Fatigue Behaviour of Elastomers Used for Progressive Cavity Pumps Manufacture

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Failure of progressive cavity pumps used in oil extraction is mainly due to damage of the elastomer subjected to time-varying load cycles and intensive processes of degradation by abrasive wear. In order to increase the lifetime of progressive cavity pumps is very important to not degrade the elastomer under the influence of operating conditions and working environment. The present paper has the main objective to study the fatigue behaviour of three type of elastomers used for progressive cavity pumps manufacture.

Keywords: variable load cycles, progressive cavity pump, elastomer

Progressive cavity pumps are a special type of rotary pumps, where the fluid is moved axially through them, having a constant flow rate. Figure 1 shows schematically the principle of operation of progressive cavity pumps [1].

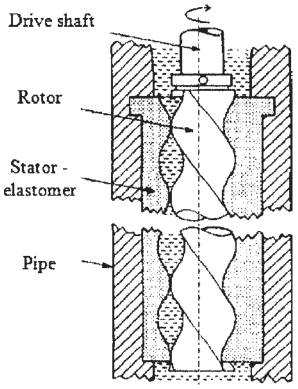

Fig.1. The operation principle of the progressive cavity pumps, [1]

The progressive cavity pump are largely used in petroleum industry for oil pumping in artificial lift activities. They consist of a rotary helical steel rotor and a helical rubber/elastomer stator. The teethes of the screw rotor and of the rubber stator are weared as a result of the sliding friction and plastic deformation between the moving teeth in the abrasive and corrosive fluids.

The rotor of the pump is made of steel coated with corrosion and erosion resistant materials, usually chrome plated, and the stator is made of moulded rubber/elastomer inside a metal thick-walled steel pipe.

Failure of progressive cavity pumps is mainly due to damage of the elastomer subjected to variable load cycles and intensive processes of degradation by abrasive wear. The behaviour of elastomers to variable load cycles is relatively less studied, addressing mainly to applications in the automotive industry.

In this article an investigation of the fatigue behaviour of there types of elastomer used for stator manufacture was undertaken.

Experimental part

Fatigue tests were conducted on cylindrical specimens subjected to oscillating compression loading in a displacement controlled machine. Two maximum compression strains of 2 mm and 4.45 mm were applied and the minimum strain was zero, at a frequency of 16.33 Hz.

In order to characterize the materials behaviour at time-varying load cycles the following aspects were used:

- the temperature increasing of the specimen, by recording the variation of the temperature versus time, with the possibility of determining both the stabilized temperature (of equilibrium) and the rate of heat generation (the temperature increase over a period of time);
- dimensional changes of the specimen;
- hardness modification of the elastomer in order to determine any stiffening or softening processes;
- observing the material behaviour during 500,000, 1,000,000 and 3,000,000 cycles.

The standard ASTM D 623-99, [2], states that the fatigue test results may not be correlated with the service performance of components made from the researched elastomer. The data can be used only to estimate comparatively the service quality of different types of elastomer.

Materials, methods and equipments

In order to compare the fatigue characteristics and the heat generation rates, cylindrical specimens having F17.8 mm diameter and 25 mm length, manufactured from three type of elastomers, where used:

- Elastomer-A, representing a mixture based on hydrogenated nitrile rubber (HNBR type), with a hardness of 75 grade Shore A.
- Elastomer-B, representing a rubber mixture based on nitrile acrylonitrile (NBR type), with a hardness of 75 grade Shore A.
- Elastomer-C, representing a rubber mixture based on nitrile acrylonitrile (NBR type), with a hardness of 70 grade Shore A.

Experimental research program is presented in table 1.

The servo-hydraulics fatigue testing machines allow the fatigue test with constant strain amplitude, but the testing frequency is inversely proportional to the amplitude of deformation. So, for a strain amplitude of 4.45 mm, the maximum possible frequency is 4 Hz and, in this condition, the time of testing for one specimen is too long (for example 200 h at 3,000,000 cycles). This

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Table 1
EXPERIMENTAL RESEARCH PROGRAM FOR COMPRESSIVE FATIGUE TEST WITH FREQUENCY OF 16.33 Hz

Number of load cycles	Deformation, mm	Number of specimen tested		
		Elastomer-A	Elastomer-B	Elastomer-C
500.000	2	1	1	1
500.000	4.45	2	2	2
1.000.000	2	1	1	1
1.000.000	4.45	2	2	2
3.000.000	2	1	1	1
3.000.000	4.45	1	1	1
Total specimens	**-**	**8**	**8**	**8**

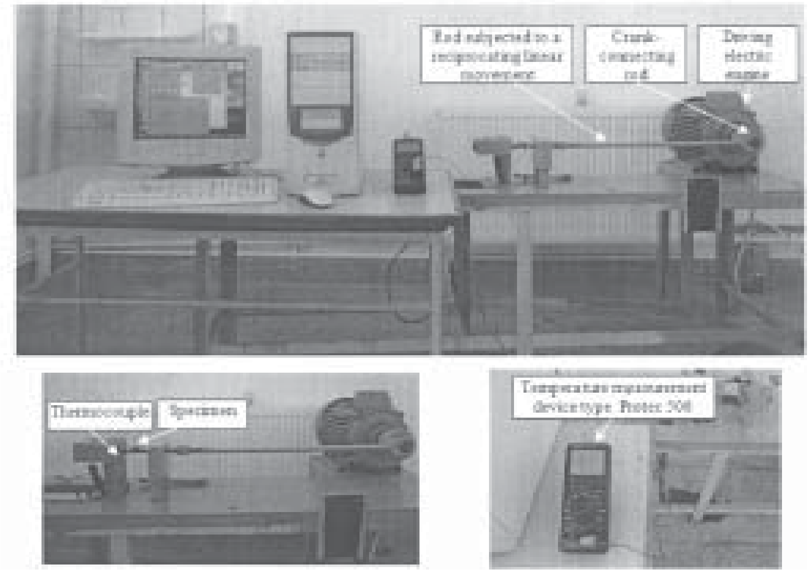

Fig. 2. Photographs of the fatigue test stand and apparatus for measuring and recording the temperature of the specimen

situation imposed to design and to manufacture a fatigue testing equipment, capable to control the strain amplitude, the frequency and the total number of load cycles, imposed to each specimen tested [3-6]. Figure 2 shows photographs of the fatigue test equipment and apparatus used for measuring and recording the temperature of the specimen.

The specimen is subjected to compression fatigue cycles by using a rod having a reciprocating linear movement performed by an adjustable eccentric driven by an electric engine with a speed of 980 rot/min, a power of 3.2 kW which allows the testing of the specimen at frequency of 16.33 Hz. Specimen deformation is controlled and kept constant with high accuracy by adjusting the eccentric and checked with a dial gauge with accuracy of 0.01 mm. The temperature increase of the specimen was measured by using a thermocouple type J (Fe/Constantan) located at the base of the test specimen. Temperature values are recorded every 25 s by using a measuring temperature instrument type Protec 506, and an electronic computer, which allowed to record continuously the temperature values of the specimen.

The specimen is fixed between two metallic parallel supports, without pre-compression, and then is subjected to pulsating compression fatigue cycles.

The tests were performed with a constant stroke, at ambient temperature. The force-deformation dependence is linear in the range 0-5 mm, for the tested elastomers.

Dimensional modifications of the specimen were determined in two situations, by using a micrometer (0.01 mm precision):

-measuring the initial height of the specimen and then during the test at intervals of about 2-2.5 h, by interrupting the test for a short-time, in order to record the dimensional changes occurring during the test; this procedure was applied for one specimen of each type of elastomer subjected to compression fatigue cycles with deformation of 4.45 mm and 1,000,000 load cycles; remaining specimens were tested continuously until the requested number of load cycles programmed was achieved;

-measuring the initial dimensions (height and diameter) of the specimen and then on completion of the test, after the cooling of the specimen; this procedure was applied for the remaining specimens of each type of elastomer, tested continuous to compression fatigue cycles, with strokes of 2 and 4.45 mm, respectively 500,000, 1,000,000 and 3,000,000 load cycles.

Modification of the elastomer hardness was determined in two versions, using a mechanical hardness tester Shore D:

-measuring the initial hardness of the elastomer and then during the test at intervals of about 2-2.5 h, by interrupting the test for a short-time, in order to record the hardness changes occurring during the test; this procedure was applied for one specimen of each type of elastomer subjected to compression fatigue cycles with deformation of 4.45 mm and 1,000,000 load cycles; remaining specimens were tested continuously until the requested number of load cycles programmed was achieved;

-measuring the initial hardness of the elastomer and then on completion of the test, after the cooling of the specimen; this procedure was applied for the remaining specimens of each type of elastomer, tested continuous to compression fatigue cycles, with strokes of 2 and 4.45 mm, respectively 500,000, 1,000,000 and 3,000,000 load cycles.

Shore D hardness was determined, which was converted to Shore A hardness according to hardness conversion data [7-9].

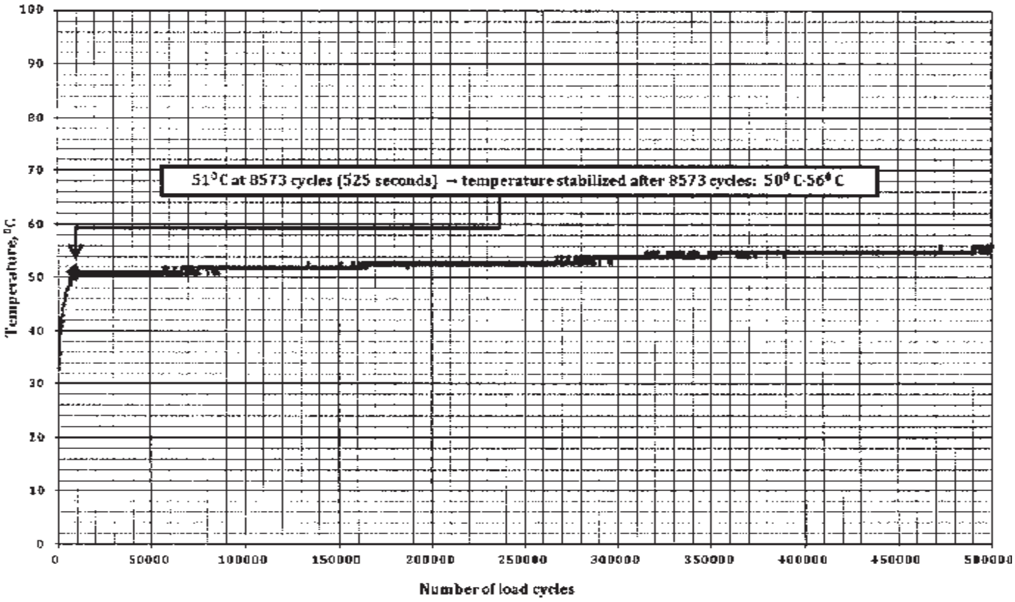

Fig. 3. The variation of elastomer temperature according to the number of load cycles

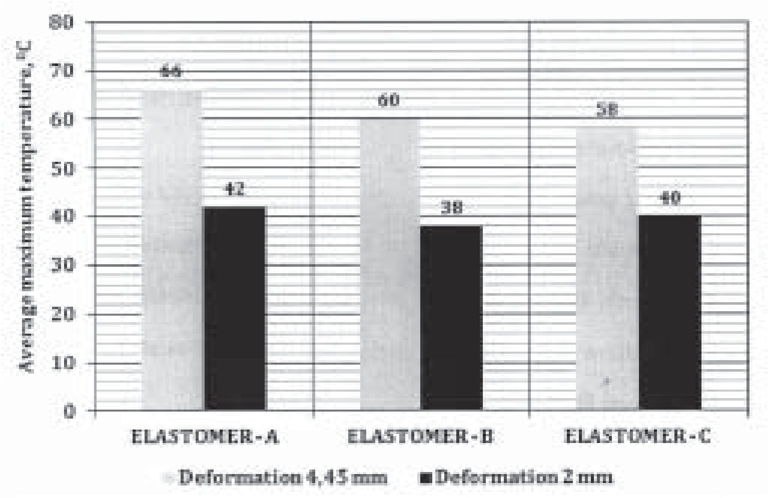

Fig. 4. Variation of average maximum temperatures for tested elastomers

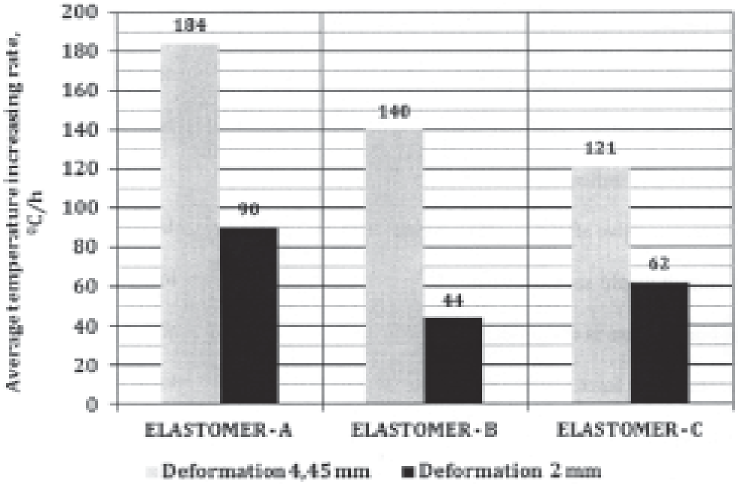

Fig. 5. Variation of average temperature increasing rate for tested elastomers

Results and discussions

The results of the fatigue tests are plotted in figures 3 to 11.

- Figure 3 presents the rate of heat generation. The temperature of the specimen during the test increase very fast and than is stabilized at a relatively constant value for the entire test (thermal plateau), with some minor fluctuations between a minimum and a maximum value.

The maximum temperature reached is greater when testing the specimen at compression fatigue cycles with a deformation of 4.45 mm than with a deformation of 2 mm, for all tested materials, as shown in figure 4.

The values of maximum temperatures achieved in the fatigue test of the three types of elastomers are relatively the same. The maximum temperature reached for elastomer-A is approx. 10% higher than the maximum temperatures reached for elastomers B and C, which have very close values.

- The stabilized temperature is reached after a relatively short period of time from the beginning of the test. The rate of temperature increase was considered as a significant parameter to characterise the fatigue behaviour of the specimen.

The rate of temperature increase is higher when testing the specimen at compression fatigue cycles with

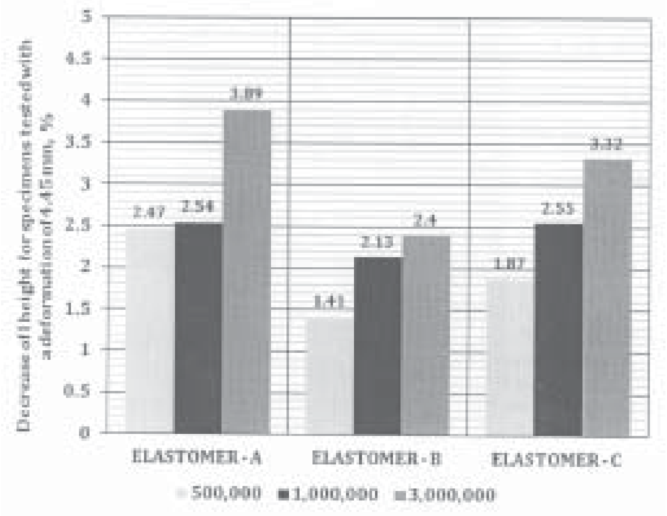

Fig. 6. Variation of specimens height for different type of elastomers tested at compression fatigue cycles with a deformation of 4.45 mm

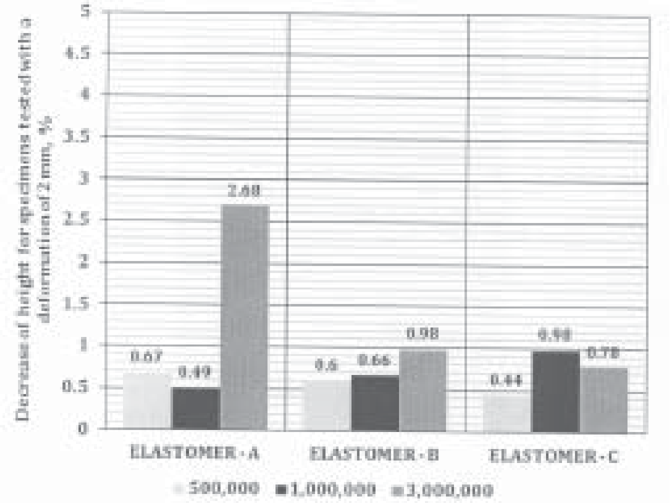

Fig. 7. Variation of specimens height for different type of elastomers tested at compression fatigue cycles with a deformation of 2 mm

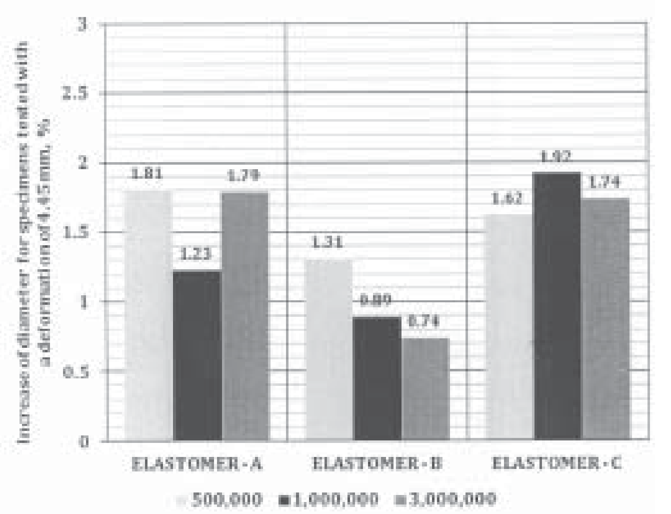

Fig. 8. Variation of specimens diameter for different type of elastomers tested at compression fatigue cycles with a deformation of 4.45 mm

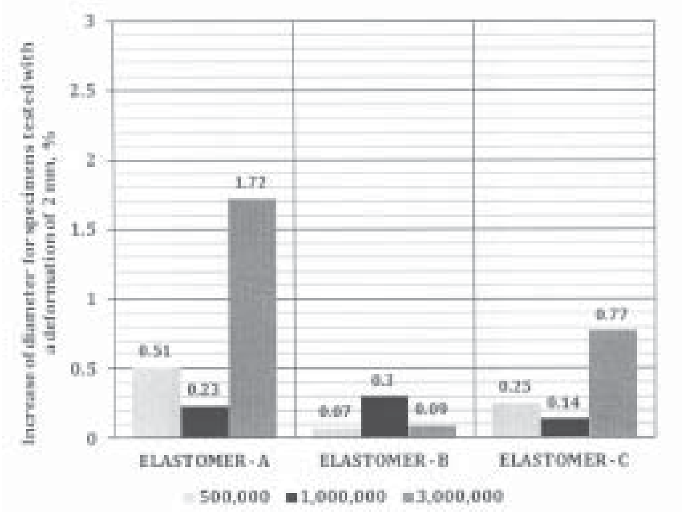

Fig. 9. Variation of specimens diameter for different type of elastomers tested at compression fatigue cycles with a deformation of 2 mm

a deformation of 4.45 mm than with a deformation of 2 mm, for all materials tested, as shown in figure 5.

It is noted that the rate of temperature increase is approx. twice higher when the specimen is tested at compression fatigue cycles with a deformation of 4.45 mm than with a deformation of 2 mm, for all three types of tested elastomers.

- Figures 6, 7, 8 and 9 present the modifications of the specimens dimensions for all materials tested.

In the range of applied number of cycles, the following conclusions can be drawn:

·in the case of compression fatigue test, with a deformation of 4.45 mm:

-for elastomer-A, the decreasing of the specimen height varies between 2.47 %...3.89 %, and the increasing of the specimen diameter varies between 1.23 % ...1.81 %;

-for elastomer-B, the decreasing of the specimen height varies between 1.41 %...2.40 %,, and the increasing of the specimen diameter varies between 0.74 %...1.31 %;

-for elastomer-C, the decreasing of the specimen height varies between 1.87 %...3.32 %, and the increasing of the specimen diameter varies between 1.62 %...1.92 %.

·in the case of compression fatigue test, with a deformation of 2 mm:

-for elastomer-A, the decreasing of the specimen height varies between 0.49 %...2.68 %, and the increasing of the specimen diameter varies between 0.23 %...1.72 %;

-for elastomer-B, the decreasing of the specimen height varies between 0.6 %... 0.98 %, and the increasing of the specimen diameter varies between 0.07 %...0.3 %;

-for elastomer-C, the decreasing of the specimen height varies between 0.44 %...0.98 %, and the increasing of the specimen diameter varies between 0.14 %... 0.77 %.

- Figures 10, 11 present the hardness modifications of the tested samples. Excepting one specimen, all specimens have softened at the end of the test.

In the range of applied number of cycles, the following conclusions can be drawn:

·in the case of compression fatigue test, with a deformation of 4.45 mm:

-for elastomer-A, the decreasing of the elastomer hardness (Sh-A) varies between 0 % and 3.33 %;

-for elastomer-B, the decreasing of the elastomer hardness (Sh-A) varies between 1.18 and 2.36 %;

-for elastomer-C, the decreasing of the elastomer hardness (Sh-A) varies between 1.19 and 2.36 %, excluding the anomaly presented by one specimen tested.

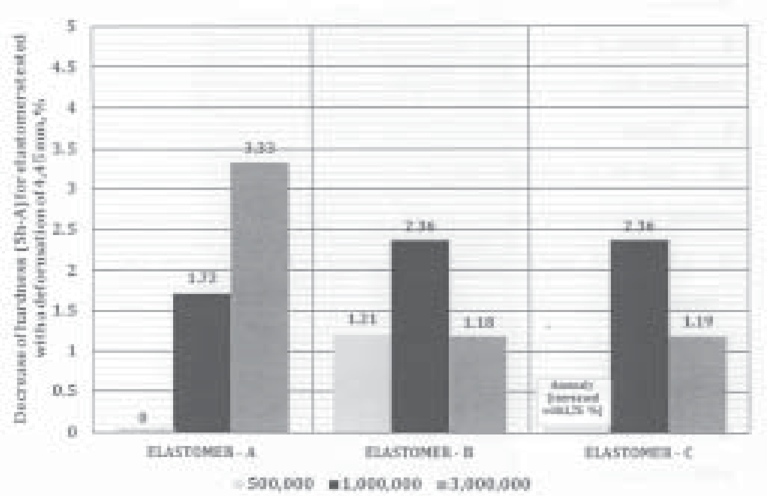

Fig. 10. The Shore-A hardness variation for different types of elastomers tested at compression fatigue cycles with a deformation of 4.45 mm

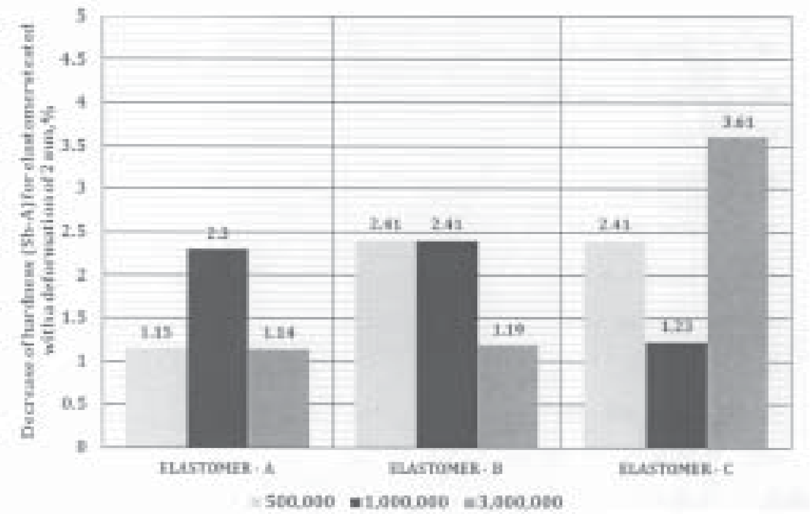

Fig. 11. The Shore-A hardness variation for different types of elastomers tested at compression fatigue cycles with a deformation of 2 mm.

·in the case of compression fatigue test, with a deformation of 2 mm:

-for elastomer-A, the decreasing of the elastomer hardness (Sh-A) varies between 1.14 and 2.3 %;

-for elastomer-B, the decreasing of the elastomer hardness (Sh-A) varies between 1.19 and 2.,41 %;

-for elastomer-C, the decreasing of the elastomer hardness (Sh-A) varies between 1.23 and 3.61.

- In the compression fatigue tests with a deformation up to 17.8 % (4.45 mm), in the range of number of applied cycles, were not recorded fatigue failures of the elastomers investigated, such as crack, fracture or another degradation forms of the specimens.

Conclusions

The paper has investigated the fatigue behaviour of three types of elastomer subjected to pulsating compression fatigue cycles (R=0) , as follows:

-Elastomer-A, representing a mixture based on hydrogenated nitrile rubber (HNBR type), with a hardness of 75 grade Shore A.

-Elastomer-B, representing a rubber mixture based on nitrile acrylonitrile (NBR type), with a hardness of 75 grade Shore A.

-Elastomer-C, representing a rubber mixture based on nitrile acrylonitrile (NBR type), with a hardness of 70 grade Shore A.

In order to characterize the material behaviour at constant strain amplitude fatigue tests the following aspects were considered:

-the temperature increase of the specimen, recording the variation of the temperature versus time, with the possibility of determining both the stabilized temperature and the temperature increase rate.The temperature increase is influenced by various factors like loading frequency, strain amplitude, heat capacity and conductivity of the elastomer type. These properties must be studied in the future, because they may affect the fatigue behavior of elastomers;

-dimensional modifications of the specimen;

-hardness modification of the elastomer in order to determine any hardening or softening process;

-observing the material behaviour during 500.000, 1,000,000 and 3,000,000 cycles.

In order to perform the experimental testing of elastomers, a fatigue testing equipment was realized to assure the strain amplitude, frequency and the total number of cycles for testing specimen.

The temperature of the specimen during the test increase very fast and after that is stabilized at a relatively constant value through the entire test (thermal plateau).Under equal conditions of ambient temperature and frequency, the maximum temperature and the temperature increasing rate depend on the applied strain amplitude.

For all materials tested, the maximum temperature reached its greatest value when testing the specimen at compression fatigue cycles with a deformation of 4.45 mm.

The maximum temperature reached for elastomer-A is approx. 10% higher than the maximum temperatures reached for elastomers, B and C, which have very close values.

The temperature increase rate is approx. twice higher when the specimen is tested at compression fatigue cycles with a deformation of 4.45 mm than with a deformation of 2 mm, for all three types of tested elastomers.

The temperature increase rates for all tested materials increase in the next order: elastomer-C, elastomer-B and elastomer-A.

The hardness is reduced with relatively small values, ranging from 0.1 to 3.61% of initial hardness.

There are no significant differences observed between the types of elastomer from the point of view of hardness decreasing, regardless of the amplitude of the deformation (2 mm and 4.45 mm) and of the number of varying load cycles.

At the end of the fatigue test with constant amplitude deformation, all specimens investigated presented for both amplitude deformations, a decrease in height and an increase in diameter.

The elastomer-A shows the highest values of reducing the height of the specimen (2.47% to 500,000 cycles.... 3.89% to 3.000.000 cycles) .

Reducing the height of the specimens is increasing by increasing the number of load cycles for all three types of elastomers, being more evident when the testing is made with 4.45 mm deformation.

This study has shown that the parameters proposed to characterize the fatigue behaviour of different types of elastomer, allow a meaningful assessment.

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Manuscript received: 5.01.2015