

**DESIGN AND DEVELOPMENT OF TEXTILE FIBRE  
REINFORCED STRUCTURAL COMPOSITES FOR  
AUTOMOTIVE APPLICATIONS**

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**DEPARTMENT OF TEXTILE AND FIBRE ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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AUTOMOTIVE APPLICATIONS**

by

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Submitted

in fulfilment of the requirement of the degree of Doctor of Philosophy

to the



**DEPARTMENT OF TEXTILE AND FIBRE ENGINEERING  
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**Dedicated To Almighty  
And My Family**

## CERTIFICATE

This is to certify that the thesis entitled “**Design and development of textile fibre reinforced structural composites for automotive applications**” being submitted by **Mr. Sandeep Olhan**, Entry No. **2018TTZ8459** 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. Mr. Sandeep Olhan has worked under my guidance and supervision. He has fulfilled all the requirements for the submission of the thesis. 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.

**Date:**

**Place:** New Delhi

**Prof. B. K. Behera**

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**Date:**

**Sandeep Olhan**

**Place:** New Delhi

## **Abstract**

The automotive industry is aggressively working on reducing vehicle weight to achieve improved fuel efficiency due to the growing concern about greenhouse gas emissions. To accomplish weight reduction and improved fuel efficiency, automotive manufacturers are currently seeking innovative lighter materials to replace traditional steel. Fuel economy and emissions are directly proportional to the weight of the vehicle. Due to strict environmental regulations aimed at reducing carbon footprints, the automotive industry is now intending to produce electric and solar-powered vehicles, with weight reduction being a key factor. This thesis focuses on the development of textile fibre reinforced structural composites using natural and man-made fibres by both conventional and novel friction stir processing (FSP) methods for automotive applications. Efforts are being made to use different textile fibres (E-glass, basalt, carbon, and sisal) to produce textile structural composites, textile nanocomposites, novel metal matrix composites, and natural fibre reinforced composites. In addition, this research introduces a novel methodical mechanics-based approach for the development of a mesoscale FEM model using SOLIDWORKS for composite reinforced with different textile structures to predict tensile, flexural, and bearing performance.

The first section of this research investigates the mechanical behavior of the textile structural composite (TSC) panels produced from different textile structures such as chopped fibre, unidirectional (UD), bidirectional (2D plain), and three-dimensional (3D) orthogonal woven structures using two different high-performance fibres (glass and basalt) for automotive components such as door and bonnet of a car. These composite specimens were manufactured by vacuum-assisted resin transfer molding (VARTM) process. Scanning electron microscope (SEM) analysis was carried out to

evaluate morphological damage and fractography of fabricated composites. In addition, the thermogravimetric analysis (TGA) and dynamic mechanical analysis (DMA) of the TSC panels were also carried out. Basalt fibre reinforced textile structural composites (BFRTSC) exhibited higher specific tensile, flexural, and impact strength as compared to glass fibre reinforced textile structural composites (GFRTSC). The basalt UD preform reinforced composite panels show a ~ 372 % increment in specific tensile strength, ~ 436 % increment in specific flexural strength, and ~ 818 % increment in specific impact strength as compared to the conventional metallic automotive components. The TGA and DMA confirmed that the developed BFRTSC panels are thermally stable and exhibited higher storage modulus compared to GFRTSC panels. The developed TSC panels are considered a potential candidate to replace traditional metallic counterparts in automotives.

The next section of this research aims to investigate the improvement in mechanical, thermal, and viscoelastic properties of textile structure-based nanocomposite material using glass and basalt fibres by incorporating graphene nanoplatelets (GNP) filler with 0, 0.25, 0.5, 0.75, and 1 wt.% into the epoxy matrix via the VARTM technique. The glass fibre-reinforced textile structural nanocomposites (GFRTSNC) and basalt fibre-reinforced textile structural nanocomposites (BFRTSNC) were investigated for their mechanical performance with respect to tensile, flexural, and impact loading. In addition, the composite samples were examined for their TGA and DMA. Optical microscopic and SEM analyses were also carried out to evaluate morphological damage and fractography of composites subjected to tensile and impact load. The basalt UD preform reinforced nanocomposites loaded with 0.5 wt.% of GNP show a ~ 15 % increment in tensile strength and ~ 34 % increment in impact strength. However, basalt UD nanocomposites loaded with 0.75 wt.% of GNP show enhancement in flexural

strength by ~ 26 %. BFRTSNC material exhibited higher tensile, flexural, and impact strength than GFRTSC panels. All the nanocomposites are thermally stable enough compared to virgin composites. The DMA confirmed that the developed BFRTSNC panels exhibited higher storage modulus compared to GFRTSNC panels. The developed nanocomposite panels are potential materials to replace traditional metals in automobile body panels.

The third section dealt with the fabrication of novel long glass fibre reinforced aluminum metal matrix composite (LGFRAMMC) material for automotive applications. The composite specimens were prepared by incorporating long glass fibre with different fibre volume percentages (50, 66, 80, and 100 vol.%) as reinforcement in aluminium alloy (Al6061) using the friction stir processing (FSP) method. The mechanical behaviour of the composite materials was investigated for their primary loading conditions, such as tensile and Izod impact stress. Microstructural characterization and fractured mechanism of the fabricated composites were carried out by SEM analysis. The tensile strength and elongation of the developed composite specimens decreased with the incorporation of long glass fibre, whereas the Izod impact strength of the developed composite specimens was significantly improved as compared to the conventional base metal (Al6061) body panels used in automobiles. The low tensile strength of LGFRAMMC specimens compared to base metal was because of tunnel defect, brittle fracture and extreme plastic deformation (EPD) as characterized by fibre pull-out, pits, and micro cracks. The synergetic effects of EPD and reinforcing by long glass fibres lead to a remarkable improvement in the impact strength.

In this section, the author deals with the manufacturing of novel textile fibre-reinforced aluminum metal matrix composites (TFRAMMC) by incorporating high-performance

fibres in three forms (i.e., long, chopped, and flakes) using the FSP technique. The composites were characterized for their tensile, flexural, and impact performance to explore their load-bearing capacity and energy absorbency. The tensile and impact strength of long fibre-reinforced composite (LFRC) were found to be the highest among all composite samples; the value being higher than even the base metal (BM). The flexural strength of the composites was in the order of flakes-reinforced composite (FRC) > LFRC > chopped fibre-reinforced composite (CFRC), and the BM exhibited the lowest flexural rigidity. The SEM and the energy dispersive X-ray spectroscopy (EDX) analysis revealed the uniform distribution and composition of various elements of the novel composite materials developed by FSP.

Needs for lightweight materials, reducing energy consumption, enhancing sustainability, and minimizing environmental footprint are the utmost driving factors for producing natural fibre-reinforced composites (NFRC) in the automotive sector to promote a greener future. Therefore, this chapter investigates the impact of different thermoset resins, alkaline treatment (different NaOH concentrations), and fibre architecture on the mechanical behavior of sisal fibre-reinforced textile structural composite (SFRTSC) panels developed from different textile structures such as chopped fibre, UD, 2D, and 3D orthogonal woven structures for automotive applications. In addition, the TGA and DMA of the SFRTSC panels were also carried out. The sisal/epoxy-based composites exhibited higher mechanical, thermogravimetric, and dynamic mechanical properties than vinyl ester and polyester-based composites. The 6 wt.% NaOH treated sisal fibre-based composites showed higher mechanical properties (tensile, flexural, and impact) than 0, 2, 4, 8, and 10 wt.% NaOH treated sisal fibre-based composites. Furthermore, the UD-SEC(sisal/epoxy-based composites)<sub>6</sub> panel exhibited higher tensile, flexural, impact, and storage

modulus than CH-SEC6, 2D-SEC6, and 3D-SEC6 panels. Additionally, a novel systematic mechanics-based approach was developed utilizing ABAQUS to create a mesoscale finite element model (FEM) model to evaluate the tensile and flexural response of SFRTSC.

Next section of this research aims to investigate the effect of different machinability processes such as drilling, abrasive water jet machining (AWJM), and laser beam machining (LBM) along with different fibre architectures on the behavior of machined hole, bearing strength (joint performance), and failure mechanism of different textile fibre-reinforced structural composites (TFRSC) fabricated using glass, basalt, and sisal fibres suitable for automotive applications. Different structural preforms such as chopped fibre, UD, 2D, and 3D woven orthogonal structures were developed and subsequently converted to their respective composite forms using the VARTM process. Morphological damage evaluation and fractography of the developed composite materials were carried out by optical microscopic analysis. The experimental observations revealed that the basalt fibre reinforced textile structural composite (BFRTSC) specimens exhibited the highest bearing strength compared to glass fibre reinforced textile structural composites (GFRTSC) and sisal fibre reinforced textile structural composites (SFRTSC) for all the processes. The bearing strength of composites was in the order of 3D > chopped > 2D > UD, respectively. Additionally, a novel methodical mechanics-based approach was introduced to develop the FEM mesoscale model using SOLIDWORKS to study the bearing response of pin-loaded TFRSC. The well-established 3D Hashin's failure and Puck's failure models were used to predict the woven-based composite material damage modes, and it was implemented through a user subroutine along with LS-DYNA. The bearing response predicted by the FEM simulation was found in a good agreement with the experimental observations.

In the last section of this research, weight reduction and fuel-saving analysis were carried out by employing textile fibre reinforced structural composite material as a substitute for traditional automotive metal body panels. By substituting metal doors, hood, and bumper in a vehicle with TSC panels, a combined weight reduction of 72.11 kg can be achieved. The calculated weight reduction corresponds to approximately 7.75 % of the total vehicle weight. The fuel economy analysis demonstrated that a weight reduction of 7.75% could lead to a fuel consumption decrease of about 5.4%.

This research confirmed that the developed TSC and nanocomposite panels (UD, 2D, and 3D) showed higher specific tensile, flexural, and impact strength (strength-to-weight ratio) than conventional automotive metal body panels. These composites also offer weight savings compared to traditional automotive metal body panels. The mechanical properties of metal matrix composites reinforced with textile fibres were determined to surpass those of the base metal matrix. Furthermore, the FEM model incorporated a material damage concept based on the 3D Hashin's failure and Puck's failure criterion to predict the woven-based composite material damage modes, and it was successfully implemented through a user subroutine along with LS-DYNA. Composites reinforced with natural fibres also possess the capability to substitute non-structural components within the automotive industry. This work was carried out predominantly to promote the application of textile fibre-reinforced structural composites for advanced load-bearing automotive components in order to reduce the vehicle weight which leads to fuel economy and ensure carbon free environment.

## सार

वाहनों द्वारा ईंधन की मार के कारण ग्रीनहाउस गैस उत्सर्जन के बारे में बढ़ती चिंता के कारण ऑटोमोटिव उद्योग बेहतर ईंधन दक्षता प्राप्त करने के लिए वाहन के वजन को कम करने पर आक्रामक रूप से काम कर रहा है। वजन घटाने और बेहतर दक्षता हासिल करने के लिए, ऑटोमोटिव निर्माता वर्तमान में पारंपरिक स्टील को बदलने के लिए नवीन हल्की सामग्री की तलाश कर रहे हैं। ईंधन अर्थव्यवस्था और उत्सर्जन वाहन के वजन पर सीधे आनुपातिक हैं। कार्बन फुटप्रिंट को कम करने के उद्देश्य से सख्त पर्यावरणीय नियमों के कारण, ऑटोमोटिव उद्योग अब इलेक्ट्रिक और सौर ऊर्जा से चलने वाले वाहनों का उत्पादन करने का इरादा रखता है, जिसमें वजन में कमी एक प्रमुख कारक है। यह थीसिस ऑटोमोटिव अनुप्रयोगों के लिए कपड़ा फाइबर प्रबलित संरचनात्मक कंपोजिट के विकास पर केंद्रित है। कपड़ा संरचनात्मक कंपोजिट, कपड़ा नैनोकम्पोजिट, नवीन धातु मैट्रिक्स कंपोजिट और प्राकृतिक फाइबर प्रबलित कंपोजिट का उत्पादन करने के लिए विभिन्न कपड़ा फाइबर (ई-ग्लास, बेसाल्ट, कार्बन और सिसल) का उपयोग करने का प्रयास किया जा रहा है। इसके अलावा, यह शोध तन्यता, लचीलेपन और असर प्रदर्शन की भविष्यवाणी करने के लिए विभिन्न कपड़ा संरचनाओं के साथ समग्र प्रबलित के लिए सॉलिडवर्क्स का उपयोग करके मेसोस्केल एफईएम मॉडल के विकास के लिए एक उपन्यास पद्धतिगत यांत्रिकी-आधारित दृष्टिकोण पेश करता है।

इस शोध का पहला खंड कटा हुआ फाइबर, यूनिडायरेक्शनल (यूडी), द्विदिशात्मक (2 डी सादा), और त्रि-आयामी (3 डी) ऑर्थोगोनल बुने हुए संरचनाओं जैसे विभिन्न कपड़ा संरचनाओं से उत्पादित कपड़ा संरचनात्मक समग्र ( टीएससी) पैनलों के यांत्रिक व्यवहार की जांच करता है। कार के दरवाजे और बोनट जैसे ऑटोमोटिव घटकों के लिए दो अलग-अलग उच्च-प्रदर्शन फाइबर (ग्लास और बेसाल्ट) का उपयोग करना। इन मिश्रित नमूनों का निर्माण वैक्यूम-असिस्टेड

रेज़िन ट्रांसफर मोल्डिंग (VARTM) प्रक्रिया द्वारा किया गया था। निर्मित कंपोजिट की रूपात्मक क्षति और फ्रैक्टोग्राफी का मूल्यांकन करने के लिए स्कैनिंग इलेक्ट्रॉन माइक्रोस्कोप (एसईएम) विश्लेषण किया गया था। इसके अलावा, टीएससी पैनलों का थर्मोग्रैविमेट्रिक विश्लेषण (टीजीए) और गतिशील यांत्रिक विश्लेषण (डीएमए) भी किया गया। बेसाल्ट फाइबर प्रबलित टेक्सटाइल स्ट्रक्चरल कंपोजिट (बीएफआरटीएससी) ने ग्लास फाइबर प्रबलित टेक्सटाइल स्ट्रक्चरल कंपोजिट (जीएफआरटीएससी) की तुलना में उच्च विशिष्ट तन्यता, लचीलेपन और प्रभाव शक्ति का प्रदर्शन किया। बेसाल्ट यूडी प्रीफॉर्म प्रबलित मिश्रित पैनल पारंपरिक धातु ऑटोमोटिव घटकों की तुलना में विशिष्ट तन्यता ताकत में ~ 372% वृद्धि, विशिष्ट फ्लेक्सुरल ताकत में ~ 436% वृद्धि और विशिष्ट प्रभाव शक्ति में ~ 818% वृद्धि दिखाते हैं। टीजीए और डीएमए ने पुष्टि की कि विकसित बीएफआरटीएससी पैनल थर्मल रूप से स्थिर हैं और जीएफआरटीएससी पैनल की तुलना में उच्च भंडारण मापांक प्रदर्शित करते हैं। विकसित टीएससी पैनल को ऑटोमोटिव में पारंपरिक धातु समकक्षों को बदलने के लिए संभावित उम्मीदवार माना जाता है।

इस शोध के अगले भाग का उद्देश्य 0, 0.25, 0.5, 0.75 और 1 के साथ ग्राफीन नैनोप्लेटलेट्स (जीएनपी) भराव को शामिल करके ग्लास और बेसाल्ट फाइबर का उपयोग करके कपड़ा संरचना-आधारित नैनोकम्पोजिट सामग्री के यांत्रिक, थर्मल और विस्कोलेस्टिक गुणों में सुधार की जांच करना है। VARTM तकनीक के माध्यम से एपॉक्सी मैट्रिक्स में wt.% ग्लास फाइबर-प्रबलित टेक्सटाइल स्ट्रक्चरल नैनोकम्पोजिट्स (जीएफआरटीएसएनसी) और बेसाल्ट फाइबर-रीइन्फोर्स्ड टेक्सटाइल स्ट्रक्चरल नैनोकम्पोजिट्स (बीएफआरटीएसएनसी) की तन्यता, लचीलेपन और प्रभाव लोडिंग के संबंध में उनके यांत्रिक प्रदर्शन के लिए जांच की गई। इसके अलावा, समग्र नमूनों की जांच उनके टीजीए और डीएमए के लिए की गई। तन्यता और प्रभाव भार के अधीन कंपोजिट की रूपात्मक क्षति और फ्रैक्टोग्राफी का मूल्यांकन करने के लिए ऑप्टिकल माइक्रोस्कोपिक और एसईएम विश्लेषण भी किए गए थे। बेसाल्ट यूडी प्रीफॉर्म प्रबलित

नैनोकम्पोजिट्स जीएनपी के 0.5% के साथ लोड किए गए हैं जो तन्य शक्ति में ~ 15% वृद्धि और प्रभाव शक्ति में ~ 34% वृद्धि दर्शाते हैं। हालाँकि, 0.75 wt.% GNP से भरे बेसाल्ट UD नैनोकम्पोजिट लचीली ताकत में ~ 26% की वृद्धि दर्शाते हैं। बीएफआरटीएससी सामग्री ने जीएफआरटीएससी पैनलों की तुलना में उच्च तन्यता, लचीलेपन और प्रभाव शक्ति का प्रदर्शन किया। वर्जिन कंपोजिट की तुलना में सभी नैनोकंपोजिट थर्मल रूप से पर्याप्त रूप से स्थिर होते हैं। डीएमए ने पुष्टि की कि विकसित BFRTSNC पैनलों ने GFRTSNC पैनलों की तुलना में उच्च भंडारण मापांक प्रदर्शित किया है। विकसित नैनोकम्पोजिट पैनल ऑटोमोबाइल बॉडी पैनल में पारंपरिक धातुओं को बदलने के लिए संभावित सामग्री हैं।

यह अनुभाग ऑटोमोटिव अनुप्रयोगों के लिए नवीन लंबे ग्लास फाइबर प्रबलित एल्यूमीनियम मेटल मैट्रिक्स कंपोजिट (LGFRAMMC) सामग्री के निर्माण से संबंधित है। घर्षण हलचल प्रसंस्करण (एफएसपी) विधि का उपयोग करके एल्यूमीनियम मिश्र धातु (एएल6061) में सुदृढीकरण के रूप में विभिन्न फाइबर मात्रा प्रतिशत (50, 66, 80, और 100 वॉल्यूम%) के साथ लंबे ग्लास फाइबर को शामिल करके मिश्रित नमूने तैयार किए गए थे। मिश्रित सामग्रियों के यांत्रिक व्यवहार की जांच उनकी प्राथमिक लोडिंग स्थितियों, जैसे तन्यता और इज़ोड प्रभाव तनाव के लिए की गई थी। SEM विश्लेषण द्वारा निर्मित कंपोजिट के सूक्ष्म संरचनात्मक लक्षण वर्णन और खंडित तंत्र का प्रदर्शन किया गया। विकसित मिश्रित नमूनों की तन्य शक्ति और बढ़ाव लंबे ग्लास फाइबर के समावेश के साथ कम हो गए, जबकि ऑटोमोबाइल में उपयोग किए जाने वाले पारंपरिक बेस मेटल (A16061) बॉडी पैनल की तुलना में विकसित मिश्रित नमूनों की इज़ोड प्रभाव शक्ति में काफी सुधार हुआ था। आधार धातु की तुलना में LGFRAMMC नमूनों की कम तन्यता ताकत सुरंग दोष, भंगुर फ्रैक्चर और अत्यधिक प्लास्टिक विरूपण (ईपीडी) के कारण थी, जो कि फाइबर पुल-आउट, गड्ढों और सूक्ष्म दरारों की विशेषता थी। ईपीडी के सहक्रियात्मक प्रभाव और लंबे ग्लास फाइबर द्वारा सुदृढीकरण से प्रभाव शक्ति में उल्लेखनीय सुधार होता है।

इस खंड में, लेखक एफएसपी तकनीक का उपयोग करके तीन रूपों (यानी, लंबे, कटे हुए और गुच्छे) में उच्च प्रदर्शन वाले फाइबर को शामिल करके उपन्यास कपड़ा फाइबर-प्रबलित एल्यूमीनियम धातु मैट्रिक्स कंपोजिट (टीएफआरएमसी) के निर्माण से संबंधित है। कंपोजिट को उनकी भार-वहन क्षमता और ऊर्जा अवशोषण का पता लगाने के लिए उनके तन्यता, लचीलेपन और प्रभाव प्रदर्शन के लिए चित्रित किया गया था। लंबे फाइबर-प्रबलित कंपोजिट (एलएफआरसी) की तन्यता और प्रभाव शक्ति सभी मिश्रित नमूनों में सबसे अधिक पाई गई; इसका मूल्य आधार धातु (बीएम) से भी अधिक है। कंपोजिट की लचीली ताकत फ्लेक्स-प्रबलित कंपोजिट (एफआरसी) > एलएफआरसी > कटा हुआ फाइबर-प्रबलित कंपोजिट (सीएफआरसी) के क्रम में थी, और बीएम ने सबसे कम लचीली कठोरता का प्रदर्शन किया। एसईएम और ऊर्जा फैलाने वाले एक्स-रे स्पेक्ट्रोस्कोपी (ईडीएक्स) विश्लेषण से एफएसपी द्वारा विकसित नवीन मिश्रित सामग्रियों के विभिन्न तत्वों के समान वितरण और संरचना का पता चला।

हरित भविष्य को बढ़ावा देने के लिए ऑटोमोटिव क्षेत्र में प्राकृतिक फाइबर-प्रबलित कंपोजिट (एनएफआरसी) के उत्पादन के लिए हल्के पदार्थों की आवश्यकता, ऊर्जा की खपत को कम करना, स्थिरता को बढ़ाना और पर्यावरणीय पदचिह्न को कम करना सबसे महत्वपूर्ण प्रेरक कारक हैं। इसलिए, वर्तमान अध्याय कटे हुए फाइबर जैसे विभिन्न कपड़ा संरचनाओं से विकसित सिसल फाइबर-प्रबलित कपड़ा संरचनात्मक समग्र (एसएफआरटीएससी) पैनलों के यांत्रिक व्यवहार पर विभिन्न थर्मोसेट रेजिन, क्षारीय उपचार (विभिन्न NaOH सांद्रता), और फाइबर वास्तुकला के प्रभाव की जांच करता है। ऑटोमोटिव अनुप्रयोगों के लिए यूडी, 2डी, और 3डी ऑर्थोगोनल बुनी संरचनाएं। इसके अलावा, एसएफआरटीएससी पैनल का टीजीए और डीएमए भी किया गया। सिसल/ एपॉक्सी-आधारित कंपोजिट ने विनाइल एस्टर और पॉलिएस्टर-आधारित कंपोजिट की तुलना में उच्च यांत्रिक, थर्मोग्रैविमेट्रिक और गतिशील यांत्रिक गुणों का प्रदर्शन किया। 6 wt.% NaOH उपचारित सिसल फाइबर-आधारित कंपोजिट ने 0, 2, 4, 8 और 10 wt.% NaOH

उपचारित सिसल फाइबर-आधारित कंपोजिट की तुलना में उच्च यांत्रिक गुण (तन्यता, लचीलापन और प्रभाव) दिखाया। इसके अलावा, यूडी- एसईसी ( सिसल/एपॉक्सी-आधारित कंपोजिट)<sup>6</sup> पैनल ने सीएच-एसईसी<sup>6</sup>, 2डी-एसईसी<sup>6</sup> और 3डी-एसईसी<sup>6</sup> पैनल की तुलना में उच्च तन्यता, लचीलापन, प्रभाव और भंडारण मापांक प्रदर्शित किया। इसके अतिरिक्त, SFRTSC की तन्यता और लचीली प्रतिक्रिया का मूल्यांकन करने के लिए मेसोस्केल परिमित तत्व मॉडल (FEM) मॉडल बनाने के लिए ABAQUS का उपयोग करके एक उपन्यास व्यवस्थित यांत्रिकी-आधारित दृष्टिकोण विकसित किया गया था ।

ड्रिलिंग, अपघर्षक जल जेट मशीनिंग (एडब्ल्यूजेएम), और लेजर बीम मशीनिंग (एलबीएम) के साथ-साथ मशीनीकृत छेद के व्यवहार , असर शक्ति (संयुक्त प्रदर्शन) पर विभिन्न फाइबर आर्किटेक्चर के साथ विभिन्न मशीनेबिलिटी प्रक्रियाओं के प्रभाव की जांच करना है। ), और ऑटोमोटिव अनुप्रयोगों के लिए उपयुक्त ग्लास, बेसाल्ट और सिसल फाइबर का उपयोग करके निर्मित विभिन्न कपड़ा फाइबर -प्रबलित संरचनात्मक कंपोजिट (टीएफआरएससी) की विफलता तंत्र । कटे हुए फाइबर, यूडी, 2डी, और 3डी बुने हुए ऑर्थोगोनल ढांचे जैसे विभिन्न संरचनात्मक प्रीफॉर्म विकसित किए गए और बाद में वीएआरटीएम प्रक्रिया का उपयोग करके उनके संबंधित समग्र रूपों में परिवर्तित कर दिए गए। ऑप्टिकल सूक्ष्मदर्शी विश्लेषण द्वारा विकसित समग्र सामग्रियों की रूपात्मक क्षति मूल्यांकन और फ्रैक्टोग्राफी की गई। प्रयोगात्मक अवलोकनों से पता चला कि बेसाल्ट फाइबर प्रबलित टेक्सटाइल स्ट्रक्चरल कंपोजिट ( बीएफआरटीएससी) नमूनों ने सभी प्रक्रियाओं के लिए ग्लास फाइबर प्रबलित टेक्सटाइल स्ट्रक्चरल कंपोजिट (जीएफआरटीएससी) और सिसल फाइबर प्रबलित टेक्सटाइल स्ट्रक्चरल कंपोजिट (एसएफआरटीएससी) की तुलना में उच्चतम असर शक्ति का प्रदर्शन किया । कंपोजिट की असर शक्ति क्रमशः 3डी > कटा हुआ > 2डी > यूडी के क्रम में थी। इसके अतिरिक्त, पिन-लोडेड टीएफआरएससी की असर प्रतिक्रिया का अध्ययन करने के लिए सॉलिडवर्क्स का उपयोग करके

एफईएम मेसोस्केल मॉडल विकसित करने के लिए एक उपन्यास पद्धतिगत यांत्रिकी-आधारित दृष्टिकोण पेश किया गया था। अच्छी तरह से स्थापित 3डी हाशिन की विफलता और पक के विफलता मॉडल का उपयोग बुने हुए-आधारित समग्र सामग्री क्षति मोड की भविष्यवाणी करने के लिए किया गया था, और इसे एलएस-डीवाईएनए के साथ एक उपयोगकर्ता सबरूटीन के माध्यम से कार्यान्वित किया गया था। एफईएम सिमुलेशन द्वारा अनुमानित असर प्रतिक्रिया प्रयोगात्मक टिप्पणियों के साथ एक अच्छे समझौते में पाई गई थी।

इस शोध के अंतिम खंड में, पारंपरिक ऑटोमोटिव मेटल बॉडी पैनल के विकल्प के रूप में कपड़ा फाइबर प्रबलित संरचनात्मक समग्र सामग्री को नियोजित करके वजन में कमी और ईंधन-बचत विश्लेषण किया गया था। किसी वाहन में धातु के दरवाजे, हुड और बम्पर को टीएससी पैनल से प्रतिस्थापित करके, संयुक्त रूप से 72.11 किलोग्राम वजन कम किया जा सकता है। गणना की गई वजन में कमी कुल वाहन वजन के लगभग 7.75% के अनुरूप है। ईंधन अर्थव्यवस्था विश्लेषण से पता चला कि 7.75% वजन में कमी से ईंधन की खपत में 5.4% तक की कमी हो सकती है।

इस शोध ने पुष्टि की कि विकसित टीएससी और नैनोकम्पोजिट पैनल (यूडी, 2डी, और 3डी) ने पारंपरिक ऑटोमोटिव मेटल बॉडी पैनल की तुलना में उच्च विशिष्ट तन्यता, लचीलापन और प्रभाव शक्ति (शक्ति-से-वजन अनुपात) दिखाया है। ये कंपोजिट पारंपरिक ऑटोमोटिव मेटल बॉडी पैनल की तुलना में वजन में बचत भी प्रदान करते हैं। कपड़ा फाइबर के साथ प्रबलित धातु मैट्रिक्स कंपोजिट के यांत्रिक गुणों को बेस मेटल मैट्रिक्स से बेहतर करने के लिए निर्धारित किया गया था। इसके अलावा, FEM मॉडल में बुने हुए-आधारित समग्र सामग्री क्षति मोड की भविष्यवाणी करने के लिए 3D हैशिन की विफलता और पक की विफलता मानदंड के आधार पर एक सामग्री क्षति अवधारणा को शामिल किया गया था, और इसे LS-DYNA के साथ एक उपयोगकर्ता सबरूटीन

के माध्यम से सफलतापूर्वक कार्यान्वित किया गया था। प्राकृतिक रेशों से प्रबलित कंपोजिट में ऑटोमोटिव उद्योग के भीतर गैर-संरचनात्मक घटकों को प्रतिस्थापित करने की क्षमता भी होती है। यह काम वजन बचाने की भारी क्षमता के कारण उन्नत लोड-बेयरिंग ऑटोमोटिव अनुप्रयोगों के लिए कपड़ा फाइबर-प्रबलित संरचनात्मक कंपोजिट को बढ़ावा देने पर केंद्रित था।

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## List of Abbreviations

Abbreviation	Description
<b>2D</b>	Bidirectional
<b>3D</b>	Three Dimensional
<b>AMMC</b>	Aluminum Metal Matrix Composites
<b>ASTM</b>	American Society for Testing and Materials
<b>AWJM</b>	Abrasive Water Jet Machining
<b>DMA</b>	Dynamic Mechanical Analysis
<b>EDX</b>	Energy Dispersive X-ray Spectroscopy
<b>EPD</b>	Extreme Plastic Deformation
<b>FEM</b>	Finite Element Model
<b>FRPC</b>	Fibre-Reinforced Polymeric Composites
<b>FSP</b>	Friction Stir Processing
<b>FTIR</b>	Fourier Transform Infrared Spectroscopy
<b>FVF</b>	Fibre Volume Fraction
<b>GNP</b>	Graphene Nanoplatelets
<b>LBM</b>	Laser Beam Machining
<b>SEM</b>	Scanning Electron Microscope
<b>TFRSC</b>	Textile Fibre-Reinforced Structural Composites
<b>TGA</b>	Thermogravimetric Analysis
<b>TSC</b>	Textile Structural Composite
<b>UD</b>	Unidirectional
<b>VARTM</b>	Vacuum Assisted Resin Transfer Molding