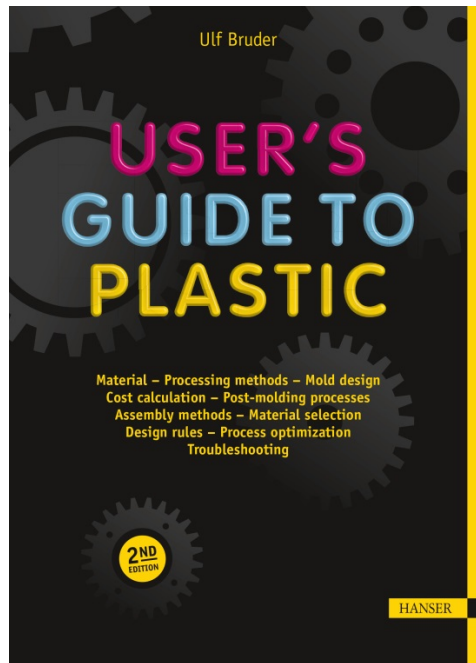


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Sample Pages

User's Guide to Plastic

Ulf Bruder

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Foreword

For many years, I had the idea of writing a book about injection molding, as I have spent over 45 years of my working life on this subject.

When I retired in 2009 I was given great support by my friends Katarina Elner-Haglund and Peter Schulz of the Swedish plastics magazine *Plastforum*, who asked me to write a series of articles about thermoplastics and their processing for the magazine.

I was also hired at this time to work with educational programs at the Lund University of Technology, the Royal University of Technology in Stockholm, and a number of industrial companies in Sweden, as a result of which this book was developed.

My aim has been to write in such a way that this book can be understood by everyone, regardless of prior knowledge about plastics. The book has a practical approach with lots of pictures and is intended to be used in secondary schools, universities, industrial training, and self-study. In some of the chapters there are references to worksheets in Excel that can be downloaded free from my website: www.brucon.se.

In addition to the above-mentioned persons, I would like to extend a warm thanks to my wife Ingelöv, who has been very patient when I've been totally absent in the "wonderful world of plastics" and then proofread the book; my brother Hans-Peter, who has spent countless hours on adjustments of all the images etc; and my son-in-law Stefan Bruder, who has checked the contents of the book and contributed with many valuable comments.

I would also like to thank my previous employer, DuPont Performance Polymers and especially my friends and former managers Björn Hedlund and Stewart Daykin, who encouraged the development of my career as a trainer until I reached my ultimate goal and dream job of "global technical training manager". They have also contributed with a lot of information and many valuable images in this book.

I also want said a big thank you to my friends and business partners in all educational programs in recent years, who have supported me and contributed with many valuable comments, information and images for this book, and a special thanks to those who have made this printing possible thanks to the ads in the beginning. The whole list would be very long but you will find some of them in the list of internet links in Chapter 31.

In this Second Edition:

This edition contains greatly expanded coverage of extrusion, collected into a new Chapter 20. There are also a number of new and updated figures, with numerous small improvements and corrections throughout the text. These are complemented by an all-new professional layout and structure, which I hope will help readers to navigate the book comfortably.

I would like to thank Mark Smith at Carl Hanser Verlag for all the support that I received during the last years with my book in various languages.

Ulf Bruder

Karlskrona, Sweden

3) LDPE is used for film blowing and extrusion.

A large part of all the polyethylene produced is used for film blowing. If the film is soft and flexible, it is either made of LDPE or LLDPE. If it has the rustle of the free bags at the grocery store, it is probably made of HDPE. LLDPE is also used to improve the strength of LDPE film.



Figure 2.7 Garbage bags.

LDPE is excellent for film blowing and is the most common material used in bags, plastic sacks, and construction film.



Figure 2.8 Cable jacketing.

LDPE is used in the extrusion of jacketing for high voltage cables

4) PEX

Cross-linked polyethylene is mainly used in the extrusion of tubes. The cross-linking provides improved creep resistance and better high-temperature properties.



Figure 2.9 Tubes in PEX resist both high temperatures (120°C) and pressure and are used for the hot water supply of cleaning or washing machines.

You can even copolymerize ethylene with polar monomers and get everything from viscous products (e. g. melting glue) to tough films and impact-resistant hard shells such as golf balls.

A common copolymer is EVA (ethylene-vinyl-acetate). By varying the concentration of vinyl acetate (VA) from 2.5 to 95%, you can control the properties and produce a range of different types of material. Increased VA content leads to higher transparency and toughness.

Adhesives, carpet underlay, cable insulation, carriers of color masterbatches, stretch film, and coating film for cardboard and paper are typical uses of EVA.

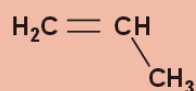
2.2 Polypropylene (PP)



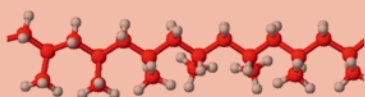
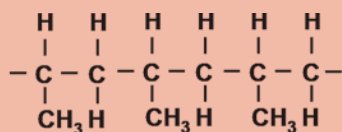
Chemical facts:

PP has a simple structure and is made up, like PE, only of carbon and hydrogen. It also belongs to the category of plastics called olefins.

Polypropylene is made up of a chain of carbon atoms, where every other carbon atom is bonded to two hydrogen atoms and every other to a hydrogen atom and a methyl group. The monomer formula is:



Graphically you describe polypropylene:



Polypropylene is a semi-crystalline commodity, denoted by— and commonly referred to as—PP. It is also known as “polypropylene.” It is the second-largest plastic on the market, after LDPE.

Polypropylene was discovered in 1954, almost simultaneously by two independent researchers Ziegler and Natta, who went on to share the Nobel Prize in 1963.

The Italian chemical company Montecatini launched the material on the market in 1957.

The polymerization of polypropylene can control both crystallinity and molecule size. One can also copolymerize polypropylene with other monomers (e.g. ethylene).

Polypropylene can occur as a homopolymer, random or block copolymer depending on the polymerization method. Polypropylene can also be mixed with elastomers (e.g. EPDM), filled with talc (chalk), or reinforced with glass fiber. In this way it is possible to obtain more grades with widely differing characteristics than can be achieved for any other plastic. Certain grades of polypropylene can handle a continuous temperature of 100 °C plus peaks of up to 140 °C and can therefore be classified as engineering plastics.

2.7.1 Properties of PMMA

- + Very high transparency (98%)
- + High rigidity and surface hardness
- + Very good UV resistance
- + Good optical properties
- + Can be used in implants
- High thermal expansion coefficient
- Scratch resistance
- Low resistance to stress-cracking
- Solvent resistance
- High melt viscosity (difficult to fill thin walls)

2.7.2 Recycling

PMMA can be easily recycled, and is denoted by the recycling code > PMMA <.

2.7.3 Application Areas

PMMA can be injection molded and extruded. Semi-finished products in PMMA can be processed with conventional machining. PMMA is superior to polycarbonate and polystyrene for laser marking.



Figure 2.27 PMMA works really well in reflective items.



Figure 2.28 PMMA is much used by the lighting industry, e.g. as a screen for fluorescent tubes.

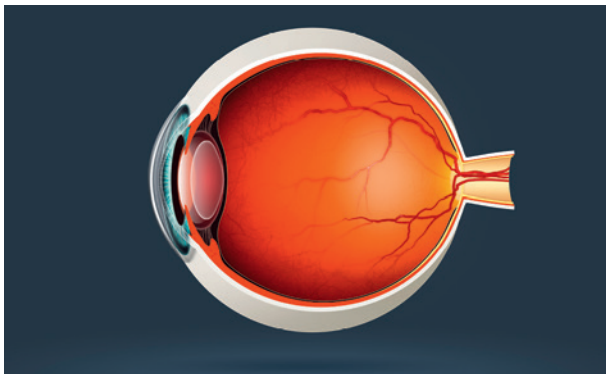


Figure 2.29 Ophthalmic lenses. PMMA is highly compatible with the human body and is therefore used in implants. Due to its extremely good optical properties, PMMA is used in artificial lenses that are surgically inserted into the eye.



Figure 2.30 Safety glass at sports arenas. The protective glass shields around hockey rinks are usually made of PMMA as the material has high transparency and sufficient toughness.

Engineering Polymers

3.1 Polyamide or Nylon

Polyamide is a semi-crystalline engineering plastic, denoted by PA. There are several different types of polyamide, of which PA6 and PA66 are the most common. Polyamide was the first engineering polymer launched on the market. It is also the largest in volume since it is widely used in the automotive industry.

Polyamide was invented by DuPont in the United States in 1934 and was first launched as a fiber in parachutes and women's stockings under the trade name Nylon.

A few years later, the injection-molding grades were launched. Nylon became a general term; DuPont lost the trademark and currently markets its polyamides under the trade name Zytel. Ultramid from BASF, Durethan from Lanxess, and Akulon from DSM are some of the other famous trade names on the market.

3.1.1 Classification

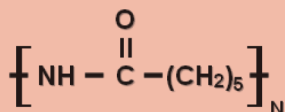
The development of polyamide has focused on improving the high-temperature properties and reducing water absorption. This has led to a number of variants where in addition to PA6 and PA66 the following types should be mentioned: PA666, PA46, PA11, PA12, and PA612.

About a decade ago, aromatic "high performance" polyamides were introduced, usually known as PPA, which stands for polyphthalamide. The latest trend is "bio-polyamides" made from long-chain monomers, e.g. PA410, PA610, PA1010, PA10, PA11, and PA612.

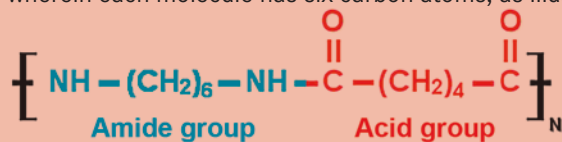


Chemical facts:

Polyamide is available in a number of variations, labeled alpha-numerically, e.g. PA66, indicating the number of carbon atoms in the molecules that make up the monomer. PA6 is the most common type of polyamide and has the simplest structure:



PA66 has a monomer that consists of two different molecules wherein each molecule has six carbon atoms, as illustrated below:



3.4.1 Properties of Polycarbonate

- + Crystal clear (light permeability 89%)
- + Very high impact strength (at low temperatures down to -40°C)
- + High operating temperature (120°C constant, and 145°C short-term peak load)
- + Negligible moisture absorption and good dimensional stability
- + Lower mold shrinkage than most other plastics
- + Good electrical properties
- + Self-extinguishing V-2 and can be V-0 with additives
- + Food-approved grades available
- High tendency to stress-crack under constant load
- Solvent triggers cracking
- Degrades in water hotter than 60°C , but can be machine washed

3.4.2 Recycling

Material recycling is preferable for PC, although incineration for energy extraction is also an option. The recycling code is > PC <.

3.4.3 Application Areas

Polycarbonate can be processed by injection molding and extrusion, both with and without glass fiber. PC sheets can be vacuum formed.



Figure 3.26 Polycarbonate has a poor chemical resistance, as can be seen from the cracks caused by vinegar in the salad bowl here.



Figure 3.27 Extruded tubes of glass fiber reinforced polycarbonate are both stiff and strong and can withstand tough impact, as the paddle in this picture shows.



Figure 3.28 The glass for car headlamps is made of polycarbonate and coated with a thin layer of siloxane to improve scratch resistance, UV protection, and protection against solvents.



Figure 3.29 Polycarbonate is both incredibly impact resistant and suitable for painting, making it an excellent material for motorcycle helmets. The visor is also produced in polycarbonate.

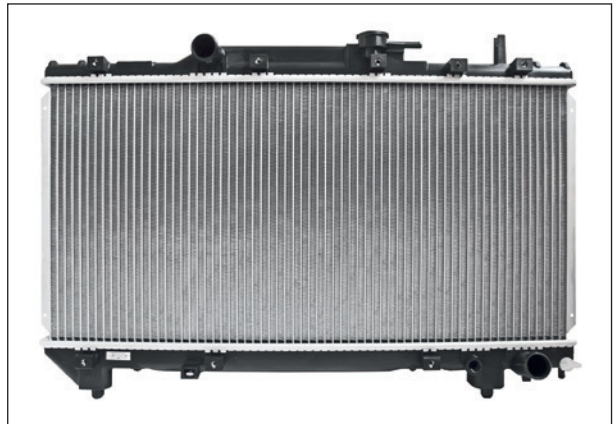


Figure 6.9
Castor bean plant



Figure 6.10 Gas pipes and fittings for gas pipes can be made of PA11. This material is the first high-performance polyamide that has been approved to be used for pipes up to 100 mm (4 inches) in diameter at operating pressures up to 14 bars. This material may be biobased and contain 100% renewably sourced ingredients by weight.

Figure 6.11 Automotive radiator end tanks can be produced from PA610 bio-polyamide and resist the hot, chemically aggressive underhood environment. PA610 also has low water absorption. Some PA610 contains more than 40% renewably sourced ingredients by weight.



6.7 Biobased Polymers from Microorganisms

PHA (polyhydroxyalkanoate) is a linear semi-crystalline polyester produced by the bacterial fermentation of sugar, glucose, or lipids, i.e. a group of substances consisting of fats and fat-like substances. The material was developed by ICI in the 1980s, and there are very few producers in the market. The material has good weathering properties and low water permeability. Overall, it has properties similar to PP.



Figure 6.12 PHA has many medical applications. PHA fibers can be used to suture wounds.

6.8 Bioethanol or Biomethanol

PE is a commodity that has begun to be produced again of renewable biobased raw materials.

In the 1970s, a substantial proportion of India's ethanol was used for the manufacture of PE, PVC, and PS. In the 1980s, companies in Brazil began to manufacture biobased PE and PVC. However, when oil prices dropped in the early 1990s, production stopped. Twenty years later, production is beginning to build up again.

Today, the Brazilian company Braskem is a world leader in biobased PE. Commercial production started in September 2010, using sugar cane as a raw material to prepare bioethanol, which is then converted into ethylene, used in the production of PE. Total production is currently around 200,000 tons and represents 17% of the market for bioplastics.

Bio-PE is nonbiodegradable.

Other commodities that can come from renewable resources are PP and PVC.



Figure 6.13 A plastic shopping bag produced in green Bio-PE.

Modification of Polymers

This chapter describes the polymerization of thermoplastics and how to control their properties by using various additives.

Figure 8.1 95% of all the plastics produced are based on natural gas and oil. The remaining 5% comes from renewable sources, i.e. plants. In 2010 plastics accounted for about 4% of the total oil consumption, as follows:

- Heating 35%
- Transport 29%
- Energy 22%
- Plastic materials 4%
- Rubber materials 2%
- Chemicals and medicine 1%
- Other 7%



8.1 Polymerization

The polymerization of monomers obtained by cracking of oil or natural gas creates polymers (synthetic materials) that can be either plastic or rubber. The type of monomer determines which type of material you get, while the polymerization process itself can create different variations of the molecular chains, such as linear or branched as shown below.

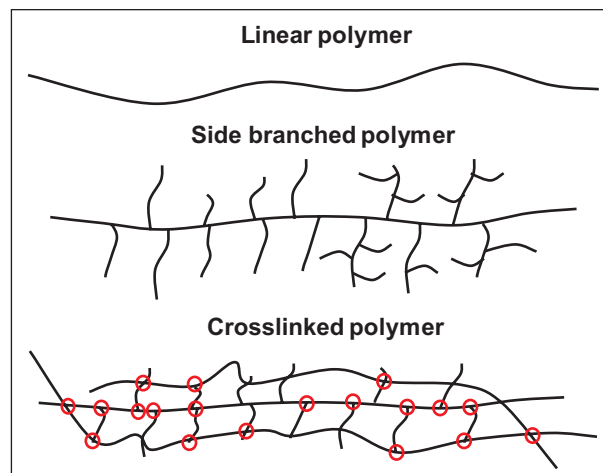


Figure 8.2 Polymerization of ethylene can produce different variants of polyethylene. LLDPE is made up of linear chains like the one at the top of the figure. LDPE has a branched chain structure, as shown in the middle. And PEX has cross-linked chains, i.e. where there are molecular bonds between the chains, as shown at the bottom.

If a polymer is made up of a single monomer it is called a homopolymer. If there are more monomers in the chain it is called a copolymer. Acetal and polypropylene are resins that can occur in both these variations. The copolymer group (the second monomer) is mainly located after the main monomer in the chain. In the case of acetal there are about 40 main monomers between every copolymer group. The copolymer may also occur as a side branch in the main chain, in which case it is known as a graft copolymer.

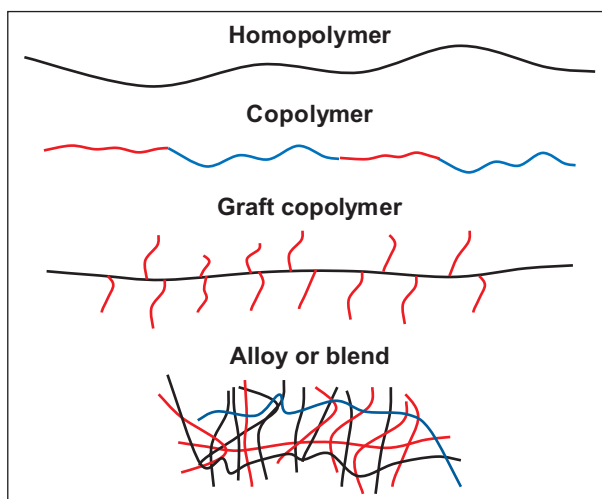


Figure 8.3 At the top we can see the linear chain of a pure polymer, such as polypropylene. By adding ethylene you get a polypropylene copolymer with a block structure according to the second chain from the top. This material has much better impact resistance than normal polypropylene. By adding EPDM (rubber monomer) you get a graft polymer with a chain structure and a material with extremely high impact strength. You can also create a copolymer by mixing the granules from different polymers. In this case, the material is known as an alloy or blend. ABS + PC is an example of this type of copolymer.

An additional way to modify the polymer is to control where the different molecules end up in the chain (see next).

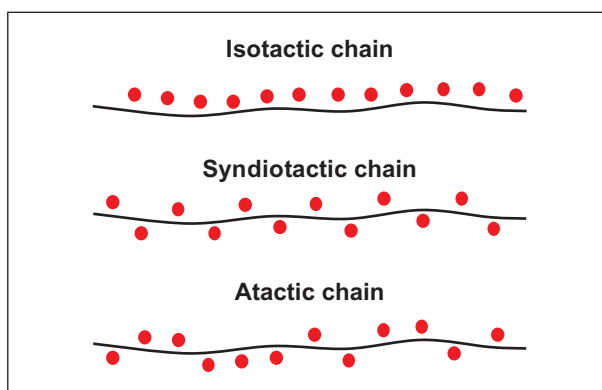


Figure 8.4 To a certain extent, we can control the properties of a polymer by influencing how a particular molecule in the chain is oriented. The red circles in the top two chains symbolize the $-\text{CH}_3$ group in polypropylene. If all the $-\text{CH}_3$ groups are oriented in the same direction, it is called isotactic. In polypropylene, with the help of a so-called metallocene catalyst, you can orient the groups so that they are evenly distributed in different directions. In this case the chain is called syndiotactic. In a material such as polystyrene, there is an aromatic molecule with 6 carbon atoms in a ring (symbolized by the red circle in the lower chain). This molecule ends up completely random both in orientation and distribution in the chain. Such a chain is called atactic.

Heat deflection temperature

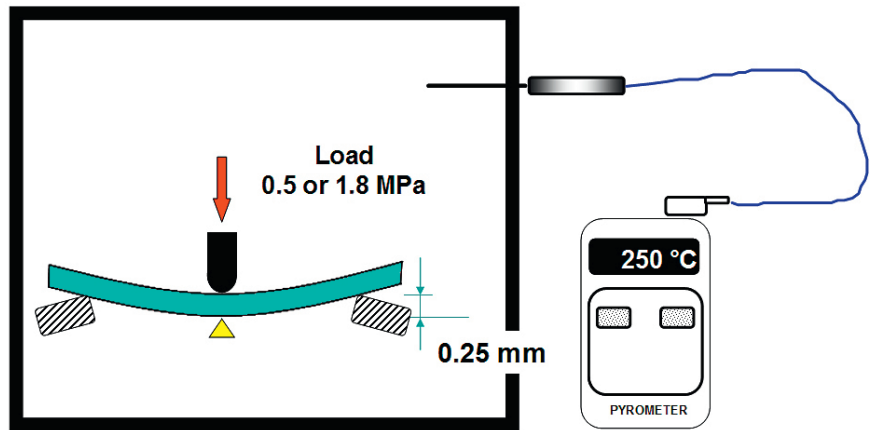


Figure 9.13 When measuring HDT you have to fix a test bar horizontally at both ends. Then you put it into an oven and load it in the middle with either 0.45 or 1.8 MPa. You let the oven temperature rise by 2 °C per minute and record the temperature at which the sample bar has bent down 0.25 mm as the HDT.

In the tables below with values from the CAMPUS materials database (see next chapter) you will find HDT for a number of thermoplastics. NOTE! Some deviation from the values below may occur depending on the viscosity and additives of the materials.

Table 9.1 Table with common plastics heat deflection temperatures

Type of polymer	HDT at 0.45 MPa	HDT at 1.8 MPa	Melting point
ABS	100	90	–
Acetal copolymer	160	104	166
Acetal homopolymer	160	95	178
HDPE, polyethylene	75	44	130
PA 6	160	55	221
PA 6 + 30% glass fiber	220	205	220
PA 66	200	70	262
PA 66 + 30% glass fiber	250	260	263
Polyester PBT	180	60	225
PBT + 30% glass fiber	220	205	225
Polyester PET	75	70	255
PET + 30% glass fiber	245	224	252
PMMA (acrylic plastic)	120	110	–
Polycarbonate	138	125	–
Polystyrene	90	80	–
PP, polypropylene	100	55	163
PP + 30% glass fiber	160	145	163

Note: The amorphous materials have no melting point

9.4 Flammability Tests

The international testing institute Underwriters Laboratories has developed various tests to specify a material's fire resistance. You select test bars with different thickness and ignite them either horizontally or vertically. We specify this as HB (= horizontal burning) or V-2, V-1, or V-0 (V = vertical burning). For a material to be classified as fire resistant, it must be extinguished by itself within a certain distance (HB) and at a certain time. When testing a material for V-0 to V-2 you will also give attention to possible drops that ignite cotton (see below).

9.4.1 HB Rating

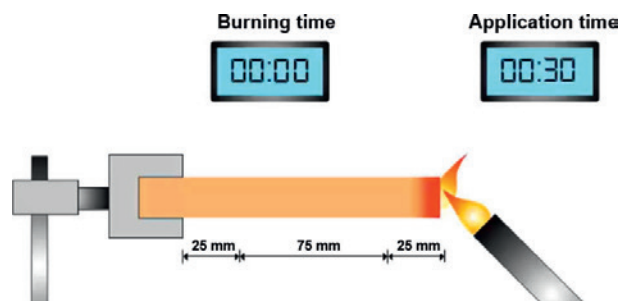


Figure 9.14 The flame is applied for 30 seconds before the ignition speed is measured. HB classification is obtained if the ignition speed measured between two points does not exceed:

1. 40 mm/min for 3–13 mm test bars
2. 75 mm/min for test bars < 3 mm
3. If the flame goes out before the first mark

9.4.2 V Rating

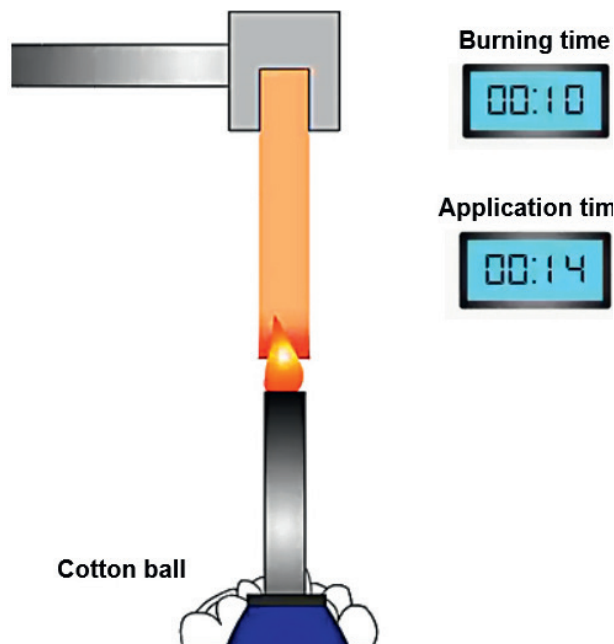


Figure 9.15 When testing a test bar in a vertical position you will apply the flame twice during each 10 seconds. The contact time of the second ignition begins immediately after extinguishing the test bar of the first flame.

Cost Calculations for Moldings

Most molders are using advanced computer-based software to calculate costs or post-costs of injection-molded parts. Unfortunately, it is very seldom that injection machine setters have insight into or get the opportunity to use such software, even though they have great potential to affect the costs by adjusting the injection-molding parameters.

How often does it happen that setters add a few seconds of extra cooling time when they have a temporary disturbance of the injection-molding cycle? And then forget to change back to the original settings before the parameters are saved for the next time the mold will be set up? Those extra seconds can mean thousands of Euros or Dollars in unnecessary production costs per year and may also reduce the company's competitiveness.

The purpose of this chapter is to show how a fairly detailed cost calculation for injection-molded parts can be made. The setter also gets a tool that enables him/her to see how changes that are made in the process can influence the cost of the molded part. This tool is based on Microsoft Excel and is available for downloading at www.brucon.se. The user does not need any extensive knowledge of Excel in order to fill in the input values required to immediately obtain the final cost picture at the bottom of the page.

The rest of this chapter will explain how to use the Excel file and what the different input values mean.

When you open the file called *Costcalculator.xls* you must first make a copy of this file to your computer's hard drive, otherwise the macro functions will not work. Depending on how the default values are set for your own Excel program, it may be necessary to make modifications of the security settings. Detailed information of how this is to be done can also be found on the author's homepage. The Excel file is also in "read-only" mode, so it should be saved under a different name once you have completed it.

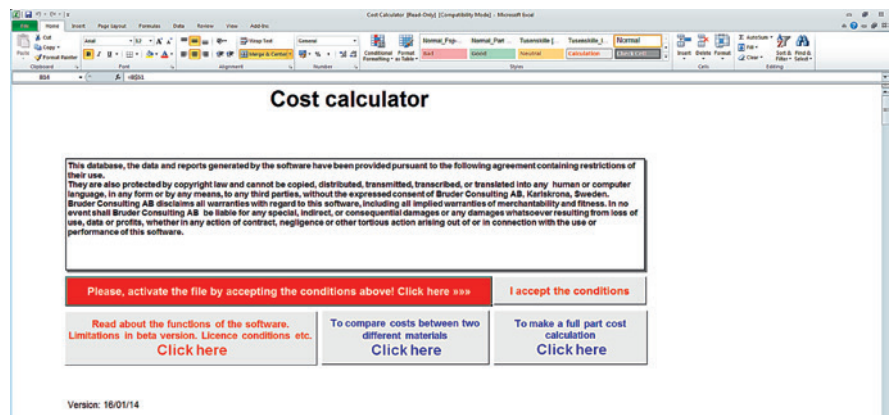


Figure 19.1 The start menu once the Excel file has been opened.

There are three different functions to choose between:

1. Read about the functions of this software
2. Compare the costs between two different materials
3. Make a full part cost calculation

Before you click on the key “I accept the conditions” you are only able to “Read about the functions of the software”. The two other keys will only display blank pages.



Figure 19.2 Once you have clicked on “I accept the conditions” you will see “The file is active”, and all the different functions can now be used.

19.1 Part Cost Calculator

We will start with the “Part cost calculator”. This is the most advanced function, and we will go through all input values before we end the chapter with the “Material comparison calculator”.

In “Part cost calculator” you can make a relatively complete cost calculation for a single part, total delivery volume, or annual volume. When filling in the white input fields with blue text a quick way to get to the next field is to use the “Tab” key on your computer keyboard.

The final result is obtained at a given sales price but it is also possible to get the sales price using a predetermined profit that you wish to achieve.

INPUTS:		Currency:	Euro
Estimated annual volume	1000000	pcs	
No of deliveries per year	10	times	
Part net weight	13,00	g	
Reject	1,0	%	
Calc. part weight (incl. reject)	13,13	g	
Material price per Kg	5,20	Euro	
Dead time	0,7	sec	
Percent of an operator per machine	20,0	%	
Direct labour + general expences	20,00	Euro	
Dir. labour + gen. expences/sec	0,006	Euro	

Customer:		Automolder Inc	File name:	Cable_clips.xls
Part name:	Cable Clips	Part no.:	55-123789	
Material grade	Zytel® ST801	Delivery date:	W46	
Parts per delivery	100000	Machine:	Engel 100 Tons No.141	
Est. annual volume	1000000	Deliveries/year	10	pcs

DIRECT MOULDING COSTS:		Per part	Per delivery	Per year
Material:	0,067	Euro	6691	Euro
Direct labour + gen. expences	0,004	Euro	406	Euro
Tool changing cost:	0,000	Euro	45	Euro
Packaging:	0,001	Euro	100	Euro
Masterbatch colouring cost:	0,003	Euro	263	Euro
SUMMARY OF COSTS:	0,075	Euro	7504	Euro

SUMMARY OF COSTS:		Per part	Per delivery	Per year
Material:	0,067	Euro	6691	Euro
Direct labour + gen. expences	0,004	Euro	406	Euro
Tool changing cost:	0,000	Euro	45	Euro
Packaging:	0,001	Euro	100	Euro
Masterbatch colouring cost:	0,003	Euro	263	Euro
SUMMARY OF COSTS:	0,075	Euro	7504	Euro

Figure 19.3 If you wish to practice with the same values that are shown above, just click on the key “Fill in an example” and the spreadsheet will automatically be filled with the values.

The Injection-Molding Process

26.1 Molding Processing Analysis

In this chapter, we will go through the main injection-molding parameters that affect the quality of the moldings. We will also emphasize the value of working systematically and having good documentation.

Figure 26.1 shows a document called “Injection Moulding Process Analysis”. There is an Excel file that can be downloaded at www.brucon.se. On this sheet we can record most of the parameters that need to be documented to describe the injection-molding process for a molded part.

This document was designed by the author of this book when he was responsible for the technical service at one of the leading plastic suppliers in the Nordic region.

You may think: Why should I spend time to fill it in when I can get all the parameters printed out directly from the computer system in my molding machine?

The answer is that you would probably drown in all the figures and only with difficulty find the cause of the problem. You would also have difficulties in finding the key parameters as the printouts from different machines are completely different.

This document is perfect for use both in problem solving and as a basis for process and cost optimization as well as for documenting a test drive or a start-up of a new job. If you fill in the document when the process is at its best you will have good benchmarks for comparison when there is a disturbance in the process. Therefore, we will closely examine the structure of this document and explain the meaning of the information in each input field. On the last page of this chapter, the document is presented in full-page format (Figure 26.48).

INJECTION MOULDING PROCESS ANALYSIS				Please, use tab button when filling in this sheet	
Customer	<input type="text"/>	Location	<input type="text"/>	Date	<input type="text"/>
Contact person	<input type="text"/>	Phone no	<input type="text"/>	Email	<input type="text"/>
Problem / Desire <input style="width: 100%; height: 80px;" type="text"/>					
Material	<input type="text"/>	Alternative usable material	<input type="text"/>		
Lot no	<input type="text"/>	Masterbatch	<input type="text"/>	MB content	<input type="text"/> % Regrind <input type="text"/> %
Machine	<input type="text"/>	Hold pressure profile possible	<input type="checkbox"/>	Clamping force	<input type="text"/> kN
Screw type	<input type="text"/>	Shut-off nozzle	<input type="checkbox"/>	Vented barrel	<input type="checkbox"/>
				Screw diameter	<input type="text"/> mm
Mould / part name	<input type="text"/>	Hot-runner system	<input type="text"/>	No of cavities	<input type="text"/>
Wall thickness at gate	<input type="text"/> mm	Max. wall thickness	<input type="text"/> mm	Min. wall thicken.	<input type="text"/> mm
Sprue dimension	<input type="text"/> mm	Runner dimension	<input type="text"/> mm	Gate dimension	<input type="text"/> mm
Nozzle diameter	<input type="text"/> mm	Parts weight (sum)	<input type="text"/> g	Full shot weight	<input type="text"/> g
Drying	Hot air dryer... <input type="checkbox"/>	Dehumidified dryer... <input type="checkbox"/>	Direct transport of dried resin to hopper... <input type="checkbox"/>		
	Drying temp	<input type="text"/> °C	Drying time	<input type="text"/> hours	
Processing					
Cylinder temp: Nozzle (front)	<input type="text"/> °C	Zone 4	<input type="text"/> °C	Zone 3	<input type="text"/> °C
		Zone 2	<input type="text"/> °C	Zone 1	<input type="text"/> °C
Melt temperature	<input type="text"/> °C	Mould temp. moving	<input type="text"/> °C	Mould temp. fixed	<input type="text"/> °C
				Temp. checked by pyrometer	<input type="checkbox"/>
Injection pressure	<input type="text"/> MPa	Hold pressure	<input type="text"/> MPa	Hold press. time	<input type="text"/> sec
		>>> Profile? <<<			
Injection speed	<input type="text"/> %	<input type="checkbox"/>	mm/sec	<input type="checkbox"/>	Fill time <input type="text"/> sec
		>>> Profile? <<<			
Back pressure	<input type="text"/> MPa	Screw rotation	<input type="text"/> RPM	Peripheral screw speed	Calculated m/sec
Dosing time	<input type="text"/> sec	Cooling time	<input type="text"/> sec	Total cycle time	<input type="text"/> sec
				Hold-up time	Calculated min
Dosing length	<input type="text"/> mm	<input type="checkbox"/>	cm ³	Max. dosing length	<input type="text"/> mm
		<input type="checkbox"/>			<input type="text"/> cm ³
				Suck-back	<input type="text"/> mm
					<input type="checkbox"/>
					cm ³ <input type="checkbox"/>
Hold pressure switch	<input type="text"/> mm	Cushion	<input type="text"/> mm	Cushion stable	<input type="checkbox"/>
Comments <input style="width: 100%; height: 80px;" type="text"/>					

www.brucon.se / 2016

Figure 26.1 The working tool “Injection moulding process analysis”, which is described in this chapter.

rotation speed compared to a less viscous standard grade. For example, impact-modified acetal with a melt index of 1–2 g/10 min has a recommended maximum peripheral speed of 0.2 m/s, compared to 0.3 m/s for a standard grade with melt index of 5–10 g/10 min. For glass fiber reinforced grades you will usually find the recommended maximum peripheral speed to be 30–50% of the speed for the unreinforced grade. Also, impact modified, flame retardant grades used to be more sensitive to shear than standard grades.

Having sufficiently high **Hold pressure** is especially important for semi-crystalline plastics. Usually it is recommended to have as high a pressure as possible without getting flashes in the parting line or having ejection problems. We provide hold pressures because many molders sometimes in good faith set far too low a hold pressure, resulting in poorer quality.

Other important parameters such as hold pressure time, hold pressure switch, back pressure, injection speed, and decompression are more dependent on the part design and machine conditions. We therefore cannot give any general values of these parameters, but refer you instead to Chapter 26.

Table 27.1 Typical processing data for unmodified standard grades of common thermoplastics.

Semi-crystalline commodities										
Material	Type	Melt temperature		Mold temp.	Drying				Hold pressure	Max peripheral speed
		Nominal	Range		Temp.	Time	Max moisture	Dew point		
Unit		°C	°C	°C	°C	Hours	%	°C	MPa	m/s
Polyethylene	PEHD	200	200–280	25–60	Does not normally need to be dried				25–35	1.3
Polyethylene	PELD	200	180–240	20–60	Does not normally need to be dried				25–35	0.9
Polyethylene	PELLD	200	180–240	20–60	Does not normally need to be dried				25–35	0.9
Polyethylene	PEMD	200	200–260	25–60	Does not normally need to be dried				25–35	1.1
Polypropylene	PP	240	220–280	20–60	Does not normally need to be dried				35–45	1.1

Amorphous commodities										
Material	Type	Melt temperature		Mold temp.	Drying				Hold pressure	Max peripheral speed
		Nominal	Range		Temp.	Time	Max moisture	Dew point		
Unit		°C	°C	°C	°C	Hours	%	°C	MPa	m/s
Polystyrene	PS	230	210–280	10–70	Does not normally need to be dried				45–50	0.9
HIPS	PS/SB	230	220–270	30–70	Does not normally need to be dried				45–50	0.6
SAN		240	220–290	40–80	Does not normally need to be dried				45–50	0.6
ABS		240	220–280	40–80	80	3	0.1	– 18	45–50	0.5
ASA		250	220–280	40–80	90	3–4	0.1	– 18	40–45	0.5
PVC	Soft	170	160–220	30–50	Does not normally need to be dried				40–45	0.5
PVC	Hard	190	180–215	30–60	Does not normally need to be dried				50–55	0.2
PMMA		230	190–260	30–80	8	4	0.05	– 18	60–80	0.6

Semi-crystalline engineering polymers										
Material	Type	Melt temperature		Mold temp.	Drying				Hold pressure	Max peripheral speed
		Nominal	Range		Temp.	Time	Max moisture	Dew point		
Unit		°C	°C	°C	°C	Hours	%	°C	MPa	m/s
Acetal	POM Homo	215	210-220	90-120	Does not normally need to be dried*				60-80	0.3
Acetal	POM Copo	205	200-220	60-120	Does not normally need to be dried*				60-80	0.4
Polyamide 6	PA6	270	260-280	50-90	80	2-4	0.2	-18	55-60	0.8
Polyamide 66	PA66	290	280-300	50-90	80	2-4	0.2	-18	55-60	0.8
Polyester	PBT	250	240-260	30-130	120	2-4	0.04	-29	50-55	0.4
Polyester	PET+ GF	285	280-300	80-120	120	4	0.02	-40	50-55	0.2

Amorphous engineering polymers										
Material	Type	Melt temperature		Mold temp.	Drying				Hold pressure	Max peripheral speed
		Nominal	Range		Temp.	Time	Max moisture	Dew point		
Unit		°C	°C	°C	°C	Hours	%	°C	MPa	m/s
Polycarbonate	PC	290	280-330	80-120	120	2-4	0.02	-29	60-80	0.4
Polycarbonate	PC/ABS	250	230-280	70-100	110	2-4	0.02	-29	40-45	0.3
Polycarbonate	PC/PBT	260	255-270	40-80	120	2-4	0.02	-29	60-80	0.4
Polycarbonate	PC/ASA	250	240-280	40-80	110	4	0.1	-18	40-45	0.3
Mod. PPO		290	280-310	80-120	110	3-4	0.01	-29	35-70	0.3

Semi-crystalline advanced thermoplastics										
Material	Type	Melt temperature		Mold temp.	Drying				Hold pressure	Max peripheral speed
		Nominal	Range		Temp.	Time	Max moisture	Dew point		
Unit		°C	°C	°C	°C	Hours	%	°C	MPa	m/s
Fluoroplastic	FEP/PFA	350	300-380	150	Does not normally need to be dried**				Low***	****
Aromatic polyamide	PA6T/66	325	320-330	85-105	100	6-8	0.1	-18	35-140	0.2
	PA6T/XT	325	320-330	140-160	100	6-8	0.1	-18	35-140	0.2
LCP		355	350-360	60-120	150	3	0.01	-29	20-60	Max
PPS		330	300-345	70-180	150	3-6	0.04	-29	45-50	0.2
PEEK		370	360-430	160-200	160	2-3	0.1	-18	50-65	0.2

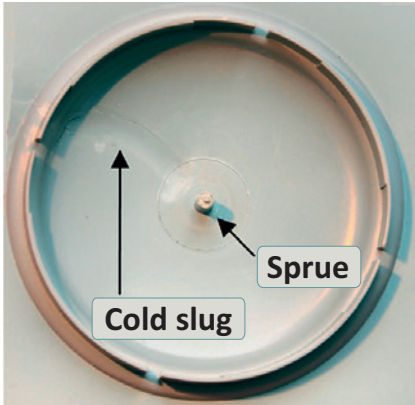


Figure 29.21 The picture shows the center of a hubcap. The gate is located on the opposite side. During the opening and closing phase, melt material has flowed into the cavity due to the injection unit abutting the mold.

29.3.13 Cold Slug

Possible causes (listed in the most likely order):

1. The material freezes in the nozzle
2. None or incorrectly located cold slug pocket in the runner
3. The melt flows into the fixed half during the opening or closing phase of the injection-molding cycle

Suggested remedies (according to the causes above):

1. Increase the nozzle temperature
2. Locate the cold slug pocket opposite the sprue in the mold
3. Reduce the risk of melt leakage into the mold:
 - Increase the decompression (suck-back)
 - Reverse the injection unit during the opening and closing phase
 - Increase the injection speed



Figure 29.22 Here there are visible ejector pin marks looking like white crescent moons. You can also see a clear sink mark.

29.3.14 Ejector Pin Marks

Possible causes (listed in the most likely order):

1. The part sticks too tightly in the cavity
2. The part is not cold enough (stiff) at the ejection
3. Mold problems or a faulty design

Suggested remedies (according to the causes above):

1. Reduce the mold shrinkage:
 - Reduce the hold pressure
 - Reduce the hold pressure time
 - Increase the release agent (surface lubrication) in the resin
 - Use a release spray (initially)
2. Eject or cool the part more efficiently:
 - Increase or decrease the ejection speed
 - Reduce the mold temperature
 - Increase the hold pressure time or the cooling time
3. *Workshop action required (see also Chapter 16):*
 - Increase the draft angles in the cavity
 - Change the size or design of the ejector pins

29.3.15 Oil Stain – Brown or Black Specks

Possible causes (listed in the most likely order):

1. Leaking cooling fluid when an oil temperature control unit is used
2. Leaking hydraulic oil hoses (cores)
3. Lubrication drops from the mold
4. Contamination from the gripper of the robot
5. Micro-cracks in the walls or plates of the mold

Suggested remedies (according to the causes above):

1. Check hoses
2. Check hose connections
3. Clean the mold
4. Clean the gripper of the robot
5. *Workshop action required (see also Chapter 16):*
Repair the mold



Figure 29.23 Here there are brown greasy oil stains on a white plastic cap.

29.3.16 Water Stain

Possible causes (listed in the most likely order):

1. Leaking temperature-control hoses in the mold
2. Leaking gaskets in the mold
3. Cracks in the plates of the mold

Suggested remedies (according to the causes above):

1. Check hose connections and hoses
2. Check O-rings and gaskets in the mold
3. *Workshop action required (see also Chapter 16):*
Repair the mold



Figure 29.24 Here there is a diagonal mark on the surface that was formed when plastic melt came in contact with water in the cavity.

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