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Properties of rubber-like materials and their blends in both positive and negative temperatures – experimental and numerical study

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ABSTRACT: Hyper elastic materials are widely used in many industries. Their use requires thorough knowledge of their strength parameters over a wide temperature range. However, determination of the parameters of hyper elastic materials is still a challenge. Therefore, the paper presents research methodology allowing determination of the properties of hyper elastic materials in a wide range of stretch and temperatures (from +50°C to -25°C) on the example of SBR (styrene-butadiene) and NR (natural rubber) elastomers. Additionally, two blends, CR/NBR and NR/SBR blends were also considered. On the basis of physical premises, a polynomial and Arruda-Boyce hyper elastic constitutive models parameters were determined using two different methods: curve-fitting and Successive Response Surface Method.

KEYWORDS: polymers, uniaxial tension, temperature effects, optimization

1. Introduction

Hyper elastic materials are currently one of the most commonly material groups used in modern industry. Their usage spreads from automotive industry, where are used mostly for car tires and suspension components, up to civil engineering, aviation and biomechanics.

Due to such a wide spectrum of a usage, it is crucial to precisely determine their mechanical properties. In the case of hyper elastic materials, as in other elastomers and polymers, the mechanical properties are highly depended of the temperature [1-3]. In the literature we can find parameters for such materials mostly determined in the both ambient and elevated temperature [4-8]. However, in the case of the negative temperatures there is a significant lack of the data. The need of the research in the negative temperature range is all the more important due to the fact that their behavior in temperatures other than ambient can be counterintuitive. We could assume that in the elevated temperatures the deformation of such materials will be larger than in the negative temperatures. However, in the elevated temperatures a rapid degradation of the polymer chains occurs, which results in lowering the strain at the fracture in comparison to tests performed in the negative temperature range [9].

2. Specimen preparation and test methods

The test samples were cut from the premade 300 x 300 mm and 2 mm thick sheets made from SBR (styrene-butadiene) and NR (natural rubber) hyper elastic materials. Additionally, two blends in the form of CR/NBR (chloroprene/ nitrile butadiene rubber) and NR/SBR were used in the research.

In the first step of the research the mechanical properties of the materials were determined. The typical tensile tests were carried out in the following temperature range: -25°C, 0°C, 25°C and 50°C. In order to determine the deformation of the samples the motion tracking method was used. Each test was recorded using a high resolution (1920x1080 px.) camera. In next step the image analysis was carried out using TEMA software. Every test sample had a set of markers placed in the predefined position. A motion tracking method was used due to the large deformations of the tested materials during the tensile tests.

In order to determine the thermomechanical properties of selected materials two method were utilized: dynamic mechanical analysis (DMA) and differential scanning calorimetry (DSC). With use of these methods the determination of the glass transition temperature of every considered material was possible.

3. Results

Analysing the strain-extension curves from tensile tests we can note, that of all the materials tested, the most pronounced temperature influence can be observed for NBR material. In this case at a temperature of 0°C, a significant change in material stiffness is visible. In all other cases, the change has a much more linear characteristic, which means that these materials behave in a more predictable manner over the entire range of considered temperatures.

The obtained results from the DMA allow the conclusion that for all samples except NR/SBR, the glass transition process was one-stage. In the case of sample NR/SBR a two-stage of the glass transition process was observed, due to the presence of a two-component system with different glass transition temperatures. The results of the DMA are presented in Tab. 1.

Table 1. Glass transition temperature received by DMA

	E’	E’’	tan δ
SBR	-40.73	-32.34	-24.71
NR	-51.66	-45.54	-37.43
NR/SBR	-56.22	-48.36	-32.75
CR/NBR	-55.84	-45.70	-33.15

4. Material model parameters identification

After the review of the available models, two commonly used in various types of analyses with the use of finite element method were selected, i.e. the polynomial and Arruda-Boyce models. In order to determine the values of the both constitutive models the curve-fitting technique was used. This method principle is determining the function that describes the series of data, in this case the strain and stress values obtained during the experimental tests, in the best possible way, while taking into account predefined constraints.

In the case of the polynomial mode, the values of all material constants (C10, C01, C11, C20, C02 and C30) were determined, with the proviso that all values must be greater than zero. Such a limitation was adopted due to the fact that negative values of the constants, despite potentially very good curve fitting, may lead to instability during numerical analyses.

Arruda-Boyce material model requires a much smaller number of constants. In practice only two, in addition to density and bulk modulus, are needed: shear modulus (G) and number of statistical links (N). The constraint was that both values should be greater than zero and number of statistical links must be an integer. The obtained parameters are presented in Tab. 2.

Table 2. Arruda-Boyce constitutive material model constants

	Temp. [°C]	N	G
SBR	50	4	1.02686
	25	6	1.62532
	0	6	1.55613
	-25	6	2.18831
NR	50	7	1.33213
	25	12	1.92605
	0	6	1.66705
	-25	5	1.86775
NR/SBR	50	5	1.58015
	25	5	1.61376
	0	7	1.99259
	-25	5	2.19817
CR/NBR	50	3	1.03194
	25	4	1.53908
	0	6	1.93717
	-25	9	2.90620

5. Conclusions

1) A change in the stiffness and strength of the SBR at 25°C can be observed. Maximum stress value is equal to 17.5 MPa for -25°C, while the lowest value of 7 MPa was obtained at 50°C,
2) the NR material is characterised by the even distribution of the strain-extension curves in the whole temperature range. The lowest value of stress (9 MPa) was obtained at 50°C,
3) the stiffness of the NR/SBR blend is almost identical at both 25 and 50°C, while in the case of the CR/NBR the stiffness at 0 and 25°C is almost identical up to extension of 2.5,
4) the most pronounced temperature effect can be observed for a NBR material, in which at 0°C a rapid change in stiffness is visible.

In the next step a series of material parameters for both polynomial and Arruda-Boyce constitutive models were determined and numerical analyses were performed in order to validate and compare the results with the experimental research. On the basis of these analyses, we can conclude that in most cases the true strain vs. true stress curve representing the polynomial model coincides with the average curve obtained from experimental test, while for the Arruda-Boyce material model the discrepancies are greater. The average difference between the values of the true stress obtained from the Arruda-Boyce model and experimental tests is about 16%, which is four times greater than from the polynomial model, where the difference is about 4%.

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