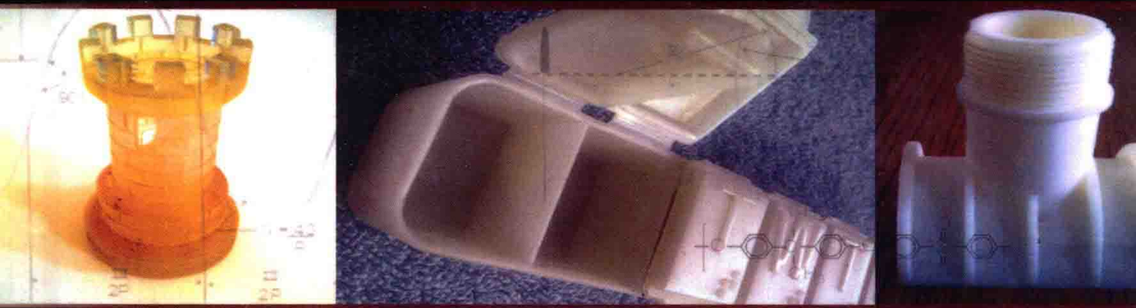
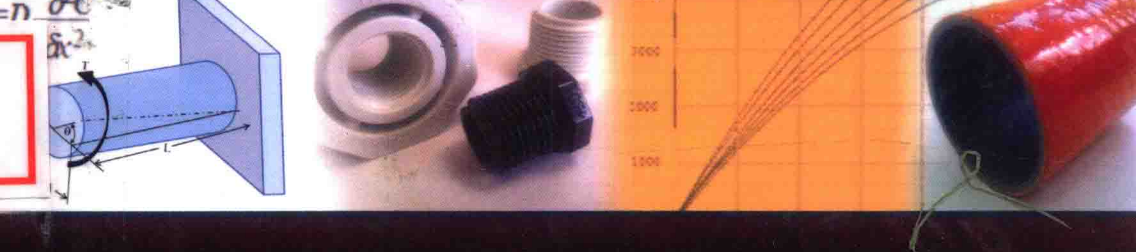


Plastics Product Design

Paul F. Mastro



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Preface

My first job as a plastics engineer fresh out of college was working for a large custom molder. That gave me a wonderful opportunity to be involved in the design and manufacture of a wide array of different products spanning a number of different industries. What that experience taught me was that in the myriad of different products that I got to work on, the basic engineering principles were the same, but each different industry or product group had constraints and requirements unique to them and often used very specialized engineering techniques that one would not necessarily be aware of if they did have experience in that industry. Working on different products every day gave me an appreciation for how important this knowledge was and how difficult it could be to quickly acquire it. This was reinforced throughout my career as I worked in engineering and product design in a number of different industries. The main purpose of this book is to convey the knowledge I obtained in all of these experiences to help facilitate the design process for people involved in designing or manufacturing similar kinds of parts.

Plastic materials provide the design engineer a wide variety and ever increasing number of possible solutions to some of the most difficult design problems for an ever widening scope of applications. The purpose of this book is to provide the reader with a basic understanding of the range of plastics materials, properties, and processes available to them and an understanding of how to design a variety of basic components from plastic materials.

While the basic design principles that will be discussed in the first section of the book are applicable to the design of any plastic part, each product type or industry has specific or unique requirements, many of which will be discussed in detail in the chapters in part two that should help someone unfamiliar with them to begin to develop a part design.

This book is intended for use by designers who have had limited or no experience with plastics materials as well as a more experienced designer who is designing a part for a use, process or an application that they are not familiar with. Also, the book has an extensive discussion of materials and processes that will provide a solid introduction to plastics for anyone.

In Section 1, Plastics as a Design Material, the reader is provided with an introduction to plastics as a design material. The section is introduced with a brief history of the plastics industry and a discussion of general plastics material properties. The next two chapters will give an overview of the plastics materials commonly in use today and a discussion of a variety of processes available to the designer to make a part along with the design considerations each process will entail. This section also includes a discussion of useful prototyping processes, including advantages and disadvantages of each. Finally, chapter 5 will discuss general design considerations that are applicable to most plastics product designs.

In Section 2, Plastics Product Design, the discussion will turn to the specific design and manufacturing requirements for a number of different product types and components. This section starts with an introduction to plastic materials being used as structural components, where many basic mechanical engineering principles are reviewed as well as a discussion of how they need to be adapted to account for the viscoeleastic behaviour of plastics materials. Chapters follow on enclosures, packaging, gears, hinges, bearings, snap fits, pressure vessels, including pipe, and optical components. These sections will discuss the general considerations that are relevant to these applications as well as specific insights about each particular application. Discussions of plastic joining techniques that are applicable across all product groups will layout the design choices available for putting these components together. The book concludes with a discussion of the product development process and role of the past design and designer in this process.

This book is the result of my experiences as a design and manufacturing engineer and is intended to provide the reader with a basic understanding of plastics materials and processes and to provide a resource to assist them with the design of a number of different components.

I would like to thank my wife Lois for her help and support throughout my career and in this endeavour.

Contents

PART 1

PLASTICS AS A DESIGN MATERIAL

Plastics materials have a number of unique properties that allow a wide variety of solutions to many design problems. The nature of some of these properties requires the designer to approach the application of these materials to a product design a little differently than many traditional design materials. This section will review common materials and processes and look at some of the general engineering approaches that need to be taken in developing a plastic product design.

1

Introduction to Plastics Materials

In this chapter we will briefly discuss the history of plastics, examine what plastics are, how they are made and some of the general properties of plastics materials. We will also look at the overall size of the plastics industry today.

1.1 History of Plastics

It is hard to imagine a world without plastics, but plastics are a family of relatively new materials and have been around for a little more than 100 years. The start of the plastics industry dates back to 1868 when John Wesley Hyatt, in search of an alternate material to ivory for billiard balls, discovered celluloid, the first commercially successful plastic material. Celluloid also found application in photographic still and movie film and shirt collars and buttons. It is still in use today to make ping pong balls.

Celluloid was a modified naturally occurring polymer, cellulose. In 1907 Dr. Leo Baekeland, through a condensation reaction of phenol and formaldehyde, invented phenolic, the first plastic produced entirely from synthetic materials. This was an easily moldable, cost effective material that became widely used in electrical components and general moldings. Its major limitation was that it was only available in dark colors. This problem was solved in 1929 when American Cyanamid Company introduced urea formaldehyde thermoset molding compounds which could be produced in a wide array of colors.

In 1934 Dr. Wallace Carothers, working for DuPont, invented nylon. This is notable because he was hired to develop a synthetic material to replace silk and he developed a polymer to meet this specific need, a first for polymer chemists.

The first inorganic polymer, polytetrafluoroethylene, more commonly known as Teflon®, was discovered by another DuPont chemist, Dr. Roy Plunkett, in 1938.

Throughout the 1940s thermoset materials dominated the plastics market, but starting in the 1950s new thermoplastic materials and processes began to take over. The first commercial reciprocating screw injection molding machine appeared in Germany in the mid-1950s from Ankerwerk. Due to its ability to produce significantly improved thermoplastic melts, numerous manufacturers around the world soon offered their own versions. Injection-molded thermoplastics started to replace many thermoset applications and many new opportunities for growth were found.

In 1953, the first reinforced plastic car bodies appeared in the Chevrolet Corvette [1], and plastics continue to make inroads in the auto industry as their low costs and high strength-to-weight ratios help engineers meet ever-increasing fuel economy requirements. Use of plastics materials to reduce the weight of cars is a major strategy of the automobile industry as they strive to meet the US National Highway Traffic Safety Administration 2025 CAFE (Corporate Average Fuel Economy) standards of 54.5 miles per gallon by 2025.

Advances in polymer chemistry and catalysts now allow polymer chemists to scientifically develop plastic materials with specific properties to meet the needs of specific applications. Stereospecific catalysts like Zeigler Natta catalysts and metallocene catalysts can help control how and where the molecules attach to one another. Ruthenium catalysts enable ring opening metathesis polymerization, which has opened the possibilities of new families of high performance polymers.

This is allowing plastics to move into areas of much more demanding functional requirements and to be used in a wide array of engineering applications. Plastic materials are not only used in housewares, toys and packaging, but also aerospace, construction, electronics, transportation and industrial applications.

1.2 Definition of Plastics

What actually is a plastic material? There are many similar definitions used, but for our purposes, plastics are materials that are composed of large molecules that are synthetically made and, under the proper conditions, can be readily formed or molded into the desired shape. The large plastic molecules are called polymers from the Greek words poly, which means many, and meros which means units. The polymer is made up of many smaller molecules called monomers which are joined together through chemical bonding, generally through either a condensation or an addition polymerization reaction. The chemical properties of the monomer will determine if and how it can form into a polymer, as well as what properties the finished polymer might have.

1.3 Thermoplastics and Thermosets

Plastics are divided into two basic families, thermoplastics and thermosets. Thermoplastics are materials that when heated will soften and flow, allowing the polymer chains to slide over one another, and when cooled, they will harden. This process can be repeated many times. This allows thermoplastic materials to be easily recycled and reused. A thermoset material will soften and flow when it is heated, but additional heat will cause a chemical reaction called crosslinking to occur. In crosslinking, chemical bonds form between the polymer chains. This crosslinking reaction locks the polymer chains together and prevents them from sliding over one another, causing the polymer to harden. This process is irreversible. As a result, parts made from thermosets cannot be easily recycled.

Figure 1.1 shows the differences in how thermoplastics and thermosets respond to changes in temperature. At lower temperatures (upper left on the chart) both thermoplastics and thermosets are solids (usually – although a thermoset resin can start out as a liquid). As the temperature is increased, the viscosity (resistance to flow) of both materials will lower until they go from a solid state to a viscous (thick)