13.7 Elastomeric materials

13.7.1 Introduction

Elastomeric materials (rubbers), as mentioned above, can undergo large deformations and have a nonlinear behavior even for low applied loads; the peculiarity is that these deformations are in any case elastic, i.e. when external forces are removed, no matter how large the deformation, the material recovers its original shape (unless, of course, the breaking point is reached at any point).

Another peculiarity is that they are incompressible, i.e. they have a Poisson's coefficient ν very close to 0.5: in fact, defined the modulus of compressibility as $\beta = \frac{E}{3 \cdot (1 - 2 \cdot \nu)}$, it is seen that by putting $\nu = 0.5$ we obtain an infinite value, while for a steel, for example, we have $\beta = 171700$ MPa (being E = 206000 MPa and $\nu = 0.3$).

This peculiarity also creates another problem in the stress-strain relationship (see Equations A.2 in Appendix A), where for any value of the strains we would have infinite stresses.

Elastomeric, or hyperelastic, materials therefore need special constitutive laws, on which we will not spend a single word. Here it is enough for us to say that computational codes capable of handling elastomeric materials must also have libraries of hyperelastic elements.

Clearly the numerical models to manage the behavior of these materials are quite complex and there are different types, each of which can adapt more or less well to the actual behavior of the rubber with which the component is made. The data in literature are few, also because if the metallic materials available in commerce are already several, for the polymeric ones or for the rubbers we are talking about a real immensity; it follows that, if we have to realize and analyze a model that includes parts realized with hyperelastic materials, it is necessary to have available also the data that characterize these materials and from these try to understand which, among the various models of behavior available (Mooney-Rivlen, Ogden, Marlow, Arruda-Boyce, etc.), better represents the behavior. Fortunately, some calculation codes have special tools that, starting from experimental data, try to find which behavior model better represents the experimental data.

And while we are on the subject of experimental tests, let's say right away that the minimum requirement for performing a calculation on a rubber component is a uniaxial tensile-compression test; since the specimen for compression tests is different from that for traction tests, we can already see that, compared to a metallic material, it is necessary to perform twice as many tests.

In order to have greater precision it is possible to perform biaxial tests, even more complex than uniaxial ones, up to even more complicated and expensive tests (figure 13.55 shows schematically the various types of tests, listed by increasing complexity, that can be performed on elastomeric materials): the more complex the test, the better the accuracy of the model used to describe the material behavior.

To complicate things further, the density and quality of the mesh necessary to discretize a body modeled with hyperelastic elements must be considered: since they can undergo large deformations, these components must be meshed in a rather fine way and with high quality elements, to avoid numerical errors due to the excessive distortion of the elements that can occur during the application of forces. Fortunately, in general, the required analyses are to be performed in the plane strain regime or for axisymmetric geometries, such as the example in figure 1.19, which we will resume later. Since we are dealing with plane models, the solution is quite fast, although it is often necessary to proceed with very small increments. When it is required to study an elastomeric component with a 3D model, things, from the numerical point of view, become very complicated both because the number of degrees of freedom increases a lot and because, unfortunately, the material behavior model must be "satisfied" with data obtained, when it is a luxury, from biaxial tests, but more frequently from uniaxial tests: in these conditions numerical convergence seems a utopia.

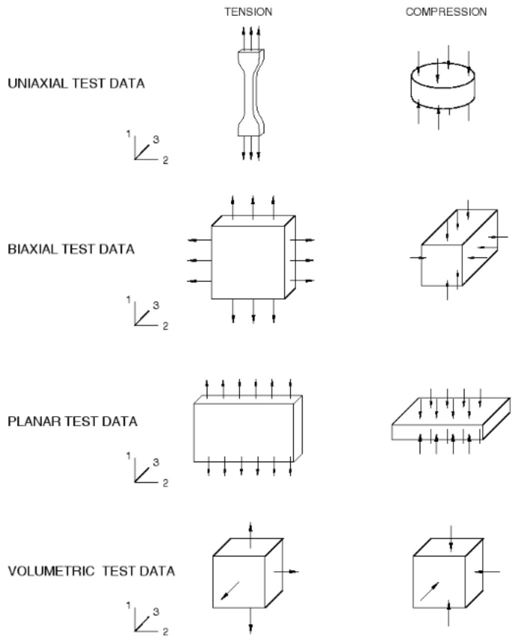

Figure 13.55. Overview of different possible tests to be performed on elastomeric materials.

13.7.2 Uniaxial tensile-compression test

As mentioned, the minimum data needed are the uniaxial tensile and compression tests.

Figure 13.56 contains a comparison between the experimental curve and the material model that best represents it. As it can be seen there are deviations, however small. We note the large deformations involved (up to 200%) in comparison to low stresses. The material model behaves well within the stress-strain values found during the test, but it becomes difficult to know what might happen outside these limits.

As mentioned above, having data also from at least biaxial tests would give greater confidence in the numerical convergence of the structural models and the accuracy of the results obtained.