn properties has been studied thoroughly using Box-Behnken design. It has been observed that increase in core content, surface treatment temperature and decrease in core twist enhance the weavability of the DREF yarn. In order to analyze the influence of interface and DREF yarn structure on unidirectional composite properties, DREF yarns are manufactured after varying the core yarn

twist and sheath percentage at three different levels and using MAgPP treated and untreated flax yarn as core. These yarns are consolidated in a compression molding machine and the resultant composites are tested for tensile, flexural and Izod impact properties. MAgPP treatment of the core flax yarn, low core yarn twist and sheath content improve the tensile and flexural properties of the hybrid yarn reinforced unidirectional composites while impact strength decreases after the treatment and with increasing flax content and core twist. Further, these DREF spun yarn compressed (DYC) composites are compared with the conventional film stacked (FSC) composites at 40%, 50% and 60 % flax content levels. It has been observed that irrespective of composite structure, the tensile and flexural properties of both composite samples increase with increasing flax content but the impact strength decreases with increasing flax content. However, at constant fibre volume fraction, the DYC composites demonstrate better properties than the FSC composites. This is mainly due to better fibre-matrix distribution and lower void content of the DYC composites than the FSC composites.

In order to improve the fibre orientation and fibre/matrix distribution in the composite structure further, a novel, flax-polypropylene (PP) based twist-less, thermally bonded, flexible roving (TBR) has been developed. Flax and PP fibres in this roving structure remain in a mingled state and are highly oriented towards the roving axis. Fibres in TBR structure are held together by means of thermoplastic resin at the roving surface while the roving core remain unaffected. The effect of different process parameters on TBR properties relevant to fabric formation have been studied using Box and Behnken design. The test results conclude that the TBR samples are sufficiently strong as well as flexible enough to produce structural woven textile preform. TBR based unidirectional composites are produced to study the effect of TBR structure on their composite properties. Further, the properties TBR composites are

compared with the DYC composites. It has been observed that the tensile, flexural and Izod impact properties of the TBR-composites increase with increasing flax content and with increasing degree of flax and PP fibre mixing in the roving structure. Whereas, at constant flax content, the TBR-composites demonstrate better tensile and flexural Izod impact properties than DYC composites. Two woven fabrics with different fabric architecture (i.e. plain woven and unidirectional) are manufactured using the optimized hybrid yarn i.e TBR made of 60% flax and drawn through 6 drawing passages. The produced fabrics are consolidated and the resultant composite laminate properties are then probed and compared with glass-PP composites. It is observed that the TBR based plain woven fabric composites demonstrate better impact performance and lower tensile and flexural properties than TBR based UD-Fabric composites. However, the glass/PP composite exhibits better tensile, flexural and low velocity impact properties than TBR based woven prepreg compressed composites.

सार

पिछले कुछ दशकों से, प्राकृतिक रेशा प्रबलित बहुलक सम्मिश्रण/कंपोजिट्स (प्रारेप्रबस) भौतिक समुदाय में बहुत तेजी से उभर रहे हैं। अभी प्रारेप्रबस का उपयोग ऑटोमोबाइल, निर्माण, पैकेजिंग इत्यादि जैसे क्षेत्रों में हो रहा है। विशेषज्ञों का अनुमान है कि निकट भविष्य में इसकी मांग और भी तेजी से बढ़ेगी। पर प्रारेप्रबस सामग्रियों में कुछ कमियां हैं जैसे की रेशा का मैट्रिक्स की और असंबेदनशील होना, सम्मिश्रण में रेशा का यादृच्छिक अभिविन्यास, रेशा और मैट्रिक्स का आसमान बितरण इत्यादि। जिसकी कारन सम्मिश्रण खराब यांत्रिक गुण प्रदर्शन करती है। वर्तमान शोध में प्रारेप्रबस सामग्रियों की जंत्रिक गुणों में सुधर करने की कोसिस की गयी है। इस उद्देश्य में, दो अलग-अलग शंकर धागा, ड्रेफ और थर्मल बॉन्डेड कलाओं से प्रस्तुत किया गया है और इन धागे की क्षमता का मूल्यांकन करने के लिए उनके विभिन्न गुणों की जांच की गई है। इसके बाद, इन धागे को एकदिशा में और बुने हुए कपड़े की रूप में समेकित किया जाता है। अंत में इन सब सम्मिश्रण का विभिन्न गुणों का जाज की गयी है।

कोर-शीथ संरचित ड्रेफ धागे का खराब बुनन-खमता होती है, क्योंकि शीत फाइबर कोर के चारों ओर ढीले से अटका रहते हैं। वर्तमान अध्ययन में, ड्रेफ धागे की बुनन-खमता का सुधर के लिये इसकी थर्मल उपचार की गयी है। इसके बाद, शंकर धागे की गुणों पर कोर-शीथ अनुपात, थर्मल उपचार तापमान जैसे विभिन्न प्रक्रिया मानकों का प्रभाव बॉक्स-बेहेनकेन डिज़ाइन का उपयोग करके पूरी तरह से अध्ययन किया गया है। यह देखा गया है कि शीत सामग्री में वृद्धि, उपचार तापमान और कोर मोड़ में कमी ड्रेफ धागे को कमजोर करती है। इससे बाद, एकदिशक कंपोजिट्स गुणों पर इंटरफेस और ड्रेफ धागा-संरचना के प्रभाव का विश्लेषण करने के लिए, ड्रेफ धागे का अलग-अलग स्तरों पर कोर-मोड़ और शीथ प्रतिशत को परिवर्तित कि गयी है और कोर के रूप में एमएजीपीपी उपचार और उपचार न किए गए फ्लेक्स यार्न का उपयोग कि गयी है। ये देखा गया है की एमएजीपीपी उपचार किया हुए कम मोड़ युक्त कोर, कम म्यान सामग्री युक्त संकर धागा का उपयोग एकदिशक समग्रका टेंसिल और फ्लेक्सोरल गुणों में सुधर करते हैं जबकि समग्रका इम्पैक्ट स्ट्रेंथ कम हो जाता है। इसकेबाद, इन ड्रेफ-धागा संपीडित समग्रका (ड्रेधासंस) की तुलना पारंपरिक फिल्म स्टैकड समग्रका (पाफिस्टैस) से 40%, 50% और 60% फ्लेक्स सामग्री स्तर पर की गये है। यह देखा गया है की दोनों समग्र की टेंसिल और फ्लेक्सोरल गुण फ्लेक्स सामग्री की बढ़ने के साथ बढ़ते हैं लेकिन बढ़ती हुई फ्लेक्स सामग्री के साथ इम्पैक्टशक्ति कम हो जाती है। हालांकि, निरंतर रेशा वॉल्यूम पर, ड्रेधासंस कंपोजिट्स, पाफिस्टैस कंपोजिट्स की तुलना में बेहतर गुण प्रदर्शित करते हैं। यह मुख्य रूप से बेहतर फाइबर-मैट्रिक्स वितरण के कारण है।

कम्पोजिट संरचना में फाइबर अभिविन्यास और फाइबर / मैट्रिक्स वितरण को और बेहतर बनाने के लिए, एक नया, फ्लेक्स-पॉलीप्रोपाइलीन (पीपी) आधारित मोड़-रहित, थर्मली बॉन्ड, लचीला रोविंग (टीबीआर) विकसित किया गया है। इस टीबीआर संरचना की सतह पर सरे फाइबर थर्मोप्लास्टिक

बहुलक मेल्ट के सहारे जुड़ा रहते हैं जबकि टीबीआर कोर अप्रभावित रहता है। इसके बाद, टीबीआर शंकर धागो की गुणों पर फ्लेक्स-पॉलीप्रोपाइलीन की अनुपात, उनका मिश्रण स्तर, थर्मल उपचार तापमान जैसे विभिन्न प्रक्रिया मानकों का प्रभाव बॉक्स-बेहेनकेन डिज़ाइन का उपयोग करके पूरी तरह से अध्ययन किया गया है। परीक्षण के नतीजे यह निष्कर्ष निकालते हैं कि टीबीआर नमूने पर्याप्त रूप से मजबूत हैं और बुने हुए कपड़ा प्रीफॉर्म का उत्पादन करने के लिए काफी लचीला हैं। टीबीआर आधारित यूनियायरेक्शनल कंपोजिट्स को पर टीबीआर संरचना के प्रभाव का अध्ययन करने के लिए टीबीआर आधारित कंपोजिट्स उत्पादित किया जाता है और उनके विभिन्न गुणों का अध्ययन की जाती हैं। फिर टीबीआर कंपोजिट्स की तुलना ड्रेधासंस कंपोजिट्स से की जाती है। यह देखा गया है कि दोनों कंपोजिट्स के टेंसिल, फ्लेक्सोरल और इम्पैक्ट गुण बढ़ते फ्लेक्स सामग्री के साथ बढ़ते हैं और चलती संरचना में फ्लेक्स और पीपी फाइबर मिश्रण की बढ़ती डिग्र के साथ बढ़ते हैं। जबकि, एक/निरंतर फ्लेक्स सामग्री पर, टीबीआर-कंपोजिट्स ड्रेधासंस कंपोजिट्स की तुलना में बेहतर टेंसिल, फ्लेक्सोरल और इम्पैक्ट गुण प्रदर्शित करते हैं। इस अदाह्यान से ए निसखष निकला है कि 60% फ्लेक्स आधारित टीबीआर कंपोजिट्स सर्बाश्रेस्ट कंपोजिट्स गुण पदर्शित करता है। इसकेबाद, विभिन्न कपडा अभिविन्यास के साथ दो बुने हुए कपड़े (यानी प्लेन बुने हुए और यूनियायरेक्शनल) 60% फ्लेक्स से बने हाइब्रिड टी.बीआर का उपयोग करके निर्मित की जाती हैं, फिर उनको कंपोजिट्स रूप में समेकित किया जाता है। फिर उत्पादित कपडा- समेकित कंपोजिट्स का बीविण गुणों का जाज की जाती हैं और उनकी तुलना ग्लास-पीपी कंपोजिट्स की साथ की जाती है। यह देखा गया है कि, प्लेन-कपडा आधारित कम्पोजिट यूडी-कपडा आधारित कम्पोजिट की तुलना में कम टेंसिल, फ्लेक्सोरल गुण प्रदर्शित करते हैं। हालांकि, ग्लास / पीपी समग्र टीबीआर आधारित बुने हुए कपडा संपीडित कंपोजिट्स की तुलना में बेहतर टेंसिल, फ्लेक्सोरल, और कम वेग इम्पैक्ट गुण प्रदर्शित करता है।

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Abbreviation

FRPC	-	Fibre Reinforced Polymer Composite
°C	-	Degree Centigrade
θ	-	Theta
ELV	-	End Life Vehicles
%	-	Percentage
g/cc	-	Grams per Centimeter cubed
PP	-	Polypropylene
UD	-	Unidirectional
MAGPP	-	Maleic Anhydride grafted Polypropylene
NFRC	-	Natural Fibre Reinforced Composite
NFRTC	-	Natural Fibre Reinforced Thermoplastic Composite
DYC	-	DREF Yarn Compressed
FSC	-	Film Stacked and Compressed
TBR	-	Thermally Bonded Roving
TBRC	-	Thermally Bonded Roving Compressed
FTIR	-	Fourier-Transform Infrared spectroscopy
LVI	-	Low Velocity Impact
2D, 3D	-	Two-dimensional, Three-dimensional
SEM	-	Scanning Electron Microscopy
IR	-	Infrared
MPa	-	Mega-Pascal
GPa	-	Giga-Pascal
μm	-	Micro meter
PLA	-	Poly-Lactic Acid
kHz	-	Kilo-Hertz
m/min	-	Meter per Minute
IBI	-	Index of Blend Irregularity
cm	-	Centimeter