Chapter 12
Soft Materials in Technology and Biology –
Characteristics, Properties,
and Parameter Identification

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Abstract The growing interest in flexible structures has also brought biomechanics into the focus of engineers. Elastomers and soft tissues consist of similar networks of macromolecules. After a brief introduction to the concepts of continuum mechanics, typical isotropic models of soft materials in technology and biology are presented. Similarities and differences of the thermo-mechanical behavior are discussed. For rubber-like materials a modification of the Kilian network is suggested which greatly simplifies the identification of material parameters. Finally the dynamical loading of biopolymers and volume changes with phase transitions are considered.

12.1 Introduction

Rigid materials have shaped and characterized the technical world to a strong extent. Bridges, skyscrapers or the Eiffel tower are not allowed to deform noticeably if forces are acting. Therewith a conception of engineering and technical mechanics has arisen that turns the attention to rigid constructions. Engineers think of technical mechanics as soon as they hear the word mechanics. Technical mechanics is the mechanics of the civil engineer as it has been created by August Föppel and the mathematician Felix Klein.

The necessity to look at rigid constructions also led to materials and constructions that conform to these requirements. Further findings were always connected to this in mechanics (statics). The world of engineers is the world of rigid constructions made of metal, concrete or masonry. Only the industrial mobility, i.e. automotive engineering allowed reconsidering these classical views. One recognized that soft materials and constructions are necessary in order to reduce impact forces and to design them bearable. Therewith, bearing and vibration engineering as well as safety constructions have originated. In the case of safety constructions, one thinks
of crumple zones of cars, the airbag and the safety belt. Man himself as a transported good also became the focus of attention of engineers because it was necessary to adapt the vibrations of cars to passengers and to get to know the critical limits at which they suffer damages.

In addition to the automotive industry, areas like the military and aerospace industries acted as driving forces for the reconsideration which has just been described. In this dynamic world, areas like biology, medicine and technology get very close and interact with each other. Until recently biomechanics in the static world has not attracted much attention, but nowadays has been awakened by the demands of the technology, the variety of biological materials and structures. These influential and far reaching changes can be followed through the work of Yuan-Cheng Fung, who after a brilliant 20 years career in aeroelasticity and aeronautical engineering [14] changed completely to the field of biomedical engineering around 1965 and became the father of modern biomechanics [17]. He made important original contributions to virtually all questions of biomechanics on the levels of organs, tissues, and cells. His book [16] became a classic, enduring reference.

The similarities between soft biological tissues and rubberlike materials have already been observed as early as 1880 in the context of the mechanic of the arterial wall [2]. Both soft tissues and rubberlike materials consist of macromolecular networks with same bonds. They show entropic elasticity in addition to the energetic elasticity of metals [20]. Therefore modern continuum theories for the thermomechanical behavior of soft materials borough ideas from the physics of macromolecules. The modern material theory, as it has been created by analytical mechanists and mathematicians, has been very helpful for the development of constitutive modeling and it exists nowadays in an improved way. To the engineer the material theory is what the structure of matter is for the physicist [24, 49, 50].

This article intents to deal sketchily with this development. Starting from observed phenomena a material theory is developed which takes into account the dynamic behavior of the materials in a satisfactory way. Furthermore, in the case of statics, the behavior of soft, technical and biological substances will be described and the development of a measuring technique which permits to check certain assumptions about the material behavior will be shown. In the end, chosen examples will be discussed in order to confirm the usability of the developed ideas.

To the non-expert in continuum mechanics the references [33, 36, 44, 45, 49] are recommended. The book [44] concentrates on discussing the solutions of over 100 exercises. Results that cannot be found in other textbooks are particularly emphasized and relevant literature is quoted. Some advanced book on biomechanics also give a good introduction to continuum mechanics [10, 16, 25].