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# Injection Molding Handbook

Herausgegeben von Tim A. Osswald, Lih-Sheng Turng, Paul  
Gramann

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Vorwort

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# Preface

The injection molding manufacturing sector, with a total product value of almost \$200 billion per year, is the fourth largest industry in the United States. Today, more than a third of all polymeric materials, approximately 15 billion pounds, are used by the injection molding industry annually.

The *Injection Molding Handbook* is primarily written for engineers, processors, researchers, and other professionals with various levels of technical background. It not only serves as introductory reading for those becoming acquainted with injection molding, but also as an indispensable reference for experienced practitioners. The handbook presents a thorough, up-to-date view of injection molding processing equipment and techniques, with fundamental information on the chemistry, physics, material science, and process engineering. It also covers topics that directly affect the injection molding process, such as injection molding materials, process control, simulation, design, and troubleshooting.

The handbook presents a well-rounded overview of the underlying theory and physics that control the various injection molding processes, without losing the practical flavor that governs the manuscript between its covers. The carefully chosen contributing authors include experts in the field, as well as practitioners and researchers in both industry and academia.

The first three chapters of this handbook present the fundamental background, covering basic process principles and materials. Here, a unified approach is used by pulling in the influence of processing on the properties of a finished product. Chapters 4 through 6 present the injection molding machine, which includes the plasticating and clamping units, as well as the injection mold. Materials handling is introduced in Chapter 7 and statistical process control, as related to injection molding, is presented in Chapter 8. Chapter 9 gives an in-depth overview of special injection molding processes. Product design and injection molding simulation is presented in Chapters 10 and 11, respectively. The last two chapters present extensive process and material troubleshooting procedures that will be useful to anyone in the industry at any stage of process and product design.

It would be impossible to thank everyone who in one way or another helped us with this manuscript. Above all, we would like to thank the contributors to this handbook. They are John Beaumont, John Bozzelli, Scott Collins, Bruce Davis, Mauricio DeGreif, Robert Farrel, Lukas Guenthard, Geoffrey Holden, Chris Rauwendaal, Antoine Rios, Michael Sepe, Treasa Springett, Raghu Vadlamudi, Jerry Wickmann, and Venny Yang. They not only submitted quality contributions in a timely manner, but also served as sounding boards during all stages of the preparation. We are also grateful to Lynda Litzkow and Angela Maria Ospina for the superb drawing of some

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Madison, WI  
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tions for injection molded PS parts are pharmaceutical and cosmetic cases, radio and television housings, drawing instruments, clothes hangers, toys, and so on.

### Polyvinylchloride (PVC)

Polyvinylchloride comes either unplasticized (PVC-U) or plasticized (PVC-P). Unplasticized PVC is known for its high strength rigidity and hardness; however, PVC-U is also known for its low impact strength at low temperatures. In the plasticized form, the flexibility of PVC will vary over a wide range. Its toughness will be higher at low temperatures. When injection molding PVC-U pellets, the melt temperature should be between 180 and 210°C, and the mold temperature should be at least 30°C. For PVC-U powder the injection temperatures should 10°C lower, and the mold temperatures at least 50°C. When injection molding PVC-P pellets, the melt temperature should be between 170 and 200°C, and the mold temperature should be at least 15°C. For PVC-P powder the injection temperatures should 5°C lower, and the mold temperatures at least 50°C. Typical applications for injection molded plasticized PVC parts are shoe soles, sandals, and some toys. Typical applications for injection molded unplasticized polyvinylchloride parts are pipefittings.

## 2.6 Thermosetting Polymers

Thermosetting polymers solidify by a chemical cure. Here, the long macromolecules cross-link during cure, resulting in a network. The original molecules can no longer slide past each other. These networks prevent “flow” even after reheating. The high density of cross-linking between the molecules makes thermosetting materials stiff and brittle. The cross-linking causes the material to become resistant to heat after it has solidified; however, thermosets also exhibit glass transition temperatures that sometimes exceed thermal degradation temperatures. A more in-depth explanation of the cross-linking chemical reaction that occurs during solidification is in Chap. 3.

### 2.6.1 Cross-Linking Reaction

The cross-linking is usually a result of the presence of double bonds that break, allowing the molecules to link with their neighbors. One of the oldest thermosetting polymers is phenol-formaldehyde, or phenolic. Figure 2.25 shows the chemical symbol representation of the reaction, and Fig. 2.26 shows a schematic of the reaction. The phenol molecules react with formaldehyde molecules to create a three-dimensional cross-linked network that is stiff and strong. The by-product of this chemical reaction is water.

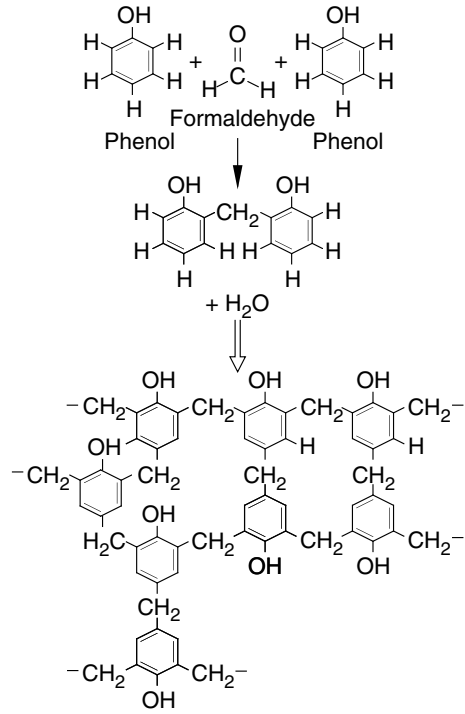


Figure 2.25 Symbolic representation of the condensation polymerization of phenol-formaldehyde resins.

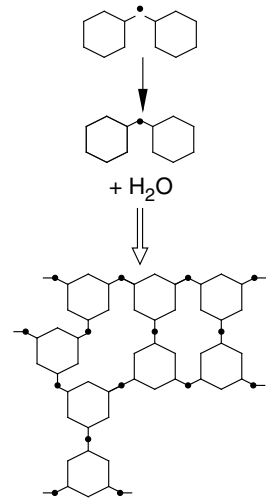


Figure 2.26 Schematic representation of the condensation polymerization of phenol-formaldehyde resins.

## 2.6.2 Examples of Common Thermosets

Examples of the most common thermosetting polymers, with a short summary, are given in the following.

### Phenol Formaldehyde (PF)

Phenol formaldehyde is known for its high strength, stiffness, hardness, and its low tendency to creep. It is also known for its high toughness, and, depending on its reinforcement, it will also exhibit high toughness at low temperatures. PF also has a low coefficient of thermal expansion. PF is compression molded, transfer molded, and injection-compression molded. Typical applications for phenol formaldehyde include distributor caps, pulleys, pump components, handles for irons, and so on. It should not be used in direct contact with food.

### Unsaturated Polyester (UPE)

Unsaturated polyester is known for its high strength, stiffness and hardness. It is also known for its dimensional stability, even when hot, making it ideal for under-the-hood applications. In most cases UPE is found reinforced with glass fiber. Unsaturated polyester is processed by compression molded, injection molding, and injection-compression molding. Sheet molding compound (SMC) is used for compression molding; bulk molding compound is used for injection and injection-compression molding. Typical applications for fiber-reinforced UPE are automotive body panels, automotive valve covers and oil pans, breaker switch housings, electric motor parts, distributor caps, ventilators, etc.

### Epoxy (EP)

Epoxy resins are known for their high adhesion properties, high strength, and excellent electrical and dielectrical properties. They are also known for their low shrinkage, their high chemical resistance, and their low susceptibility to stress crack formation. They are heat resistant until their glass transition temperature (around 150 to 190°C), where they exhibit a significant reduction in stiffness. Typical applications for epoxy resins are switch parts, circuit breakers, housings, encapsulated circuits, and so on.

### Cross-Linked Polyurethanes (PU)

Cross-linked polyurethane is known for its high adhesion properties, high impact strength, rapid curing, low shrinkage, and low cost. PU is also known for the wide variety of forms and applications. PU can be an elastomer, a flexible foam, a rigid foam, an integral foam, a lacquer, an adhesive, and so on. Typical applications for PU are television and radio housings, copy and computer housings, ski and tennis racket composites, and the like.

## 2.7 Copolymers and Polymer Blends

Copolymers are polymeric materials with two or more monomer types in the same chain. A copolymer that is composed of two monomer types is referred to as a *bipolymer*; one that is formed by three different monomer groups is called a *terpolymer*. One distinguishes between *random*, *alternating*, *block*, or *graft* copolymers depending on how the different monomers are arranged in the polymer chain. The four types of copolymers are schematically represented in Fig. 2.27.

A common example of a copolymer is an ethylene-propylene copolymer. Although both monomers would result in semi-crystalline polymers when polymerized individually, the melting temperature disappears in the randomly distributed copolymer with ratios between 35/65 and 65/35, resulting in an elastomeric material, as shown in Fig. 2.28. In fact EPDM\* rubbers are continuously gaining acceptance in industry because of their resistance to weathering. On the other hand, the ethylene-propylene block copolymer maintains a melting temperature for all ethylene/propylene ratios, as shown in Fig. 2.29.

Another widely used copolymer is high impact polystyrene (PS-HI), which is formed by grafting polystyrene to polybutadiene. Again, if styrene and butadiene are randomly copolymerized, the resulting material is an elastomer called *styrene-butadiene-rubber* (SBR). Another classic example of copolymerization is the terpolymer acrylonitrile-butadiene-styrene (ABS).

Polymer blends belong to another family of polymeric materials which are made by mixing or blending two or more polymers to enhance the physical properties of each individual component. Common polymer blends include PP-PC, PVC-ABS, PE-PTFE, and PC-ABS.

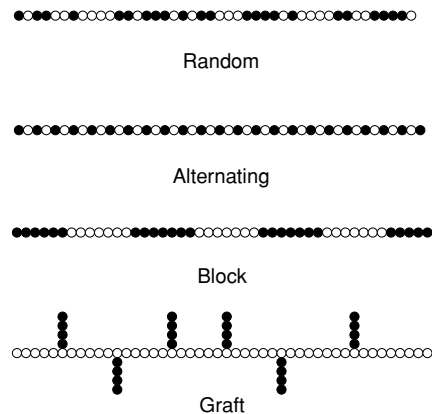


Figure 2.27 Schematic representation of different copolymers.

\* The D in EP(D)M stands for the added unsaturated diene component that results in a cross-linked elastomer.



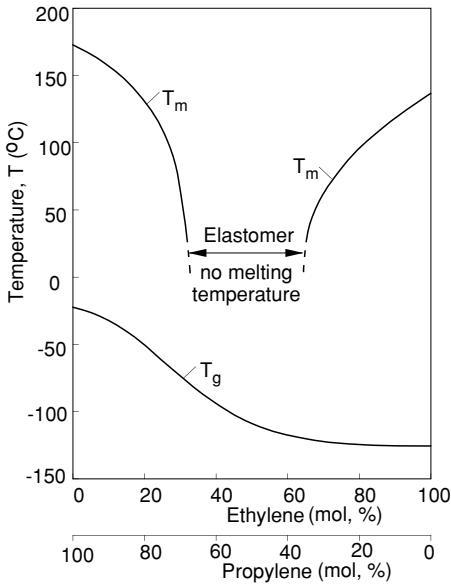


Figure 2.28 Melting and glass transition temperature for random ethylene-propylene copolymers.

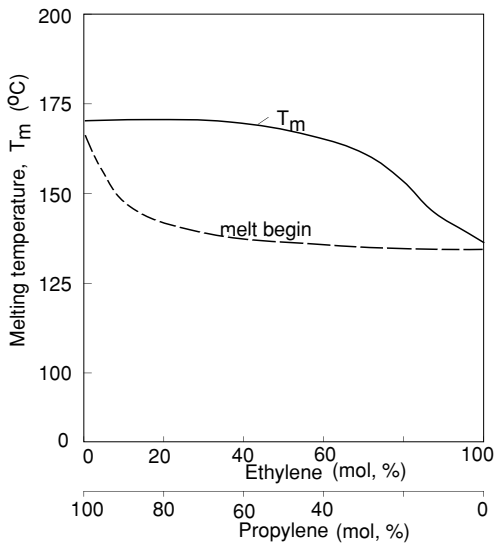


Figure 2.29 Melting temperature for ethylene-propylene block copolymers.

## 2.8 Elastomers\*

A manufacturer transferring from a compression to an injection molding process may carry out the first trials fairly safely without modifying the compound, relying on adjustments of barrel temperature to obtain reasonable operating conditions.

Some typical formulations for NR and NBR polymers are listed in following table together with curing systems selected to offer a range of processing and cure requirements. These are based either on MBTS, sulphenamides, or Sulfasan R because of the need for a certain minimum of scorch safety in the compounds.

### *Black NR Formulations*

Natural Rubber	70
Whole tyre reclaim	60
Carbon black	75
Zinc oxide	40
Stearic acid	5
Paraffin wax	2
Antiozonant	1

Curing Systems	A	B	C	D	E
Sulphur	2.5	2.5	2.5	—	—
Dithiodimorpholine—DTM	—	—	—	1.4	1.2
Sulphenamide	1.2	1.2	—	1.4	1.2
MOR	—	—	1.2	—	—
Thiuram	0.3	—	—	0.2	0.5

A, B, and C are suitable for thin-section products and are in ascending order of scorch time. D and E are efficient vulcanizing systems suitable for thick sections. They give much reduced reversion and improved ageing resistance.

### *Nitrile Rubber Formulations (NBR)*

Nitrile	100
Carbon black	80
Dioctyl phthalate	5
Zinc oxide	5
Stearic acid	1

\* Contributed by M. DeGreiff.

Curing Systems	A	B	C	D
Sulphur	1.5	1.5	0.5	—
TMTD	0.5	—	3.0	—
MBTS	1.0	1.5	—	3.0

A and B are conventional curing systems which may be adequate where aging resistance is not a particular problem. C is a low sulphur system giving much improved aging but its scorch time is usually sufficient only for ram-type injection. D combines excellent ageing with a scorch time long enough for most applications.

## 2.9 Efficient Vulcanizing Systems

Efficient vulcanizing (EV) systems are defined as those where a high proportion of the sulphur is used for cross-linking purpose. These systems have two main advantages over conventional systems, giving vulcanizates with reduced reversion and better aging characteristics. In addition to these advantages, EV systems based on dithiodimorpholine (DTM) are very versatile, enabling a wide range of scorch times, cure rates, and states of cure to be chosen at will.

It is particularly important to avoid reversion for injection molding of thick sections, and EV systems give the complete answer to this problem. The conventional system (sulphur/MBTS/DPG) shows reversion immediately after the maximum modulus is reached, whereas the EV system (DTM/MBTS/TMTD) shows no reversion even after three times the optimum cure time. EV systems can be developed to give equivalent cure properties with much improved aging as compared with a conventional cure, even when antioxidants are omitted.

Accelerator systems for injection molding should be chosen to give adequate scorch time, fast cure without reversion, and appropriate product properties.

When molding thick sections from polymers which revert (e.g., NR) EV systems should be used to minimize reversion. Combinations of a sulphenamide, dithiodimorpholine and TMTD are ideal, and the ratios can be varied to meet precise machine operating conditions and product requirements.

Where reversion is not a problem conventional sulphur/accelerator systems can be used and the following accelerators will give the best cure rates for each scorch time requirement:

MOR	↓	Decreasing
TBBS		scorch
CBS/TMTD		time

Accelerator loadings may be increased to give improved product properties or to counter the effect of oil addition.

## 2.10 Thermoplastic Elastomers\*

Thermoplastic elastomers are a series of synthetic polymers that combine the properties of vulcanized rubber with the processing advantages of conventional thermoplastics. In other words, they allow the production of rubberlike articles using the fast processing equipment developed by the thermoplastics industry.

There are many different of thermoplastic elastomers, and details of their composition, properties, and applications have been extensively covered in the literature [22–29]. The commercially available materials used in injection molding can be classified into 10 types (Table 2.6). The commonly used abbreviations are listed in Table 2.7. The various thermoplastic elastomers are discussed in more detail later in this chapter.

Before dealing with each type individually, we can consider some features that thermoplastic elastomers have in common. Most thermoplastic elastomers listed in Table 2.6 have one feature in common: They are phase-separated systems (i.e., the chlorinated olefin interpolymer alloys are the exception). One phase is hard and solid at room temperature in these phase-separated systems. The polymer forming the hard phase is the one listed first in this table. Another phase is an elastomer and fluid. The hard phase gives these thermoplastic elastomers their strength. Without it, the elastomer phase would be free to flow under stress and the polymers would be unusable. When the hard phase is heated, it becomes fluid. Flow can then take place, so the thermoplastic elastomer can be molded. Thus, the temperature at which the hard phase becomes fluid determines the processing temperature required for molding.

**Table 2.6 Thermoplastic Elastomers Used in Injection Molding**

- 
1. Polystyrene/(S-B-S + Oil) Blends
  2. Polypropylene/(S-EB-S + Oil) Blends
  3. Polypropylene/(EPR + Oil) Blends
  4. Polypropylene/(Rubber + Oil) Dynamic Vulcanizates
  5. Polyethylene/(Polylefin Rubber) Block Copolymers
  6. PVC/(NBR + Plasticizer) Blends
  7. Chlorinated Olefin Interpolymer Alloys
  8. Polyurethane/Elastomer Block Copolymers
  9. Polyester/Elastomer Block Copolymers
  10. Polyamide/Elastomer Block Copolymers
- 

\* Contributed by G. Holden.

**Table 2.7 Abbreviations**

ABS	Poly(acrylonitrile-co-butadiene-co-styrene)
ABS/PC	Blend of ABS and PC
BCP	Block Copolymer
DV	Dynamic Vulcanizate
EPR	Ethylene propylene rubber; i.e., poly(ethylene-co-propylene)
EPDM	Ethylene propylene diene rubber, an EPR that also contains a small number of out-of-chain double bonds
DOP	Diethyl phthalate, a plasticizer for PVC
HIPS	High Impact Polystyrene
NBR	Nitrile butadiene rubber; i.e., poly(acrylonitrile-co-butadiene)
SAN	Poly(styrene-co-acrylonitrile)
PA	polyamide (e.g., nylon)
PC	Polycarbonate
PE	Polyethylene
PEst	Polyester
PET	Poly(ethylene terephthalate)
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinylchloride
SBR	Styrene butadiene rubber; i.e., poly(styrene-co-butadiene)
S-B-S	Poly(styrene-b-butadiene-b-styrene) elastomeric block copolymer
S-EB-S	Poly(styrene-b-ethylene-co-butylene-b-styrene) elastomeric block copolymer
SMA	Poly(styrene-co-maleic anhydride)
TPE	Thermoplastic Elastomer

### 2.10.1 Service Temperatures

In these phase-separated systems, the individual polymers that constitute the phases retain many of their characteristics. For example, each phase has its own glass transition temperature ( $T_g$ ), or crystal melting point ( $T_m$ ) if it is crystalline. These determine the temperatures at which a particular thermoplastic elastomer goes through transitions in its physical properties. Thus, when the properties (e.g., modulus) of a thermoplastic elastomer are measured over a range of temperatures, there are three distinct regions (see Fig. 2.30). Both phases are hard at very low temperatures, so the material is stiff and brittle. At a somewhat higher temperature the elastomer phase becomes soft and the thermoplastic elastomer now resembles a conventional vulcanizate. As the temperature is further increased, the modulus stays relatively constant (a region often described as the “rubbery plateau”) until the hard phase finally softens. At this point, the thermoplastic elastomer as a whole becomes fluid. Thus, thermoplastic elastomers have two service temperatures. The lower service temperature depends on the  $T_g$  of the elastomer phase, whereas the upper service temperature depends on the  $T_g$  or  $T_m$  of the hard phase. The difference between the upper and lower service temperatures is the service temperature range. Values of  $T_g$  and  $T_m$

for the various phases in some commercially important thermoplastic elastomers are given in the literature [22–28]. The thermoplastic elastomers with polypropylene or polyethylene as the hard phase have excellent processing stability and can be left in the hot barrel of the injection molder for an hour or two without thermal degradation. There is also usually no need to purge the machine at shutdown. The other types are generally less forgiving. Some may degrade if left hot for more than about 30 minutes, and purging is often recommended.

## 2.10.2 Examples of Common Thermoplastic Elastomers

Features of each individual types are described in various publications [22–29], particularly [28], and in manufacturers literature. A short summary of their structure, properties and molding conditions is given later and in Chap. 3.

### Polystyrene/(S-B-S + Oil) Blends

S-B-S and S-EB-S block copolymers form a physically cross-linked network (see Fig. 2.31). This network loses its strength at high temperatures, allowing the block copolymer to flow; however, at room temperature it has a combination of strength and elasticity similar to good quality vulcanizates [30,31]. Both S-B-S and S-EB-S block copolymers are difficult to injection mold as pure polymers, so they are always

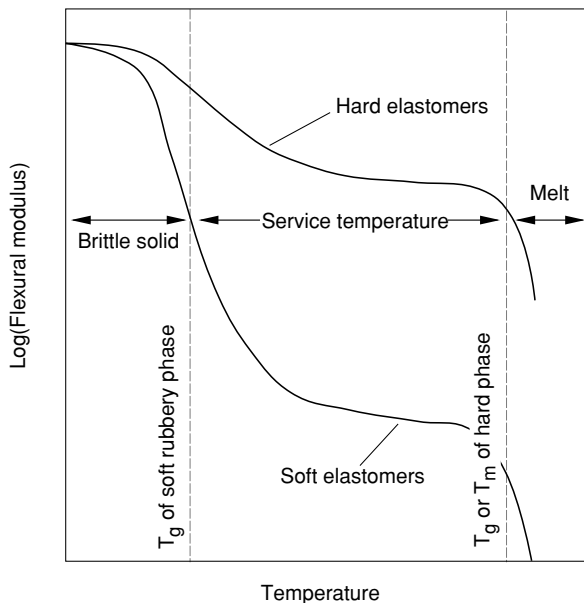


Figure 2.30 Stiffness of typical thermoplastic elastomers at various temperatures.

blended with other materials in this application. For S-B-S, the most important ones are polystyrene and mineral oils (quite large amounts of fillers can also be added, but they do not have much effect on physical properties). The structure of the polystyrene/(S-B-S + oil) blends is an interdispersed co-continuous network of the polystyrene hard and (S-B-S + oil) elastomer phases (Fig. 2.32). Both phases are strong materials at room temperature, so they can be blended together in almost any proportions, giving a wide range of product properties. Some general formulations are given in the literature [24].

Many of these blends are intended for footwear products, typically shoe soles. Because of the range of sizes and variety of styles, the use of tool steel molds is uneconomic in this application. Instead, aluminum molds are commonly used. These mold can only withstand low clamping pressure, which in turn restricts the injection pressure. Thus, blends intended for footwear products have relatively low melt viscosities and are molded on special low-pressure injection machines. There are three types: conventional reciprocating screw machines, fixed screw machines (essentially extruders that operate intermittently), and fixed screw machines that pump the melt into an accumulator, from which it is forced into the mold by the action of a piston. Despite the relatively low shear conditions, blends of the components can often be used with these machines and final compounding carried out during molding. The polybutadiene segment in the S-B-S elastomer is unsaturated (i.e., it contains double bonds). If S-B-S is overheated, these begin to cross-link the polymer and so reduce its viscosity. Thus, although flow into the mold can be improved by raising a low melt temperature, at some point (about 225°C) this approach becomes counterproductive.

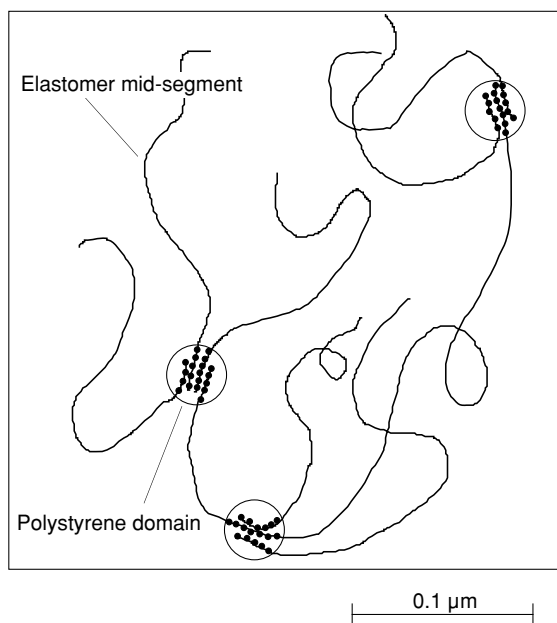


Figure 2.31 Morphology of styrenic block copolymers.

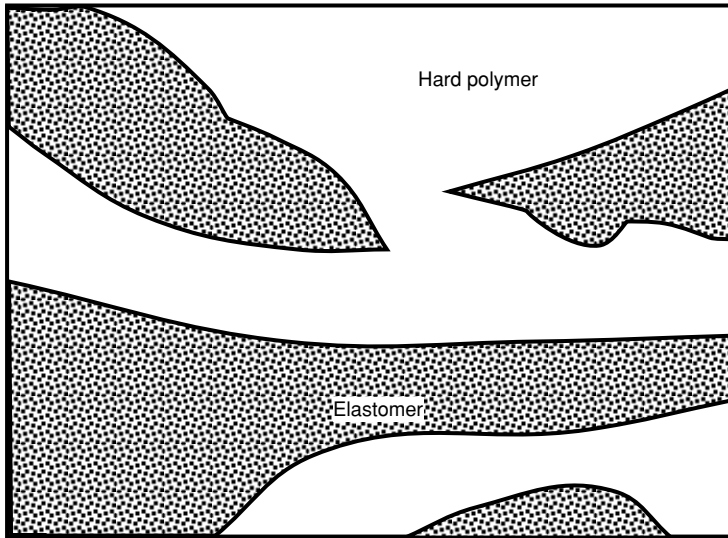


Figure 2.32 Morphology of hard polymer/elastomer blends.

#### Polypropylene/(S-EB-S + Oil) Blends

The structure of the polypropylene/(S-EB-S + oil) blends is similar to that of the polystyrene/(S-B-S + oil) blends [i.e., an interdispersed co-continuous network of the hard polypropylene phase and the strong, elastic (S-EB-S + oil) elastomer phase]. Again, the two phases can be blended together in almost any proportions and typical formulations are given in the literature [24]. These blends differ from the polystyrene/(S-B-S + oil) blends in several ways. Polypropylene is a relatively high melting material, so the blend requires higher processing temperature. The poly(ethylene-butylene) segment in the S-EB-S elastomer is completely saturated (i.e., it contains no double bonds). Thus, S-EB-S is more thermally stable (by about 75°C) than S-B-S and can tolerate the increase in processing temperatures. S-EB-S is extremely compatible with paraffinic mineral oils, so very soft blends (less than 10 Shore A) can be produced. Finally, the polypropylene/(S-EB-S + oil) blends have highly non-Newtonian viscosity. They are usually molded at high injection rates using small gates. This high injection rate requires good mold venting (vacuum assist is often helpful) and careful placement of the vents.

#### Polypropylene/(EPR + Oil) Blends

The structure of these blends is again an interdispersed co-continuous network—in this case, of the hard polypropylene phase and the EPR elastomer phase (which often contains oil). The difference is that in this case the EPR elastomer phase has little strength and can flow at room temperature. This limits the amount of the EPR phase that can be added to the polypropylene before there is a significant loss in strength. For this reason, these blends are relatively hard (greater than 60 Shore A). Similar



blends can be made using polyethylene/(polyolefin rubber) block copolymers in place of EPR. Polypropylene/EPR blends are injection molded under conditions generally similar to those used for pure polypropylene but with higher injection pressures.

#### Polypropylene/(Rubber + Oil) Dynamic Vulcanizates

The structure of the dynamic vulcanizates, such as PP/(Rubber + Oil) dynamic vulcanizates, is quite different. The important point is that although the hard polypropylene phase is continuous, the elastomer phase is a fine dispersion of strong vulcanized rubber particles (Fig. 2.33). Thus, quite large proportions of elastomer can be used without significant loss of strength, and products as soft as 35 Shore A are manufactured. EPDM is the most commonly used elastomer, but dynamic vulcanizates based on nitrile rubber (these have improved oil resistance), butyl rubber, and natural rubber are also available. All these dynamic vulcanizates can be overmolded against polypropylene. Grades suitable for overmolding against more polar thermoplastics such as ABS, PC PA and PS have recently been announced [32]. All these products (especially those based on EPDM and butyl rubber) are thermally stable and degradation should not present a problem under the recommended processing conditions (see Chap. 3). Virgin product should be dried before molding, although this may not be necessary with the recycled scrap as long as it is used shortly after it is reground.

#### Polyethylene/(Polyolefin Rubber) Block Copolymers

These are multiblock copolymers consisting of alternating hard and soft segments of polyethylene and a poly(ethylene/ $\alpha$ -olefin) copolymer, respectively. They form a two-

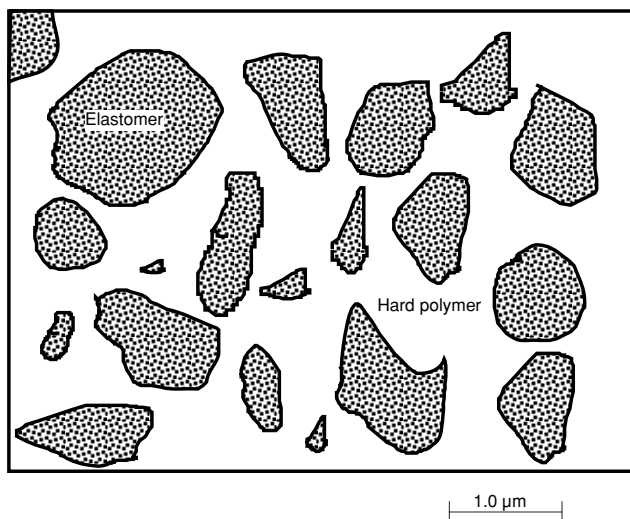


Figure 2.33 Morphology of dynamic vulcanizates.

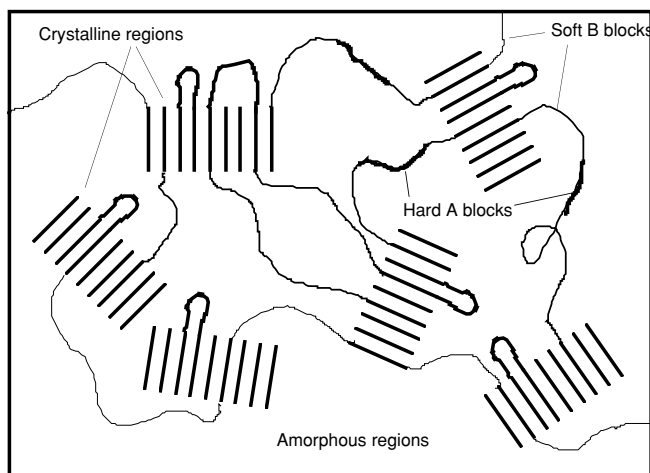


Figure 2.34 Morphology of multiblock polymers with crystalline hard segments.

phase network (see Fig. 2.34) similar in some ways to the physically cross-linked network formed by the S-B-S and S-EB-S block copolymers shown in Fig. 2.32. At high temperatures the network similarly loses its strength, allowing the material to flow. One difference is that the hard polyethylene phase is crystalline. Another is that in these and other multiblock copolymers, each polymer molecule can be part of several hard and soft regions. Polyethylene/(polyolefin rubber) block copolymers are transparent, low-density materials with excellent thermal stability. They have very non-Newtonian flow characteristics and are molded at high injection rates. The melting point of the polyethylene segment is low (from 50 to 100°C) [33,34]. Molded products must be cooled to well below this temperature range before they can be ejected from the mold, so these polymers require a very cold mold (10°C is recommended, which will require refrigerated coolant). Air-assisted ejection is also recommended. The polyethylene/(polyolefin rubber) block copolymers can be added to polypropylene to improve impact resistance. [If enough is added, the products become relatively hard, heat resistant thermoplastic elastomers analogous to the harder versions of the polypropylene/(EPR + oil) blends.]

#### PVC/(NBR + Plasticizer) Blends

These blends present a somewhat different picture to the previous five types. They are much more polar, and therefore have improved oil and solvent resistance. PVC has limited thermal stability. If it degrades, then it can produce hydrogen chloride, which is both toxic and corrosive. Thus, in molding these materials, the same precautions must be used as with molding plasticized PVC. Melt temperatures must be below 200°C, and preferably below 190°C. Shear heating (by the use of high compression screws and/or high back pressures) must be avoided. The molten material

must not be allowed to sit in the hot barrel of the injection molder and the machine should be purged at shutdown. Corrosion-resistant barrel liners and screws should be used. The user can buy precompounded products or make his own custom compounded material. In this case the PVC and the plasticizer (typically DOP) are mixed together in a tumble blender or high shear mixer until the plasticizer is completely absorbed, after which the powered NBR is added. Compounding can then be completed on the injection molding machine. Special types of NBR, with properties optimized for this end use, are commercially available.

Because they are polar materials, these blends cannot be overmolded against non-polar hard thermoplastics such as polypropylene. Instead, they are recommended for use with polar thermoplastics such as PVC, SAN, ABS, and SMA. Gradual migration of the plasticizer may present a problem, and overmolded products should be checked for this after a period of storage. The molded parts should not be allowed to come into prolonged contact with polystyrene or other materials whose properties are affected by DOP.

#### Chlorinated Olefin Interpolymer Alloys

The exact composition of these materials has not been disclosed. They are claimed to be single-phase systems, and in this they differ from the other thermoplastic elastomers. Like the PVC/(NBR + plasticizer) blends described earlier, they have limited thermal stability; thus, molding temperatures must be carefully controlled to avoid degradation, and the material must not be allowed to sit in the hot machine for extended times. Corrosion resistant barrel liners and screws similarly should be used and shear heating must be avoided. Melt temperatures should be less than 190°C. Resistance to flow is not much affected by temperature within the recommended range, so molding is not usually improved by increasing the processing temperatures. These interpolymer alloys have highly non-Newtonian flow characteristics, so they are also molded at high injection rates through small gates. They can be overmolded against polar thermoplastics such as PVC and polycarbonate/ABS blends, as well as against thermoplastic elastomers based on polyurethanes or polyesters, discussed later. Grades with adhesion to other hard thermoplastics are under development [35].

#### Polyurethane/Elastomer Block Copolymers

These polymers (as well as those discussed later) are structurally similar to the polyethylene/(polyolefin rubber) block copolymers described in Section 2.3.5. Their morphology is shown in Fig. 2.34. In this case the crystalline hard segments are polyurethanes, and the soft segments usually are polyesters or polyethers. Melting temperatures for the polyurethane segments are high (typically greater than 180°C), so melt temperatures for injection molding must be more than this value. They are generally a little higher for the harder products. These polymers are quite susceptible to thermal degradation, which starts above 230°C, and gives foaming or bubbles in the final part. They should not be allowed to sit in the hot injection molding machine, and the machine should be purged with polystyrene or ABS before shut-

down. Polyurethane/elastomer block copolymers readily absorb water, which causes severe degradation of the molten material. Both virgin polymer pellets and reprocessed scrap must be thoroughly dried (down less than 0.1% moisture) before being molded. Injection rates should be moderate, and fairly large gates with rounded edges are recommended. Further crystallization and crystal rearrangement will take place after molding is completed, and the properties of the product will improve with time for a period of about 6 weeks. The process can be speeded up by overnight annealing at about 115°C.

### Polyester/Elastomer Block Copolymers

In these polymers the crystalline hard segments are polyesters and the soft segments are polyethers. They are more thermally stable than the polyurethane analogs described earlier, so they can be processed at somewhat higher temperatures, up to about 260°C. Again, processing temperatures should be higher for the harder products. The melt viscosity changes significantly with temperature, so processing can be improved by increasing the melt temperature, although this will also increase the cycle time. The molten polymer can be allowed to sit in the hot injection molding machine for an hour or two. Purging before shutdown is generally not necessary, but if desired, it is best to use a thermally stable material such as polyethylene. As with the polyurethane/elastomer block copolymers, both virgin polymer pellets and reprocessed scrap must be thoroughly dried (less than 0.1% moisture) before use.

### Polyamide/Elastomer Block Copolymers

In these polymers the crystalline hard segments are polyamides and the soft segments are usually polyethers. Processing temperatures depend on the melting temperature of the polyamide (e.g., nylon-6,6, nylon-6, nylon-11) and should be higher for the harder grades. Other processing conditions are essentially similar to the polyester analogs described earlier. Processing detail is given in Chapter 3.

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