

Thesis Title: Design and Development of 3D Woven Based Structural Composite for Automotive Leaf Spring

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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) and, Izod impact strength. 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 a 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 orthogonal structure 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 Interlock exhibited a lower coefficient of friction than 3D orthogonal because the position of binder yarns are 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 the chassis of the vehicle is always a complex process and it needs fabrication in terms of machining operation like drilling a hole for making a joint. Therefore damage analysis 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 (which indicates 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 were 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 savings 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.