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Analysis viscoelastic properties of the composite leaf spring

A A Belyaeva and K B Evseev*

Bauman Moscow State Technical University, 5/1, 2-ya Baumanskaya street, Moscow, 105005, Russia

* kb_evseev@bmsrtu.ru

Abstract. In modern conditions of market competition leading manufacturers of wheeled vehicles and their components actively introduce new technologies in the process of production of their products. One of the directions of modern automobile industry development is application of new materials, which include polymeric composite materials (PCM). In the given research the analysis of elastic properties of a leaf spring made of application of polymeric composite materials is carried out. In the study the analysis of the construction by finite element (FE) method and the analysis of the results of bench tests are carried out. To carry out the research, the appropriate design was made, the methods of testing of the elastic element under consideration were developed, the composite spring was mathematically simulated for the purpose of its verification and the possibility of its further use. As a result of the work performed, the maximum deflections of the leaf spring under consideration were established when loading the corresponding load in the suspension system of GAZ-2752 "Sobol" car. The executed bench experiment has established he maximum deflection of a spring. Similar values were obtained by the FE-method. These results show that it is impossible to use the leaf spring in the suspension system of a GAZ-2752 car.

1. Introduction

One of the trends in the development of modern industry is the use of polymeric composite materials (FRP) in the design. They are used in various industries, such as aircraft building [1], shipbuilding [2] and space production [3].

Automotive industry is a rapidly developing industry with great competition. Each manufacturer strives to produce the best quality product with the best operational properties, but with minimal resource costs. One of the ways to solve this problem is the use of polymeric composite materials in the design of a car, which are superior to traditional structural materials in terms of mass and strength [4]-[7]. For today composite materials are widely used at manufacturing of details of a car body and its interior, but it is necessary to notice that composite materials most effectively to apply in designs where their unique physical and mechanical properties are especially involved. An example of effective application of composite materials in the automotive industry is the use of composite elastic elements in suspension systems [8]. A particular case of such use are composite leaf springs that provide a reduction in the weight of the car, the required elastic characteristics of the suspension, in addition, they are not subject to corrosion when compared with their steel counterparts.

The article presents the results of research of elastic and strength properties of fiberglass spring for a car with GVW of 3.5 tons. On the basis of the developed test program the bench tests of composite spring were carried out. Calculation of the springs by finite element method (FEM) was performed. On the basis of the obtained results of the FEM calculation and experiment the verification of the mathematical model of the composite spring was carried out.

2. Design

Composite spring, researched in this work, is made in accordance with the patent RU 2600970 [9], the advantages of such a spring are less weight and high manufacturability of the manufacturing process. Composite spring is made of prepreg material, each layer of which is a glass cloth T13 (GOST 19170-73), impregnated with epoxyphenolic resin EP-5122. Dimensions of the object under study and its general appearance are presented in Figures 1 and 2, respectively. Spring width is 80 mm. The thickness of the elementary layer is 0.2 mm. The warp threads of the reinforcing layer are located parallel to the horizontal support surface, the weft threads are perpendicular to it. This direction of material reinforcement is preserved along the entire length of the composite spring, so at the ends of the spring both groups of threads (warp and weft threads) are directed to its middle surface at sharp angles.

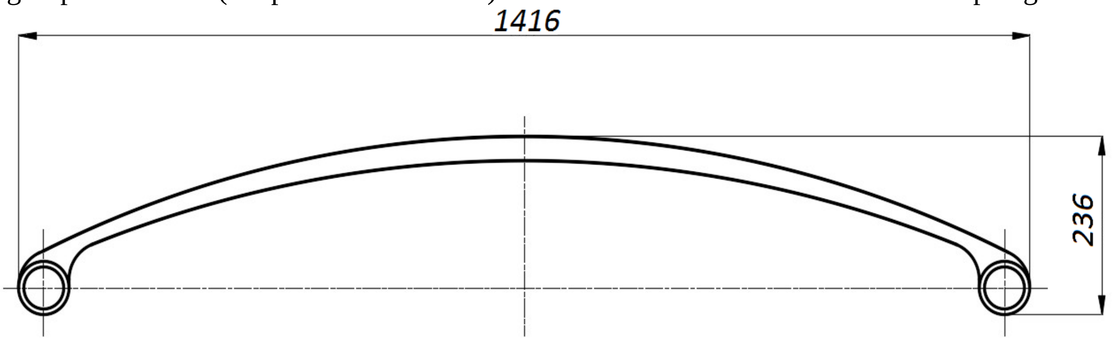

Figure 1. Sketch of composite leaf spring

Figure 2. External view of the testing machine

3. Leaf spring tests

The purpose of bench tests of springs made with the use of FRP is to determine the possibility of its use in the system of suspension of GAZ 2752. For this purpose, the main tasks for static bench tests were formulated: to determine the elastic characteristic of a composite spring, to determine the value of the ultimate destructive load and to evaluate the possibility of using the spring in the suspension system of the car.

The receiver on the stand is set up so that its symmetry plane is perpendicular to the base. The test bench is shown in Figure 3. The force is created by the hydraulic press (1). The fixing of the spring ends on the stand corresponds to the fixing of the spring on the vehicle: the fixed support (3) limits all the progressive degrees of freedom and rotational degrees of freedom, except for the rotation around the axis of the eye hole; the movable support (2) ensures the free movement of the spring end only along its longitudinal axis and rotation around the axis of the eye hole, thus simulating the installation of the spring on the vehicle. The forces and deflections of the composite spring are determined by an S-shaped load cell and an electronic measuring device (indicator), respectively. The external view of the testing machine is shown in Figure 4.

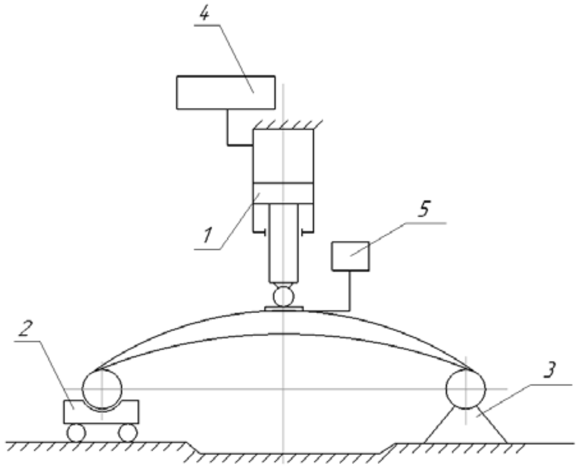

Figure 3. Test bench drawing

Figure 4. Bench with composite leaf spring

Metal analogue of composite spring is used in the rear suspension system of GAZ-2752 "Sobol" car suspension, so the program of tests for composite spring was developed taking into account the force factors arising in the system of car suspension.

The static load on the rear wheel of this vehicle is 7765 N. Taking into account the coefficient of dynamic is 2 for trucks [9], the maximum static load on the rear wheel will be 15530 N.

For the development of the test program, the full stroke of the suspension system was determined, which amounted to 160 mm. In view of the above, a loading program was formed. Reservoir is consistently loaded to the force corresponding to the static load on the wheel, then the force is increased to achieve a deflection value of 160 mm, then the spring is unloaded. The second part of the experiment is aimed at determining the ultimate destructive load of the object of study. For this purpose, the spring is gradually loaded to destruction.

As a result of a number of tests, an elastic characteristic of a composite spring was constructed, which is shown in Figure 5. At the deflection corresponding to structurally possible suspension stroke (160 mm), the load perceived by the spring does not exceed 10000 N. This value is 1.5 times less than the force applied to the elastic element in case of suspension of one of the wheels. According to the results obtained in the first part of the experiment, we can conclude that this elastic element of composite materials is unsuitable for use in the system of suspension, because it does not have the required stiffness in comparison with its metal analogue, installed on the car GAZ-2752.

In the second part of the experiment, the maximum force was determined, leading to the destruction of the spring. When the loading force of 10500 N was reached, the elastic element was destroyed. As a result of the tests it was found that the spring has insufficient rigidity and strength and is not able to support the static load on the wheel of GAZ-2752 "Sobol". Destroyed spring and character of the received destructions are presented on figure 6. The static load on the rear wheel of this vehicle is 7765 N. Taking into account the coefficient of dynamic $k_d = 2$ for trucks [10], the maximum static load on the rear wheel is 15530 N.

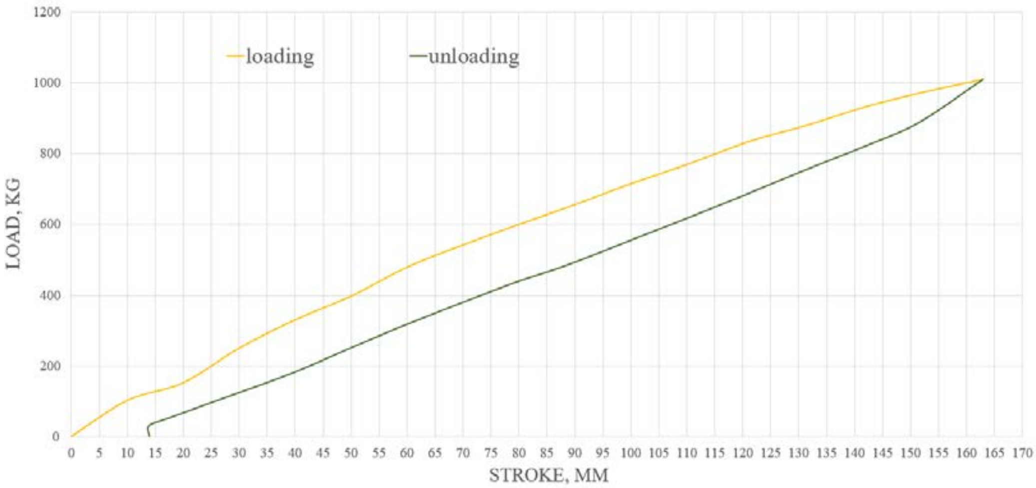

Figure 5. Results of the first part of the bench test

Figure 6. The leaf spring is destroyed

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4. Composite leaf spring finite element analysis

Carrying out of bench tests is not always possible, for this purpose certain material and time expenses are necessary, therefore it is expedient at a stage of designing of products from composite materials to use various software for finite element method (FEM) analysis, this technique is also described in the article [11], [12].

In order to determine the rigidity of the elastic element from composite materials and to analyze its strength features, a model of a spring was created, which is shown in Figure 7. Calculation of spring parameters by the usual analytical method [13] from composite materials is impossible, as the material has different properties in its axes. Therefore, the finite element consists of volumetric finite elements, which allow to define the properties of the anisotropic material. Such problems are solved with the help of different software complexes: Altair HyperWorks and ANSYS CompositePrepPost, etc.

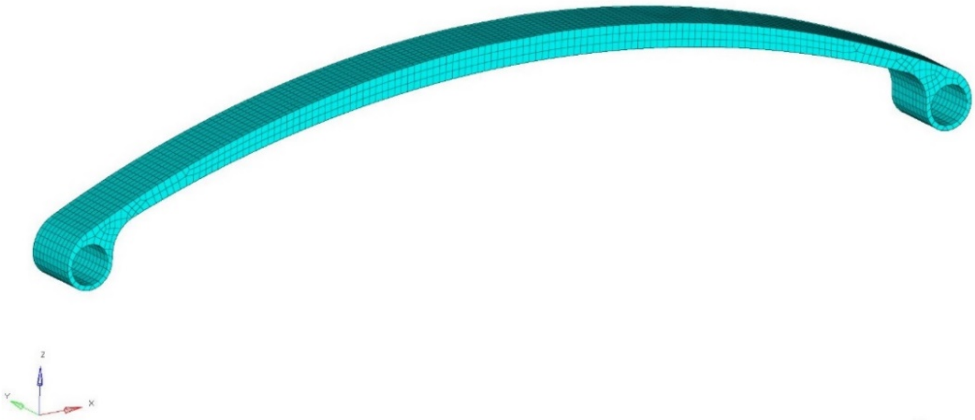

Figure 7. FE model of spring from PKM

The peculiarity of calculating structures from composite materials by methods of FE is the need to take into account the design features of the material: the number of layers of material and their orientation in space.

The considered spring is a compressed prepreg layer. One elementary layer of fiberglass plastic has elastic strength characteristics, given in Table 1.

Table 1. Characteristics of elementary layer of material T13

Parameter	Unit of measurement	Value.
Tensile Strength Limit	MPa	- on the general direction: 534
		-on the second direction: 317
Poisson's coefficient		- on the general direction: 0.4
		- on the second direction: 0.34
Shear module	GPa	9
Modulus of elasticity	GPa	- on the general direction: 20
		- on the second direction: 17
Layer thickness	mm	0,2
Orientation of reinforcement threads		plain weave

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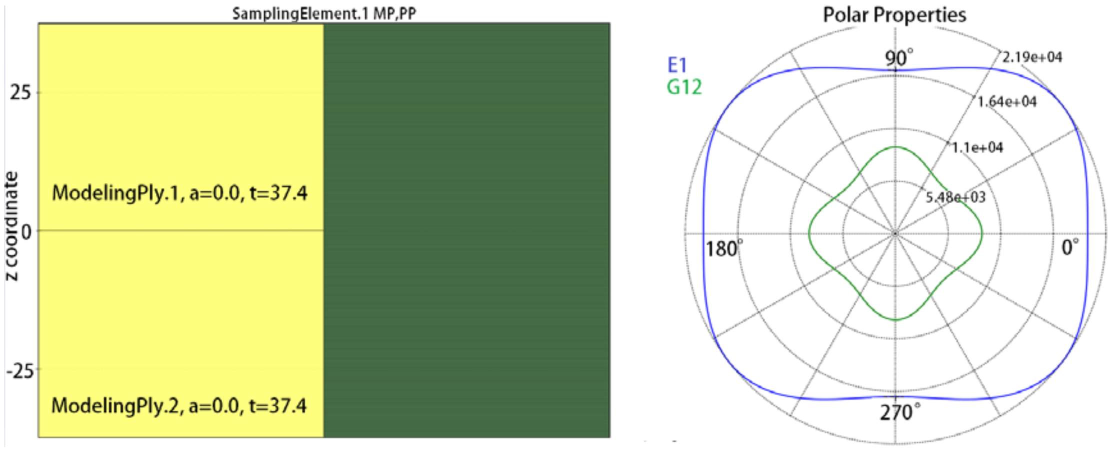

Figure 8. Material model diagrams showing thickness, modulus of elasticity and shear modulus

The 80 mm thick springs form about 400 compacted layers of prepreg. Figure 8 shows the integral elastic characteristics of the material.

The FE model of the spring consists of more than 2800 finite elements. The boundary conditions must be set for the FE calculations. The fixed end of the spring is fixed by three progressive degrees of freedom and two rotational ones. Rotating around the axis of the spring eye hole is allowed. The second end of the spring is not fixed on the 1st progressive degree of freedom and is fixed relatively to the other two, and the rotation around the axis of the eye is allowed, thus simulating the fixation in the earring of the spring.

The force is applied to the compressor taking into account large movements, quasi-static calculation is used, the maximum value of the load corresponds to the load obtained in the first part of the bench test of the spring - 10140 N.

The material of the investigated spring can be presented in the form of a large number of orthotropic layers. The elastic characteristics of the material in the orthotropy plane are different in different directions. Each component of the deformed state depends on each component of the stress state. The stiffness matrix, the inverse of the pliability matrix, describes the elastic properties of the spring material and consists of stiffness coefficients that depend on the orientation of the selected axes x, y, z. The FE model is constructed in such a way that the x-axis of all finite elements is directed perpendicularly to the lateral surface of the spring, while the y and z axes are located in a plane parallel to the lateral surface of the spring. The stiffness matrix underlying the solution of the system of equations describing the stress-strain state of the orthotropic material has the following form:

$$X := \begin{bmatrix} \frac{1}{E_1} & \frac{-\nu_{21}}{E_2} & \frac{-\nu_{31}}{E_3} & 0 & 0 & 0 \\ \frac{-\nu_{12}}{E_1} & \frac{1}{E_2} & \frac{-\nu_{32}}{E_3} & 0 & 0 & 0 \\ \frac{-\nu_{13}}{E_1} & \frac{-\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{13}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}.$$

The maximum spring deflection at 10140 N is 157 mm. For the preliminary calculation it is possible to estimate the diagram of the distribution of equivalent stresses according to vonMisses [12]. Maximum stresses according to vonMisses are 141 MPa.

This method of assessment is applicable only to classical structural isotropic materials, while composite materials are anisotropic materials in general. In this connection, the strength analysis of a composite spring should be carried out using the criteria of composite material destruction. For this purpose, the ANSYS CompositePrepPost software package is used.

In ANSYS CompositePrepPost it is possible to get a clear picture of the structure failure by several criteria of failure: maximum deformation, maximum stress, Tsaiah Hill and Pack criteria, etc.[12]. The results of the calculation are shown in Figures 9 and 10, where for each section of the spring the most vulnerable element is defined and the maximum value of the function of the fracture criteria is determined.

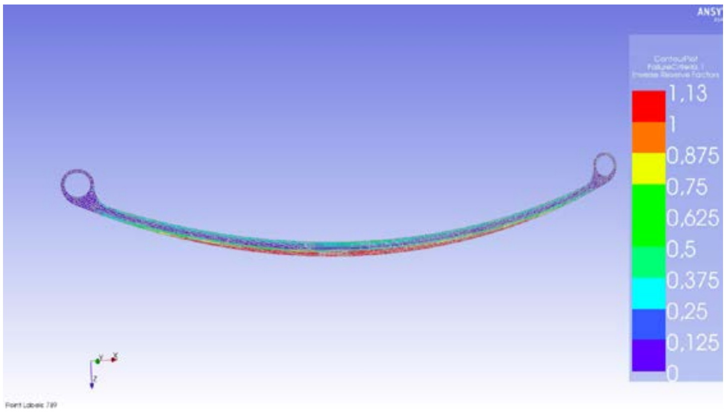

Figure 9. Distribution of the values of the destruction criteria function of the strength distribution criteria when applying load 10140 N

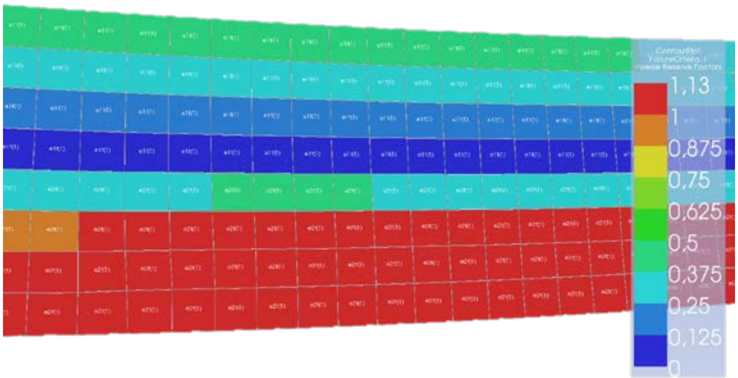

Figure 10. Maximum values of the fracture criteria function at the load location

The value of the function of the fracture criteria determines whether the material has failed or not. When the value of the destruction criterion function is reached, the structure loses its efficiency and the material is destroyed. Thus, when the force of 10140 N of the spring is applied, it is destroyed.

5. Conclusions

In the course of the study, the results of bench tests of the springs from the composite materials were obtained, the spring deflection was determined and the calculation of the strength of the object according to various destruction criteria was described. The maximum spring deflection during the bench tests was 162 mm, while the value of FE analysis did not exceed 158 mm. Thus, comparing the data obtained as a result of FE analysis and the experiment, it is possible to draw a conclusion about the accuracy and adequacy of FE model, the relative deflection error was 2.5 %. As a result of the conducted researches the unsuitability of the considered spring for use in the suspension of GAZ-2752 "Sobol" car was established.

As a solution to the problem of low stiffness of such elastic element the following recommendations can be offered:

1) another technology of manufacturing springs made of composite materials with a high volume content of reinforcing material;
2) changing the direction of reinforcement of the material;
3) change of spring production technology.

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