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Experimental study of termo-visco-elastic material behavior at low temperatures

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Abstract

In this contribution results of experimental works aimed at dynamic behavior of rubber segments for lower temperatures are summarized. The segments are used for vibration damping at composed railway wheels. Besides static and dynamic characteristics, curves of lifetime and the limit line of Smith`s diagram for 10% permanent deformation of rubber are presented.

Keywords: static and dynamic characteristics, lifetime curves, limit lines

1. Introduction

The contribution summarizes results of works the aim of which was to determine behaviour of rubber elements made of thermo-viscous-elastic material 42-809 at low temperatures. It is a further stage of works which were performed within a solution of the grant No. 101/05/2669 aimed at the study of behaviour of rubber segments used for railway vehicle noise and vibration damping in spring-loaded assembled wheels. Subjected to monitoring were changes of static and dynamic characteristics in a range of temperatures from 0 to – 50°C, the process of rubber relaxation after its removal from the chamber and the effect of cyclic loading on the change of rubber static characteristics. The rubber specimens life curves at the temperatures of 0, -20 and -40°C were also determined. The limit lines of the Smith diagram for 10% permanent deformation and temperatures of + 23°C, 0°C and -20°C were evaluated from the life curves.

2. Experimental programe

2.1. Conditioning chamber for rubber testing at low temperature

Fig. 1 shows a conditioning chamber used for tests of rubber at low temperatures. The chamber was purchased from firm INOVA Praha and built in a fatigue machine ZUZ 200. It allows to perform static and dynamic tests of rubber and metal specimens in a range of temperatures from -50°C to +180°C. To enhance the accuracy of measurements and loading of rubber the testing machine was fitted with a smaller 40kN dynamometer made by firm Rumburk. For the rubber testing purposes the original mechanical jaws were replaced by tierods with support disk going through the chamber upper and lower cover. Silicon rubber was used to seal the tie-rods in places of passages. Fig. 2 shows a front view inside the chamber.

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Two vents can be seen on the wall to allow circulation of cold (or hot) air coming from the aggregate and the light to iluminate the inside of the chamber.

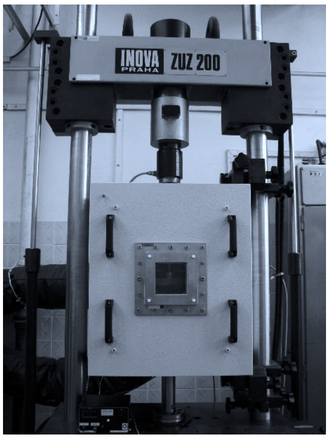

Fig. 1. View of the conditioning chamber.

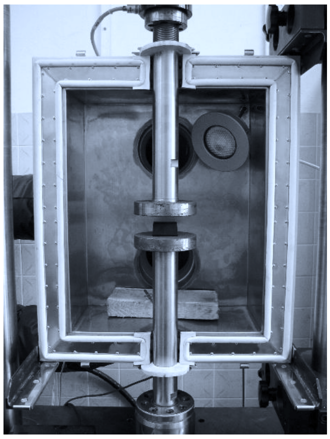

Fig. 2. View of a specimen under loading in the chamber.

2.2. Test specimens

Subjected to measurements were rubber elements obtained by cutting the segments in fig. 3 in the centre of connecting bridge, the reason being to save material as each of the characteristics was measured on a so far unloaded rubber, i.e. in its "virgin state".

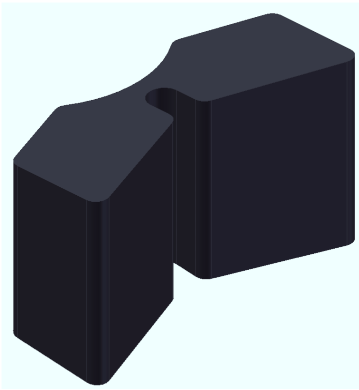

Fig. 3. A shape of rubber segment.

2.3. Test program

- Measurements of static characteristics in a range of temperatures 0 ÷ -50°C
- Measurements of dynamic characteristics in a range of temperatures 0 ÷ -50°C
- Monitoring of the cyclic loading effect on the shape of rubber static characteristics
- Determination of rubber specimen life curves at temperatures of 0, -20 and -40°C and constructing of the Smith diagram limit lines for 10% permanent deformation and temperatures of +23, 0 and -23°C.

3. Test results

3.1. Measurement of rubber static characteristic at low temperatures

The characteristics were obtained in a usual way with a controlled path until the compression of a rubber element by a value of 7 mm. The first three loops were taken at a loading rate of 30 mm/min which was followed by a loop taken at a rate of 10 mm/min. The characteristics were taken at temperatures of 0, 10, -20, -30, -35, -40 and -50°C. After reaching the required temperature in the chamber the specimen was left for four hours at a steady temperature in order to balance the temperature and only after that the specimen was subjected to loading. In all cases the rubber specimen height was measured before inserting it into the chamber and after its removal and relaxation for 2,4 hours. Figures 4, 5 and 6 show the comparison of rubber static characteristics measured at a room temperature of +23°C, at 0°C and -40°C.

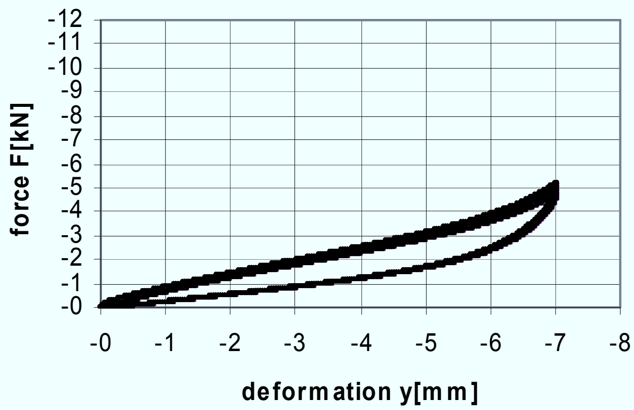

Fig. 4. Static characteristic at a temperature of +23°C.

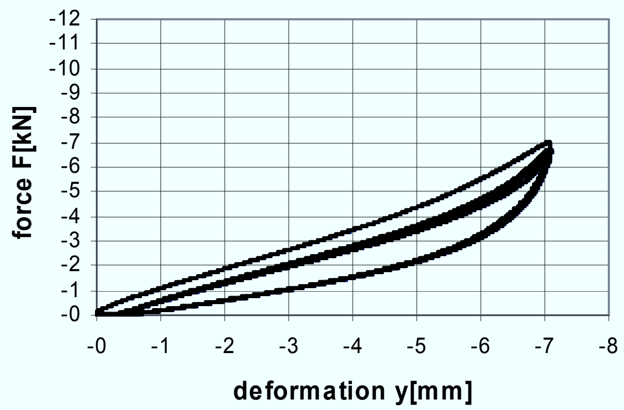

Fig. 5. Static characteristik at a temperature of 0°C.

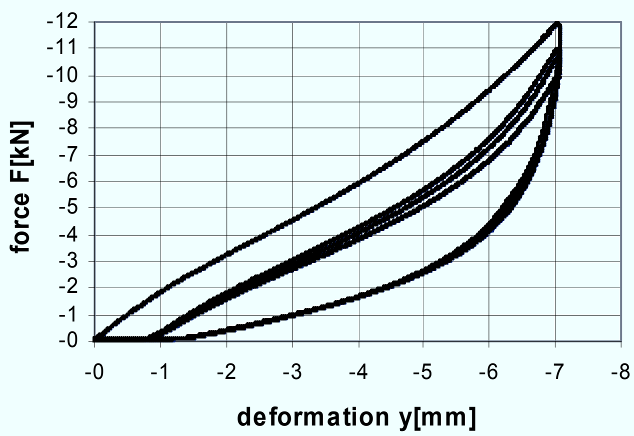

Fig. 6. Static characteristics at a temperature of -40°C.

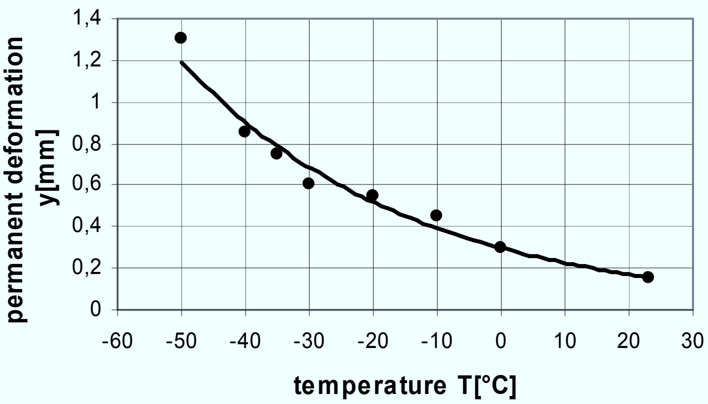

Fig. 7. Permanent deformation temperature dependence.

Fig. 7 shows the rubber specimen permanent deformation dependence on the temperature. To be more precise it shall be stated that these are permanent deformations obtained based on the above mentioned static characteristics. After unloading the rubber specimen and removing it from the chamber the specimen is regenerated and practically returns to its original shape after several hours. However, the specimen material remembers the hardening due to low temperatures and the new hysteresis loops are not the same as those in case of a "virgin specimen". Their steepness increases. This effect clearly manifests itself at the cyclic loading of the specimen.

3.2. Measurement of rubber dynamic characteristic at low temperatures

Figures 8, 9 and 10 show dynamic characteristics of rubber specimens loaded by forces F_m = -5kN and F_a = ±3kN at harmonic oscillation with a frequency of f = 2Hz. The tests were carried out at temperatures 0, -10, -20, -30, -40 and -50°C. The loops in the above figures are taken at temperatures 0, -30 and -50°C. The hysteresis loops were taken after 150, 5000, 10000, 50000 and 75000 cycles. If we compare the above figures, we will find at the applied amplitude of loading, the rubber shows the biggest deformation at a temperature of 0°C (possibly higher). With dropping temperature the oscillation deformation decreases and the hysteresis loops steepness increases. With an increased number of cycles the hysteresis loops move to the right. The rubber hardens and this hardening is identical to the value of permanent deformation after unloading. With an increasing number of cycles the rubber does not harden any more, at the same time the steepness of loops is changed.

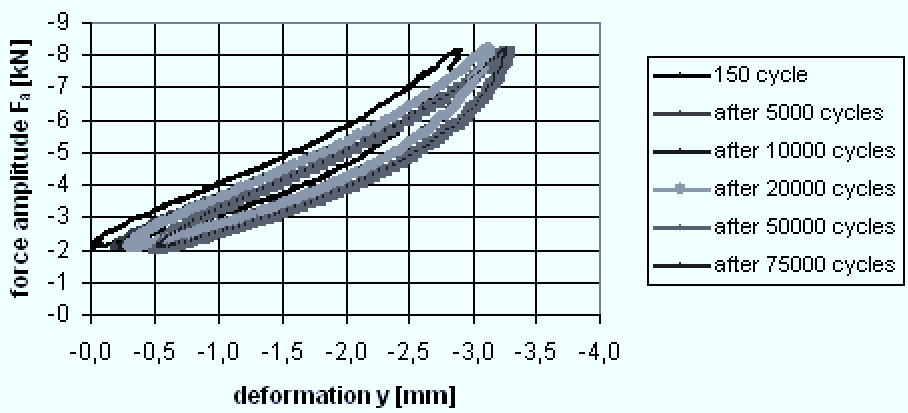

Fig. 8. Rubber dynamic characteristics at 0°C.

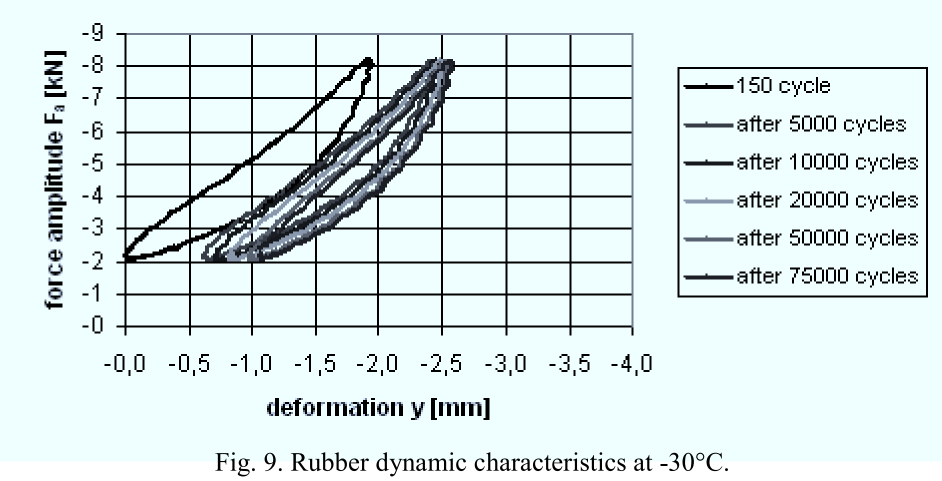

Fig. 9. Rubber dynamic characteristics at -30°C.

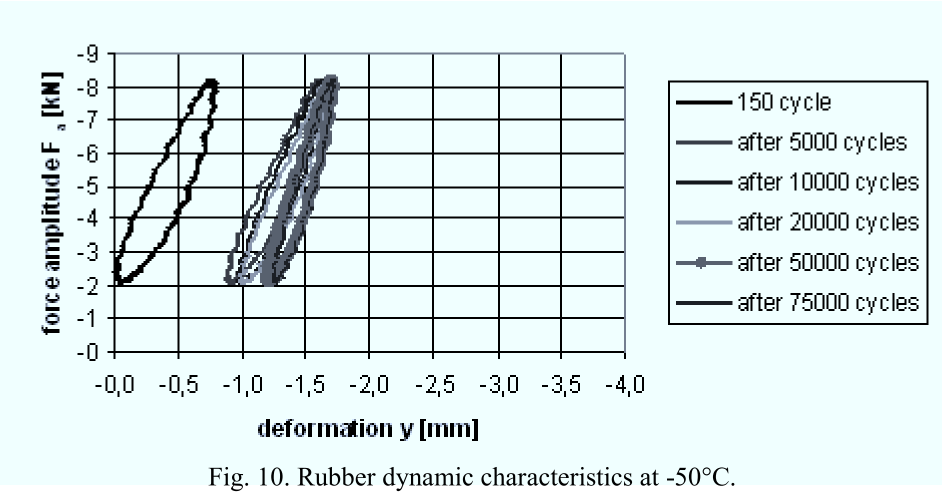

Fig. 10. Rubber dynamic characteristics at -50°C.

3.3. Cyclic loading effect on the shape of rubber static characteristics

Fig. 11 shows the comparison of two static characteristics obtained at a room temperature of +23°C (loop No. 1 – a specimen in "virgin state") and after oscillation of 15000 cycles at -40°C (loop No. 2 – loading the specimen by a force F_m = -8kN and F_a = ±4kN).

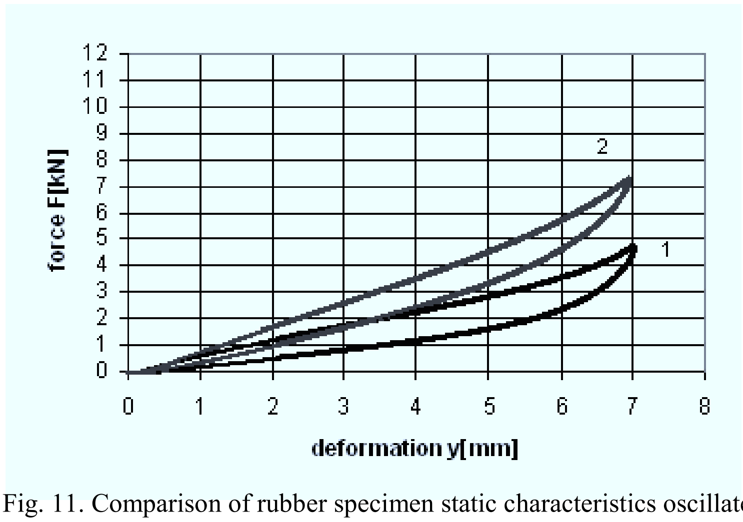

Fig. 11. Comparison of rubber specimen static characteristics oscillated at -40°C and a specimen in a so called "virgin state."

It is obvious from the figure that the cyclic loading of the specimen at a temperature of -40°C caused increased rigidity of rubber and by that also a relatively significant change of its static characteristic. To achieve the same deformation we need to have an approx. 35% higher force. It was found by monitoring the relaxation of rubber removed from the chamber that even after 62 hours of relaxation the rubber would not return to the original state and would remain permanently deformed. However, it was precised based on other experiments that the change of static characteristics shape was not caused only by the temperature at which the rubber is dynamically loaded but by the level and evidently also by the number of cycles of applied cyclic loading which cause irreversible changes in rubber material.

3.3. Determination of life curves at low temperatures

The tests objective was to determine the number of cycles after which the cyclic-loaded rubber specimen reaches 10% permanent deformation. These were permanent deformations after relieving the specimens at a set temperarure, i.e. not after relieving the specimens at a room temperature with the view of the specimens regeneration. The tests were carried out at temperatures of 0°C, -20°C and -40°C and for the purpose of comparison also at a room temperature of +23°C. The curves were determined for the size of static pre-stress of F_m = -5 and -8kN, only in case of the temperature of -20°C at -6 and -8kN. Figures 12 and 13 show life curves for temperatures of +23°C, -20°C and -40°C. Having a mere look at the above figures we will find that the individual curves differ from one another. The number of cycles N until reaching permanent deformation (specified life time) is affected not only by the temperature but also by the level of rubber static pre-stress. Both the low temperature and the level of static pre-stress affect the rubber rigidity and by that also the oscillation amplitude. With increasing static pre-stress F_m the life curves shift to the right to the area of higher number of cycles. At a temperature of -20°C, the life curves character remains similar to those at temperatures higher that 0°C, however, the number of cycles is determined not only by the size of static pre-stress but also by decreased temperature. This was manifested in figure 13 by returning the trend of static pre-stress effect. This effect was again increased by further decreasing the temperature, as shown in Fig. 14. In addition to that, there is alife curves displacement at a temperature of -40°C which is manifested by earlier achievement of 10% permanent rubber deformation.

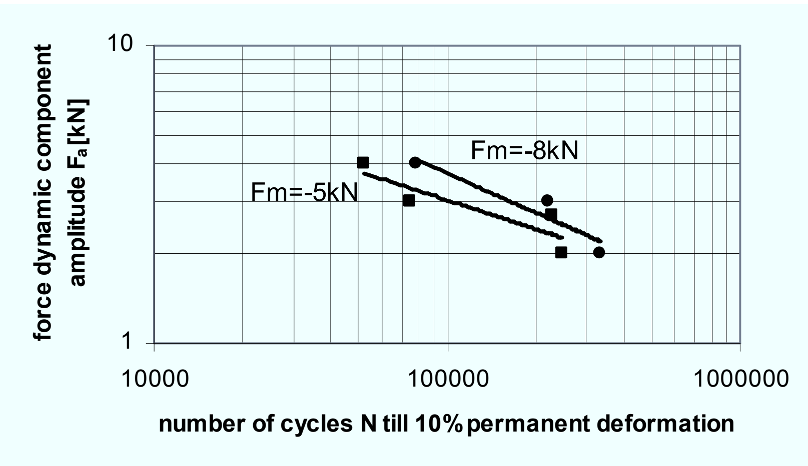

Fig. 12. Rubber specimens life curves at +23°C.

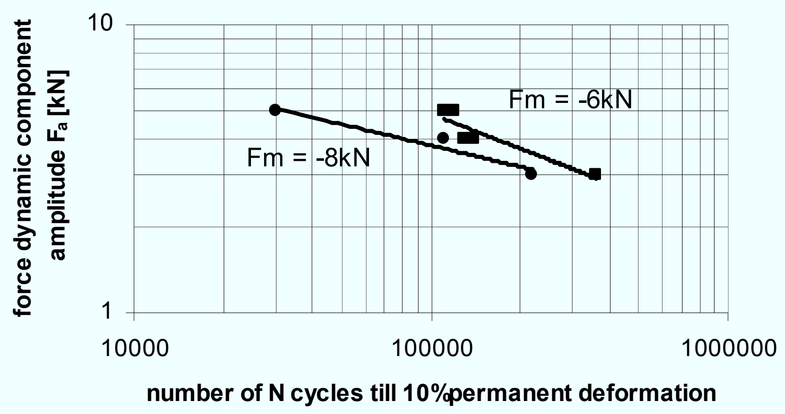

Fig. 13. Rubber specimens life curves at -20°C.

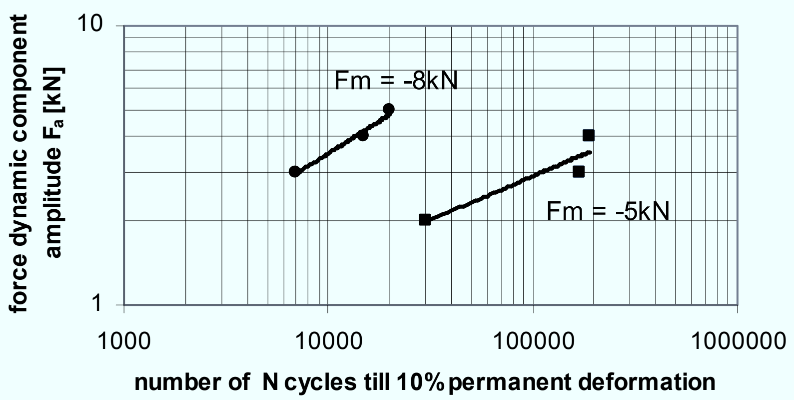

Fig. 14. Rubber specimens life curves at -40°C.

Based on the obtained life curves we constructed Smith diagram limit lines for 10% permanent deformation and temperatures of +23°C, 0°C and -20°C. For this purpose we analytically expressed regression equations of these curves from which corresponding force amplitudes F_a were calculated for the chosen number of N cycles to construct the limit lines. Fig. 15 shows these limit lines for the temperature of -20°C.

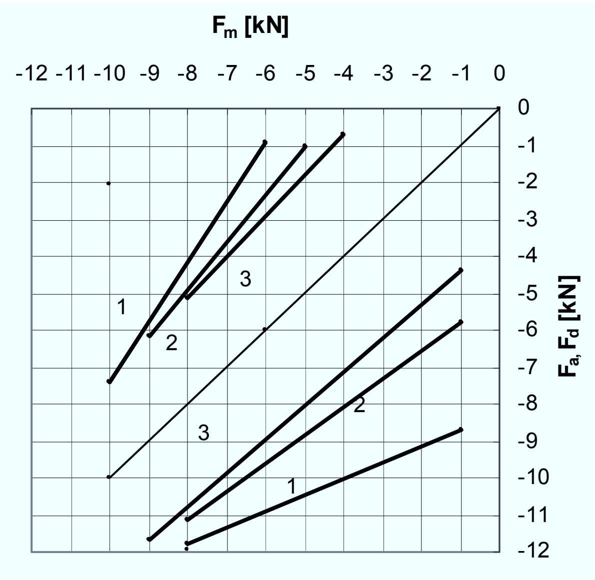

Fig. 15. Limit lines for 10% permanent deformation - temperature -20°C.

Limit line 1 in fig. 15 corresponds to 100000 cycles, limit line 2 to 200000 cycles and limit line 3 to 300000cycles.

4. Conclusion

In our contribution we focused on the monitoring of changes in properties of rubber 42 – 809 at low temperatures up to -50°C. It results from the tests that low temperatures affect the shape of static characteristics only from temperatures lower than -35°C. The shape of rubber dynamic characteristics are affected by low temperatures more notably. With a decreasing temperature the oscillation deformation decreases and the steepness of hysteresis loops increases. Both the low temperature and the level of static pre-stress affect the rigidity of rubber and by that also the amplitude of deformation of cyclically loaded rubber. It was also shown during the observation of the above mentioned life curves. More information concerning the performed tests is indicated in report [1].

Acknowledgements

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References

[1] J. Svoboda, L. Pešek, V. Fröhlich, Properties of Thermo-Visco-Elastic Material 42 – 809 for the Manufacture of Vibration-Damping Elements – Part 3, Research Report Z – 1406 / 07 of the Institute of Termomechanics, Academy of Sciences of the CR, v.v.i., 2007.