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Introduction

Glass, existing for millions of years, has fascinated and attracted much interest both scientifically and technologically. For long, glass was considered a 'fourth state of matter' before realizing its 'liquid-like' structure. Glass appears on cooling down a liquid continuously until its viscosity becomes so high that it freezes to a glassy state. This happens at some range of temperatures that depends on thermal history. This lets glass be a mysterious material, since the way it is prepared changes its properties. Open questions are still raised and we shall address some of these within the present book. These theoretical considerations did not however prevent the development and use of glass over the centuries. Empirical knowledge and know-how have developed through the ages so that, nowadays, glass is a commonly available material. The application of glass science to the improvement of industrial tools, so-called research and development (R&D), occurred only in the past century, with a few exceptions, as for instance regarding porcelain researches focussed on developing processes in Sax and Worcester (Dr. J. Wall's group by 1750, refer also to Limoges [France] and Worcester [United Kingdom] museums). In their article 'Perspective on the History of Glass Composition', Kurkjian and Prindle (1998) noted that glass science was born only in 1886 with the disclosure of the work of Schott and Ernst (Chapter 3). Science and technology were then becoming more and more interrelated.

Glass has been employed in many forms to fabricate glazing and containers for centuries while it is now entering new applications that are appearing in nanotechnology (fibres and displays). Many qualities make glass attractive since it is transparent, chemically inert, environmentally friendly and keeps very strong. In fact, no other materials being mass produced have shown such qualities over so many centuries. Nowadays, glass offers recycling opportunities and allows for tailoring new and dedicated applications. The glass industry has been developing considerably in efficiency in terms of production rate and quality over the past few decades. Studying glass history in terms of raw materials and process offers an interesting perspective and understanding of how the glass industry progressively developed. These progresses were achieved because of further knowledge on materials properties and tools. While great achievements were accomplished empirically, R&D offered new opportunities.

Glass: Mechanics and Technology, Second Edition. Eric Le Bourhis.

It is much accepted nowadays that an industry has to progress continuously to face the strong competition that has been developing since globalization (with the emergence of low-labour-cost countries). The evolution in technology varies much according to the area of application. As far as glass is concerned, many different fields are to be considered, from mass production (glazing, containers) to nanotechnology processing (optical fibres, coatings, displays). The glass industry encompasses several international industrial groups that have strengthened their own R&D units. New products and tools are developed and patented before being launched in production. Research products become of utmost importance for these groups that face always stronger technological competition. As the glass industry covers so many different applications, this supposes important technological investment and know-how. Conventional soda-lime-silica glass industry covers large application fields comprising glazing (for transportation and buildings; Figure 1.1) and

Figure 1.1 Modern building with glass walls (near the author's university).

containers, and this still represents the most important areas of glass production in terms of volumes. At the same time, value-added functions have been developed to sustain industrial competition. Glass R&D has allowed great progress in the manufacturing of new functional glasses, improving continuously performance and quality. Nowadays, R&D is aimed at adding functions to glass objects with an interdisciplinary approach involving chemistry, mechanics and optics. New fields are emerging in electronics and displays and glass technology is expected to play an important role in nanotechnology. Different routes are being employed by manufacturers to add the designed functions, either modifying the glass substrate or using coatings. The former alternative is more expensive since upstream operations have to be modified to adjust the tools to the changes in melt composition (high-temperature flow). The development of new coatings looks more attractive and would be preferred since no upstream operations need to be changed; however, this field is newly opened and many issues are still to be solved. In particular, one has to tailor coating strength; otherwise, the designed function would not resist against abrasion over time. In fact, the overall development and production of glass involve important and interdisciplinary knowledge and know-how.

This book presents an overview of background science and technology used in the glass industry and R&D. It focusses on mechanics that is to be considered throughout the industrial process. It is well known that glass is a brittle material and one understands why it is important to improve the strength of glass objects. Not so well accepted is that to achieve such a result and also to improve other performances (optical, dielectrical), one has to consider mechanics at most steps of the production. A literature survey reveals strong interest in glass mechanics, with 15% of articles addressing glass science focussing on its mechanical properties. This is the reason for the focus of this book. The most important technological property of glass is its viscosity. It determines the melting conditions, the temperatures for working and annealing and the upper temperature for use (devitrification rates). Glass quality is directly dependent on the way it is homogenized, and this is also related to the viscous flow in the glass melt (Chapter 6). Proper quenching or chemical surface exchange of the glass allows for the production of residual stresses that will strengthen the glass and protect it from subcritical crack growth (Chapters 7–9). The dimensional adjustment of display front and back plates at the pixel resolution requires control of the thermal history and knowledge of the structural relaxation of glass substrates (Chapter 10). Contact mechanics controls the density of superficial defects generated while transferring products or in use (including elevated temperatures; Chapter 8). The distribution and importance of the superficial defects affect the strength of the manufactured object (Chapter 7). Amongst the few examples listed above, one understands that glass mechanics is a very broad field while being one of the most important issues for the glassmaker.

The book is composed of 13 chapters; Chapters 2 to 4 are introductory while Chapters 5 to 12 propose a progressive route into glass mechanics and technology, with a main text that could be first read following the proposed chronology. Notes, appendices and further references (books, scientific papers, videos and web sites) are proposed throughout the text for deeper insight. Appendices recall basic concepts and also illustrate through exercises and applications parts of the book. Examples throughout the text allow one to employ the concepts used to describe glass behaviour while their application to glass technology is extensively discussed. Some parts with more mathematics will help in getting more insight into glass behaviour. For a first lecture, these can be skipped.