Food Materials Science and Engineering

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Preface

Materials science is a multidisciplinary field that integrates the knowledge of physics, chemistry and processing. Material science involves the control of the properties of the materials by changing the chemical composition and structure. The spectrum of these properties includes chemical (composition, structure, phases etc.), physical (electrical, thermal, magnetic, optical, acoustic), mechanical (strength, ductility, toughness, rigidity) and dimensional (size, shape, surface texture). The structure can be altered by invoking a process. In conventional terms materials science categorises the materials into three classes: metal, polymer and ceramics. In the metallurgy area materials science is well developed. Many composites are now being developed to generate new materials with desired properties. A composite is a mixture of two or more materials that has properties different than any single material. At the moment there is an extensive research being undertaken on composites in the metal, polymer and ceramic industries to develop novel materials with enhanced properties. Materials science normally represents the solid state of matters.

Food science is a new discipline that has evolved in the past few decades. The activities within this discipline also include the development of new food products, design of processes to produce these foods. The control of structure of the food for consumer acceptability and shelf-life has become extremely important. In materials science we can treat food as another material that has a dominance of polymer. The major components of foods such as protein and carbohydrates are called biopolymers. When we compare conventional materials science (mentioned above) and food science, there are many similarities, except the food system is already a complex composite system. Bringing the knowledge of materials science to food materials is a novel attempt to advance the food science in a newer direction. Actually, many food scientists are already working within the area of materials science knowingly or unknowingly.

As a recent development, food science has embraced the area of phase transition and nanotechnology. Researches in these two areas have helped to better understand the behaviour of the food components and food as a composite mixture during processing and storage. These two emerging fields and the growing importance of food micro- and macro-structures have encouraged shifting the research direction to materials science. Although conventional material science involves mainly the solid state of matter, food science discipline greatly includes the liquid state structures such as emulsions and colloids.

In the food science curriculum, food physics, food chemistry and food processing and engineering are normally the core courses. Food materials science combines all this inter-disciplinary knowledge into a single domain within food materials science and engineering. The materials science approach helps to explain why food materials behave as they do. Students require better understanding and analytical capability of how the food system behaves based on the knowledge of composition, structure and processing conditions. Thus, materials science is a new integrated approach of thinking as compared to conventional food science that involved separated study on chemistry, physics, processing and engineering. Materials science is also very important for teachers and researchers in food science as a better way of evaluating the behaviour of the food materials from the way they are formulated and processed. Food packaging is certainly one area that has already used the materials science approach since the packaging materials can be composites of polymer, metal and ceramics.

In this book we have tried to bring together most of the relevant areas of food science that are related to materials science. The introductory part (Chapter 1) introduces the historical background of materials science and its relevance to food materials science. It is important for the students to understand the molecular basis of a matter to understand materials science. This book is intended to help the students and food scientists to understand the actual meaning of materials and materials science. There are other chapters in the book that incorporate food materials properties, processing and performance. There are some chapters that include the content that is relevant to the microstructures and sensory properties. Since food is a multicomponent mixture and properties of the food materials vary widely, it is impossible to include all the food materials science related topics. Therefore, one might find this book lacking in certain areas.

The editors hope that this book covers novel information which is helpful to the students and research communities in food science. There is a very limited number of consolidated books that cover food materials science, although a number of books in food science can provide scattered information related to food materials science. We anticipate that this book can be instrumental in developing new concepts or in applying new concepts to new food products and processes. We have selected contributors with an experienced background in food materials science. This has greatly enhanced the quality of materials included in the book. Somewhat later than planned, the book has finally taken shape. We would like to thank all the contributors of the book. Without their contributions publication of this book may not have been possible.

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Contents

1 Food Materials Science and Engineering: An Overview

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1.1 INTRODUCTION

Materials science deals with the relationships of processing, performance, properties and structures of materials. It covers chemical, physical and engineering areas of almost all materials used in industries and includes practical and theoretical aspects of materials from atomic to molecular and bulk levels. Originally materials science covered metallurgy and solid-state physics. Various metals and metal alloys and ceramics were manufactured to provide materials with diversified properties and strengths. The developments of science and engineering have led to the introduction of materials science concepts to almost every field of science and engineering. It is adapted from metallurgy to polymers, ceramic, biomedical implants materials, textiles, paper, pharmaceutical, agricultural and food materials. Some common fields of materials science are described in Table 1.1. Material scientists and engineers improve traditional materials, develop new materials and produce them efficiently and economically. Thus they need knowledge of science and engineering or can be a part of a multidisciplinary team. In fact, gastronomy is often the artwork of food materials science.

In human civilisation, materials science started to develop during the Stone Age when humans began to use tools and weapons made from stone. This development grew through the bronze and steel ages, and now in the twenty-first century materials science has been revolutionised by new technologies in plastic, semi-conductors and biomaterials manufacture. The early focus of materials science prior to the 1960s was on the relationship between the structure and properties of materials. During the past two decades processing has become a major concern of materials science (National Research Council, 1989; Bensaude-Vincent and Hessenbruch, 2004). This development has established modern materials science with its four major interdependent components: process, structure, properties, and performance (Figure 1.1). It may be stated that a process for a material will determine its structure; the structure and the process contribute to the properties of the material; and the properties will dominate the performance of the material. In many industries, including the food industry, the process-structure-properties relationship may be altered by an intelligent selection of the formulation or the composition of raw materials. In food process and product development and design, materials science is essential in guiding the specific process selection for sensitive materials to produce a desirable product because, as in other areas, science and engineering

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Table 1.1 General materials science areas.

Materials Science field	Descriptions
Ceramography	High temperature ceramics and silicons and their microstructure.
Cystallography	Crystal structures, defects and physical properties.
Electronic and magnetic materials	Fabrication of semiconductors, sensors, electrical integrated circuits, etc.
Materials characterisation	Thermal analysis, NMR, X-ray diffraction, electron and neutron spectroscopies, Raman spectroscopy, energy-dispersive spectroscopy (EDS), electron microscope analysis, atomic force microscopy, x-ray photoelectron spectroscopy, Small angle neutron scattering (SANS), Small angle X-ray scattering (SAXS).
Metallurgy	Study of metals and their alloys, and their structure and mechanical strength.
Microtechnology	Manufacturing processes of 'micron' size materials, ink-jet printers, electrical devices, transistors, integrated circuits.
Nanotechnology	Materials fabrication in nanoscale, nanocomposites to improve mechanical properties and hygiene of materials (such as packaging materials).
Surface science	Interactions of materials and structures of gas-solid, solid-solid, solid-liquid and liquid-gas dispersions.
Tribology	Study of friction, lubrication and wear of a materials in motion.

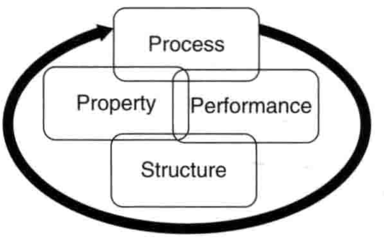

Figure 1.1 Four interacting components of materials science and engineering.

are interwoven as *food materials science and engineering* (Shackelford, 2004, Callister, 2007). A significant recent development in materials science across all its areas has been the development of nanoscience and nanotechnology, which expand materials science to the nanostructural level of understanding and engineering materials, including foods. Materials science and engineering have a wide impact on the control of processes producing materials, either by controlling properties and composition of original raw materials, or changes occurring in materials during specific processes. This requires a deep physicochemical and structural characterisation of the materials. Several material science areas are dominated by physical and structural aspects of solid materials. However, the physicochemical properties of biological materials are significant determinants of food processing, performance and structural characteristics. These properties are also temperature and water content dependent.

Solid materials have been classified into three basic groups: metals, ceramics and polymers (food is a multicomponent mixture of these three basic groups). Materials that are typical of the 'high-technology' fields are termed as advanced materials: such as semiconductors, biomaterials and future materials (composites, smart and nanoengineered materials). Composites of base materials have been used to improve the mechanical, electrical and magnetic properties of solid materials. Materials science has allowed the increase of the strength of the materials by thousands of times as a result of the development of composite metallic materials (alloys) and fibres (such as aramid and carbon fibres). Superalloys and

Table 1.2 Food materials science and engineering areas.

Food Materials Science area	Examples of attributes
Food gels and soft-materials	Gel formation and gel structures.
Solid foods (e.g., food powders, dried foods, extruded foods)	Crispness, crunchiness, dispersion properties, flowability, cracking, friability, reconstitution properties, stickiness.
Interfacial science	Adhesion-cohesion and fouling mechanisms, colloidal dispersions, emulsification, foams, interfacial migration of surface active components.
Material characterisation techniques	Chemical, microscopic, nutritional, physical, rheological, sensory and thermal property characterisation of food materials.
Nanotechnology	Nanoparticle formation, nanoparticles for nutrient delivery, textural modification.
Oral processing and Tribology	Physics, physiology, and psychology of eating, lubrication, deformation and sensory perception.
Phase transition and separation	Crystallisation, glass transition, melting, phase separation in multi-component systems (composites), size fractionation and vitrification.
Restructuring and product design	Texture modification, texturised products.
Rheology	Flow and deformation properties of solid and semi-solid foods.

special ceramic composites are newly developed materials which are stable at very high temperatures and improve the energy conversion efficiency of heat engines (such as thermal power engines and automobiles) (Nitta, 1999; Mileiko, 2005). Magnetic strength of the newly developed composite metallic material has been increased by more than 100 times (Shackelford, 2004). The strength of tools and abrasive materials has been improved exponentially owing to the development of new materials. Similarly, there are great achievements in the development of superconductor and superelectronic materials (Johrendt, 2011).

Materials science requires new levels of understanding and control of the basic building blocks of materials: atoms, molecules, crystals, and noncrystalline single and multiphase systems (glassy matrix). The whole spectrum of novel materials in bioscience includes soft-gels, colloids, emulsions and dispersed particulate suspensions and their manufacturing processes and structure. Since the quality and functionality of food products are highly dependent on their components and component properties their structure needs to have a robust design to achieve the desired quality and sensory properties. Food materials science and engineering is also expected to contribute significantly to the development of advanced nutrient delivery systems with specific structural, sensory and nutrient release properties. Thus, 'Food Materials Science and Engineering' is an interdisciplinary field involving the properties of food materials and its applications, for example, to food process engineering and product manufacturing, product design, sensory properties, quality enhancement and shelf-life extension. In food materials science, the major food components of foods, such as starch and proteins, are considered as food polymers. Their molecular and structural properties are related to those of many other polymers (such as plastics). The mechanical and rheological properties of foods are considered important not only because they contribute to sensory properties but also because of their effects on physical stability and shelf-life. Food materials science has developed along with the introduction and wider availability of several frontier technologies, such as Atomic Force Microscopy, Electron Microscopy, Confocal Laser Microscopy, Nuclear Magnetic Resonance spectroscopy, X-ray Diffractometry and thermal analysis. Various fields within food materials science are evolving (Table 1.2) as the importance of the food materials science approach in food product manufacturing and quality is growing.

The present chapter introduces the area of food materials science and highlights developments and achievements in applying the materials science principles across the disciplines of food science and engineering.

1.2 MOLECULAR BASIS OF FOOD MATERIALS

Materials consist of molecules with various physical states. These exhibit diverse levels of energy and molecular mobility. Molecular mobility may include translational (three-dimensional displacement from one location to another), rotational (movement around an axis), and vibrational (stretching and bending of the bonds between the atoms, which changes the shape of the molecules) mobility. Translational and rotational motions relate to the movement of the entire molecule, whereas vibrational motions occur within the molecule. The magnitude of these motions depends on the physical state of the matter whether it is in a liquid, solid, or gaseous state. These states exhibit different degrees of intermolecular interactions and free volume (intermolecular space) between the molecules. The possible interactions between atoms are covalent and noncovalent bonds. *Noncovalent bonds* involve electrostatic forces such as hydrogen, ionic, and dipole interactions and van der Waals forces. Noncovalent bonds exist more in macromolecules and are common in biological molecules, such as proteins and carbohydrates. Noncovalent bonds are important in forming the secondary and tertiary structures of the molecules. *Covalent bonds* involve the equal or unequal sharing of one or more pairs of electrons between atoms. *Nonpolar bonds*, a term which signifies an equal sharing of electrons, are described as nonpolar because of the nonaccumulation of electrons and the absence of dipole movement. Covalent bonds are stronger than the noncovalent bonds. The state of the matter determines the extent of these intermolecular forces and molecular mobility. Therefore, the melting and phase transition temperatures of the materials are dependent on the strength of these bonds. Material properties are thus highly dependent on these molecular level differences and their relative molecular mobility.

Food materials science and engineering is a sub-area of biological materials science which belongs to the field of general materials science rather than having an independent identity. Components of food materials exist in gas, liquid and solids states. The reactivity of the molecules, shelf-life and properties is often related to their relative mobility. Table 1.3 depicts how various physico-chemical and nutritional properties of food materials are related to molecular mobility. Food can be a mixture of a number of components present in different phase or state with different degrees of molecular mobility; such as, in simple terms, rigid (solid), mobile (liquid) and very mobile (gas) components. The fraction of each of the components and reactivity of each of these components within food systems is important for an overall stability/shelf-life of products. Addition of small molecules or plasticisers can increase food system mobility influencing the physical properties and shelf-life.

Table 1.3 Properties of materials (including food materials) that are related to molecular mobility.

Attributes	Properties
Physical	Softness, hardness, crispness, fracture properties, fluidity, viscosity, sensory
Chemical	Reaction rate/degradation- collision of molecules
Nutritional	Bioactivity, bioavailability, viability