FRI-LB-P-1-BFT(R)-21

THERMOMECHANICAL CHARACTERISTICS OF HIGH ELASTIC VULCANIZATES USED IN FOOD MACHINERY

Assis. Prof. Delian Gospodinov, PhD
Department of Machinery and Equipment for the Food and Flavour Industry,
University of Food Technologies Plovdiv, Bulgaria
Tel.: +35932 603 859
E-mail: dgosp@abv.bg

Assoc. Prof.Vilheln Hadjiiski, PhD
Department of technical mechanics and machine science,
University of Food Technologies Plovdiv, Bulgaria
Phone: +35932 603 825
E-mail: hawi@abv.bg

Prof. Stafan Stafanov, PhD
Department of Machinery and Equipment for the Food and Flavour Industry,
University of Food Technologies Plovdiv, Bulgaria
Phone: +35932 603 814
E-mail: stvstefanov@yahoo.com

Abstract: *The object of the study in this article is the thermomechanical characteristics of highly elastic materials. On the basis of the analysis of the variation of the location of the individual sections of the curves, the occurrence of transition regions, which determine the temperature range of use of the materials studied in the article, is analyzed. The paper examines the influence of the change of the transition sections on the deformation properties of the highly elastic materials for specific application in the conditions of the food industry.*
Keywords: *thermo-mechanical characteristics, highly elastic materials, experimental research.*

INTRODUCTION

The usage of rubber-based materials in the equipment used in the food processing industry has broadened noticeably for the past ten years. Appart from common uses such as vibration absorbents, impact protection elements, flexible components and seals, there are some recently adopted applications such as components for gear transmissions, different moving parts in systems intended to direct streams of fluids and gases, sound absorbing elements, moulding, etc. The reason for this growth of popularity of the rubber-based materials is related to their low cost, satisfying strength characteristics, lower noise levels, flexibility and others. Additional studies have led to the use of new ingredients which resulted in the ability to produce innovative rubber-based materials which are suitable for direct contact with food products.

Rubbers are polymer-based substances. Their structure consists of large molecule chains (macromolecules) oftenly associated with strings or fibers. There are formed by repeated bonding of atomic groups – most commonly carbon-based groups. When forming the macromolecules of rubbers, the functional atomic groups are bonded by forming one-sided arrangement which results in the molecules taking the shape of arcs additionally twisted to form helix. When external force is applied these molecules can straighten and substantion amounts of deformation is achieved. When the stress grows above certain value the straightened fibers start to slide which results of the occurance of plastic deformation. Forming of cross-fibrous bonds stops the fibers from sliding and the rubber loses the ability to sustain plastic deformation. It becomes hiper-elastic material. The process of forming of cross-fibrous bonds is known as “vulcanization” and the bonds are formed on the basis of sulfur atoms.

The amount of deformation as a result of applied external load change with the change of temperature. The effects of temperature on the ability of polymers and elastomers to sustain deformation is described by so called termomechanical characteristics [1, 4, 5]. They show the amount of deformation of one such material resulting from applied external load with constant magnitude at different temperatures.

This article examines the influence of the change of the transition sections on the deformation properties of the highly elastic materials for specific application in the conditions common for the food industry.

MATERIALS AND METHODS

Key factor when studying the destructive stresses of hyper-elastic materials is the dependency of the destructive stress from the operational temperature [1, 2, 3, 4, 5]. When constant load is applied at constant rate of deformation the local stresses (mainly related to the presence of defects in the structure of the material) reach values equal to the strength of the of the bonds between the atoms of the polymer materials.

The external loading practically affects one non static structure of atoms which vibrate with an intensity depending on the temperature. This explains the kinetic characteristics of the process of destruction of solid bodies. The internal dynamics of the process of destruction is based on the local fluctuations of energy which govern the break of the bonds between the atoms at microscopic level. The rise of the number of bonds destroyed leads to the occurrence of macroscopic destruction of the entire solid body.

The destruction of polymer materials depends not only on the magnitude of the stress but on the heat governed movement of the atoms of the material [4, 5]. The drop of the energy which activates the process of destruction is related to the effect of the rise of the external loading, which leads to drop of the value of the potential barrier for destruction:

$$E_a = U_o - \gamma\sigma \tag{1}$$

U_o - barrier which activates the process of destruction of hyper-elastic material which is in correspondence with the energy of interaction between the chains of molecules forming the structure of the hyper-elastic material which is coincident with the energy that activates thermo-destruction of the polymer (determined by the destruction of the chemical bonds within the polymer).

γ - structurally-sensitive parameter, determined by the interaction between the chains of the molecules of hyper-elastic polymer.

The work resulting from the action of the external loading is used for the destruction of the polymer while the rest of the work is done to destroy the chemical bonds and it is based on the energy of the fluctuation of the heat governed movement of the atomic groups.

The mechanisms of the destruction of hyper-elastic materials consists of two stages. The first one is related to the initiation and growth of initial cracks and the second stage is the of rapid spreading of the crack through the cross section of the entire solid body.

To start this process certain barrier has to be passed $U_o - \gamma\sigma$ and it depends on the stress. This determines the process of destruction to be thermo-mechanical process as the mechanical stress affects the acceleration of the destruction of the carbon-carbon bonds related to the heat fluctuations.

RESULTS AND DISCUSSION

Experiments have been conducted using test samples of hyper-elastic material which is based on NBR vulcanized rubber.

The samples are standard flat specimens for tensile test with total length of 76 mm, width of the active section is $4{,}0_{0}^{+0{,}4}$ mm, distance between the markers is $20{,}0 \pm 1{,}0$ and the thickness of the specimen is $2{,}0 \pm 0{,}2$.

The testing equipment is a tensile machine for rubber materials with moving range of the active clamps up to 1000 mm with moving rate 500 ± 503 mm/min and maximal magnitude of the applied force 50 kN.

The samples are subjected to tensile test at least 6 hours after vulcanization is complete.

Figure 1 and 2 show the dependency of the relative elongation and tensile strength from the temperature.

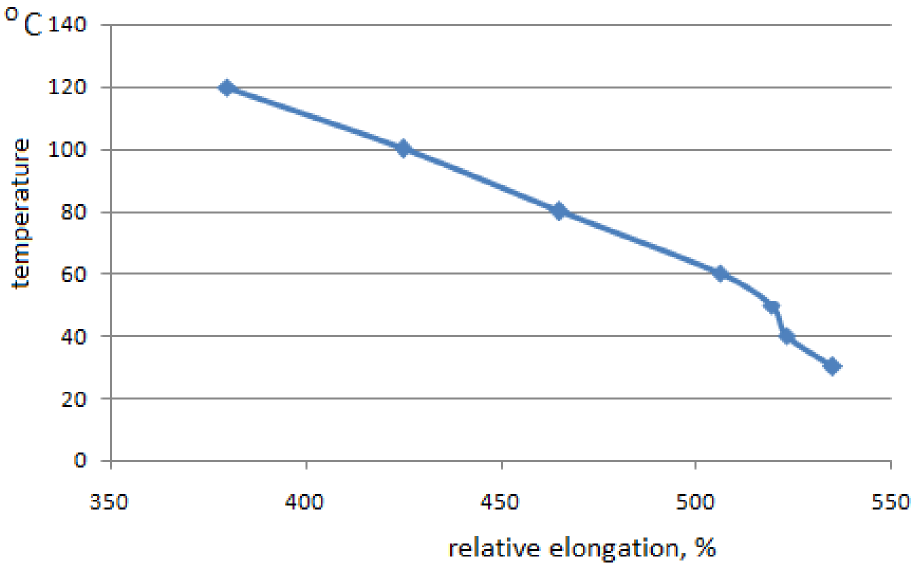

Fig 1. Dependency of the relative elongation from the temperature

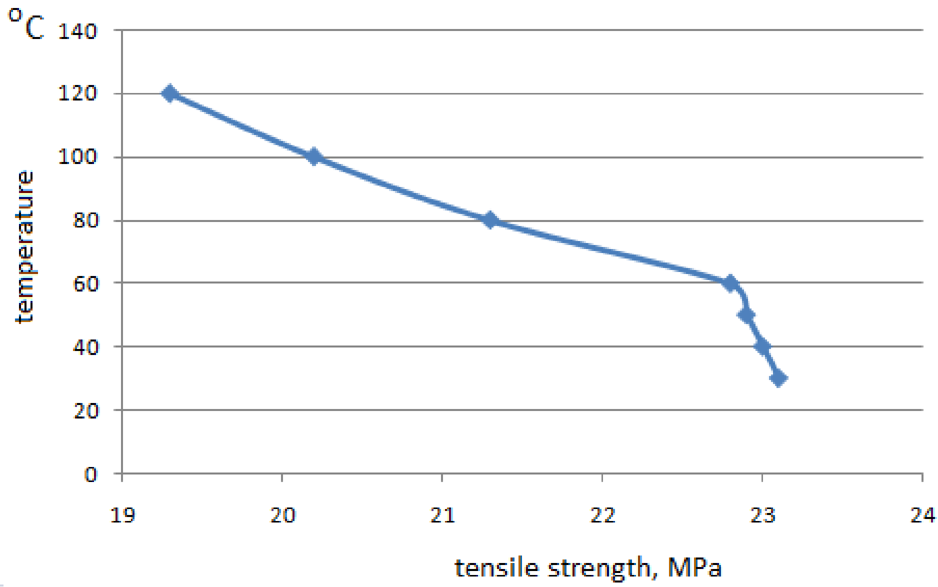

Fig 2. Dependency of the tensile strength from the temperature

Three different NBR-based rubber mixtures are tested. For the purpose of regression analysis the time to destruction is represented in logarithmic scale while the ratio 1000/T (K-1) is on the X-axis. The dependency is subjected to linearization and the methods of regression analysis can be applied.

Figure 3 represents the dependency of the time to destruction from the temperature for the three studied mixtures.

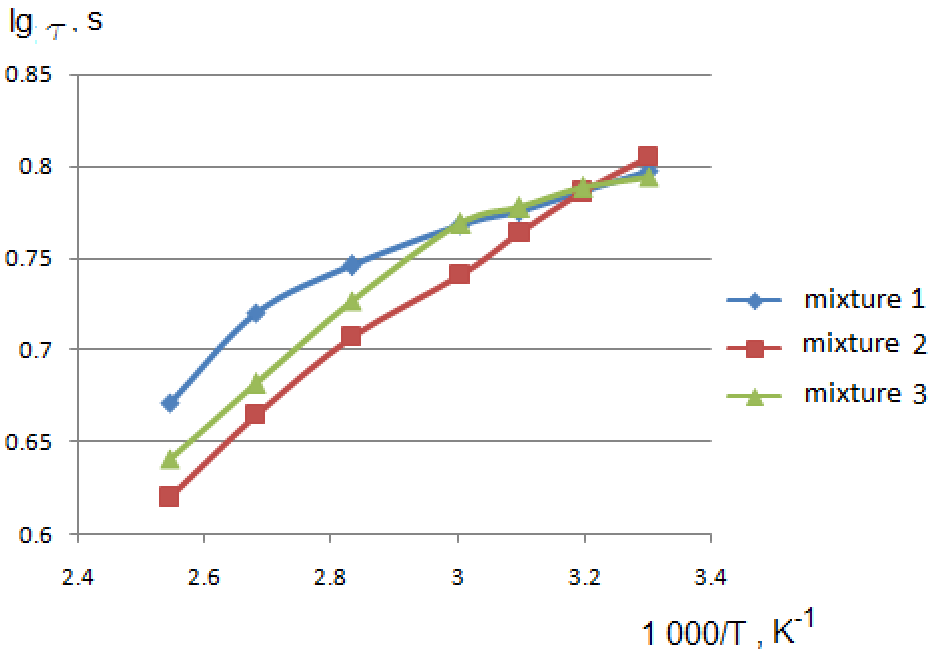

Fig 3. Time to destruction

The least squares method is one of the most frequently used algorithms for regression analysis. The parameters of the mathematical model in this case are calculated by minimizing the sum of the squares of the deviation between the experimentally determined value for the function and the value calculated using the mathematical method.

Table 1 represents the equations of the regression along with the coefficient of correlation for the three studied mixtures.

Table 1 Regression equations

Mixture	**Regression equations**	**coefficient of correlation R^2**
1	y=0,154.x+0,297	0,937
2	y=0,241.x+0,014	0,992
3	y=0,208.x+0,124	0,949

Mixture 2 is the most sensitive which also has the highest coefficient of correlation. Mixture 1 is less sensitive to the effect of the temperature at the lower temperatures of the range of study (30-50oC). Mixture 3 reacts weaker on the change of the temperature at the upper levels of the range of study (60-120oC).

The strength of the effect of the temperature on the time to destruction is determined by the ratio of the average values of the dependant and non-dependant variables.

The analysis uncovers that the average deviation of the approximation goes as follows: mixture 1: 1,2%, mixture 2: 0,6% and mixture 3: 1,4%. For all the three cases the value does not exceed 5% which is a sign for the reliability of the proposed model.

Fisher’s criterion is determined at 5% confidence level as for the all the three mixtures the obtained value is significantly higher than the critical value.

To assess the statistical significance of the parameters of regression Student's t-test is used. The values determined for the three mixtures are: 8,69; 25,9 and 9,68 which exceeds the critical value of 2,57.

The t-statistics of the coefficient of the correlation is examined which leads to obtaining values which are higher than the critical values for Student's criterion.

The confidence boundaries for the parameter of the independent variable (at 95%) are given in table 2.

Table 2 Confidence boundaries

Confidence boundaries (95%)	**Mixture 1**	**Mixtur 2**	**Mixtur 3**
Upper	0,1085	0,2173	0,1532
Lower	0,1996	0,2653	0,2639

Additionally, an analysis is performed to determine the residual dispersion which allow the determination of the confidence boundaries for prediction of individual values of the time to destruction at different temperatures.

The predicted values $\hat{y}(x_{pr})$ and the confidence boundaries for the change of the dependant variable at $x_{pr} = 1.05 * x_{cp}$ are given in table 3.

Table 3 Predicted values and confidence boundaries

	Mixture 1	**Mixture 2**	**Mixture 3**
$\hat{y}(x_{pr})$	0,7746	0,7624	0,7703
Conffidence	$0{,}6872 \le \hat{y} \le 0{,}8619$	$0{,}7162 \le \hat{y}) \le 0{,}8086$	$0{,}6635 \le \hat{y} \le 0{,}8771$

The conducted regression analysis shows good correlation between the data which confirms the reliability of the method to process all the data recorded from the experimental testings.

CONCLUSIONS

1) Thermo-mechanical tensile diagrams at constant rate of deformation for the range 30-120oC are represented for NBR-based vulcanized hyper-elastic materials which are used in the food-processing industry.

2) Mathematical model of the dependency of the temperature on the time to destruction at tensile loading with constant rate is represented based on a single-factor experiment and use of the algorithm of the linear regression.

3) The presented equations of regression show good correlation with the values recorded from the experimental testings.

4) Confidence boundaries for the significant effect of the temperature on the mechanical characteristics of rubber samples used in the food-processing industry are presented.

5) The represented results and analysis show the need from conducting of additional experiments in the lower temperature areas for uncovering their effect on the mechanical characteristics of rubber used in food-processing equipment.

REFERENCES

Andre M., Wriggers P. (2005). Thermo-mechanical behaviour of rubber materials during vulcanization. *International Journal of Solid tructures,* Volume 42, Issue 16-17, August 2005, 4758-4778.

Datta J. et al. (2014). *Mechanical and thermo-mechanical properties of natural rubber composites with submicron- and nano-sized silica particles.* Conference: VII International Scientific-Technical Conference: Advance in Petroleum and Gas Industry and Petrochemistry (19-24.05.2014), At Lviv, Ukraine.

Hassan M. M. et al. Thermo-mechanical properties of devulcanized rubber/high crystalline polypropylene blends modified by ionizing radiation. *Journal of Industrial and Engineering Chamistry,* Volume 19, Issue 4, July 2013, 1241-1250.

Paipetis S. A. , Melanitis N. , Kostopoulos V. (1998). Thermomechanical properties of rubber/carbon black composites. *Journal of Materials Science,* December 1988, Volume 23, Issue 12, 4282-4286.

Staszczak M. et al. (2015). Thermomechanical Properties of Vulcanized Rubber investigated by Testing Machine and Infrared Camera. *Measurement Automation Monitoring*, Jun. 2015, vol. 61, no. 06, 206-209.