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NUMERICAL ANALYSIS OF THE STATES OF DEFORMATION
AND STRESS IN THE SEALING ELEMENTS

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The state of deformation and stress in the sealing elements is of high importance for the projecting of the sealing rings on the electronic covers in a plane. Modeling is required in order to predict the pressurization in cabins during a flight. In this study the influence of parameters on the characteristics of materials was investigated. Because of the non-linearity caused by different geometry and high deformation, the analysis of mutual effects between a sealing ring and a gutter is a very complex three dimensional problem. Experimental testing of the sealing ring was performed as an investigation of compression, which was mostly used for the analysis of an elastomer. Numerical analysis of the behavior of a sealing element was performed using the finite element method with a variant of basic tension and states through the material. Because of the present friction between the sealing element and the gutter, a friction coefficient was involved in the numerical analysis of the present deformation. The obtained experimental and numerical values were compared. The best agreement between the experimental results and numerical analysis was reached for an application of the input set for the basic states of the elongation tension and volume compression.

Keywords: straining, volume compression, hyperelasticity, contact bond, tire, finite element method, load, deformation

1. Introduction

It is known that the most of technical structures contain different types of the mechanical bonds of two different bodies. Therefore a determination of the tension-deformation state of particular parts for different load is of the most importance during construction of some architecture. In the contact zones, the friction was formed between contact surfaces of bodies resulting in an increase of tension. According to the previous mentioned in this study, an analysis of tension state of sealing ring as one contact problem will be performed. Because the tire belongs to the hyperelastic materials with high nonlinear characteristics and very small compressibility, the numerical analysis is very complex. Therefore a definition of chosen material is of the most importance for an application in aircraft industry.

After the analysis of the closed part during exploatation the most important target represents the influence of the compression nature of the chosen elastome on

the stress distribution in the tire. The numerical analysis of the sealing element was performed using the initial values of tightening and volume compression for the modeling of the materials characteristics.

2. Theoretical background

The analysis of mutual effects between a sealing ring and a gutter is a very complex three dimensional contact problem, which includes nonlinearity from different geometry and high deformation. Complete sum of loads contains an effect of a plate *3* on the sealing ring *2* and has mutual effect on a gutter *1*, what is shown in Fig. 1.
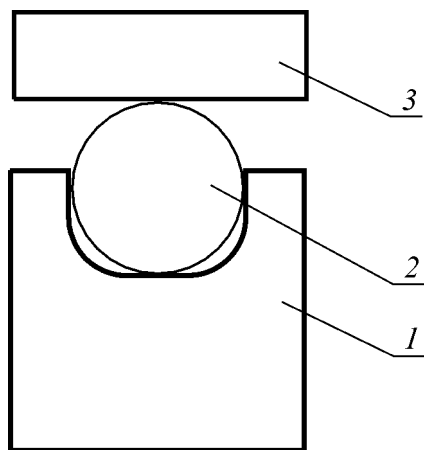

Fig. 1. Sealing element situated in a gutter down by a plate: *1* – the gutter, *2* – the sealing ring, *3* – the plate

The basis conditions along the surface contacts prevent an overlapping of materials forming the contact forces, which act along the contact zones. These forces are equal and opposite. The normal forces are responsible for the formed pressure. The tangential forces act according to the forces on the friction.

The structure analysis requires decomposition on the basic parts and its separated investigation. Therefore in this analysis, a sealing ring, gutter and cover are involved (as shown in Figs. 2 and 3). According to dimension on the Fig. 2, the analysis of a sealing element in a gutter under pressure of the cover was performed experimentally with using of the numerical method on the clip (segment) of a sealing ring.
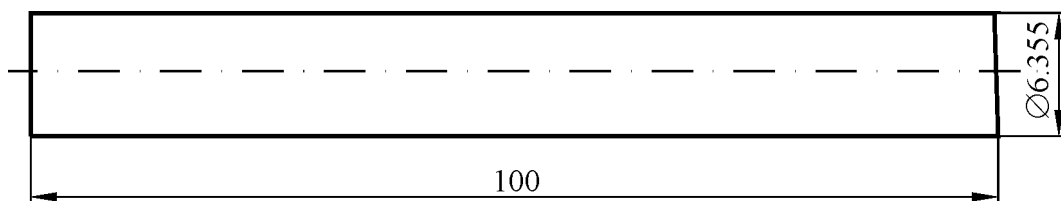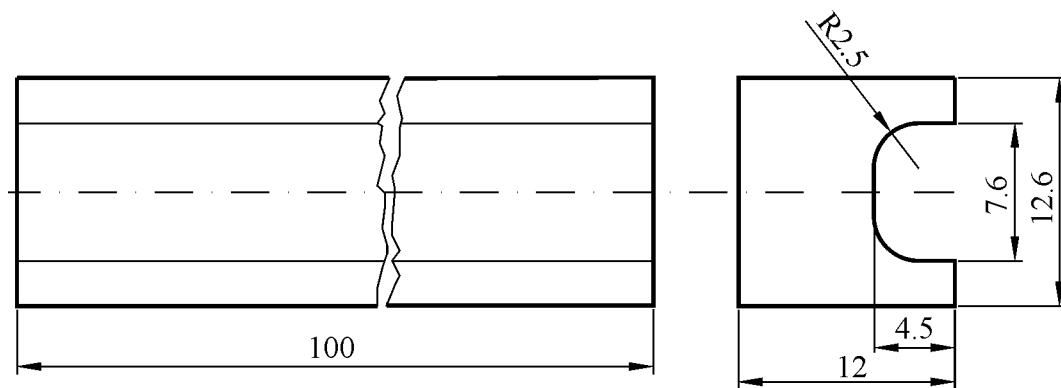

Fig. 2. Segment of a sealing ring

Fig. 3. Segment of a gutter

3. Experimental analysis

The experimental analysis of the sealing ring was performed as an investigation of compression, which was mostly used for the analysis of an elastomer. The experimental results were compared with ones by numerical analysis. Because of present friction between the sealing element and the gutter, friction coefficient will be involved in the numerical analysis of the present deformation in order to decrease the difference between numerical and experimental analysis. According to the previous mentioned, a friction coefficient can contribute to the increase of the shearing deformation.
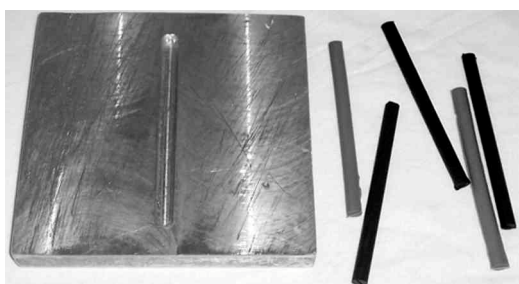

Fig. 4. The plate and the investigated samples

Experimental analysis was performed on the samples of the sealing element according to dimensions shown in Fig. 2. Look of samples and plate with an cutting gutter was shown in Fig. 4. The gutter on this plate has a form and dimensions shown in Fig. 3.

In order to investigate the compression of a sealing ring, which is closed during an application, the device «Instron» was used, as shown in Fig. 5. During the compression test, the plate with a cutting gutter was situated on the working part of the instrument, while the upper surface of device presses on a sealing element.

Investigated samples were done by two different types of tire with the hardness values of 55 and 59 Shore, respectively. The results of the analysis are given in Fig. 6.
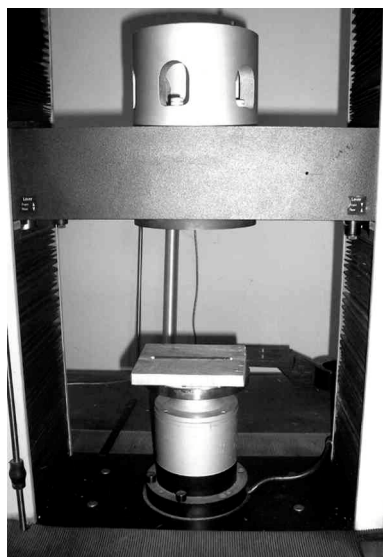

Fig. 5. The plate with the sealing element situated on the working table of the device for the investigation
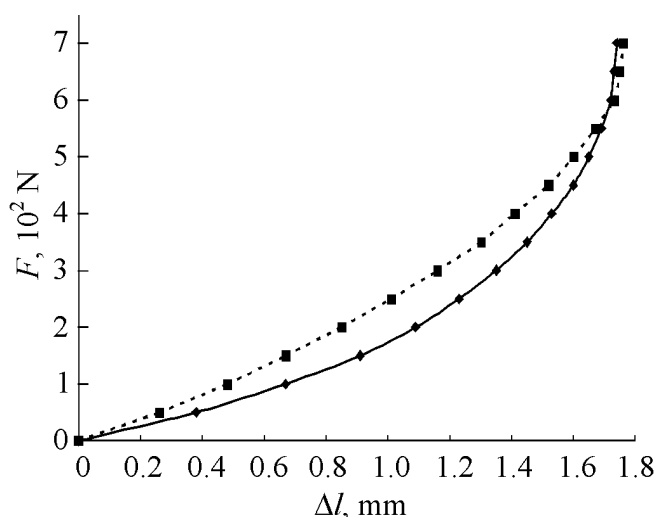
Fig. 6. Compression curve of a sealing element: $-\blacklozenge-$ – 55 Shore (experimental), $-\blacksquare-$ – 59 Shore (experimental)

4. Model by Mooney–Rivlin

In order to define the material of the sealing element, three parameter model by Mooney-Rivlin was applied. Potential deformation energy was presented in the following form according to two parameter model by Mooney–Rivlin, as shown with

$$W = {}^{\text{iso}}W + {}^{\text{vol}}W .$$ (1)

If the volume is constant, the function for deformation energy for the three dimensional system is given by

$${}^{\text{iso}}W = c_{10}\left(\overline{I}_1 - 3\right) + c_{01}\left(\overline{I}_2 - 3\right) + c_{11}\left(\overline{I}_1 - 3\right)\left(\overline{I}_2 - 3\right),$$ (2)

whereby: c_{10}, c_{01}, c_{11} are the constants for materials; $\overline{I}_1$, $\overline{I}_2$ are the main invariants of deformation tensor (volume is constant).

While the volume part is given

$${}^{\text{vol}}W = \frac{1}{d}\left(\lambda_1 \lambda_2 \lambda_3 - 1\right)^2,$$ (3)

whereby: λ_1, λ_2, λ_3 are the main elongations; d is the parameter of material non-compressibility.

5. Numerical analysis

The main aim of numerical analysis was to predict the behaviour of a sealing ring via mathematical model. In order to form a precise mathematical model a physical prototype of a gutter and sealing ring was proposed and shown in Fig. 7.

Physical and mechanical parameters of modl materials have the following values for the gutter/cover: Young'modulus of elasticity $E = 7390/21000$ daN/mm^2; Poisson' coefficient $\nu = 0.3/0.3$.

During numerical analysis of behaviour of a sealing element pressured in gutter via cover and pressure between the gutter and the plate, the finite element method was used. In this consideration, the contact problem was involved. In order to analyse the compressive nature of sealing element, friction coefficient of $\mu = 0.3$ was assumed. The coefficient of friction of 0.3 was chosen based on previous studies of compression of these materials in the range of 0.02 to 0.3, where the best consent of experimental and numerical results was obtained with the coefficient of friction of 0.3 [13].

Because the model and load are symmetrical, the half model was used in the analysis (Fig. 8). This is also possible, because the load and support are symmetrical.
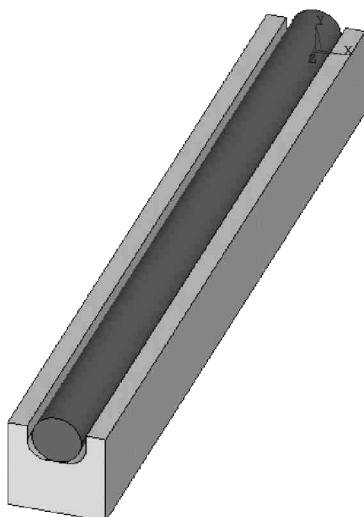
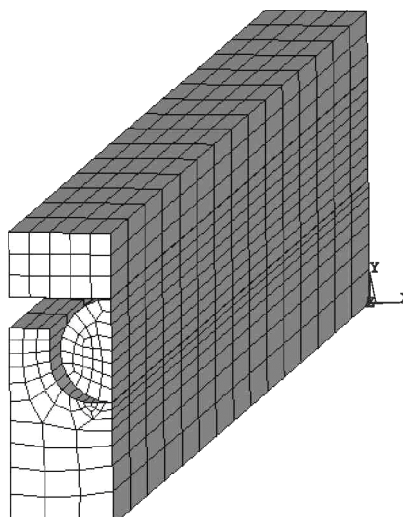**Fig. 7.** Proposed 3D-model of a sealing ring and gutter

Fig. 8. Half 3D-model

Table 1

Constants of materials for a tire with hardness of 55 Shore

Basic states of stress	Constant of Mooney−Rivlin			
	c_{10}	c_{01}	c_{11}	d
Elongation	−0.059284	0.13674	0.011473	0
Elongation and volume compression				27.589

Table 2

Constants of materials for a tire with hardness of 59 Shore

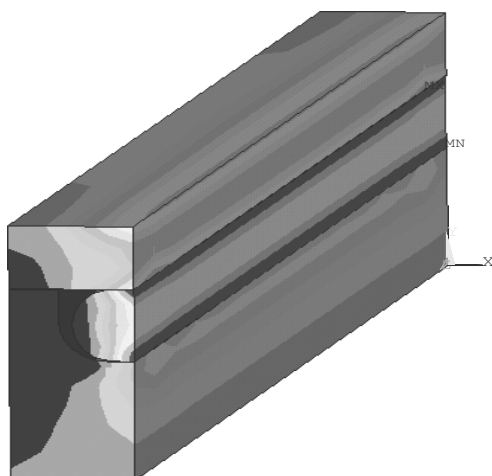| Basic states of stress	Constant of Mooney−Rivlin			
	c_{10}	c_{01}	c_{11}	d
Elongation	−0.047221	0.10954	0.0093815	0
Elongation and volume compression				27.702

Fig. 9. The Misses' tension

During the analysis of deformation and tension behaviour for a sealing ring, the model by Mooney−Rivlin was applied with different inputs related to the basic states of stress: an elongation and volume compression. Experimental values are presented in Fig. 9.

The Mooney−Rivlin constants are shown for two input sets: elongation, elongation and volume compression.

The support was defined according to the experimental part without any movement of the plate with the gutter in all

directions. The load was considered as a movement of the cover, so that the cover makes a pressure on the sealing element and fills the gutter.

Two contact bonds are identified in this analysis: 1) between the surfaces of contacts of sealing ring and the plate; 2) between the sealing element and the gutter with a friction coefficient of $\mu = 0.3$.

6. Analysis of the obtained results

The **Misses' tension** values in the sealing ring, gutter, an plate are shown in Fig. 10. As expected, the highest values of stress in the sealing element were found on the contact places with the plate and the gutter.
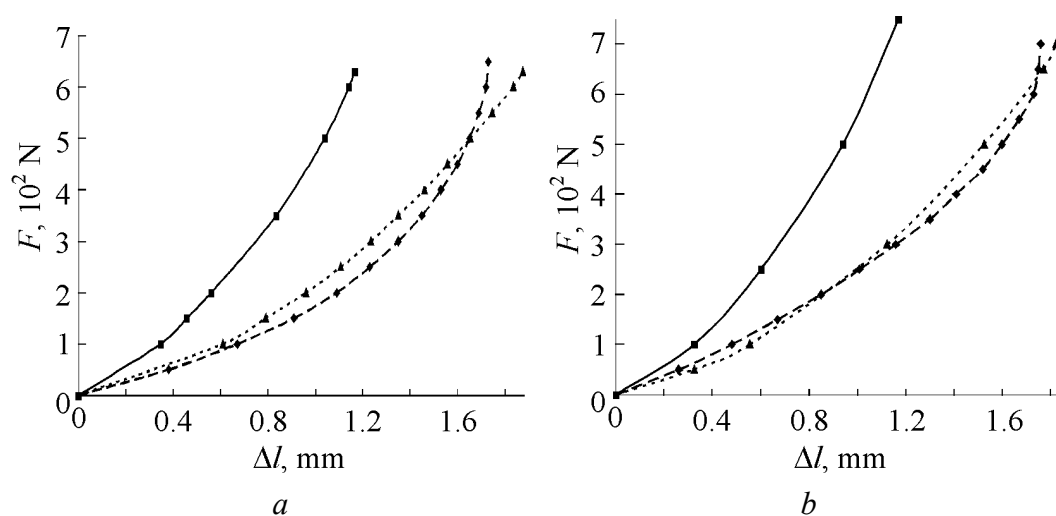

Fig. 10. Diagram of load vs deformation for the tire with hardness of 55 Shore (*a*) and 59 Shore (*b*): -- ◆ -- – experimental, —■— – simple tension (numerical analysis), --- ▲ --- – simple tension and volume compression (numerical analysis)

As previous mentioned, the most important aim of this analysis was to test an agreement for the experimental and numerical analysis. In Fig. 9 the stress-deformation diagrams are shown concerning to the experimental and numerical analysis. The friction coefficient between the sample and the gutter amounts 0.3. The comparative analysis between the experimental results and numerical analysis offers the following details of the process.

The best agreement between the experimental results and numerical analysis was done for an application of the input set for the basic states of the elongation tension and volume compression;

Using the input for an elongation in numerical analysis the calculated force for the compacting of a sealing ring of 1.3 mm was three times higher than the real value.

An application of the input set for elongation and volume compression shows deviation about 20% between the experimental results and numerical analysis.

7. Conclusion

Such as confirmed in this study the modeling of hyperelastic materials using the finite element method is of big importance for the consideration of the real closed construction. Therefore the values of obtained elongation for a compression analysis shall be not particularly used, but also combined with other set values obtained from volume compression. Although the real value of friction was established, the friction coefficient has to be used in order to perform precise analysis. The obtained results help the constructor to choose the input set (elongation and elongation and volume compression) in order to better define hyperelastic materials, which are under pressure in the closed part of a device during an application. Especially, this analysis can serve for the projecting of the sealing rings on the electronic covers in an aeroplane in order to prevent penetration of humidity. Concerning to the cabin of the battle plane, this study might be served for the providing of required pressurization in cabins during a flight on the high heights.

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ЧИСЕЛЬНИЙ АНАЛІЗ ДЕФОРМОВАНИХ І НАПРУЖЕНИХ СТАНІВ В УЩІЛЬНЮВАЛЬНИХ ЕЛЕМЕНТАХ

Аналіз деталей, виготовлених з надпружних матеріалів з додатковим покриттям, є складною процедурою, ціллю якої є прогнозування деяких деформованих і напружених станів в ущільнювальному елементі системи безпілотного літака, використовуваного для спостереження за транспортною інфраструктурою. З метою встановлення точних значень напруження і деформації в ущільнювальному елементі вивчено вплив найбільш значущих параметрів на характеристики матеріалів. Проведено чисельний аналіз поведінки ущільнювального елементу, який описує матеріал за допомогою методу кінцевих елементів при різних основних напружених і деформованих станах (розтягування й корозія з об'ємним стисненням). Представлено порівняння отриманих експериментальних даних і результатів розрахунку.

Ключові слова: розтягування, об'ємне стиснення, надпружність, контактний зв'язок, шина, метод кінцевих елементів, навантаження, деформація

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ЧИСЛЕННЫЙ АНАЛИЗ ДЕФОРМИРОВАННЫХ И НАПРЯЖЕННЫХ СОСТОЯНИЙ В УПЛОТНИТЕЛЬНЫХ ЭЛЕМЕНТАХ

Анализ деталей, изготовленных из сверхупругих материалов с дополнительным покрытием, представляет собой сложную процедуру, имеющую целью прогнозирование некоторых деформированных и напряженных состояний в уплотнительном элементе системы беспилотного самолета, используемого для наблюдения за транспортной инфраструктурой. С целью установления точных значений напряжения и деформации в уплотнительном элементе изучено влияние наиболее значимых параметров на характеристики материалов. Проведен численный анализ поведения уплотнительного элемента, описывающий материал с помощью метода конечных элементов при различных основных напряженных и деформированных состояниях (растяжение и коррозия с объемным сжатием). Представлено сравнение полученных экспериментальных данных и результатов расчета.

Ключевые слова: растяжение, объемное сжатие, сверхупругость, контактная связь, шина, метод конечных элементов, нагрузка, деформация