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Tensile and Shear Tests of a Cork/Rubber Composite

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Abstract. This paper deals with a composite consisting of cork particles and the rubber matrix. The size of the cork particles is approximately one millimetre. Testing samples were exposed to uniaxial tension, biaxial tension, and shear using special fixture for Arcan samples. Mechanical behaviour of the samples was investigated using different strain rates to provide data for the identification of parameters of a finite-strain viscoelastic constitutive model. The Poisson's ratio was measured under the uniaxial tensile loading.

Introduction

Knowledge of the mechanical properties of materials is of critical importance for the design of all products. First book devoted to the physical testing of rubbers appeared in 1965 [1]. Since rubbers have a unique combination of the properties, e.g., bulk modulus is thousand times greater than Young's modulus, special testing methods have been developed [2]. Cork is a closed-cell structure. It can be considered, in a first approximation, as a transversally isotropic material. In contrast to rubber, cork has near-zero Poisson's ratio [3].

This paper deals with a composite consisting of cork particles and rubber matrix. The size of the cork particles is approximately one millimetre (Fig. 1). This composite is often used as the core material in constrained damping layer constructions [4, 5]. Testing samples were exposed to uniaxial tension, biaxial tension, and shear using special fixture for Arcan samples [6], (Fig. 2). Mechanical behaviour of the samples was investigated using different strain rates to provide data for the identification of the parameters of a finite-strain viscoelastic constitutive model. The Poisson's ratio was measured under the uniaxial tensile loading. Obtained results supplement mechanical characteristics investigated in [7], where simple tension, simple shear, simple compression, and volumetric compression tests were performed according to recommendations for the Bergstrom-Boyce model calibration [8].

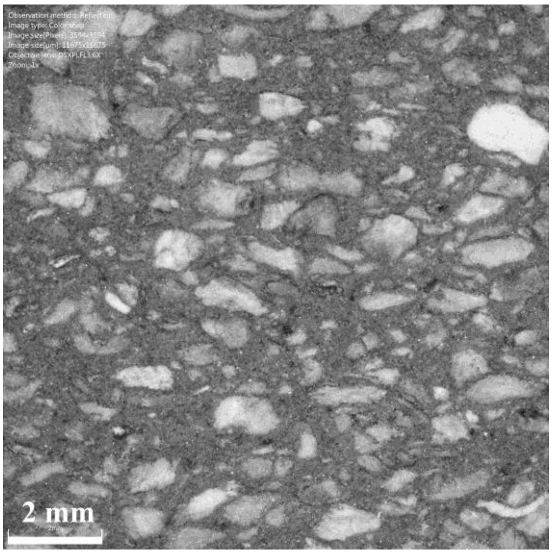
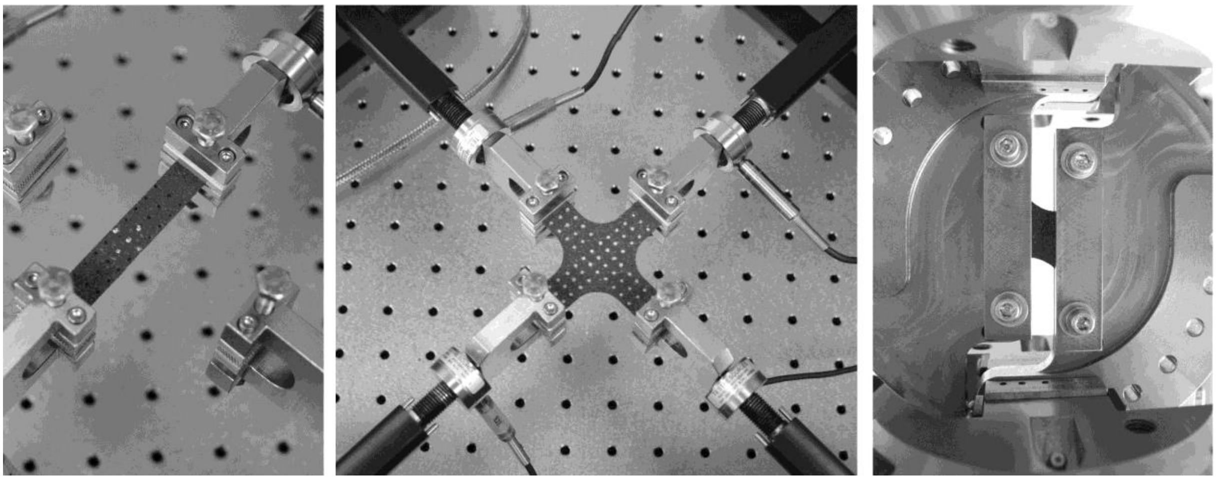


Fig. 1 Detail of cork/rubber particle composite.

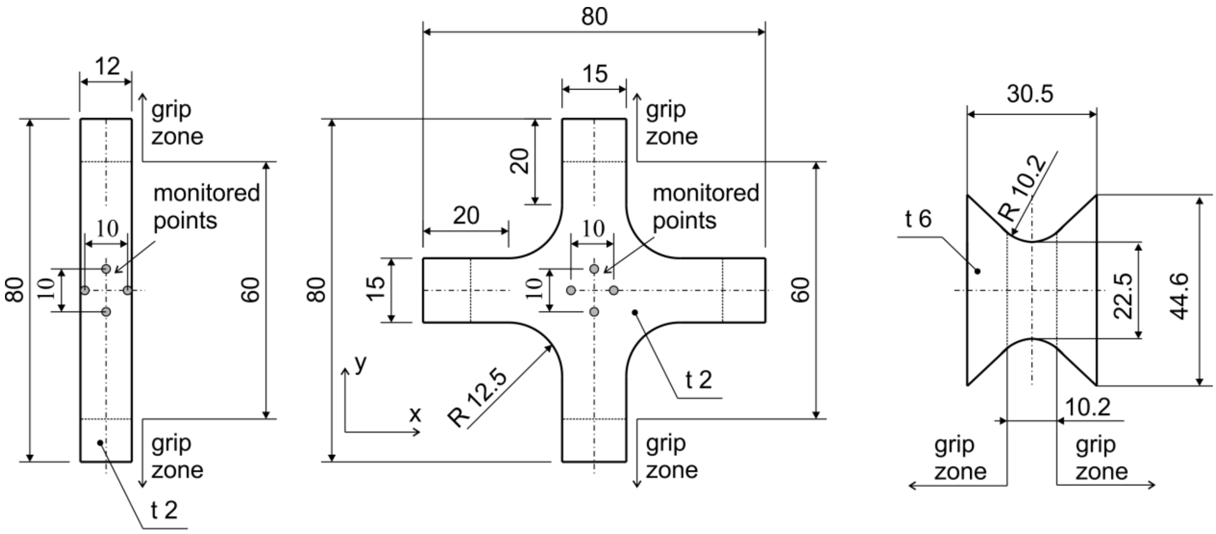


(a) (b) (c)

Fig. 2. Performed tests: uniaxial tension (a), biaxial tension (b), and shear of Arcan sample (c).

Experiments

The tests were performed on the electrodynamic planar biaxial test system TestResources 574LE and on the servohydraulic dynamic test system Instron 8850. The temperature was 23±1 °C, the atmospheric moisture was 50±6 %. Experimental samples were cut from 2 mm and 6 mm thick plates using a water jet. The geometry of the samples is shown in Fig. 3 [6, 9]. Displacements of the monitored points, depicted in Fig. 3, were monitored using a real-time digital image correlation system VIC-Gauge 2D. The strain rate range was between 0.001 s^{-1} and 1.00 s^{-1}. Three loading/unloading cycles including 60 s of relaxation time were prescribed. A virgin sample was used for each test. At least three samples were tested under identical conditions (the strain rate and maximal nominal strain).



(a) (b) (c)

Fig. 3. Samples for: uniaxial tension (a), biaxial tension (b), and shear (c).

The designation of the samples is obvious from Fig. 4. A symbols denote the type of the test, B symbols denote the strain rate used for loading and unloading, C symbols denote the maximal nominal strain (normal strain related to the initial length between the grips).

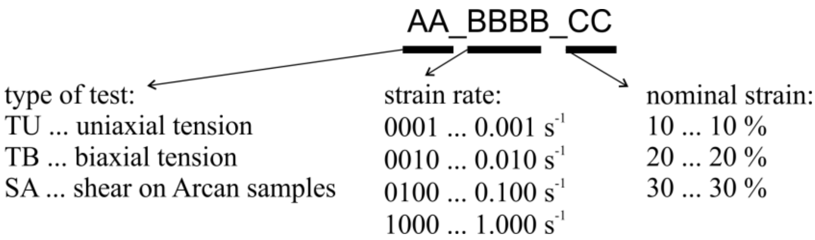
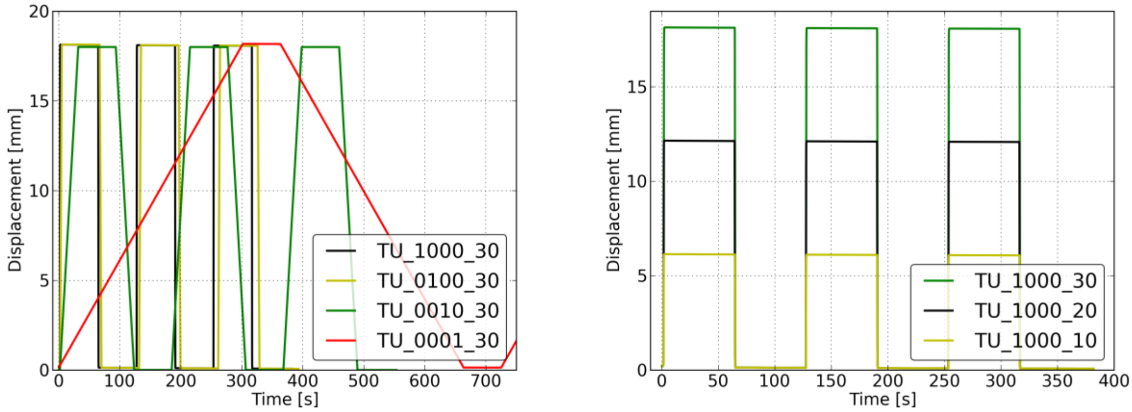


Fig. 4. Designation of samples.

Uniaxial tension. The initial sample length between the grips was 60 mm (Fig. 3(a)). The uniaxial tensile (TU) tests were performed with four different crosshead velocities: 0.03 mm·s^{-1}, 0.3 mm·s^{-1}, 3 mm·s^{-1}, and 30 mm·s^{-1}. Displacements prescribed to the crosshead are obvious from Fig. 5 (only the first cycle is shown in the case of the strain rate 0.001 s^{-1}).



(a) (b)

Fig. 5. Uniaxial tension – prescribed displacements: different strain rate (a), different maximal nominal strain (b).

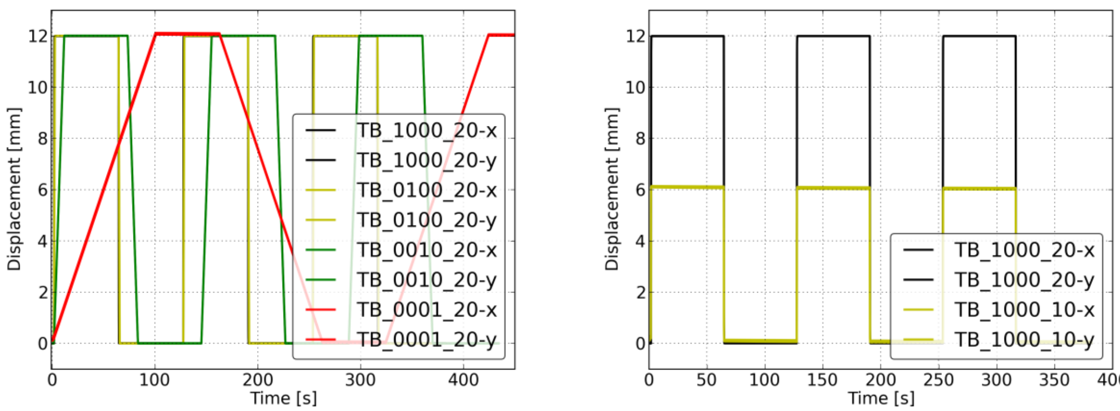


Fig. 6. Biaxial tension – prescribed displacements: different strain rate (a), different maximal nominal strain (b).

Biaxial tension. The initial sample length between the grips was 60 mm (Fig. 3(b)). Since the strain rate is not homogeneous in the biaxial samples, the biaxial tensile (TB) tests were performed with higher crosshead velocities than in the case of uniaxial tension. These four velocity values were applied to obtain strain rate values similar to the strain rate values of the TU samples (in the middle of the TB samples): 0.06 mm·s^{-1}, 0.6 mm·s^{-1}, 6 mm·s^{-1}, and 60 mm·s^{-1}. Displacements prescribed to the crosshead are obvious from Fig. 6. Since an ultimate failure occurred when the displacements were larger than 12 mm, the TB samples with the maximal nominal strain of 30 % could not be tested.

Shear. The initial sample length between the grips was 10.2 mm (Fig. 3(c)). In order to obtain principal strain values similar to the values in TU test, two times higher values of nominal shear strain than the values of nominal normal strain were applied. The shear tests of the Arcan samples (SA tests) were performed with the following four different crosshead velocities: 0.02 mm·s^{-1}, 0.2 mm·s^{-1}, 2 mm·s^{-1}, and 20 mm·s^{-1}. Displacements prescribed to the crosshead are obvious from Fig. 7.

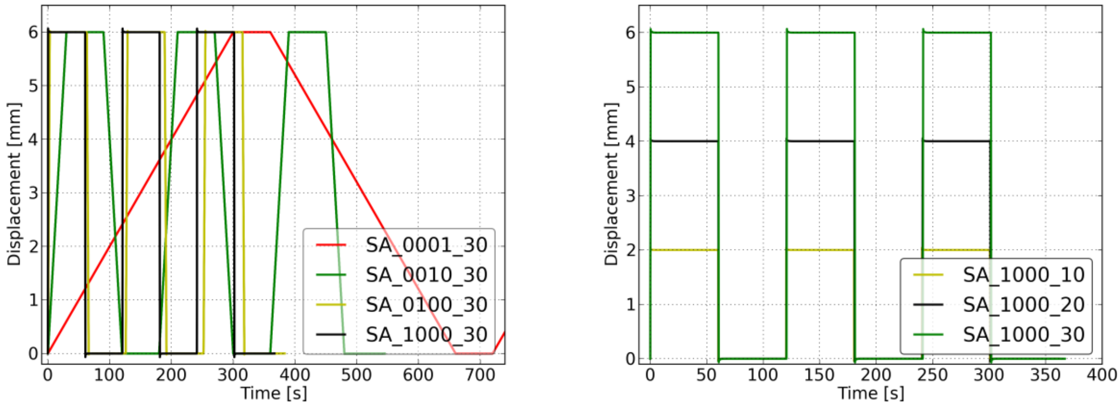


Fig. 7. Shear – prescribed displacements: different strain rate (a), different maximal nominal strain (b).

Results

Typical force responses to the prescribed displacements are shown in Fig. 9 – Fig. 11. It is obvious that the forces relaxed significantly when the strain rate was higher than 0.001 s^{-1}, especially, when the strain rate was 1 s^{-1}. Since the thickness of the tensile samples was small, the samples lost stability during unloading (this phenomenon in the case of the TB sample is shown in Fig. 8). Therefore, significant negative force values were not registered in cases of the TU and TB tests. Moreover, obtained displacements of the monitored points, when the crosshead displacements were close to zero, were not correct.

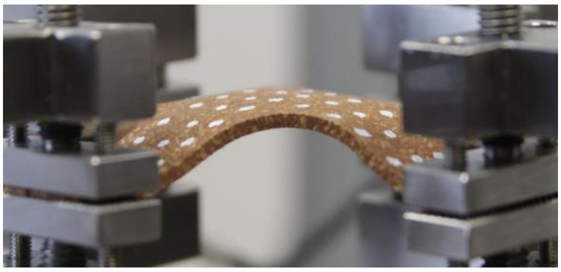
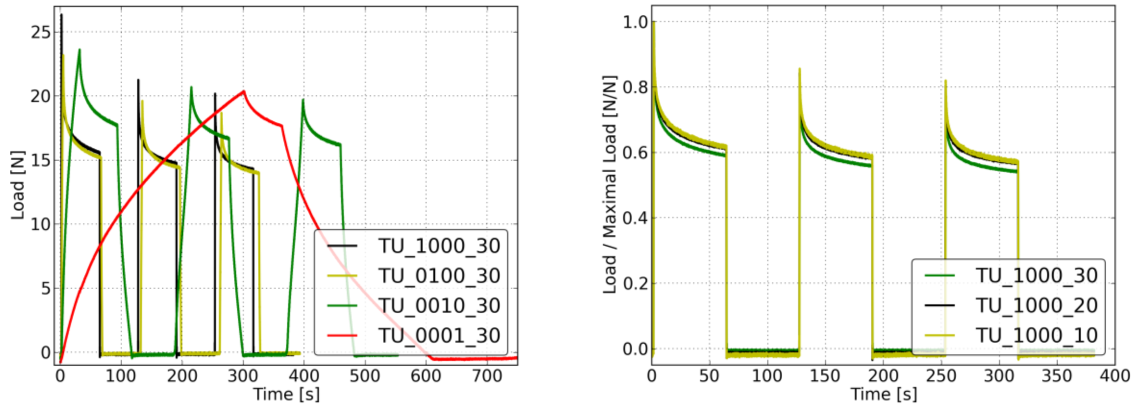


Fig. 8 Buckling of TB samples

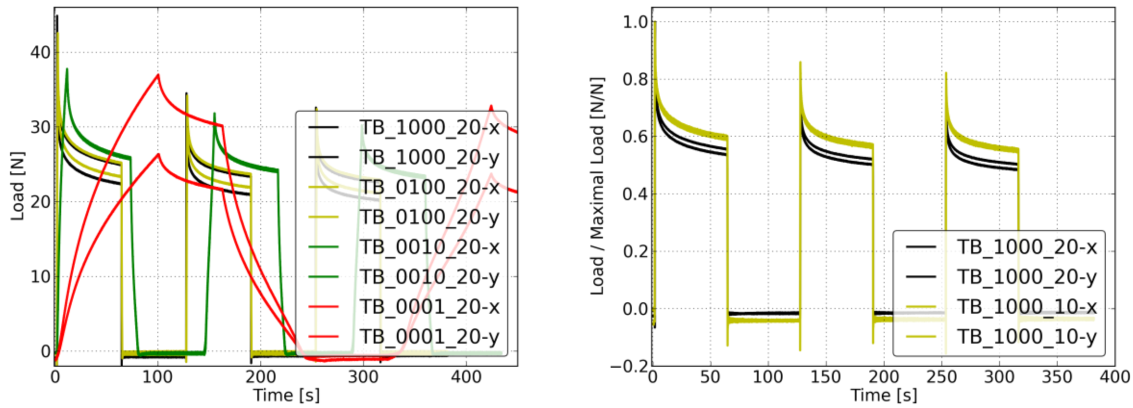
Fig. 9(b) –- Fig. 11(b) demonstrate the force-time curves of the tests when the force values of each test are divided by the maximal force value of the test. If the curves for tests with different maximal nominal strain are identical, the viscoelasticity is linear. It is obvious that the curves were very similar in the case of the tensile tests, however, the differences in the case of the shear test are significant. The reason of that can be different behaviour of the cork in tension and compression (cork is a closed-cell foam).

Anisotropy of some samples was proved in the tensile tests (see e.g. Fig. 10, sample TB_0001). Besides the fact that cork is anisotropic, cork particles exhibited a preferred orientation in some samples (see longitudinally and transversally oriented particles of TU samples in Fig. 12). Significant difference between tensile curves of samples loaded in the longitudinal direction and the transverse direction is demonstrated in Fig. 13(a).



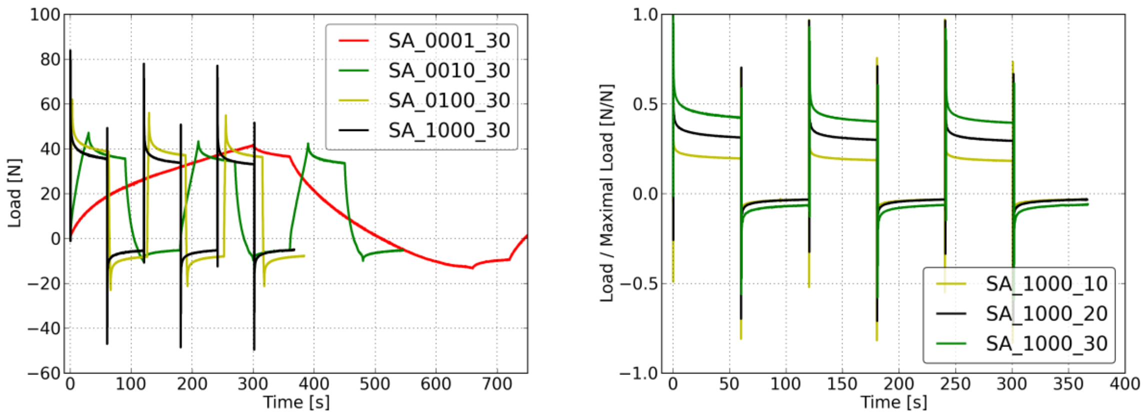
(a) (b)

Fig. 9. Uniaxial tension – force responses: different strain rate (a), different maximal nominal strain (b).



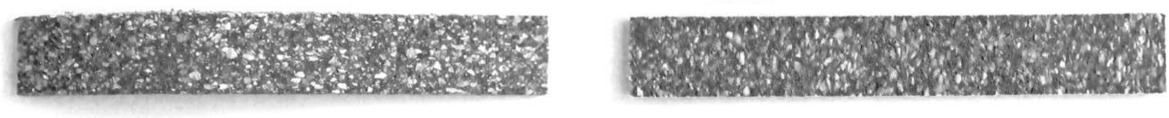
(a) (b)

Fig. 10. Biaxial tension – force responses: different strain rate (a), different maximal nominal strain (b).



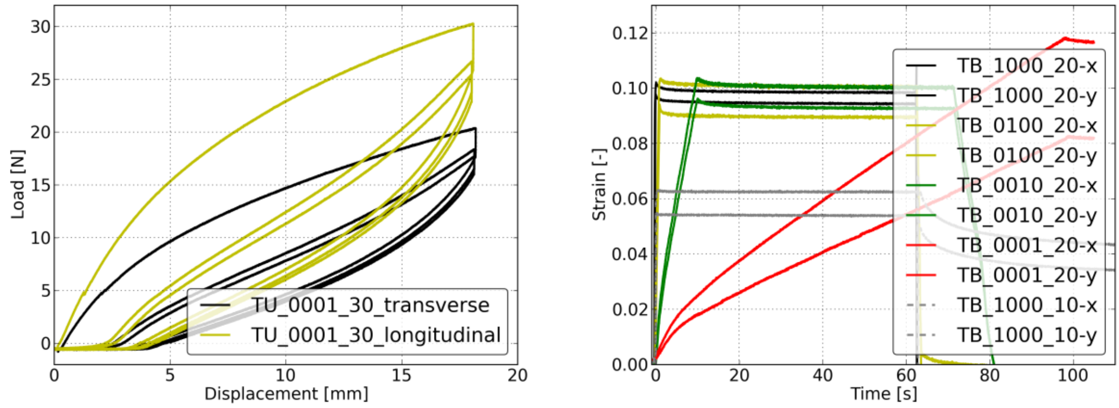
(a) (b)

Fig. 11. Shear – force responses: different strain rate (a), different maximal nominal strain (b).



longitudinal orientation transverse orientation

Fig. 12. Longitudinally and transversally oriented particles of TU samples.



(a) (b)

Fig. 13. Uniaxial tension of samples with oriented particles (a). Biaxial tension – strains in the middle of samples (b).

The anisotropy and the shape (orientation) of the cork particles probably also influenced the results of the Poisson’s ratio measurement (calculated from the displacements of the monitored points). Since area corresponding to the monitored points is relatively small (comparing to the size of the cork particles), the Poisson’s ratio was in the range shown in Fig. 14. Nevertheless, the results show a trend that the Poisson’s ratio decreased with the strain rate.

Fig. 13(b) shows normal strains ε_x and ε_y in the middle of TB samples (calculated from the displacements of the monitored points). It is obvious that the normal strain in this area reached approximately half of the values of the nominal normal strain.

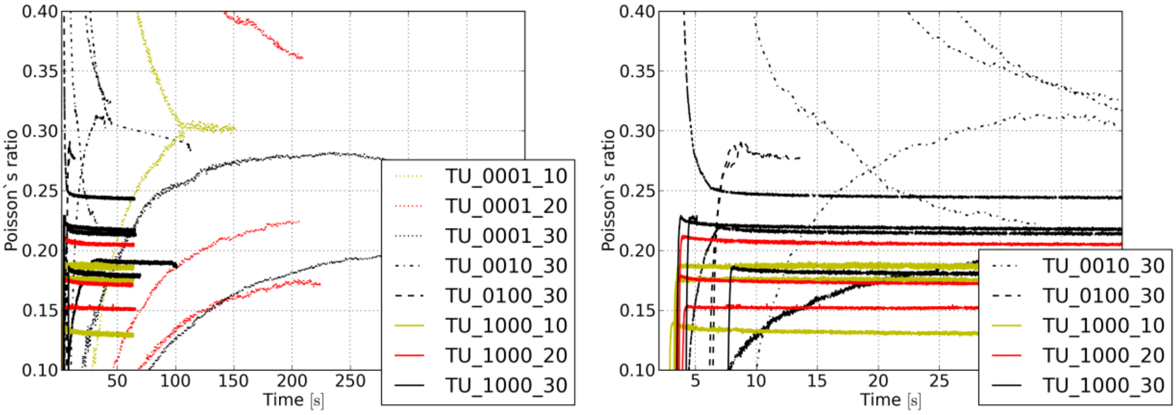


Fig. 14. Uniaxial tension – Poisson’s ratio.

Conclusions

The results of the Poisson's ratio measurement showed a trend that the Poisson's ratio decreased with the strain rate. The Poisson's ratio was in the range of 0.13 to 0.36. As expected, the maximal forces increased with the strain rate. Although the tensile tests (uniaxial and biaxial) suggested linear viscoelastic behaviour, the shear response was nonlinear with respect to the prescribed strain history.

Mechanical properties of the investigated cork/rubber composite depended on the location of a sample in a plate from which the sample was cut (based on shape and anisotropy of the cork particles). This fact complicates obtaining of reliable experimental data for the calibration of a finite-strain viscoelastic constitutive models. Testing of large-scale samples, which would correspond better to the constrained damping layers of structures, can improve the experimental data reliability (the unification of experimental results).

Acknowledgement

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