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The Author

Prof. Dr. Christoph Jaroschek studied mechanical engineering, and was then Head of Application Technology and Process Development at a well-known manufacturer of injection molding machines for 11 years. Since 1998 he has held the position of Professor in Plastics Processing, in the area of Engineering Science and Mathematics, at the Bielefeld University of Applied Sciences, Germany.

Preface

Many designers are nervous when the material requirement for a development task is a plastic. One reason also lies in the education system or the level of knowledge of the instructors and professors. Until about 1990, the world consumption of plastics was still smaller than the consumption of steels (Figure 1). The volume, not the weight, is used as a benchmark here. If one compares the two groups of materials, volume is a suitable parameter regarding a design, as it is not the weight but the size (i.e. the volume) that is important, especially in the case of plastic components.

Demand for plastics is growing faster than the increase in knowledge among design engineers

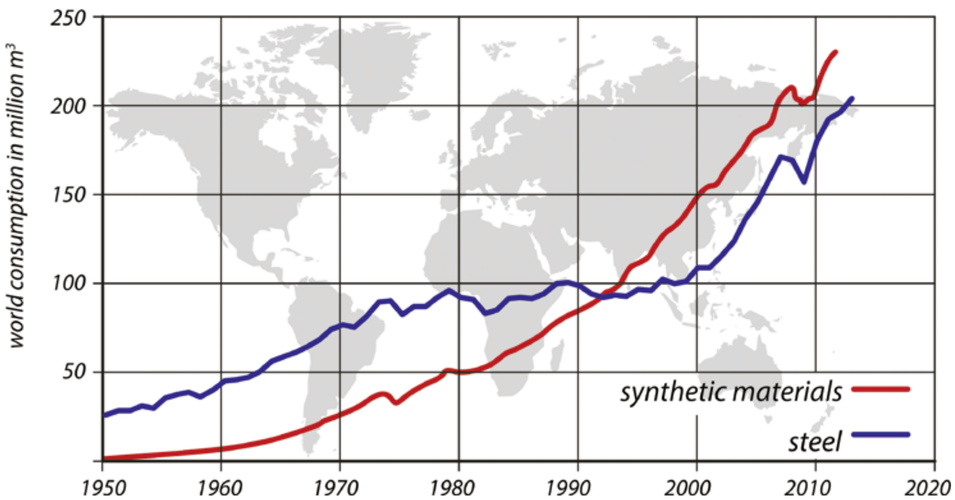

Figure 1 Temporal development of the demand for steel and plastics [Data sources: Word steel assoc., PlasticsEurope Deutschland e. V.]

Before 1990, part design was mainly for metal materials and the importance of plastics was still limited in the training of design engineers. Today, the picture has changed significantly, but it still takes time for training to adapt accordingly.

Dimensioning and calculation

Many books about plastic design have been written by proven experts in the field of plastics themselves. In many cases, the focus is on the calculation or dimensioning of components, rather than on their design. This is where this book comes in.

Injection moldable design

Since most plastic components only must withstand low loads, the actual design of the component is more important than the mechanical design in many applications. It is important to know that most plastic components are injection molded. Therefore, a designer should know first and foremost what this means for the design. This book focuses on the area of injection molds. The designer should be aware that his design specifications must ultimately be implemented with an injection mold.

In this book, the focus is on the field of injection molds. The designer should be aware that his design specifications must ultimately be implemented with an injection molding tool.

Plastics in the following are synonymous with thermoplastics

Due to the focus on injection molded parts, thermoplastics are mainly treated here. These are plastics that melt at higher temperatures. For simplicity's sake, the term plastic is therefore used synonymously for thermoplastics in the following, unless otherwise noted.

Literature

In many places, the content of this book is perhaps a little concise. The book is initially intended to show the important relationships so that the designer understands why the design of injection molded parts must be different from that of metal parts. Many specific details have deliberately not been formulated. This applies, for example, to information on draft angles or radii. Plastics of even one grade (e.g. PP) are available in an almost unmanageable variety with regard to mechanical properties. The properties mentioned here concern, among other things, the mechanical stability under load. Here, a designer should not rely on recommendations from tables but rather consider what effects a too small/large radius, for example, will have for a component. This book is therefore particularly focused on understanding, so that the concrete specifications can be sensibly selected for the respective application.

The compilation of the necessary knowledge for the designer in this book draws on existing literature.

- *Process knowledge*
  - W. Michaeli, H. Greif, G. Kretzschmar, F. Ehrig, *Training in Injection Molding,* Hanser
  - G. Pötsch, W. Michaeli, *Injection Molding,* Hanser
  - T. A. Osswald, L.-S. Turng, P. Gramann, *Injection Molding Handbook,* Hanser
  - S. Kulkarni, *Robust Process Development and Scientific Molding,* Hanser

- *Mold engineering*
  - G. Menges, W. Michaeli, P. Mohren, *How to Make Injection Molds,* Hanser
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- *Design*
  - H. Rees, *Understanding Injection Mold Design,* Hanser
  - B. Catoen, H. Rees, *Injection Mold Design Handbook,* Hanser
  - R. A. Malloy, *Plastic Part Design for Injection Molding,* Hanser
- *Material knowledge*
  - G. W. Ehrenstein, *Polymeric Materials*, Hanser
  - T. A. Osswald, G. Menges, *Materials Science of Polymers for Engineers,* Hanser

Contents

1 Plastic Parts

This chapter compares the special features of plastic parts with alternatives made of metal or other materials. There are design rules that are directly justified by the manufacturing process. The information provided here is intended to give the designer a rough overview.

■ 1.1 General Information

Difference between metal and plastic parts

Injection molded components differ from their metal counterparts in interesting ways.

- Plastic parts have a different shape for the same function.
- Often a conventional assembly can be realized in one plastic part, i. e. many functions can be implemented directly in a single component.

For example, consider compressor bars made of metal, plastic, and material combinations (Figure 1.1). First, it is important that the requirements are met. The question as to which material is better or worse is not possible until clear evaluation criteria have been established.

Figure 1.1 Metal and plastic compressor bars for ring binders

General requirements

In any event, the requirements for the compressor bars are:

- Function: Clamping force
- Economy (manufacturing costs).

The clamping force is generated by the deformation of a wire in the elastic range in the case of the metal variants and by the deformation of the plastic in the all-plastic variant. Due to the considerably lower modulus of elasticity of plastic, the plastic variant is only suitable for small forces and should not be used for very thick ring binders.

Manufacturing costs of injection molded parts are only favorable for large production runs

Manufacturing costs consist of the costs of material, production equipment (machine and mold) and labor. Roughly speaking, material costs constitute half of the manufacturing costs. Material costs range from 2 to 4 $/kg. In the all-plastic variant, the costs are very low because the product is created in a single process step. Although the machine and tooling costs are very high, if the expected number of pieces exceeds the limit of about 10,000 the tooling costs per part are low. And if many injection molded parts can be produced per hour with one machine, the machine costs per part are also low.

Functional integration leads to simpler production

The metal compressor bars consist of several elements that must be joined together. Basically, the fewer process steps that are necessary, the lower is the risk of failure in production. This should also be considered when compiling manufacturing costs.

1.1.1 Comparison of Designs (Conventional vs. Plastic)

Rethinking the design when using plastics

The use of plastics requires a fundamental design rethink. The example of a clothespin shows that the older product made of wood is cheaper than a similar plastic clamp (Figure 1.2). Both variants consist of two clamp elements that are pressed together by a metal spring. The wooden clamp can be cut very quickly from a profile-milled board. The corresponding plastic clamp is more expensive to manufacture and has inferior properties, because it can become brittle and break due to weathering.

A well-designed plastic clamp will consist of only one element, and that eliminates the need for assembly. In principle, plastic components can incorporate many functions. This is referred to as functional integration.

Cast structures can have very freely formed surfaces

A plastic component can have a very complex design if it is manufactured by injection molding. Due to the molding process used for production, the design of a plastic component can feature any type of free-form surface. In conventional components, the individual parts are predominantly milled and turned from the solid, with the result that simple shapes predominate here.

Considering a comparison to conventional products, the following generalization can be made:

Conventional components often consist of various individual parts that form an assembly. By contrast, good plastic components often consist of a single part (Figure 1.3).

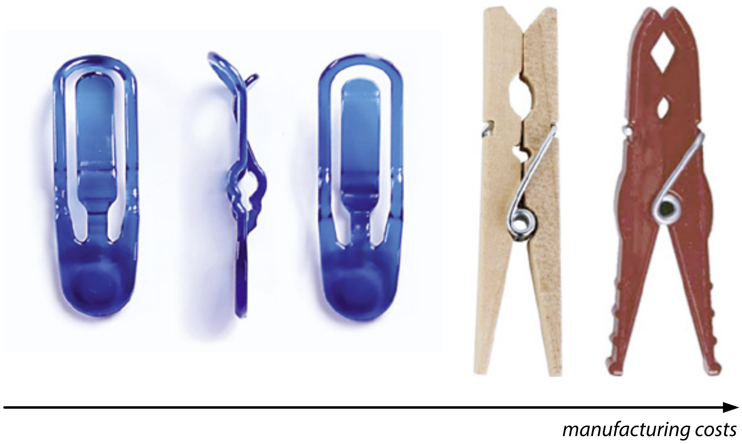

Figure 1.2 Manufacturing costs of clothespins of different designs

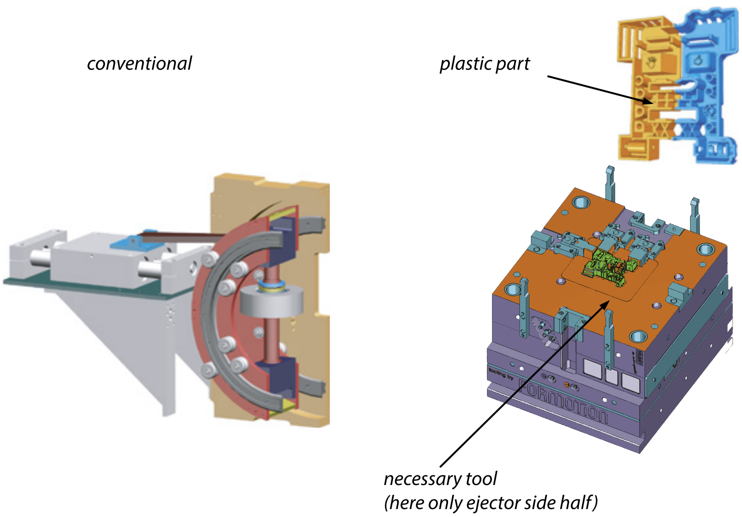

Figure 1.3 Comparison of a conventional assembly consisting of different individual parts and a plastic component, along with the mold required for production [image source: Ziebart/FH-Bielefeld, Ritter/HS-Reutlingen]

Good designs in plastic consider the feasibility of using injection molds

During the development of a plastic component, consideration must be given to the mold at the design stage, because it limits the design freedom to a certain extent. In any event, the designer of an injection molded part should be aware of the possibilities afforded by mold technology, because slight changes in the shape of a plastic component can have a very large effect on the cost of a mold. Molds consist of many individual parts and are in turn very complex assemblies. The molds must perform different tasks (Figure 1.4). The actual mold cavity has to be filled with melt and the heat of the melt needs to be dissipated (cooling) so that the plastic part will become solid and stable and can be demolded via an ejector system.

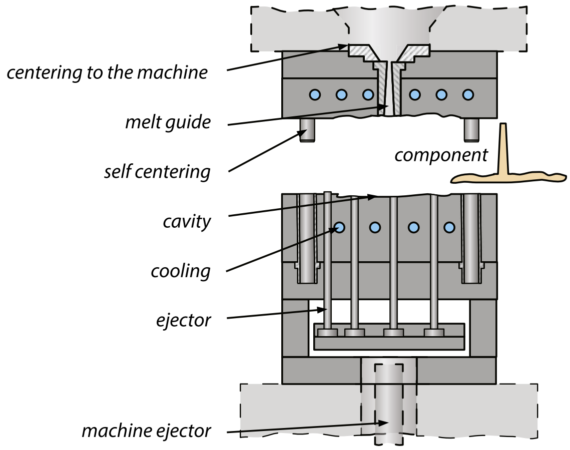

Figure 1.4
Design and functions of a simple injection mold

Demonstration mold shows effect of good component design on the mold

For demonstration purposes, the "Polyman" plastic component shown in Figure 1.3 is poorly designed on the left side and well-designed on the right side. This assessment of the design relates to the mold implementation. For the various lateral openings, three sliders are required on the poorly designed side to demold the undercuts (Figure 1.5). With a few minor changes to the shape, the well-designed side can dispense with sliders completely. This makes the mold less expensive and less susceptible to faults during production or requires less maintenance.

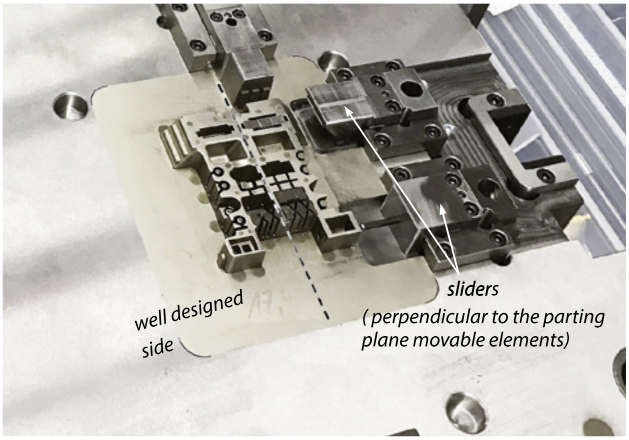

Figure 1.5
Ejector side for the Polyman demonstration part [image source: Ritter/HS-Reutlingen]

1.1.2 Special Features of Plastics

The biggest advantage of plastics is their low melting point

The most important property is the melting temperature of plastics, which is only about 1/10 that of metal (Figure 1.6). This makes it possible to cast plastics in steel molds of very complex shape. The precision of the steel molds can be transferred to the plastic component largely without the need for reworking and can be repeated almost as often as required. However, the complexity and expense of such molds render this production barely suitable for small production quantities. Plastic parts manufacture is thus almost always a mass production process.

A distinction needs to be made between melt temperature and transition temperature. In processing, the melt temperature is always much higher than the transition temperature from the solid to the melt state. Strictly speaking, only semi-crystalline plastics can melt, because melting entails the liquefaction of crystalline areas. Amorphous plastics, therefore, merely soften. This may not become clear until Chapter 5, where specific material properties and characteristic temperatures are discussed.

Temperature of the plastic melt

1.1.2.1 Comparison of the Properties of Plastics and Metals

Further comparison with metals reveals major differences in properties. Thus, specific applications may only be feasible in one of the two materials.

Mechanical properties of plastics are not as good as those of metals

Table 1.1 Comparison of Metals and Plastics

Property	Metal	Plastics
Young's modulus	high	low
Tensile strength and yield strength	high	moderate
Density/weight	high	low
Young's modulus	no	possible

- The modulus of elasticity of metals and especially steels is approx. 1000 times higher than that of plastics. Applications subject to high load requirements are therefore largely limited to metals. Plastic components would deform too much in such cases.
- Metals are stronger than plastics. The issue here is that of component failure. This can be both a fracture and an unacceptable permanent deformation.
- Young's modulus and the strength of plastics are strongly dependent on temperature. For applications involving high temperatures, which can be as low as 50 °C, particular care must be exercised in the choice of material subject to long-term loads.

Young's modulus for plastics is temperature-dependent and therefore not constant

- The density of plastics is only approx. 1/7 that of steel. Applications that require a certain weight (e. g. pendulums for clocks or curtain weights) cannot easily be made in plastic.
- Some plastics are transparent.

A close comparison of different materials reveals further advantages and disadvantages.

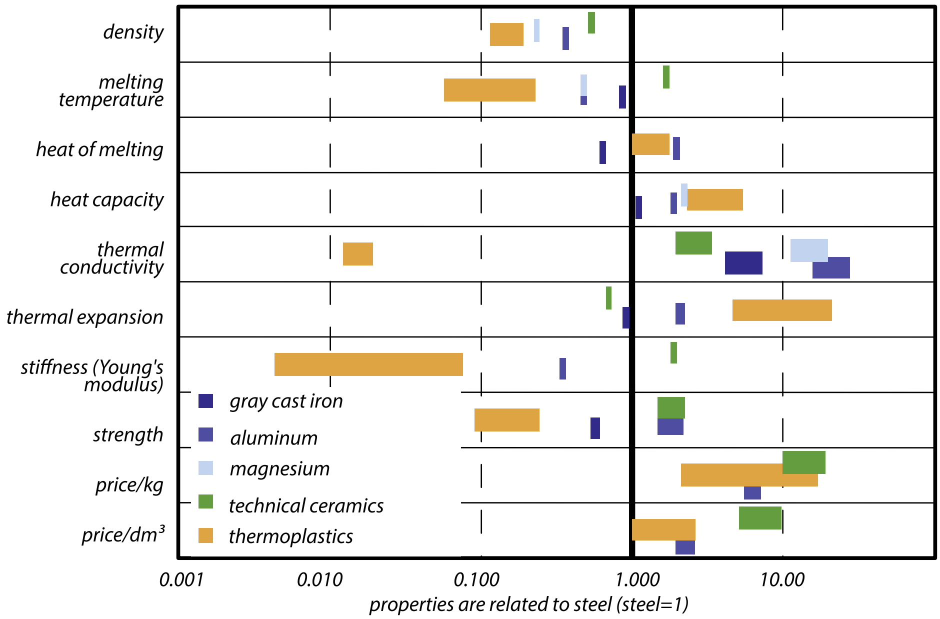

Figure 1.6 Comparison of thermoplastics with steel [source: WAK-Kunststofftechnik]

With regard to production, the low thermal conductivity of plastics makes it difficult initially to dissipate the heat of the melt from inside the component to the mold. The thicker a component is, the longer the cooling process will take. For this reason, plastic parts are thin-walled wherever possible. Jumps in wall thickness are unfavorable.

Low thermal conductivity enables precision injection molding of fine structures

The low thermal conductivity, however, also makes it possible to fill long, thin flow paths in a controlled manner. Plastic components can thus be considerably finer structured than cast metal components.

Plastics are usually more expensive per kg than metals

It is often assumed that plastics are inexpensive, but this is not the case. Especially those plastics that are intended for use at elevated temperatures can cost more than $10 per kilogram. When expressed in terms of weight, the outcome is the specific raw material price, which is given in $/kg. This is comparable to that of metals.

1.1.2.2 Special Mechanical Behavior

Metals have a definite failure limit (yield strength)

Metals are atomic in structure, i.e. they are composed of individual atoms that form crystals in regular repetition during cooling. When a load is applied, the atoms move slightly away from each other, returning to their original state after the load is removed. This elastic behavior is linear, i.e. the deformation increases in proportion to the load. Above a load limit R_p, entire atomic layers shift; when the load is removed, the deformation remains (Figure 1.7).