

**DESIGN AND DEVELOPMENT OF 3D WOVEN BASED
STRUCTURAL COMPOSITE FOR AUTOMOTIVE LEAF
SPRING**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

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Department of Textile and Fiber Engineering

Submitted

In fulfilment of the requirements of the degree of Doctor of Philosophy

to the



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**DEDICATED TO ALMIGHTY
AND MY FAMILY**

CERTIFICATE

This is to certify that the thesis entitled “**Design and development of 3D woven based structural composite for automotive Leaf Spring**” being submitted by **Mr. Vikas Khatkar**, Entry No. **2017TTZ8352** 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. Vikas Khatkar has worked under my guidance and supervision and fulfilled 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 for the award of any degree or diploma.

Prof. B K Behera

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Vikas Khatkar

Abstract

Growths of the transportation sector and vehicular emissions have increased exponentially leading to severe consequences on human health. Since 95% of the global transport energy is derived from fossil fuels gasoline and diesel so the government bodies have come up with strict regulations on transportation sectors. Keeping in view the above issue the automobile manufacturer is now looking for newer lightweight materials in place of conventional steel to achieve weight reduction and subsequently the reduction in fuel consumption. In this work, an attempt is made to replace the conventional metallic automobile leaf spring with 3D woven-based structural composite leaf spring to reduce the overall weight of a vehicle. The thesis is divided into six modules in which the first module is aimed at the design and fabrication of textile structural composite based automotive leaf spring using various textile structures (Chopped, UD (unidirectional), 2D (bidirectional) plain, 3D (3-dimensional) orthogonal and 3D interlock) as reinforcement and investigation of the basic mechanical properties (tensile, flexural, impact). All other modules are aimed at determining the primary performance attributes, fatigue and creep, damping and tribological, fabrication potential, and weight-saving analysis related to the textile structure reinforced composite leaf spring. All composite structures were prepared with similar volume fraction and identical processing condition

The first module of this work is focused on exploring the best possible textile structure that shows the proven mechanical properties required for automotive leaf spring. In this context influence of reinforcement architecture on the mechanical performance of composites was investigated for their applicability in automotive leaf spring compared to conventional steel. Mechanical properties were

analyzed in terms of tensile strength, flexural strength (3 point bending), Izod impact strength was analyzed. From the test results, it was evident that the mechanical performance of 3D orthogonal woven-based composites was found significantly better than chopped, UD, and 2D and 3D Interlock counterparts concerning lesser delamination, improved impact strength, and high energy absorption under bending stresses. Design load stresses (DLS) were found well within the range of stresses required for automotive leaf spring.

The next module was focused on determining the primary performance attributes like load-deflection behavior, the influence of strain rate on energy absorption, and relaxation characteristics of composite leaf spring developed using various textile structures as reinforcement. Leaf spring was fabricated using specially designed Teflon coated mold of semielliptical shape by employing vacuum-assisted resin transfer molding (VARIM). Woven preforms were cut to the required dimensions and placed in the mold to perform the VARIM operations. Unidirectional (UD) and bidirectional (2D) woven reforms were used in layers to achieve equivalent thickness and areal density (GSM) as compared to 3D woven fabric. Chopped fiber leaf spring was produced using a compression molding by employing a semielliptical shape Teflon coated metallic mold having a top projection and bottom cavity of leaf spring size. Spring stiffness and energy absorption of 3D Interlock reinforced composite leaf spring found highest whereas for chopped it was lowest. Spring stiffness and energy absorption of 3D ortho reinforced composite leaf spring approximately 63%, 6%, and 14% higher compared to chopped, UD, and 2D respectively. 3D Interlock being the highest stiffness and Chopped being the lowest stiffness is not suitable for leaf spring applications. This can be attributed to the above discussion that 3D orthogonal composites can be a potential material for leaf spring due to their optimum spring stiffness and energy absorption as compared

to other structures. Moreover, 3D orthogonal-based leaf spring was found to have improved performance with regard to energy absorption (at higher strain rate) and relaxation characteristics.

The next module of this work was aimed at the investigation of experimental cyclic flexural and creep behavior of different textile structure reinforced composite leaf spring. Cyclic flexural strength analysis is important because leaf spring is always subjected to fatigue load as vehicles come across various road surface irregularities of varying magnitude during their service life. Creep analysis is important because leaf spring is always subjected to a load of constant magnitude even if the vehicle is under stationary condition. Fatigue analysis is always associated with the damage progression of the leaf spring which is characterized by loss in strength and relative spring stiffness to locate failure point and type of failure. From the results obtained it was evident that the 3D orthogonal reinforced composite leaf spring exhibited improved cyclic flexural and creep performance and 3S1B stuffer-binder combination was found with the highest initial flexural strength, lowest drop in cyclic flexural strength and improved creep resistance. UD-based composite leaf spring exhibited comparable properties to 3S1B based composite leaf spring. Composite leaf springs were further analyzed for their surface damage (tensile side) due to cyclic flexural loading. Structural variation (binder percentage) of 3D structure reinforced leaf spring has a significant influence on their failure (surface damage) morphology. 3D woven composite leaf spring with minimum binder tow percentage was found to be a potential material for automotive leaf spring from cyclic flexural strength, creep resistance, stiffness retention, and failure morphology point of view.

The next module was aimed at knowing the damping and tribological behavior of various textile structures reinforced composite and their leaf spring. Energy dissipation from a vibrating structure

can be defined as damping. Improved damping behavior with minimum loss in strength and stiffness is one of the key requirements of leaf spring. The main role of damping is in eliminating the vibration transfer to the passenger and provides a smooth and comfortable ride. Leaf spring is subjected to sliding motion (during service life) between leaves in case of multi-leaf spring and connecting bolts and clamp in case of single leaf spring which may cause friction and wear. Therefore apart from damping tribological behavior is also of considerable importance. Damping was analyzed in terms of hysteresis damping, dynamic mechanical analysis and free damping of 3D orthogonal and 3D interlock composite leaf spring was found lower compared to UD and 2D plain composite leaf spring presumably due to through-thickness reinforcement. Further damping of different 3D orthogonal textile structures reinforced composite leaf spring was determined. The area under hysteresis curves increases with an increase in binder percentage. Hysteresis areas were found in order of 3S4B>3S3B>3S2B>3S1B. Similar trends were noticed in Dynamic mechanical analysis and hysteresis damping. The natural frequency of all composites was found in the range of 200-300 which is far away from the natural frequency of road irregularities. The coefficient of friction varies positively with the distribution of fiber in a different direction for a constant volume fraction were found in order of Chopped> 3D Ortho>3D Inter>2D>UD. This was because in chopped fiber composites it was highest due to the distribution of fibers in multiple directions and for UD it was lowest and increased for 2D and 3D, this was because in UD all fibers are in one direction, whereas for 2D and 3D fibers were distributed in two and three directions respectively and they offer higher resistance due to distribution of fibers from one direction in (UD) to three direction in 3D composites which caused higher coefficient of friction. 3D Inter exhibited a lower coefficient of friction than 3D ortho because the position of binder yarns is at certain angles rather

than 90 degrees as in orthogonal. Specific wear rate was found in order of 2D>3Dortho>3D inter CHOPPED>UD. Coefficient of friction and specific wear rate was found an increasing trend with increases in binder percentage and were in the order of 3S4B>3S3B>3S2B>3S1B.

The next module was aimed at investigating of fabrication potential of textile structure reinforced composite leaf spring. In advanced engineering applications, machining of composite material is a must to perform necessary assembly operations. Normally leaf spring is joined with vehicle chassis by adhesive bonding or mechanical fastening using nuts and bolts. Joining of composite leaf spring with chassis of the vehicle is always a complex process and it needs fabrication in terms of machining operation like drilling a hole for making joint. Therefore damage associated with drilling and bearing strength (double bolted joint) was carried out. Damage analysis due to drilling was primarily assessed in terms of delamination whereas Unidirectional (UD) composite was noticed with the opaque region near the hole in the direction of fibers with fiber pull-out sites near the edge of the drilled hole, which indicates the delamination failure in the longitudinal direction. In 2D composites, the opaque region (indicate internal damage of composite generally considered as delamination) was noticed all-around the drilled holes with a few fiber peel-up sites on the front side. All 3D composites found with almost negligible delamination i.e. neither the opaque region nor the fibers pull-out sites were found on either side of the drilled hole. Fiber push-out was noticed in all 3D composite (Orthogonal and Interlock) in their backside. Different bearing failure was observed for different composite structures UD composite was noticed with complete shear out failure while chopped failed due to tearing and 2D structure reinforced composite predominantly failed due to tearing and delamination failure. 3D orthogonal composite failed due to tearing in the warp direction and shear out in the weft direction whereas 3D interlock failed due to tearing in

both warp and weft direction. Overall 3D orthogonal composite reinforced leaf spring depicted the improved fabrication potential as compared to other chopped, UD, and 2D composites.

The next module was aimed at knowing the weight reduction and fuel-saving analysis due to the replacement of textiles structural composite-based leaf spring in place of conventional metallic leaf spring. It was evident from the results that the textile structural composite-based leaf spring can be up to 72% lighter in weight with the reduction in weight of approximately 33.76 kg for light/medium passenger or loading vehicle which is approximately 2% of the total vehicle weight. Fuel-saving due to this weight reduction will be approximately about 1.4 %.

3D orthogonal structure-based composite leaf spring was found superior concerning the mechanical properties, optimum primary performance like spring stiffness and energy absorption, improved cyclic flexural strength and creep behavior, better fabrication potential. These composite also offer significant weight saving as compared to conventional metallic leaf spring. The damping and tribological performance of 3D orthogonal was lower than other composite structures, however, the damping performance of 3D orthogonal can be improved by manipulating the binder thread percentage and it was evident that as the binder percentage increased the damping increased. This work focused on promoting the textile structural composite for advanced load-bearing automotive application, here we have explored their potential for automotive leaf spring due to the huge potential for weight saving.

सार

परिवहन क्षेत्र में वृद्धि और वाहनों से होने वाले उत्सर्जन में तेजी से वृद्धि हुई है जिसके कारण मानव स्वास्थ्य पर गंभीर परिणाम हुए हैं। चूंकि वैश्विक परिवहन ऊर्जा का 95% जीवाश्म ईंधन गैसोलीन और डीजल से प्राप्त होता है, इसलिए सरकारी निकाय परिवहन क्षेत्रों पर सख्त नियमों के साथ आए हैं। उपरोक्त मुद्दे को ध्यान में रखते हुए, ऑटोमोबाइल निर्माता अब वजन घटाने और बाद में ईंधन की खपत में कमी लाने के लिए पारंपरिक स्टील के स्थान पर नई हल्की सामग्री की तलाश कर रहा है। इस काम में, पारंपरिक धातु ऑटोमोबाइल लीफ स्प्रिंग को 3डी वॉवन-आधारित स्ट्रक्चरल कम्पोजिट लीफ स्प्रिंग से बदलने का प्रयास किया गया है ताकि वाहन के समग्र वजन को कम किया जा सके। थीसिस को छह मॉड्यूल में विभाजित किया गया है जिसमें पहला मॉड्यूल विभिन्न टेक्सटाइल संरचनाओं (कटा हुआ, यूडी (यूनिडायरेक्शनल), 2 डी (द्विदिशात्मक) सादा, 3 डी (3-आयामी) ऑर्थोगोनल और 3 डी इंटरलॉक) का उपयोग करके टेक्सटाइल स्ट्रक्चरल कम्पोजिट आधारित ऑटोमोटिव लीफ स्प्रिंग के डिजाइन और निर्माण के उद्देश्य से है। बुनियादी यांत्रिक गुणों (तन्यता, फ्लेक्सुरल, प्रभाव) के सुदृढीकरण और जांच के रूप में। अन्य सभी मॉड्यूल का उद्देश्य प्राथमिक प्रदर्शन विशेषताओं, थकान और रेंगना, भिगोना और जनजातीय, निर्माण क्षमता, और कपड़ा संरचना प्रबलित समग्र पत्ती वसंत से संबंधित वजन-बचत विश्लेषण का निर्धारण करना है। सभी मिश्रित संरचनाएं समान मात्रा अंश और समान प्रसंस्करण स्थिति के साथ तैयार की गई थीं

इस काम का पहला मॉड्यूल सर्वोत्तम संभव कपड़ा संरचना की खोज पर केंद्रित है जो ऑटोमोटिव लीफ स्प्रिंग के लिए आवश्यक सिद्ध यांत्रिक गुणों को दर्शाता है। इस संदर्भ में कंपोजिट के यांत्रिक प्रदर्शन पर सुदृढीकरण वास्तुकला के प्रभाव की जांच पारंपरिक स्टील की तुलना में ऑटोमोटिव लीफ स्प्रिंग में उनकी प्रयोज्यता के लिए की गई थी। तन्य शक्ति, फ्लेक्सुरल ताकत (3 बिंदु झुकने) के संदर्भ में यांत्रिक गुणों का विश्लेषण किया गया था, इज़ोड प्रभाव शक्ति का विश्लेषण किया गया था। परीक्षण के परिणामों से, यह स्पष्ट था कि 3 डी ऑर्थोगोनल बुने-आधारित कंपोजिट का यांत्रिक प्रदर्शन कटा हुआ, यूडी, और 2 डी और 3 डी इंटरलॉक समकक्षों की तुलना में कम प्रदूषण, बेहतर प्रभाव शक्ति और झुकने वाले तनावों के तहत उच्च ऊर्जा अवशोषण से काफी बेहतर पाया गया। ऑटोमोटिव लीफ स्प्रिंग के लिए आवश्यक स्ट्रेस की सीमा के भीतर डिजाइन लोड स्ट्रेस (डीएलएस) अच्छी तरह से पाए गए।

अगला मॉड्यूल लोड-डिफ्लेक्शन व्यवहार, ऊर्जा अवशोषण पर तनाव दर के प्रभाव, और सुदृढीकरण के रूप में विभिन्न कपड़ा संरचनाओं का उपयोग करके विकसित मिश्रित पत्ती वसंत की छूट विशेषताओं जैसे प्राथमिक प्रदर्शन विशेषताओं को निर्धारित करने पर केंद्रित था। लीफ स्प्रिंग को वैक्यूम-असिस्टेड रेजिन ट्रांसफर मोल्डिंग (VARIM) को नियोजित करके अर्ध-अण्डाकार आकार के विशेष रूप से डिज़ाइन किए गए टेफ्लॉन कोटेड मोल्ड

का उपयोग करके बनाया गया था। बुने हुए प्रीफॉर्म को आवश्यक आयामों में काट दिया गया और VARIM संचालन करने के लिए मोल्ड में रखा गया। 3D बुने हुए कपड़े की तुलना में समान मोटाई और क्षेत्र घनत्व (GSM) प्राप्त करने के लिए परतों में यूनिडायरेक्शनल (UD) और द्विदिश (2D) बुने हुए सुधारों का उपयोग किया गया था। कटा हुआ फाइबर लीफ स्प्रिंग एक अर्ध-अण्डाकार आकार के टेफ्लॉन कोटेड मेटालिक मोल्ड को नियोजित करके एक संपीडन मोल्लिंग का उपयोग करके उत्पादित किया गया था जिसमें एक शीर्ष प्रक्षेपण और पत्ती वसंत आकार की निचली गुहा होती है। स्प्रिंग की कठोरता और 3डी इंटरलॉक प्रबलित कम्पोजिट लीफ स्प्रिंग का ऊर्जा अवशोषण उच्चतम पाया गया जबकि कटा हुआ के लिए यह सबसे कम था। 3डी ऑर्थो रीडिफोर्सड कम्पोजिट लीफ स्प्रिंग की स्प्रिंग कठोरता और ऊर्जा अवशोषण क्रमशः कटा हुआ, यूडी और 2डी की तुलना में लगभग ६३%, ६% और १४% अधिक है। 3डी इंटरलॉक उच्चतम कठोरता और कटा हुआ सबसे कम कठोरता होने के कारण लीफ स्प्रिंग अनुप्रयोगों के लिए उपयुक्त नहीं है। यह उपरोक्त चर्चा के लिए जिम्मेदार ठहराया जा सकता है कि 3 डी ऑर्थोगोनल कम्पोजिट उनके इष्टतम वसंत कठोरता और तुलना में ऊर्जा अवशोषण के कारण लीफ स्प्रिंग के लिए एक संभावित सामग्री हो सकती है। इसके अलावा, 3डी ऑर्थोगोनल-आधारित लीफ स्प्रिंग में ऊर्जा अवशोषण (उच्च तनाव दर पर) और विश्राम विशेषताओं के संबंध में बेहतर प्रदर्शन पाया गया।

इस कार्य के अगले माँड्यूल का उद्देश्य विभिन्न कपड़ा संरचना प्रबलित मिश्रित लीफ स्प्रिंग के प्रयोगात्मक चक्रीय फ्लेक्सुरल और रेंगना व्यवहार की जांच करना था। चक्रीय फ्लेक्सुरल स्ट्रेथ विश्लेषण महत्वपूर्ण है क्योंकि लीफ स्प्रिंग हमेशा थकान भार के अधीन होता है क्योंकि वाहन अपने सेवा जीवन के दौरान अलग-अलग परिमाण की विभिन्न सड़क सतह अनियमितताओं का सामना करते हैं। रेंगना विश्लेषण महत्वपूर्ण है क्योंकि लीफ स्प्रिंग हमेशा स्थिर परिमाण के भार के अधीन होता है, भले ही वाहन स्थिर स्थिति में हो। थकान विश्लेषण हमेशा लीफ स्प्रिंग की क्षति प्रगति से जुड़ा होता है जो कि विफलता बिंदु और विफलता के प्रकार का पता लगाने के लिए ताकत और सापेक्ष वसंत कठोरता में कमी की विशेषता है। प्राप्त परिणामों से यह स्पष्ट था कि 3डी ऑर्थोगोनल प्रबलित कम्पोजिट लीफ स्प्रिंग ने बेहतर चक्रीय फ्लेक्सुरल और क्रीप प्रदर्शन का प्रदर्शन किया और 3एस1बी स्टर-बाइंडर संयोजन को उच्चतम प्रारंभिक फ्लेक्सुरल ताकत, चक्रीय फ्लेक्सुरल ताकत में सबसे कम गिरावट और बेहतर रेंगना प्रतिरोध के साथ पाया गया। यूडी-आधारित मिश्रित लीफ स्प्रिंग ने 3एस1बी आधारित मिश्रित लीफ स्प्रिंग के तुलनीय गुणों का प्रदर्शन किया। चक्रीय फ्लेक्सुरल लोडिंग के कारण उनकी सतह क्षति (तन्य पक्ष) के लिए समग्र पत्ती के झरनों का विश्लेषण किया गया था। 3डी संरचना प्रबलित लीफ स्प्रिंग की संरचनात्मक भिन्नता (बाइंडर प्रतिशत) उनकी विफलता (सतह क्षति) आकारिकी पर महत्वपूर्ण प्रभाव डालती है। न्यूनतम बाइंडर टो प्रतिशत के साथ 3डी बुने हुए कम्पोजिट लीफ स्प्रिंग को चक्रीय फ्लेक्सुरल ताकत, रेंगना प्रतिरोध, कठोरता प्रतिधारण, और विफलता आकृति विज्ञान के दृष्टिकोण से ऑटोमोटिव लीफ स्प्रिंग के लिए एक संभावित सामग्री के रूप में पाया गया।

अगले मॉड्यूल का उद्देश्य विभिन्न टेक्सटाइल स्ट्रक्चर्स रीइन्फोर्सड कंपोजिट और उनके लीफ स्पिंग के डंपिंग और ट्राइबोलॉजिकल व्यवहार को जानना था। एक कंपनी संरचना से ऊर्जा अपव्यय भिगोना के रूप में परिभाषित किया जा सकता है। मजबूती और कठोरता में न्यूनतम हानि के साथ बेहतर भिगोना व्यवहार, लीफ स्पिंग की प्रमुख आवश्यकताओं में से एक है। भिगोना की मुख्य भूमिका यात्री को कंपनी हस्तांतरण को समाप्त करने में होती है और एक सहज और आरामदायक सवारी प्रदान करती है। लीफ स्पिंग मल्टी-लीफ स्पिंग के मामले में पत्तियों के बीच स्लाइडिंग गति (सेवा जीवन के दौरान) के अधीन है और सिंगल लीफ स्पिंग के मामले में कनेक्टिंग बोल्ट और क्लैप है जो घर्षण और पहनने का कारण बन सकता है। इसलिए अवमंदन के अलावा ट्राइबोलॉजिकल व्यवहार का भी काफी महत्व है। डंपिंग का विश्लेषण हिस्टैरिसिस डंपिंग के संदर्भ में किया गया था, गतिशील यांत्रिक विश्लेषण और 3 डी ऑर्थोगोनल और 3 डी इंटरलॉक कम्पोजिट लीफ स्पिंग की फ्री डंपिंग यूडी और 2 डी प्लेन कम्पोजिट लीफ स्पिंग की तुलना में कम पाई गई थी, संभवतः थ्रू-थिकनेस रीइन्फोर्समेंट के कारण अलग-अलग 3 डी ऑर्थोगोनल टेक्सटाइल की और डंपिंग संरचना प्रबलित समग्र पत्ती वसंत निर्धारित किया गया था। हिस्टैरिसिस वक्र के तहत क्षेत्र बाइंडर प्रतिशत में वृद्धि के साथ बढ़ता है। हिस्टैरिसिस क्षेत्र 3S4B>3S3B>3S2B>3S1B के क्रम में पाए गए। इसी तरह के रुझान गतिशील यांत्रिक विश्लेषण और हिस्टैरिसिस डंपिंग में देखे गए थे। सभी कंपोजिट की प्राकृतिक आवृत्ति 200-300 की सीमा में पाई गई जो सड़क अनियमितताओं की प्राकृतिक आवृत्ति से बहुत दूर है। घर्षण का गुणांक एक अलग दिशा में फाइबर के वितरण के साथ सकारात्मक रूप से भिन्न होता है, एक स्थिर मात्रा अंश के लिए कटा हुआ> 3 डी ऑर्थो> 3 डी इंटर> 2 डी> यूडी के क्रम में पाया गया था। ऐसा इसलिए था क्योंकि कटा हुआ फाइबर कंपोजिट में यह कई दिशाओं में फाइबर के वितरण के कारण उच्चतम था और यूडी के लिए यह सबसे कम था और 2 डी और 3 डी के लिए बढ़ा था, ऐसा इसलिए था क्योंकि यूडी में सभी फाइबर एक दिशा में हैं, जबकि 2 डी और 3 डी फाइबर के लिए। क्रमशः दो और तीन दिशाओं में वितरित किए गए थे और वे 3डी कंपोजिट में एक दिशा (यूडी) से तीन दिशा में फाइबर के वितरण के कारण उच्च प्रतिरोध प्रदान करते हैं जिससे घर्षण का उच्च गुणांक होता है। 3डी इंटर ने 3डी ऑर्थो की तुलना में घर्षण के कम गुणांक का प्रदर्शन किया क्योंकि बाइंडर यार्न की स्थिति ऑर्थोगोनल की तरह 90 डिग्री के बजाय कुछ कोणों पर होती है। विशिष्ट वीर की दर 2D>3Dortho>3D inter Chopped>UD के क्रम में पाई गई। घर्षण के गुणांक और विशिष्ट पहनने की दर में बाइंडर प्रतिशत में वृद्धि के साथ बढ़ती प्रवृत्ति पाई गई और वे 3S4B>3S3B>3S2B>3S1B के क्रम में थे।

अगले मॉड्यूल का उद्देश्य कपड़ा संरचना प्रबलित समग्र लीफ स्पिंग की निर्माण क्षमता की जांच करना था। उन्नत इंजीनियरिंग अनुप्रयोगों में, आवश्यक असेंबली संचालन करने के लिए मिश्रित सामग्री की मशीनिंग आवश्यक है। आम तौर पर लीफ स्पिंग को वाहन चेसिस के साथ चिपकने वाली बॉन्डिंग या नट और बोल्ट का उपयोग करके यांत्रिक बन्धन द्वारा जोड़ा जाता है। वाहन के चेसिस के साथ कम्पोजिट लीफ स्पिंग को जोड़ना हमेशा एक जटिल

प्रक्रिया होती है और इसे मशीनिंग ऑपरेशन के संदर्भ में निर्माण की आवश्यकता होती है जैसे कि जोड़ बनाने के लिए छेद करना। इसलिए ड्रिलिंग और असर ताकत (डबल बोल्ट संयुक्त) से जुड़े नुकसान को अंजाम दिया गया। ड्रिलिंग के कारण होने वाले नुकसान के विश्लेषण का मूल्यांकन मुख्य रूप से प्रदूषण के संदर्भ में किया गया था, जबकि यूनिडायरेक्शनल (यूडी) कंपोजिट को छेद के पास अपारदर्शी क्षेत्र के साथ फाइबर की दिशा में फाइबर पुल-आउट साइटों के साथ ड्रिल किए गए छेद के किनारे के पास देखा गया था, जो कि प्रदूषण को इंगित करता है। अनुदैर्घ्य दिशा में विफलता। 2डी कंपोजिट में, अपारदर्शी क्षेत्र (आमतौर पर प्रदूषण के रूप में माने जाने वाले कंपोजिट की आंतरिक क्षति को इंगित करता है) को ड्रिल किए गए छिद्रों के चारों ओर देखा गया था, जिसमें सामने की तरफ कुछ फाइबर पील-अप साइट थे। ड्रिल किए गए छेद के दोनों ओर न तो अपारदर्शी क्षेत्र और न ही फाइबर पुल-आउट साइट लगभग नगण्य प्रदूषण के साथ पाए गए सभी 3डी कंपोजिट पाए गए। फाइबर पुश-आउट सभी 3डी कंपोजिट (ऑर्थोगोनल और इंटरलॉक) में उनके बैकसाइड में देखा गया था। विभिन्न मिश्रित संरचनाओं के लिए अलग-अलग असर विफलता देखी गई थी, यूडी कंपोजिट को पूर्ण कतरनी विफलता के साथ देखा गया था, जबकि कटा हुआ फाइबर के कारण विफल हो गया था और 2 डी संरचना प्रबलित समग्र रूप से फाइबर और गैर-परतबंदी की विफलता के कारण विफल हो गया था। ताना दिशा में फटने और बाने की दिशा में कतरनी के कारण 3डी ऑर्थोगोनल कंपोजिट विफल हो गया जबकि ताना और बाने दोनों दिशाओं में फाइबर के कारण 3 डी इंटरलॉक विफल हो गया। कुल मिलाकर 3डी ऑर्थोगोनल कंपोजिट रीइन्फोर्सड लीफ स्प्रिंग ने अन्य कटे हुए, यूडी और 2डी कंपोजिट की तुलना में बेहतर फैब्रिकेशन क्षमता को दर्शाया।

अगले मॉड्यूल का उद्देश्य पारंपरिक धातु लीफ स्प्रिंग के स्थान पर वस्त्र संरचनात्मक समग्र-आधारित पत्ती वसंत के प्रतिस्थापन के कारण वजन घटाने और ईंधन-बचत विश्लेषण को जानना था। परिणामों से यह स्पष्ट था कि टेक्सटाइल स्ट्रक्चरल कंपोजिट-आधारित लीफ स्प्रिंग वजन में 72% तक हल्का हो सकता है, हल्के / मध्यम यात्री या लोडिंग वाहन के लिए लगभग 33.76 किलोग्राम वजन में कमी के साथ जो कुल वाहन का लगभग 2% है। इस वजन में कमी के कारण ईंधन की बचत लगभग 1.4% होगी। 3डी ऑर्थोगोनल संरचना-आधारित मिश्रित लीफ स्प्रिंग यांत्रिक गुणों, वसंत कठोरता और ऊर्जा अवशोषण जैसे इष्टतम प्राथमिक प्रदर्शन, बेहतर चक्रीय फ्लेक्सुरल ताकत और रेंगना व्यवहार, बेहतर निर्माण क्षमता से बेहतर पाया गया। ये कंपोजिट पारंपरिक धातु के लीफ स्प्रिंग की तुलना में महत्वपूर्ण वजन बचत भी प्रदान करते हैं। 3डी ऑर्थोगोनल का डंपिंग और ट्राइबोलॉजिकल प्रदर्शन अन्य मिश्रित संरचनाओं की तुलना में कम था, हालांकि, बाइंडर श्रेड प्रतिशत में हेरफेर करके 3डी ऑर्थोगोनल के डंपिंग प्रदर्शन में सुधार किया जा सकता है और यह स्पष्ट था कि बाइंडर प्रतिशत में वृद्धि के कारण डंपिंग में वृद्धि हुई। यह काम उन्नत लोड बियरिंग ऑटोमोटिव एप्लिकेशन के लिए टेक्सटाइल स्ट्रक्चरल कंपोजिट को बढ़ावा देने पर केंद्रित है, यहां हमने वजन बचाने की विशाल क्षमता के कारण ऑटोमोटिव लीफ स्प्रिंग के लिए उनकी क्षमता का पता लगाया है।

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List of abbreviations

UD	: Unidirectional
2D	: Bidirectional
3D	: 3 Dimensional
FRP	: Fiber reinforced polymer composite
TSRC	: Textile structure reinforced composite
FVF	: Fiber volume fraction
SAE	: Society of automotive Engineers
DLS	: Design load stress
VARTM	: Vacuum Assisted Resin Transfer Molding
3D Ortho	: 3D Orthogonal
3D Inter	: 3D Interlock