Paradigm Academic Press
Innovation in Science and Technology
ISSN 2788-7030
SEP. 2022 VOL.1 NO.2

Research on the Application of New Composite Leaf Springs for Commercial Vehicles

Bing Li[1], Qingrui Zhang[1], Jinmeng Yang[1], Wen Li[1], Hongchen Wu[1] & Xinyu Zheng[1]

[1] ShanDong JiaoTong University

Correspondence: Bing Li, ShanDong JiaoTong University.

doi: 10.56397/IST.2022.09.05

Abstract

As the main load bearing components of commercial vehicles, leaf springs are generally heavy, and the demand for lightweighting is very urgent. Due to its unique material structure, the composite leaf springs have excellent performance and significant weight reduction effects. In this paper, the heating time during the production of composite leaf springs is shortened, and the production efficiency is greatly improved by establishing a suitable temperature-pressure-time moldflow molding window. Through the preforming process, the original multi-channel and multi-cavity molding structure is combined with the linkage demolding structure to achieve quick demolding. Finally, the molding cycle of composite leaf springs is controlled within 5min. It has achieved the same technical level as foreign countries, and effectively solved the problems of slow molding of composite leaf springs and inabilities to meet the demand of mass production in the past, which is of great significance for the large-scale industrial production and application of composite leaf springs.

Keywords: composite leaf spring, molding cycle, industrial application

1. Introduction

Today, energy demand and environmental pollution pressure are becoming increasingly severe. In September 2020, President Xi Jinping proposed China's peak carbon dioxide emissions by 2030 and carbon neutrality goal by 2060 at the 75th Session of the United Nations General Assembly. The automotive industry is an important pillar industry of the national economy, but vehicle exhaust pollution accounts for more than 70% of air pollution. Relevant studies show that the size of the commercial vehicle market in China will increase sharply from 4.16 million in 2017 to 11.8 million in 2025. The widespread application of commercial vehicle lightweighting technology can significantly reduce energy consumption, vehicle exhaust emissions, and environmental pollution, which plays a vital role in safeguarding national energy strategy security and helping the automotive industry achieve the "dual carbon" goal. *Made in China 2025* proposes to improve the engineering and industrial application capabilities of automotive lightweighting materials and promote the low-carbon development of the automotive industry. Both policies indicate that automotive lightweighting is still an important direction for the development of the automotive industry in the future.

With the official implementation of the *Items and Methods for Safety Technology Inspection of Motor Vehicles* (GB38900-2020) on January 1, 2021, the regulation mandates that the curb weight error of a new commercial vehicle is ±100kg and the in-use vehicle error is ±200kg. However, the curb weight of small light trucks with vehicle license plates (sales of about 700,000 units/year), which account for about 60% of the number of light trucks, generally exceeds the limit by more than 200kg, resulting in new license plates, in-use vehicle annual inspections difficulties. Therefore, small light trucks with vehicle license plates are urgently needed to be lightweight. In the development of lightweighting technology for commercial vehicles, high strength steel and aluminum have been widely applied, and the space for further lightweighting is very limited. With its advantages of low density and high strength, the application of composites in the commercial vehicle industry has ushered in new development opportunities.

2. Research Object

The new composite plate springs for commercial vehicles are made of composites instead of traditional leaf springs. With innovations of materials and structures, it reduces the self-weight of commercial vehicles, improves the practicality, safety and fatigue resistance, and extends the service life than leaf springs, which can achieve the same life as the vehicle. According to the *Annual Report on the Development of China's Commercial Vehicle Industry,* by the end of 2021, the overall sales of commercial vehicles reached 4.793 million, and the implementation of policies such as the elimination of old vehicles, overload management and the regulation of "high-tonnage trucks marked with low-tonnage" will be accelerated to further stimulate the stock market update demand release. The fatigue life of common leaf springs is generally about 150,000 times, and leaf springs are generally replaced once in the course of use, while the fatigue life of composite leaf springs can be the same as the life of the vehicle, which can meet the life-long use requirements of most commercial vehicles. Data indicated that the weight of a single vehicle can be reduced by 10%, the fuel consumption per 100 kilometers can be reduced by about 6% to 8%, and exhaust emissions can be reduced by about 4% to 10%. The vehicle's weight is reduced, specific fuel consumption is improved, and the effect of energy conservation and environmental protection is achieved, which is fully in line with the basic national policy of strengthening energy conservation and emission reduction and realizing low-carbon development as proposed in the outline of "13th Five-Year Plan".

3. Structural Design

Considering that the design and application of traditional longitudinal leaf springs are very mature, the new composite leaf springs for commercial vehicles preferably adopt the same structure to play the same role. The composite blade has anisotropic characteristics, the Young's modulus in the fiber orientation is significantly larger than that in other orientations, and the shear modulus without fiber action is also much lower. Leaf springs mainly bear the vertical and lateral forces and moments generated by the uneven road surface, the longitudinal forces generated during braking and starting acceleration, and the steady-state lateral forces and moments generated during the turning process. To provide higher stiffness and strength for the vertical force, the fiber orientation is generally set mainly along the length of the leaf spring. Leaf spring eyes need to bear a large torsional shear stress, vertical and longitudinal forces, and loads under different working conditions are complex. If the integral composite molding is adopted, the strength and reliability of the end cannot be guaranteed. Thus, the structural design of the bolted connection between the metal spring eyes and the blade end is adopted. At the same time, in order to ensure the tensile or compressive strength of the end and torsional and shear resistance, it needs to thicken the size of the end, while the increase in the thickness of the root significantly increases the stiffness of the leaf spring, which is not conducive to the bending resistance of the leaf spring. Therefore, it needs to match the thickness of the end and the middle of the root, and use the upper and lower concave-convex metal gussets for assembly, and the upper and lower gussets are provided with location pins to facilitate the installation of the internal and external interfaces of the suspension. Since the blade body is not wear-resistant, in order to avoid the damage to the body fiber and the stress concentration caused by the central hole, a high-strength flat tape is used to bond and fix the gusset plate and the blade.

4. Research Materials

Although the practice process is prone to problems such as deformation of fiber layups, poor operating environment, and difficulty in meeting environmental protection standards, team members analyzed the optimal number of layers and the sequence, length, and angle of each layer for 40 times within one year, and concluded the best layup plan, which ultimately significantly improved the performance index of the composite leaf springs. Finally, the structural design was further carried out to reduce the weight by finding the best variable section width. Based on this research, the following conclusions can be drawn:

Four different fiber-reinforced composites were used to model two types of leaf springs, double and single. After comparison, the results showed that the composites can replace leaf springs. The structure of the single-piece E-glass fiber composite leaf spring was optimized. Through more than 70 tests, E-glass fiber, S-glass fiber, and carbon fiber were compared in terms of temperature range, mechanical properties and process applicability. E-glass fiber was finally selected as the reinforcing material. The three types of the matrix material, polyester, vinyl ester resins, and epoxy resin, were compared in terms of thermosetting, long-term static load and dynamic load bearing capacity, impact absorption performance, and heat resistance. Epoxy resin was ultimately selected as the matrix material for composite leaf springs. After 63 mechanical properties analyses and experimental verification, our team finally selected epoxy resin + E-glass fiber. Moreover, after 5 failed tests, we determined the best material ratio scheme in the end.

5. Preload Analysis

The new composite leaf springs for commercial vehicles differ from traditional steel springs. The Young's modulus of the plate spring body in the thickness direction is very small, resulting in greater compression deformation than steel plate springs during the actual assembly preload process, thereby increasing the remaining length of the u-bolt. In order to ensure that the threads of the u-bolt are moderate and the remaining length is about 9 mm, it is necessary to simulate and check the assembly preload and compression amount of composite leaf springs to avoid insufficient thread length during the trial production. The analysis showed that the assembly preload deformation of the front spring is about 5mm, and the rear spring simulation refers to the front spring. In the process of wheel hopping, the leaf spring as a suspension elastic element will undergo elastic deformation. If the steering knuckle kingpin does not coincide with the movement track point of the plate spring, the movement of steering linkages and the suspension guide mechanism is not coordinated. The amount of interference is generated, which will lead to the deflection of the steering wheel and tire runout. The composite front spring is a single parabolic spring. Due to the variable curvature characteristics of each segment, the traditional SAE plane check method will produce large errors.

6. Process Selection

In the design of composite plate spring structure, the stiffness and strength of composite layup structure are analyzed by FEM software. Although the practice process is prone to problems such as deformation of fiber layups, poor operating environment, and difficulty in meeting environmental protection standards, team members analyzed the optimal number of layers and the sequence, length, and angle of each layer for 40 times within one year, and concluded the best layup plan, which ultimately significantly improved the performance index of the composite leaf springs. Nearly 230 tests were completed to initially set the temperature-time moldflow molding window; After half a year of testing to improve the moldflow molding window, it was finally determined to be the temperature-pressure-time moldflow molding window. Through the preforming process and the original multi-channel and multi-cavity molding structure, the molding cycle of composite plate springs was finally controlled within 5min.

7. Performance Index

While ensuring the reliability of leaf springs, the new composite leaf springs for commercial vehicles can achieve a 60% weight reduction compared with leaf springs. The fatigue life of plate springs is about 160,000 times, while the fatigue life of new composite plate springs for commercial vehicles is more than 300,000 times, and the life increase by more than 87.5%, which can achieve the same life as the vehicle. At the same time, when the vehicle is running in an extremely harsh environment, composite leaf springs can slowly crack along the length of the early warning but still keep the axle position unchanged, effectively ensuring the safety of the whole vehicle and the occupants.

Compared with the common composite plate springs, the new composite plate springs for commercial vehicles can achieve the molding cycle of composite plate spring ≤5min and the molding control of single composite plate spring blank ≤10min by preferably pre-preg, pre-pressing molding process and single-cavity with multi-mold technology, which effectively solves the problems of high production cost and slow molding cycle of composite plate springs and cannot meet the demand of the mass production in the past.

8. Conclusion

At present, high strength steel and aluminum-magnesium alloy have been widely applied in commercial vehicles, and the space for further lightweighting is very limited. In the development of automotive lightweighting technology, the lightweighting replacement of non-load bearing structural parts like vehicle bodies and cargo boxes have been basically completed. The research and development of the load bearing structural parts of the vehicle body is still in the tentative stage. Compared with other load bearing structural parts, the leaf spring has an obvious weight reduction effect in terms of weight reduction. At the same time, the structure of the leaf spring is relatively simple, and the load state is not very complicated, and the technical development difficulty is relatively small. Therefore, the composite leaf spring selection project for technological development has leading significance for the application of composites in automotive lightweighting. In order to achieve breakthrough lightweighting effects for domestic commercial vehicles, it is necessary to strengthen the application of composites with lighter density and greater strength on bearing parts.

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