В данной работе рассчитаны коэффициенты теплопроводности и вязкости для смеси $Al+O_2+Ar$. Определены термодинамические зависимости коэффициентов λ и μ от состава и температуры продуктов сгорания. Коэффициенты теплопроводности и вязкости, рассчитанные по справочным данным, рекомендуется использовать в математической модели горения потока переобогащенной алюминиево-кислородо-аргоновой смеси при коэффициенте избытка окислителя, определенного по сгоревшей части, α_{com} = 0,4…5,6. При α_{com} < 0,4 рекомендуется использовать термодинамические значения коэффициентов теплопроводности и вязкости, определенные в данной работе.

Подставив полученные в настоящем исследовании данные в математическую модель горения потока полифракционной, переобогащенной алюминиево-воздушной смеси, описанную в работе [1], можно определить кинетические параметры процесса горения смеси $Al+O_2+Ar$, такие как скорость протекания реакции и необходимое время пребывания смеси в форкамере.

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Determination of Coefficients of Viscosity and Heat Conductivity in Aluminum Mixtures and Oxygenic Gases in the Prechamber of Nanooxide Synthesizing Plant

Coefficients of viscosity and heat conductivity depend on gas composition and temperature of aluminum gas mixture. These coefficients defined by thermodynamic calculations are compared with oxygen-argon mixture referenced data reflected in scientific and technical literature. It is determined that referenced data calculated coefficients can be used in mathematical model of combustion aluminum-oxygen-argon mixture to determine the kinetic parameters of combustion process.

Key words: synthesis of nanooxide, coefficients of viscosity and heat conductivity.

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AN APPROACH TO DESIGN A COMPOSITE MONO LEAF SPRING USING FEA

The aim of this paper is to design a mono leaf spring with a minimum weight and the same stiffness as a conventional mono leaf spring for a passenger vehicle. Finite element analysis using ANSYS 14 of the steel leaf spring and unidirectional E-glass epoxy composite (UEC) with fiber volume fractions (Vf) 0.5, 0.6 and 0.7 has been carried out. For each Vf the thickness of the spring was estimated to obtain the same stiffness as the conventional steel mono leaf spring. The analysis showed that safe composite mono leaf springs with same stiffness, same strain energy stored and with a beneficial reduction in weight can be designed by changing the thickness of the spring depending on the Vf.

Key words: leaf spring, composite material, strain energy.

The leaf spring is still widely used because it is considered more consistent on tacky and rough roads. The leaf spring has several functions as it supports the chassis weight, controls braking forces and absorb shocks. The stored elastic strain energy in a leaf spring can be expressed according to [1–3]

$$u = \frac{1}{2}\frac{\sigma^2}{\rho E}, \qquad (1)$$

where σ is the allowable stress, E is the young's modulus and ρ is the density. The stored strain energy is an important parameter in the selection of leaf spring material. Equation (1) shows that increasing the strength of material and decreasing both modulus of Elasticity E and density ρ of material lead to an increase in the stored strain energy. The composite material is a suitable selection as it has higher strain energy and lower weight.

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Sancaktar and Gratton [4] achieved the final design for the composite leaf spring using an iteration process based on the initial design. The initial design consists of two curved leaves hinged at ends and flat out under maximum load. They determined the required thickness of the leaf to achieve the target deflection by analyzing tapered beam using FEM package ANSYS. Al-Qureshi [5] designed a single leaf spring with variable thickness of glass fiber reinforced plastic. He used finite element software to model the behavior of the leaf spring. He demonstrated that composite material can be used for leaf spring for light trucks and meet there requirement, together with substantial weight saving. Shankar, Vijayarangan [6] designed a mono composite leaf spring with varying width and varying thickness using computer algorithm. They carried out analysis using ANSYS software for composite leaf spring with bonded end joints for Glass/Epoxy, Graphite/Epoxy and Carbon/Epoxy composite materials. They compared the FEM results for conventional steel leaf spring and mono composite leaf spring. The comparison showed that mono composite leaf spring reduces the weight by 85 % for E-Glass/Epoxy, 91 % for Graphite/Epoxy and 90 % for Carbon/Epoxy over conventional steel leaf spring.

In the present paper the design of safe flat and parabolic unidirectional E-glass/epoxy composite (UEC) mono leaf springs with same stiffness, same strain energy stored and a substantial reduction in weight compared with flat and parabolic steel mono leaf spring has been achieved using ANSYS 14 by changing the thickness depending on the fiber volume fraction (Vf = 0.5, 0.6 and 0.7).

FINITE ELEMENT ANALYSIS (FEA)

In the present work, the dimensions of an existing conventional mono steel leaf spring of a passenger vehicle: 965 mm length, 50 mm width and 10 mm thickness, are taken for modeling and analysis [7].The mechanical properties of the steel [8] are listed in Table 1. The mechanical properties of the unidirectional E-glass/epoxy composite (UEC) are calculated for various fiber volume fractions 0.5, 0.6 and 0.7. The elastic constants [9], the tensile strength [10] and the compression strength [11] are given in Table 2. The principal axes considered in the analysis are x axis along the fiber length and represents the longitudinal direction of the unidirectional fiber lamina, z and y axes represent the transverse in-plane and through the thickness directions respectively. The design parameters of the mono leaf springs used in this work are given in Table 3. As the spring is symmetrical, so only one half is considered with cantilever beam boundary conditions for the analysis to save the calculation time.

A validation of the FEA used has been done first by comparing the obtained results of maximum longitudinal stress using ANSYS 14 and analytical solution [12] for a steel cantilever beam with dimensions of the half mono leaf spring under consideration. The obtained results from the two analyses are presented in Fig. 1 which shows good agreement.

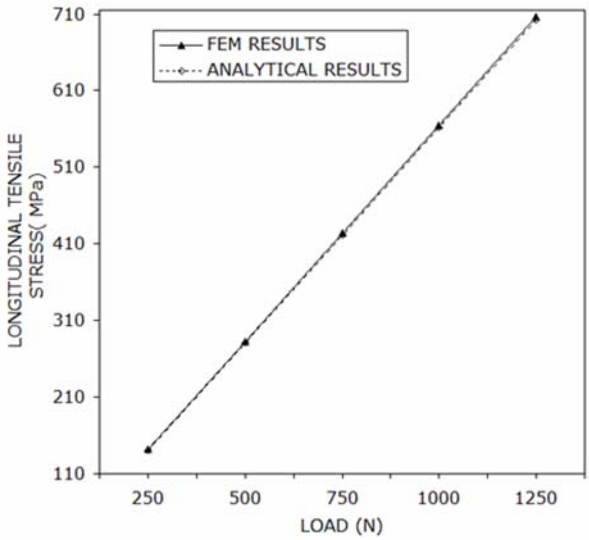

Fig. 1. Validation of FEM and analytical results

Table 1. **Mechanical properties of the steel, [8]**

Young modulus (MPa)	210000
Poisson ratio	0.266
Yield tensile strength (MPa)	1158
Yield compression strength (MPa)	1158

Table 2. **Mechanical properties of E-glass unidirectional / epoxy composite [9–11]**

Properties	Vf = 0.5	Vf = 0.6	Vf = 0.7
EX (MPa)	39300	46240	53180
EY (MPa)	11872	14966	19490
EZ (MPa)	11872	14966	19490
PRXY	0.33	0.31	0.3
PRYZ	0.31	0.29	0.28
PRXZ	0.33	0.31	0.3
GXY (MPa)	4253	5690	8957
GYZ (MPa)	4891	6544	10301
GXZ (MPa)	4253	5690	8957
Tensile strength (MPa)	640	770	895
Compressive strength (MPa)	680	815	966

Table 3. **Design parameters of mono leaf springs**

Parameter	Flat mono leaf spring	Parabolic mono leaf spring
Total length (eye to eye) (mm)	965	965
Free camber (at no load conditions) (mm)	0	68
No. of full length leave (Master Leaf)	01	01
Width of leaf spring (mm)	50	50
Maximum load on spring (N)	2500	2500

A stress analysis is performed using finite element analysis (FEA). All the calculations are done using ANSYS 14 software [13] and loading conditions are assumed to be static. Element selected for this analysis is Solid-Shell 3D finite strain190. The equivalent thickness of a composite mono leaf spring is the desired thickness to obtain the same deflection as that of the steel mono leaf spring under the same load (i. e. same stiffness). The finite element analysis is carried out on mono flat and parabolic leaf springs of various thickness (12, 14, 16, 18, 25 mm) made of unidirectional E-glass/epoxy composite (UEC) with various fiber volume fractions. The obtained results of deflection from the finite element analysis of the composite mono flat and parabolic leaf springs at various thicknesses (12, 14, 16, 18, 25mm) are shown in Table 4. The relation between the thickness and the deflection has been plotted and the curve fitting for this relation has been plotted as shown in Fig. 2. By substituting the value of deflection of steel mono leaf spring in the equation of curve fitting the equivalent thickness of composite mono leaf spring has been determined. The equivalent thicknesses of composite mono leaf spring are listed in Table 5.

Table 4. **FEM deflection of composite flat and parabolic mono leaf spring at various thicknesses t**

	Composite flat mono leaf spring			Composite parabolic mono leaf spring		
	Vf = 0.5	*Vf* = 0.6	*Vf* = 0.7	*Vf* = 0.5	*Vf* = 0.6	*Vf* = 0.7
Load	2500	2500	2500	2500	2500	2500
Deflection (mm) *t*= 12mm	164.9	140.2	121.8	161.3	137.1	119.1
Deflection (mm) *t*= 14mm	103.9	88.4	76.8	101.7	86.4	75.1
Deflection (mm) *t*= 16mm	69.7	59.2	51.5	68.2	57.9	50.3
Deflection (mm) *t*= 18mm	49.0	41.6	36.2	47.9	40.7	35.4
Deflection (mm) *t*=25mm	18.4	15.6	13.5	17.9	15.2	13.2

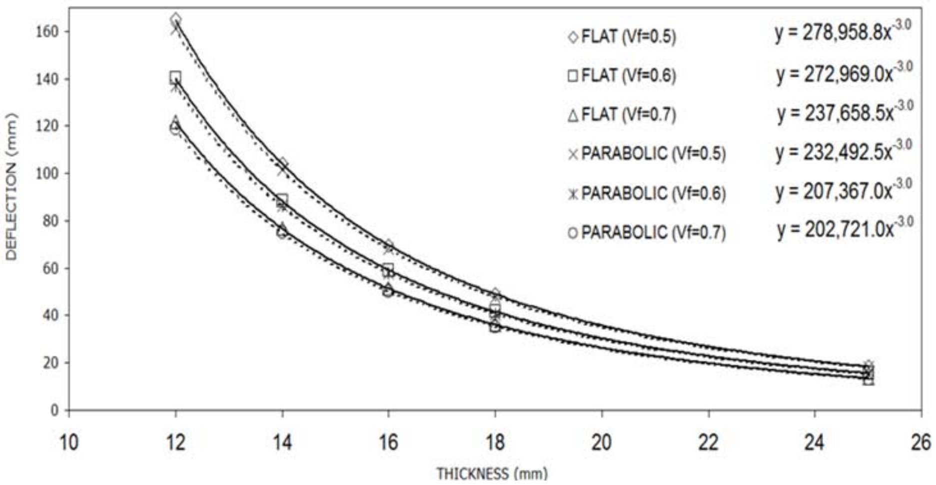

Fig. 2. Relation between leaf spring thickness and deflection for flat and parabolic shaped springs

Table 5. **Equivalent thickness of composite mono leaf spring obtained**

	Composite flat mono leaf spring			Composite parabolic mono leaf spring		
	Vf = 0.5	*Vf* = 0.6	*Vf* = 0.7	*Vf* = 0.5	*Vf*= 0.6	*Vf* = 0.7
Equivalent thickness of leaf spring (mm)	17.53	16.6	15.84	17.53	16.6	15.84

RESULTS AND DISCUSSION

The finite element analysis has been carried out on flat steel and composite (UEC) for various fiber volume fractions mono leaf springs with the equivalent thickness. The results are compared with the analytical calculations [12] as given in table 6 . As the composite is unidirectional, in the calculations of composite springs the modulus of elasticity in the longitudinal direction is used. It can be seen that the FEA results is in agreement with analytical results.

The same FEA has been carried out on parabolic mono leaf springs. Table 7 represents the results.

Figures 3 and 4 show the FEA results for the beam deflection and longitudinal stress results for one of the investigated parabolic composite mono leaf springs cases with volume fraction 0.6. The results show that the maximum deflection is 51.9 mm see Figure 4.It also shows that the maximum longitudinal stress is +259.7 MPa on the upper surface and –265 MPa compressive on the lower surface.

The presented analysis shows that FEA can be used with good accuracy to design composite mono leaf springs with same stiffness as that of the conventional steel mono leaf springs. Lower stress, higher factor of safety, and substantial weight reduction could be attained by changing the thickness of the composite springs, Table 8.It is noted that for both the flat and the parabolic UEC leaf springs, increasing *Vf* normally affects the composite weight by a relative increase in the strength of the material.

However, in the present analysis, by considering same spring stiffness, higher safety factor could be attained by changing thicknesses and *Vf* of the composite leaf spring. Compared to steel leaf springs, a gain in the spring weight without stored strain energy loss could be achieved Table 8.

Table 6. **FEM and analytical [12] results of steel & composite flat mono leaf springs**

		Flat mono leaf spring			
		Steel	Composite		
			$Vf = 0.5$	$Vf = 0.6$	$Vf = 0.7$
Load (N)		2500	2500	2500	2500
Thickness (mm)		10	17.53	16.6	15.84
Deflection (mm)	FEM	53.03	53.04	53.06	53.03
	Analytical	53.5	53.1	53.1	53.1
Von Mises stress (MPa)		707.3	230.7	257.2	282.2
Longitudinal stress (MPa)	FEM	+794 –794	+239.3 –239.3	+267.6 –267.6	+295.4 –295.4
	Analytical	+723 –723	+235.5 –235.5	+262.6 –262.6	+288.5 –288.5
Stiffness (N/ mm)		47.1	47.1	47.1	47.1
Strain energy dueto bending load 2500N (J)	FEM	33.1	33.1	33.2	33.1
	Analytical, [12]	33.4	33.2	33.2	33.2
Weight (kg)		3.79	1.61	1.63	1.67

Table 7. **FEA results of steel & composite parabolic mono leaf springs**

	Parabolic mono leaf spring			
	Steel	Composite		
		$Vf = 0.5$	$Vf = 0.6$	$Vf = 0.7$
Load (N)	2500	2500	2500	2500
Thickness (mm)	10	17.53	16.6	15.84
Deflection (mm)	51.8	51.9	51.9	51.8
Von Mises stress (MPa)	748.4	232.7	259.9	287.5
Longitudinal stress (MPa)	+783.4 –788.7	+232.2 –237.2	+259.7 –265.2	+286.1 –293.3
Stiffness (N/ mm)	48.2	48.2	48.2	48.2
Strain energy due to bending load 2500N (J)	32.4	32.4	32.4	32.4
Weight (kg)	3.79	1.61	1.63	1.67

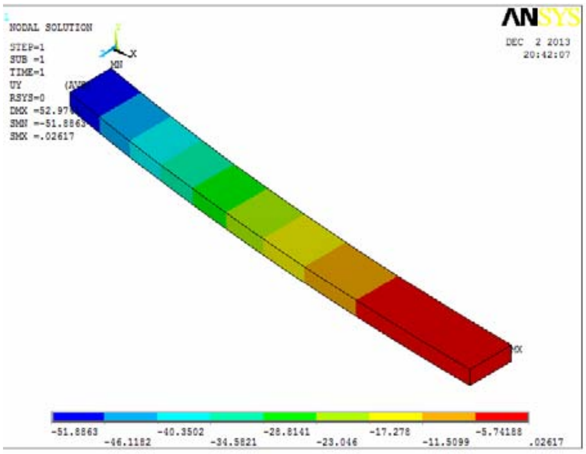

Fig. 3. Deflection of (UEC, $Vf = 0.6$) parabolic mono leaf spring

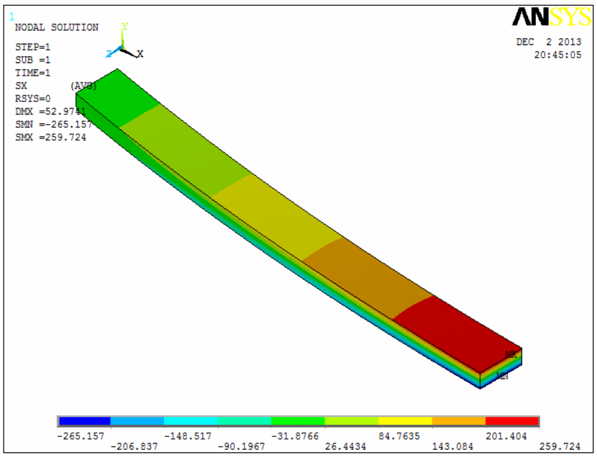

Fig. 4. Longitudinal stress of (UEC, $Vf = 0.6$) parabolic mono leaf spring

Table 8. **Factor of safety and weight reduction of composite over steel spring results**

	Flat mono leaf spring				Parabolic mono leaf spring			
	Steel	Composite			Steel	Composite		
		$Vf = 0.5$	$Vf = 0.6$	$Vf = 0.7$		$Vf = 0.5$	$Vf = 0.6$	$Vf = 0.7$
Factor of safety in tensile	1.46	2.67	2.88	3.03	1.48	2.76	2.96	3.13
Factor of safety in compression	1.46	2.84	3.05	3.27	1.47	2.87	3.07	3.29
Weight reduction over steel leaf spring%	–	57.50	57.00	55.90	–	57.50	57.00	55.90

CONCLUSION

Safe composite mono leaf springs UEC can replace conventional steel mono springs with same deflection and same load capacity (same stiffness) without any loss in stored energy and with good reduction in weight by choosing the convenient thickness. This could be attained by the use of a specially adopted FEA technique. The use of FEA is therefore, a convenient method to analyze and design composite leaf springs.

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Подход к проектированию композитной монолистовой рессоры с использованием метода конечных элементов

Целью работы является проектирование автомобильной монолистовой композитной рессоры меньшего веса и той же жесткости, как и традиционная стальная монолистовая рессора. Методом конечных элементов с использованием ANSYS 14 был выполнен анализ стальной рессоры и рессоры, изготовленной из материала UEC (однонаправленных волокон алюмо-боро-силикатного стекла E-glass и эпоксидного связующего) с объемом волокна (Vf) 0,5, 0,6 и 0,7. Для каждого значения Vf оценивалась толщина рессоры из условия получения такой же жесткости, как и у стальной монолистовой рессоры. Анализ показал, что безопасная композитная монолистовая рессора с такими же параметрами жесткости, запасаемой энергии деформации, и с уменьшенной массой по сравнению со стальной рессорой может быть спроектирована путем изменения толщины рессоры в зависимости от параметра Vf.

Ключевые слова: рессоры, композитный материал, энергия деформации.

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РАСЧЕТ НАГРУЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ РОЛИКА ПЛАНЕТАРНОЙ ПЕРЕДАЧИ ТИПА *K-H-V*

Представлен расчет распределения нагрузки по длине ролика с учетом поперечной силы и изгибающего момента, действующих со стороны как диска, так и сателлита зубчато-роликовой планетарной передачи, основанный на решении дифференциальных уравнений совместности перемещений сопрягаемых элементов механизма.

Ключевые слова: планетарная передача, ролик, нагруженно-деформированное состояние.

Планетарные передачи с одним или двумя внутренними зацеплениями зубчатых колес при небольшой разнице в числах их зубьев выгодно отличаются от других типов планетарных передач простотой конструкции, высоким КПД, большим передаточным отношением в одной ступени [1]. Основным недостатком, сдерживающим их применение, является необходимость использования неэффективного механизма восприятия момента сил, действующих на сателлит.

Наиболее эффективной является передача с внутренними зацеплениями колес и механизмом восприятия момента в виде дисков с отверстиями, в которых установлены цельные или составные ролики (рис. 1). Отверстия такого же диаметра имеют и сателлиты [2]. Разница диаметров отверстий дисков,

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