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Theoretical and experimental analysis of the physical behavior of gaskets in shock absorber

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ABSTRACT

The current study examines the theoretical and experimental behaviour of gaskets when using different cases of disc samples (free-free, free-fix and fix-fix). The samples are made of rubber. The deformation of the gasket as a function of loading depends significantly on how it is fixed to the rigid supports. Physical properties have been explained. In experimental analysis of the sample disc "Free-Free", the loading velocity does not have a significant influence on the range of values of the mentioned velocity. All the curves in the "Free-Fix" disc load illustrate that at the same deformation, the average pressure is higher than in the case of the "free-free" disc. At the deformation of 1.49 mm, the average pressure is 33% higher than all other graphs. In the case of the "Fix-Fix" disc, it is observed that the load, evaluated by the average pressure, is clearly higher than in the case "Free-Fix" disc. At a deformation of 1.49 mm, the average pressure was found to be 15 times higher.

Keywords: Gasket, Deformation, Average Contact Pressure

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1. Introduction

The behaviour of the damping gasket rings material at compression and expansion, as well as the radial fixing of the rings, require a detailed analysis of these rings. In recent studies, rubber has been used for damping because of its viscoelastic properties. Compressive stress tends to result in deformations which shorten the object and at the same time expand it outwards. With some materials like elastomers and polymers, which undergo large deformations, the engineering definition of strain cannot be applied as the typical engineering strains are greater than 1% [1].

Rubber is known to be a unique material for its elastic and viscous features. Therefore, rubber parts may be of use in shock and vibrating isolation and/or damping. Despite the loose usage of the word "rubber", it is often used referred to as the compound and vulcanized material that is known as elastomer in its raw state. Rubber has a low modulus of elasticity and can sustain deformations up to 1000 percent. Such deformation is followed by a quick and forcible retraction into its original dimensions. It is resilient and yet exhibits internal damping. Rubber can be processed into different shapes and could also be adhered to metal inserts or mounting plates. It can be compounded to have various features. The load deflection curve could be altered through the change in shape. In order to determine the theoretical behavior of the shock absorber gasket, the case of the cylindrical gasket (disc) of outer radius R and thickness h (shown in Figure 1) is analysed. It is made of rubber characterized by the longitudinal coefficient of elasticity E. The material is considered to be incompressible (Poisson's ratio $\nu = 0.5$).

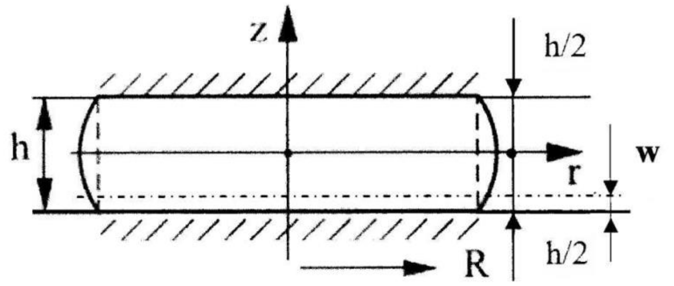


Figure 1. Contact of a gasket ring in shock absorber with a rigid plane

The damping phenomenon is based on the radial deformation of the elastic rings [2], as a result of the geometry of the metal rod and the body of the shock absorber. The average contact pressure value depends on the low velocity [3]. Knowing the contact pressure between the ring and the metal rod, and the kinetic and static friction contributes to the determination of the nominal performance of the shock absorber and to the forecast of durability. A cylindrical coordinate stem is attached (r - radial direction and z - axial direction).

2. Method

2.1. Theoretical analytical

There are two cases of a shock absorber ring under compression load are analyzed:

Case1. "**Fix-Fix"** This case involves fixing the gasket on the two rigid plates. In this situation, the radial displacement u (r, z) has zero values on the two plates, for any radius [4-7].
Where z is the axial displacement, u_a is the radial displacement, and w is the displacement.

$$u_a(r_q, z_a) = \frac{3}{4} w_a (1 - 4z_a^2) r_a \qquad (1)$$

$$r_a = \frac{r}{R};\ w_a = \frac{w}{h};\ h_a = \frac{h}{R};\ z_a = \frac{z}{h};\ u_a = \frac{u}{R}$$

Where (r_a, w_a, h_a, z_a, u_a) are dimensionless parameters. The deformation will be as follows:

$$\varepsilon_{rz} = r\frac{\partial u_r}{\partial z} = -\frac{6w}{h^3} rz = -\frac{6w_a r_a z_a}{h_a} \qquad (2)$$

where G_e is the modulus of transverse elasticity of the material. The normal force on the disc transmitted through the rigid supports is:

$$F_n = \frac{\partial u_t}{\partial w} = \frac{3\pi}{2} G_e \frac{R^4 w}{h^3} = \frac{3\pi}{2} R^2 \frac{w_a}{h_a^2} G_e \qquad (3)$$

The average pressure (p_m) relative to the longitudinal elastic modulus E is considered as the loading parameter. For the incompressible material $G_e = E / 3$, thus:

$$p_{am} = \frac{p_m}{E} = \frac{F_n}{E\pi R^2} = \frac{1}{2}\frac{w_a}{h_a^2} \qquad (4)$$

The expression of the normal force deduced for the stated case (elastic disc subjected to compression force and stiffened on both front surfaces). The effective modulus of elasticity of the disc material (E_{ef}) is deduced[4]:

$$E_{ef} = \frac{1}{2} * E(R/h)^2 = \frac{E}{2h_a^2} \qquad (5)$$

For the usual extreme values $h_a = 0.05\ldots 0.2$, the results are $E_{ef} = (12\ldots 200)E$.

Case2. "**Free –Fix** "This case involves fixing the gasket on the upper support, leaving it free on the lower support. The function of radial displacements becomes:

$$u_{rla}(r_a, z_a) = \frac{u_l(r,z)}{R} = \frac{1}{4} r_a w_a \left[\frac{9}{4} - 3z_a - 3z_a^2\right] \tag{6}$$

The shear deformation of the disc is

$$\varepsilon_{rzl} = \frac{\partial u_{rl}}{\partial z} = -\frac{3rw}{4h^2}\left(1 + 2\frac{z}{h}\right) = -\frac{3}{4}\frac{r_a w_a}{h_a}(1 + 2z_a) \tag{7}$$

Thus, the normal force on the disc is:

$$F_{nl} = \frac{\partial u_{tl}}{\partial w} = \frac{3\pi}{8} R^2 \frac{w_a}{h_a^2} G_e \tag{8}$$

It is observed that at the axial deformation of the disc, the normal force is 4 times smaller than when the disc is fixed (stiffened) on one surface only:

$$p_{aml} = \frac{1}{8}\frac{w_a}{h_a^2} \tag{9}$$

As with the full disc fixation, the effective modulus of elasticity is determined. In the case of fixing only on the rigid upper support, the actual modulus of elasticity is obtained as follows:

$$E_{ef} = \frac{1}{8} E \left(\frac{R}{h}\right)^2 = \frac{1}{8} E \left(\frac{1}{h_a^2}\right) \tag{10}$$

It is important to note that, given the analysis of the gasket deformation and loading, the two extreme cases are obtained whenever there is a sliding friction with the support, as follows:

- for $u_{0a} = 0$, the case one is obtained (**Fixed - Fixed**);
- for $u_{0a} = 3w_a / 4$, the second case is obtained (**Fixed - Free**) which in turn corresponds to the ideal case (zero coefficient of friction).

2.2. Experimental setup

For the experimental study, the damping gasket was obtained by removing a real shock absorber and sectioning the ring. The tests were performed on the CETR-UMT2 (Universal Materials Tester) as shown in Figure 2. The works are conducted in the laboratory of the Department of Machine Organs and Tribology at the POLITEHNICA University of Bucharest.

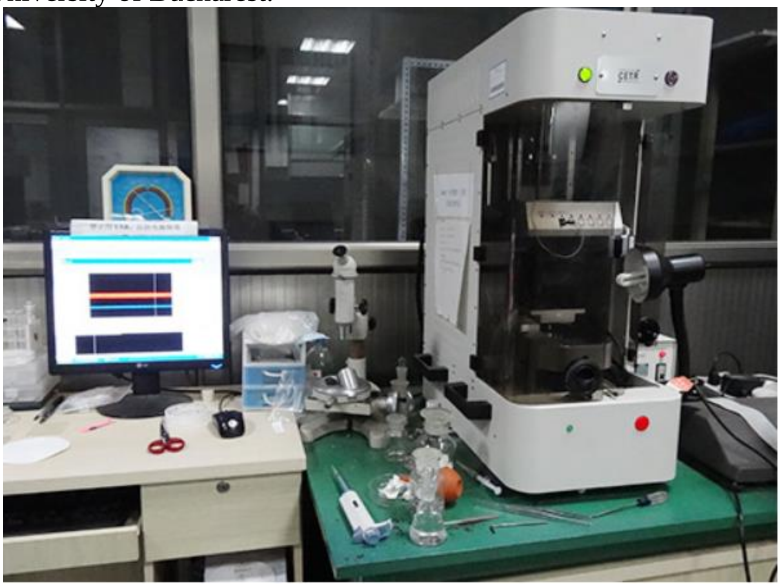
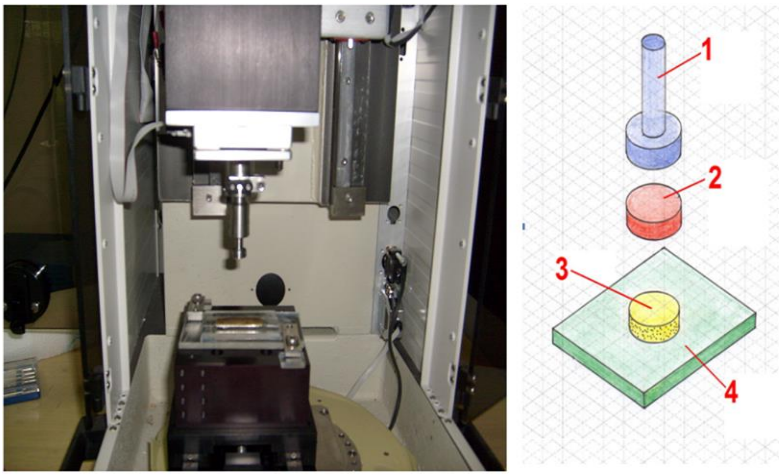


Figure 2. CETR-UMT2 (Universal Materials Tester)



Sample being tested *Test parts in the CETR-UMT2*

Figure 3. Sample being tested and test parts in the CETR-UMT2

1 - Indenter with large diameter Φ12.7 mm
2 - Intermediate element for full length pressing
3 - Sample to be tested
4 - Squeeze test support plate for sample (3)

The geometry of the sample subjected to compression tests is cylindrical with a diameter of D = 6.8 mm, corresponding to the width of the gasket. The thickness is equal to the actual thickness of a gasket in a new shock absorber (h = 3.61 mm).

The experiments regarding the deduction of the contact pressure-deformation curve at loading and unloading were done for constant velocities with maximum load 200 N. Each attempt is repeated 4 times under identical conditions. The behaviour of the rubber sample disc in the process of a loading-unloading cycle was analyzed experimentally, in the following three cases of fixing on rigid supports.

3. Results and discussion

For case1 "Free-Free", the sample is free on both sides, and can be deformed freely radially. It is important to point out that it is experimentally impossible for the sample to be completely free, as there is friction of the disc with the loading plate (support). The friction process is essential for the performance of a shock absorber. The graphs in Figures 4 and 5 exemplify loading and unloading at a speed of v = 0.6 mm / s for the case of the "Free-Free" disc. The load is evaluated by the average contact pressure $p_m = 4 F_n / (\pi D^2))$, with the D-diameter of the sample disc.

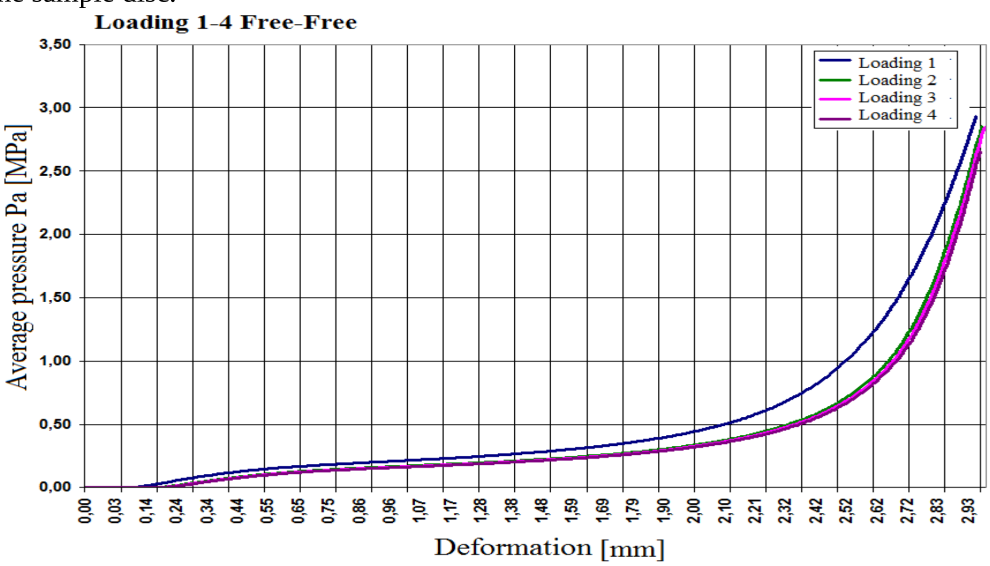


Figure 4. Loading curve of the "Free-Free" disc at v = 0.6 mm / s

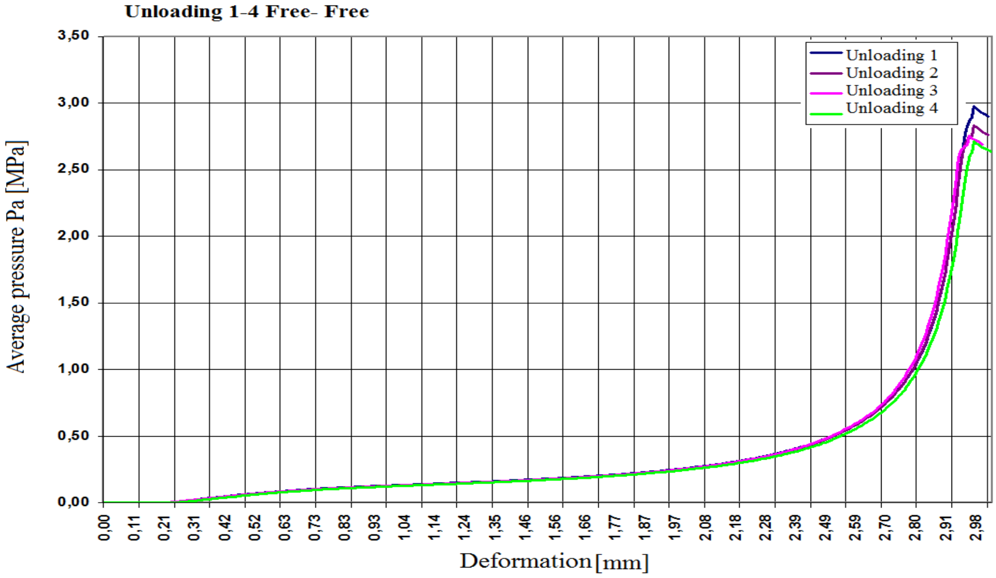


Figure 5. Unloading curve of the "Free-Free" disc at v = 0.6 mm / s

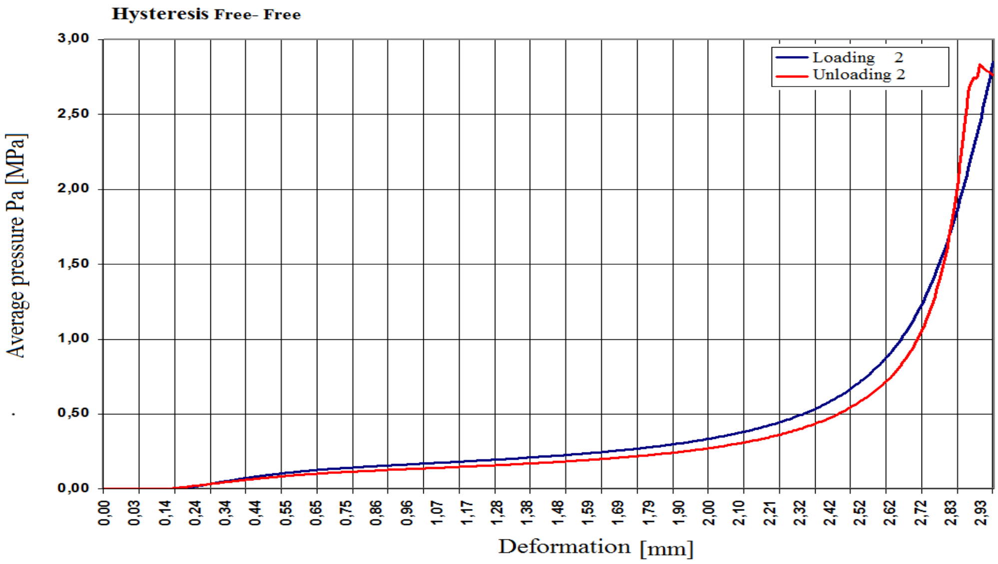


Figure 6. Loading -unloading curve (hysteresis) of the "Free-Free" at v = 0.6 mm / s

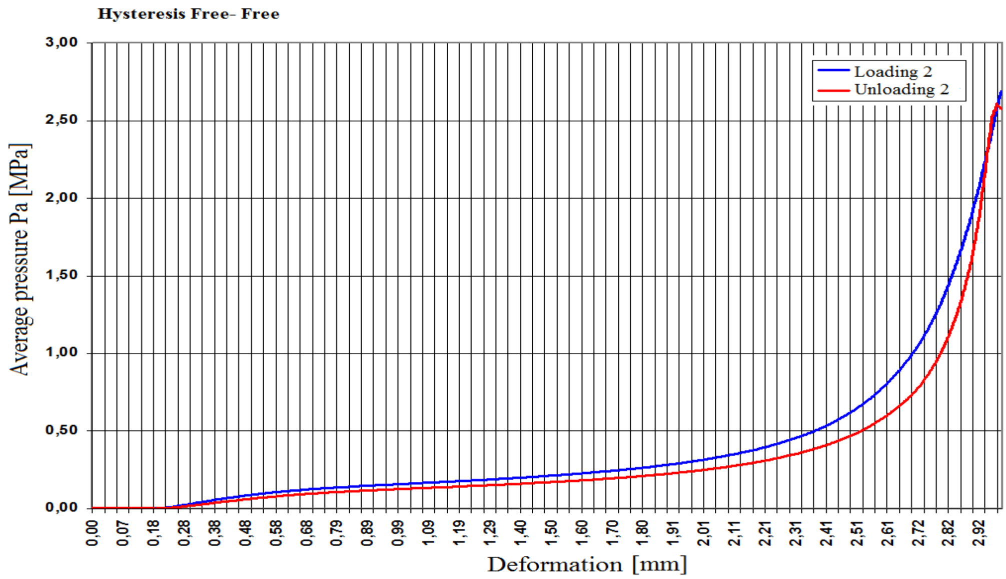


Figure 7. Loading -unloading curve (hysteresis) of the "Free-Free" disk at velocity v = 0.15 mm / s

It is noted that in the case of the sample disc "Free-Free" the loading velocity does not have a significant influence on the range of values of the mentioned velocity. Based on the loading curves (compression), the modulus of average effective elasticity (E_{mef}) is defined as the ratio between the variation of the average pressure (Δp_m) and the variation of the specific deformation ($\varepsilon = \Delta f / h_o$) for the linear variation area. Thus, this average modulus of elasticity for the "Free-Free" disc has the value E_{mef} = 0.86 MPa. The relative variation of this speed coefficient is 4%.

For case2 "Free-Fix", this sample is free on one side and glued with an adhesive on the other, being able to deform radially freely, within the limit of friction on the non-stick face only. The tests are performed similarly to the first case. The loading and unloading curves are exemplified in Figures 8 and 9, respectively. The unloading hysteresis curves are shown in Figure 10 for the speed v = 0.15 mm / s.

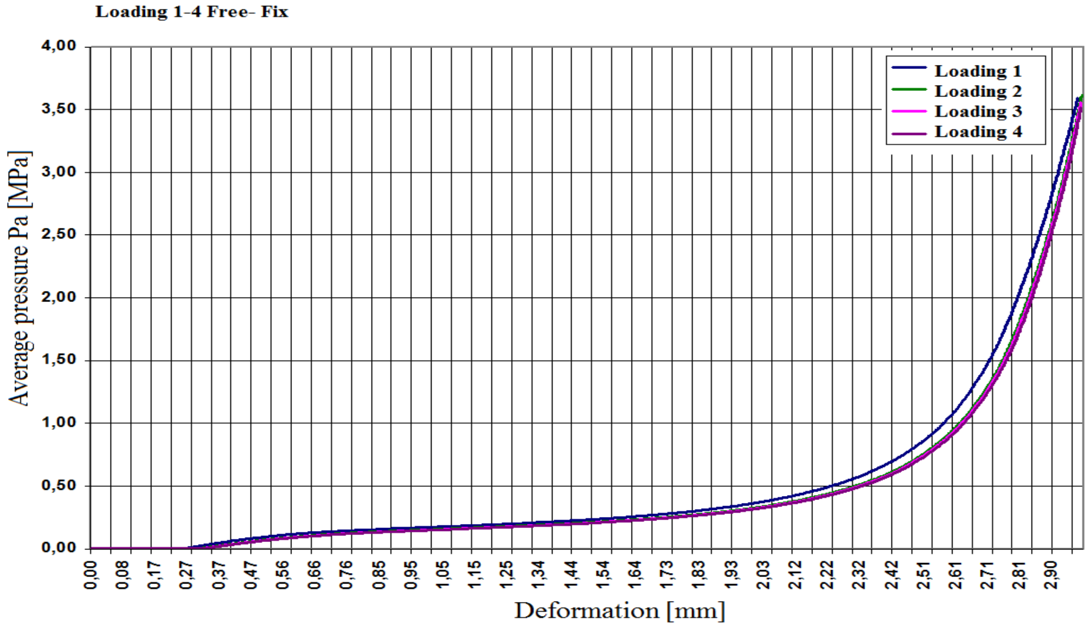


Figure 8. Loading curve of the "Free-Fix" disc at velocity v = 0.15 mm / s

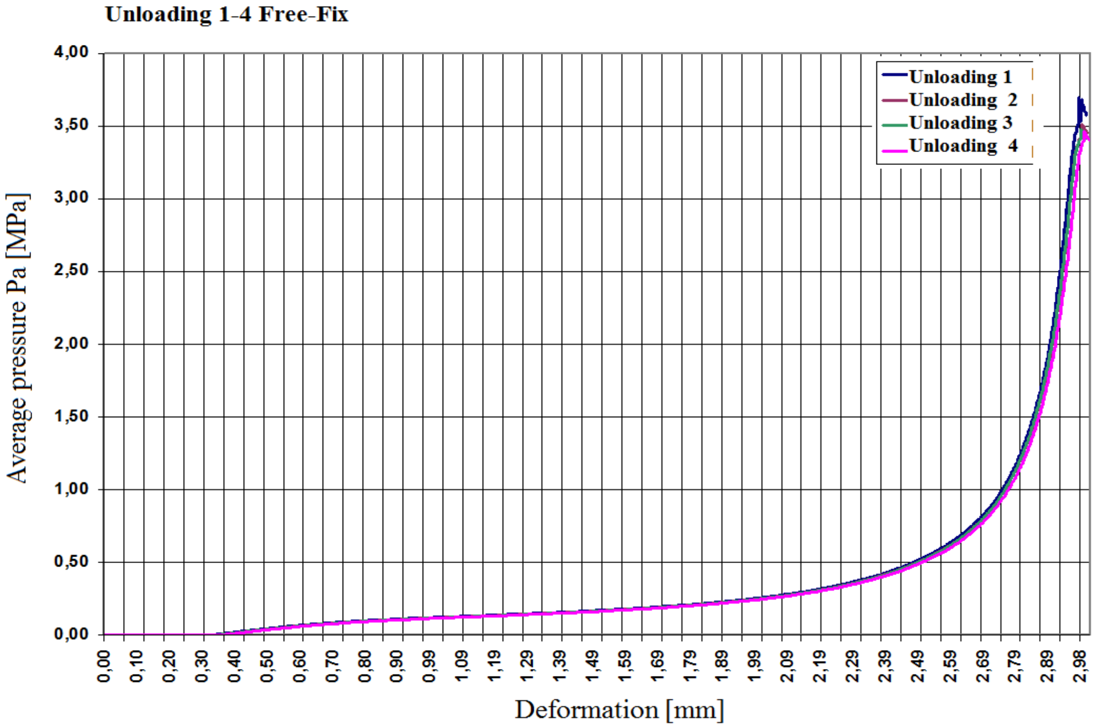


Figure 9. Unloading curve of the "Free-Fix" disc at velocity v = 0.15 mm / s

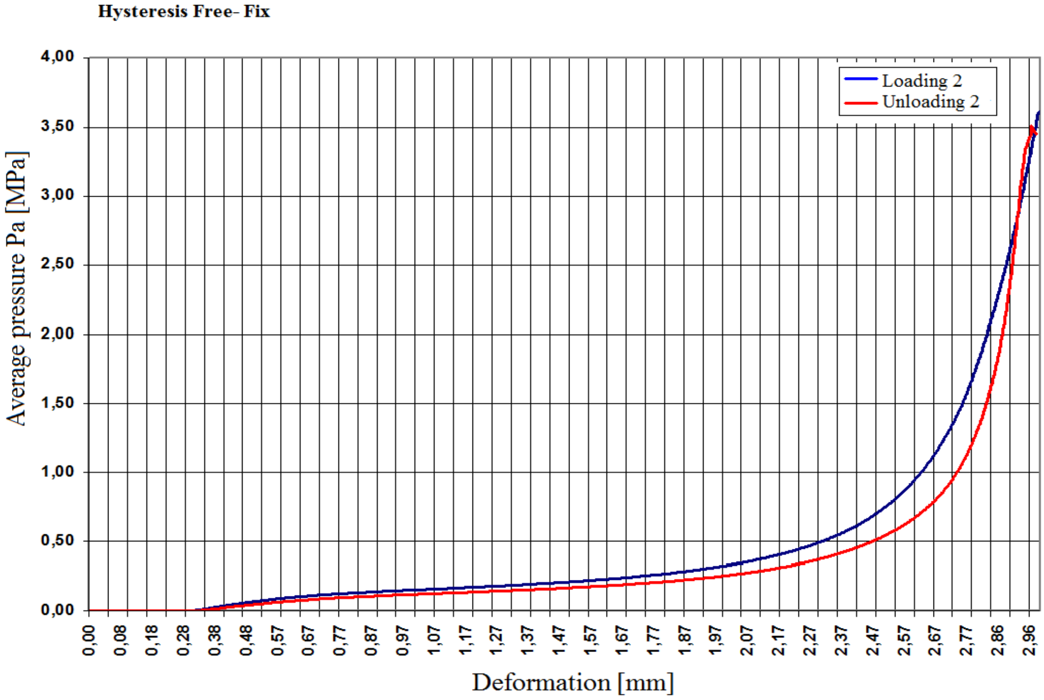


Figure 10. Loading-unloading curve (hysteresis) of the "Free-Fix" disc at velocity v = 0.15 mm / s

For other compression-unloading velocities, the curves are similar, whereby the velocity is not significant even for the "Free-Fix" disc case. All the curves for the "Free-Fix" disc load illustrate that at the same deformation, the average pressure is higher than in the case of the "Free-Free" disc. For example, at the compression load with the deformation 1.49 mm, the average pressure is 33% higher. As for the "Free-Fix" disc, the average effective modulus of elasticity (E_{mef}) is 1.16 MPa, with a relative variation of 4% at the change of velocity in the experimentally studied interval.

For case3 "Fix-Fix", as for this type of sample, which is glued on both sides, the radial deformation is being prevented on both sides. The experimental analysis of the theoretical model is performed by fixing the disc to two rigid supports with a quick-drying adhesive. The loading and unloading curves are exemplified in Figures 11 and 12, respectively. The hysteresis curves are illustrates in Figure 13 for a velocity of v = 0.4 mm / s.

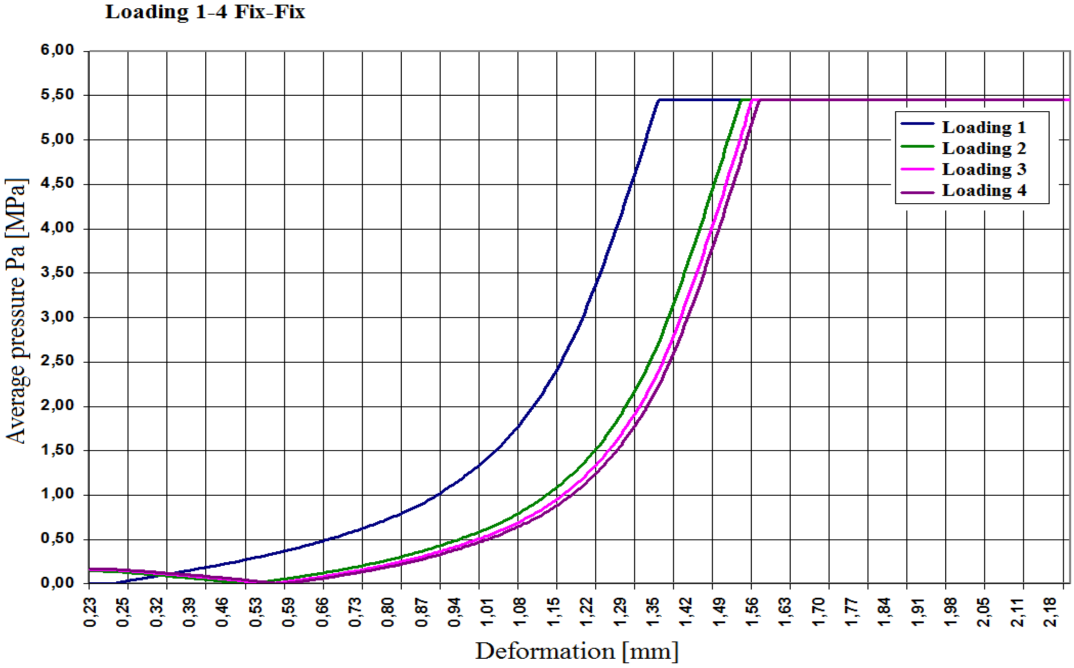


Figure 11. Loading curve of the "Fix-Fix" disc at velocity v = 0.4 mm / s

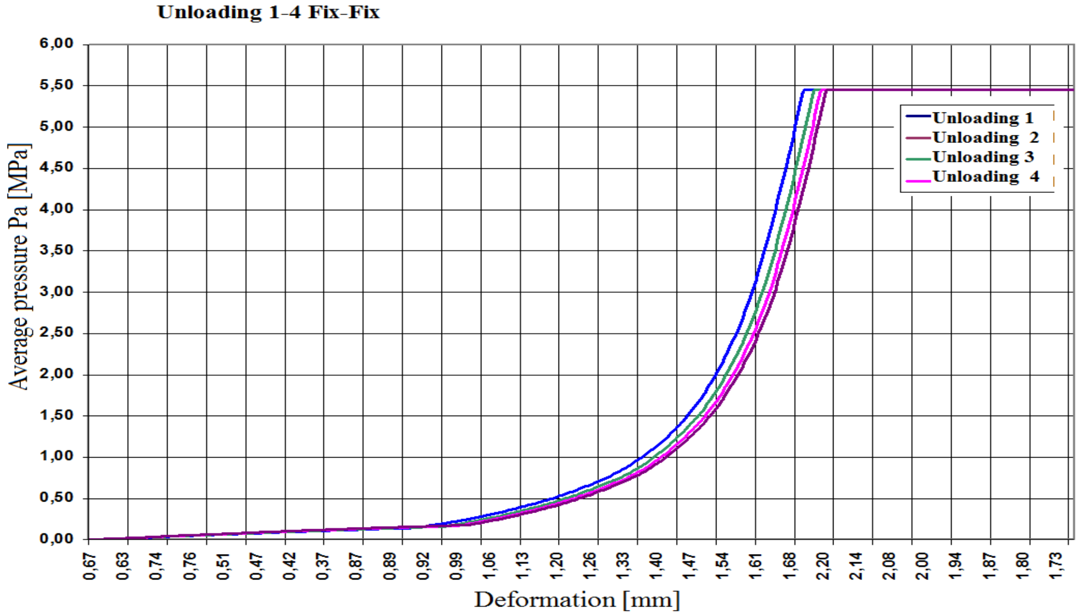


Figure 12. Unloading curve of the "Fix-Fix" disc at velocity v = 0.4 mm / s

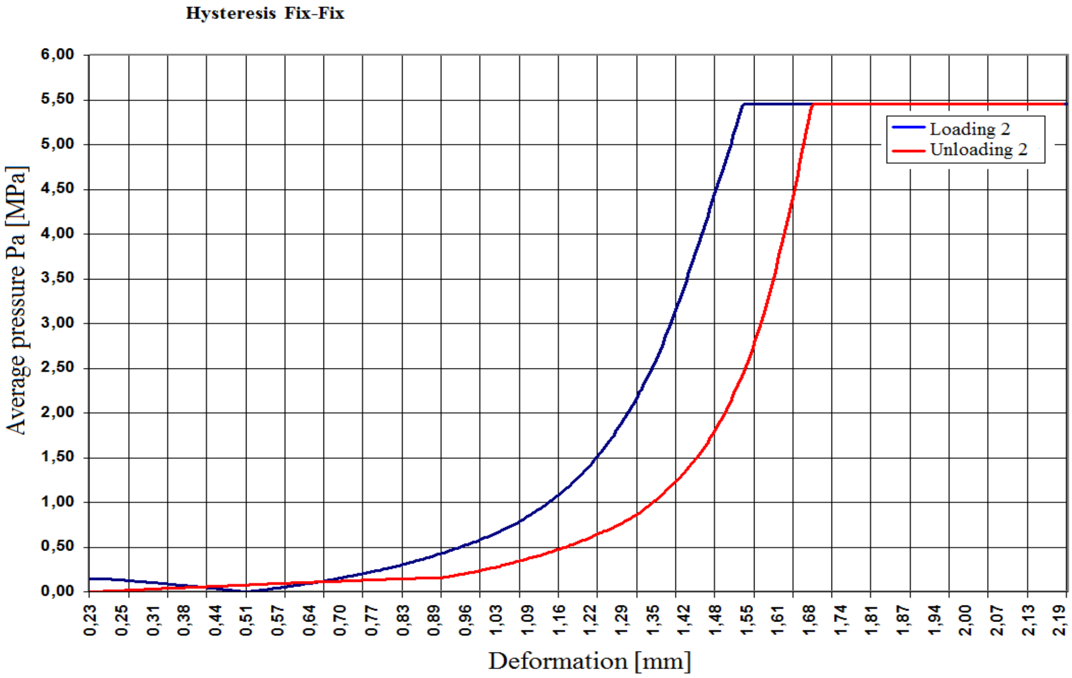


Figure 13. Loading -unloading curve (hysteresis) of the "Fix-Fix" disc, at velocity v = 0.4 mm / s

From all the graphs for the "Fix-Fix" disc, it is observed that the load, evaluated by the average pressure, is clearly higher than in the case of the "Free-Fix" disc. At a compression load with a deformation of 1.49 mm, the average pressure is 15 times higher. This experimental finding qualitatively confirms the theoretical model. In the theoretical model, the load increases only 4 times for the "Fix-Fix" case as compared to the "Free-Fix" case. The differences stem from the experimental impossibility of achieving complete prevention of radial deformation on one of the rigid supports, and from the theoretical assumptions regarding the perfectly elastic deformation of the gasket on an area with high compression and the preservation of the disc volume.

4. Conclusions

The deformation of the gasket as a function of loading depends significantly on how it is fixed to the rigid supports. Compression curves for small deformations (relative deformations less than 0.22) are similar both theoretically and experimentally. It is experimentally confirmed that the disc can be considered partially stiffened by friction. The average effective modulus of elasticity of the disc, made from the rubber gasket of a real shock absorber, depends significantly on how it is fixed upon the rigid supports, increasing 5.8 times for the case "Fix-Fix" as compared to the "Free-Free" disc. Fixing the gasket on rigid supports is essential for increasing the force taken, a fact found on real shock absorbers, protected as constructive solutions by patents. The deformation velocity range 0.15 – 0.5 mm / s has no significant influence upon the loading-unloading curves, as the effect was found to be about 3-4%.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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