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Thermoplastic Elastomers

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About To Jump

The requirements of mechanical and optical properties of plastic parts and their economic production are rising continuously. Manufacturing processes shall have short cycle times and a high degree of automation. Accordingly the number of single production steps should be reduced to a minimum. Thus machine and material provider are asked. One step in this direction has been made by the invention and proceeded development of thermoplastic elastomers. These materials can be processed on thermoplastic machinery economically and parts can be manufactured with almost the identical mechanical properties of curing cross-linking elastomers.

Similar to the development of thermoplastics the different applications for thermoplastic elastomers (TPE) have been taken to account by inventing many different types of material. By means of the chemical construction, a wide range of thermal and mechanical properties can be covered by the specific material. Thus it is possible to substitute also rigid thermoplastic and elastic elastomers by TPEs. Table 1 shows several different types of TPE and their proportion of the worldwide TPE production.

thermoplastic elastomer		production proportions (worldw.) (1991)	application
SBC	styreneblockcopolymer	44%	EPDM-substitut
TPO&TPV	thermoplastic olefins	29%	automobile, PE-,PP-modification
TPU	thermoplastic urethane	13%	shoe soles, wires
COPE	thermoplastic copolyester	5%	springs, expansion bellows
PEBA	thermoplastic polyetherblockamide	1%	sport equipment, catheter, expansion bellows, sealings, watch band

table1: proportions of the world market and applications of the different TPE types

As a traditional processor and user of polymers the automotive industry makes extensive use of TPEs. Nevertheless one important and huge application of curing elastomers will stay unreachable for TPEs: due to the reduced heat distortion the use as tyres for automobiles is not possible.

The following shall simplify the entrance to the processing of this interesting materials on BOY-injection moulding machines. In order to explain the differences between thermoplastics and traditional elastomers, we have to start with the material's chemistry.

Molecular properties

The molecular constructions of the polymer chains of different TPEs are quite similar to each other. Usually the molecules exist of two different segments (figure 1). The first segment is built of monomers that provide a relatively high flexibility. The connections between the single parts are not stiff but turn able. In contrast the latter segments are rigid and accordingly less flexible.

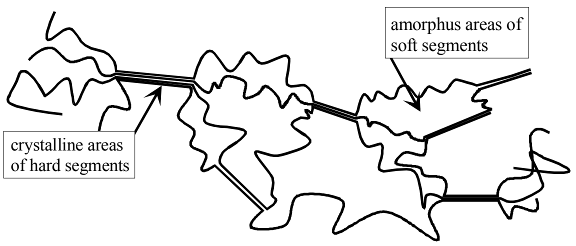


figure 1: Molecular structure of thermoplastic elastomers

Also the connections between the segments and those within the separate segments can not be rebuilt. Once they are destroyed by thermal, chemical or mechanical stresses, the material is damaged permanently.

The choosen basic polymers for the rigid and the soft segments are miscible poorly. The results are described in the next chapter.

Macro molecular properties

The macro molecular properties are describing the interactions between the molecule chains. As already mentioned, the two components of the main chain are miscible poorly. For the macro molekular struture of the melt this means, that agglomerates are built that either contain only elastic or only rigid segments of the macro molecules (figure 1). This results in two different phases:

- a rigid and stiff phase and
- a soft and elastic phase.

The bondings between the two phases are weak whereas within the phases the inter-molecular bonding forces are high. They are similar to those, seen in standard thermoplastic polymeres. However, both types of bondings are rebuilt after stresses decay.

The closer the chains are to each other the higher the bridges' strengths are. Especially the molecules' hard segments, which are built straight and linear, built up those dense packages: crystalline areas develope. This crystalline structures are in charge for the mechanical properties of thermoplastic elastomers.

In contrast the flexibility within the soft phase leads to relatively long distances between chains. On the one hand this results in reduced strength and on the other hand these areas are flexible and elastic even at lower temperatures. Consequentely the soft phase is responsible for the low temperature behaviour of thermoplastics elastomers.

It becomes obvious that the compilation of different connections inside molecules and between their segments results in the special characteristics of thermoplastic elastomers.

The properties can be fixed in a wide range by varying the segments' lengths and/or the polymers that built the soft or hard phases .

For example, a higher fraction of soft segments leads to improved low-temperature properties but to reduced overall mechanical properties as well.

comparison: cross-linking elastomers-
thermoplastic elastomers

Comparing this two material families one can detect distinct differences concerning their macromolecular structures.

Whereas the molecules of thermoplastic elastomers are simply connected by „magnetic“ or to be more exact by physical means, cross-linking elastomers contain other inter-molecular bondings. These are of the same kind as the ones within the molecule chains: chemical principal valency bonds.

For the processor this results in changes in the manufacturing methods as well as in the mechanical, thermal and chemical material properties of TPEs.

For example the inter-molecular bondings can be torn off and shifted to another place by means of rebuilding. This process can lead to staying deformations. It is described by the physical value compression set (cs). (table 2)

properties	TPE
elasticity	worse
thermal stability	worse
low temperature behaviour	similar
compression set	worse
medium resistance	worse
weather resistance	improved
density	less

table 2: TPE properties compared to cross-linking elastomers

Due to the fact that those bondings break up at much lower levels of applied energy the thermal stability of thermoplastic elastomers is relatively low. However, in contrast to cross-linking elastomers these distortions can be temporary.

Though the properties of TPEs are mostly worse than the ones of cross-linking elastomers these materials have increased their market proportions permanently since the introduction in the 1960'. The main advantages can be certainly found in their processability.

thermoplastic elastomers are

- ready-to-process straight from the material provider (costly mixing can be dropped),
- processable with well-known thermoplastic machinery (extrusion, blow moulding, injection moulding and the like) with a reduced number of operations,
- useable with other thermoplastics (2-component injection moulding),
- mouldable with very short cycle times (no curing necessary),
- diffusion-free (i.e. softener) and
- recyclable.

Moreover the moulded parts are

- free of cross-linkage residues,
- usually suitable for varnishing or coating and
- free of necessary refinishing.

As a matter of fact they do have decent advantages over articles made of cross-linking elastomers or soft PVC, especially if huge quantities are to be made.

However, those disadvantages of thermoplastic elastomers mentioned above also hold for rubbers when making safety relevant parts.

Comparison: soft-PVC - thermoplastic elastomers

Another important application for TPEs is the substitution of PVC. Apart from the well-known problems when processing this thermal unstable and accordingly aggressive materials, they have been blamed for their halogen content. This leads possibly to health hazards.

Hence, in spite of the material price TPEs are used as a PVC-substitute in several applications

Additionally TPEs have improved rigidities at identical hardnesses. Resulting savings in weight make TPEs even more compatible to PVC.

The processing

Very often the word „elastomer“ makes the processor uncertain. The following will clear away these insecurities. Those who have processed standard and technical thermoplastics successfully will have no problems with TPEs either.

The TPE mould

The first (and most important !?!) step for a successful production of TPE parts is, as already known, the part development and the mould construction.

For this reason, some special properties and characteristics of TPEs have to be considered at this stage of development.

Basically a TPE injection mould is more similar to a thermoplastic mould than to an elastomer mould. TPEs are compounded in a „hot“ cylinder before being injected into a „cold“ mould. Therefore no mould heating but a tempering or cooling is appropriate.

When determining the dimensions of the cavity(s) one has to assume a considerable direction-dependent shrinkage of the moulded parts.

Besides, TPEs are provided with a distinct pseudoplastic flow behaviour. This means their viscosity (their flow resistance) decreases dramatically if the melt is stressed to a certain extent. Hence, with the setting of descent injection speeds parts with huge melt flow-wall thickness ratios can be filled properly with one or a few gates.

Therefore the moulds can have a less complicated construction usually.

However the fast filling of the cavity makes venting channels, exact tolerances and round, flow improving runner systems necessary. The high injection speeds can be achieved by fine runner channels and small gates. Accordingly one can manufacture parts without refinishing work steps.

In order to reduce the pressure losses during injection and minimize production scrap the moulds can be equipped with hot runner systems. One material provider asks the provider to pre-dry the material then.

The mould designer should also concentrate on demoulding of TPE parts. On the one hand even bigger undercuts can be ejected by force. Depending the material the part can be deformed up to 300% without permanent damages. On the other hand this elasticity as well as the reduced mechanical properties result in moulds for TPEs having ejector pins that are area-measured and closer to each other.

If you process considerable soft types of TPE the mould should be equipped with mould wipers for ejection. Another means is to support the demoulding by means of a brushing device.

In addition especially TPE types with low shore hardnesses tend to stick to the cavity. Similar to classical elastomer moulds the release can be simplified by structured or eroded surfaces.

The following concludes the main items:

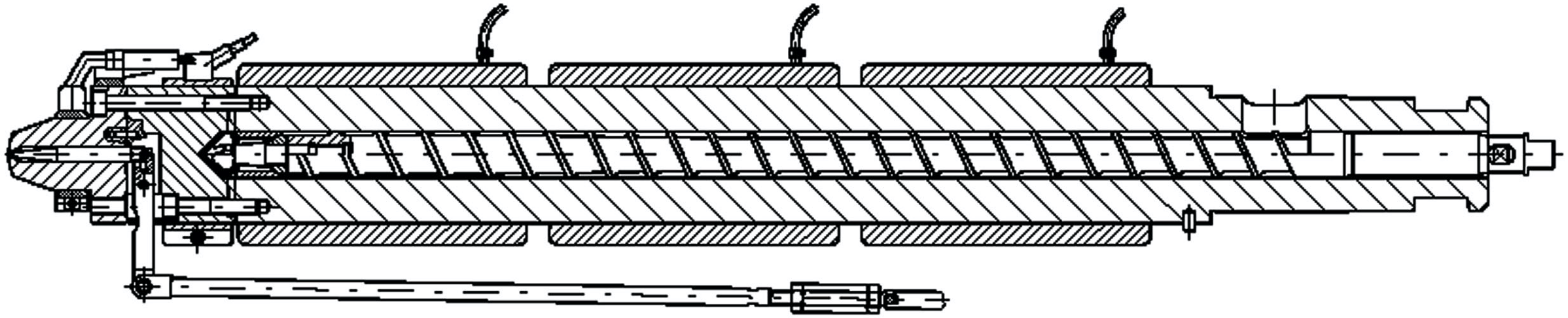
- mould tempering system
- flow improving, but relatively small gates
- venting channels (eventually)
- structured cavity surface
- area-measured ejector pins

The injection moulding machine

All BOY injection moulding machines can process TPE. Due to the fact that raw-materials are provided as granules usually the standard hoppers are suitable.

Moreover all available BOY plasticising units for thermoplastics have a decent compression ratio and L/D-ratio. The granule is melted and homogenized gently and properly. If needed a shut-off nozzle can be used, Mostly this is not necessary because the melt usually does not drool.

Plasticising unit for thermoplastic elastomers



	BOY 12			BOY 22							BOY 35				
	129-11	129-15	129-18	220-15	220-18	220-52					350-52		350-92		
Screw diameter mm	12	14	18	14	18	18	22	24	28	32	18	22	24	28	32
Screw-L/D ratio	18	18	20	18	20	20	17,5	22	18,6	16,3	20	17,5	22	18,6	16,3
Max. stroke volume (theoretical) ccm³	4,5	6,1	10,1	6,1	10,1	20	30	36	49	64	20	30	43	58,5	76,5
Max. shot weight in PS g	4,45	5,6	9,6	5,6	9,6	19,4	28,4	34	47	61,6	19,4	28,4	41	55,8	73,7
Max. spez. injection pressure bar	2450	2413	1795	2413	1795	2587	1732	1455	1069	818	2587	1732	2146	1577	1207

	BOY 55									BOY 90						
	550-52		550-79			550-205				900-205				900-370		
Screw diameter mm	18	22	24	28	32	28	32	38	42	28	32	38	42	36	42	48
Screw-L/D ratio	20	17,5	22	18,6	16,3	22,7	20	16,7	15	22,7	20	16,7	15	23	20	17
Max. stroke volume (theoretical) ccm³	20	30	43	58,5	76,5	73,9	96,5	136,1	166,3	73,9	96,5	136,1	166,3	157,8	214,7	280,5
Max. shot weight in PS g	19,4	28,4	41	55,8	73,7	70,1	91,1	129,7	157,9	70,1	91,1	129,7	157,9	142	193	252
Max. spez. injection pressure bar	2587	1732	1810	1340	1030	2778	2127	1508	1235	2778	2127	1508	1235	2347	1724	1320

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The parallelism of the moving and the fixed platen is very important since, especially during the injection phase, the melt is of extremly low viscosity. The four tiebars and the very rigid construction of the clamping units of BOY machines assure minimal deflection. Accordingly flash-free parts can be produced.

Besides the force and the the speed of the ejector movement can be adjusted hence the demoulding is no problem at all.

Injection moulding of TPEs

Actually the proccesing of TPEs is very similar to that of normal thermoplastics.

Nevertheless we will list some hints that are valid for all types of TPEs.

Pre-drying has to be performed only sometimes. The moisture content usually has no influence on the flow behaviour but on the structure of the moulded parts: voids show up. However, production scrap should always be dried prior to re-processing.

Due to the striking pseudo plastic behaviour a high injection speed results in a superb flow behaviour, reduced required injection pressure and perfect surfaces.

The flow behaviour can be influenced much better by means of the injection speed than by means of the cylinder or mould temperatures.

The stress related viscosity has another interesting and positive effect. The considerable small-area gates and the part itself cool down quickly, and demoulding can be carried out earlier: reduction of cycle time.

A optimisation of the cooling time has to take place if extreme undercut must be demoulded by force. On the one hand a part that is too cold might break during ejection. On the other hand demoulding a part that is to warm might result in permanent deformations.

Inserted parts that are surrounded by TPE have to be dust and grease free in order to achieve a good adhesion between the two materials. When using metal inserts, subject to application and geometry, the use of coupling agents is inevitable.

Table 3 can serve as guidelines for processing themoplastic elastomers.

parameter	range of values
back pressure	10-25 bar
cylinder temperature	180-240 °C (according to the material)
injection speed	high
injection speed	low
holding pressure	shorter than for thermoplastics
mould temperature	approx. 30 °C
cooling time	according to the recommended demoulding temperature
cycle time	much shorter than when processing cross-linking elastomers

table 3: range of processing parameters

The different types and their properties

An exact description of all the different types would be far too extensive. Though, in order to offer you some help, there are some tables and diagrams provided which allow you to compare the materials.

Since especially the mechanical properties of TPEs can be adjusted in quite wide ranges in particular the product designer has to check the application and select the material according to the aspects listed below:

- required mechanical properties
- thermal properties
- medium resistance
- price

Finally we want to emphasise the main and most interesting properties of this special group of thermoplastics:

- high abrasion resistance
- low compression set
- high ultimate and tear propagation strength
- high stretchability
- improved stiffness at same shore hardness (compared to PVC and cross-linking rubbers)
- high hydrolsis resistance
- high medium resistance
- similar properties in a wide temperature range (even at temperatures below 0 °C)
- partly FDA approved
- transparent or colourable as required

The market

In addition to it's pysical properties the price of a certain material is an important factor. Table 5 shows the prices of the mentioned TPEs. Several material providers are listed in table 4.

TPE type	material provider
SBC	Shell, Eni, Fina
SBS	Kraiburg
TPO	Exxon
TPV	AES, Bayer
TPU	Bayer, Elastogran
COPE	Du Pont, GEP
PEBA	Atochem, Hüls

table 4: TPE -provider

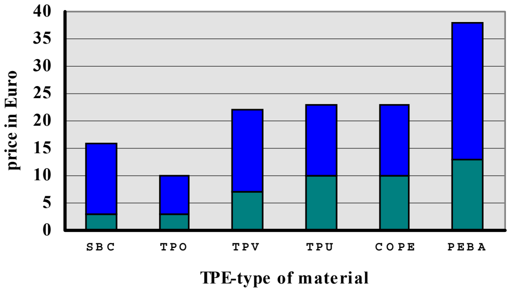

table 5: prices for some thermoplastic elastomers

The outlook

The ever increasing demands of mechanical and optical properties and the search for economical manufacturing processes make thermoplastic elastomer perfectly suited materials for many applications. As a matter of fact the overall market proportions of thermoplastic elastomers compared to the whole polymer market will increase. Thus one main goal for the processor should be to get used to TPEs in order to get ahead of his competitors for the future.

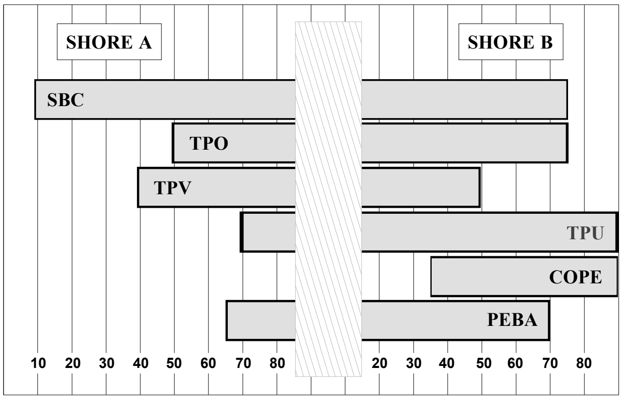

table 6: range of shore hardnesses of some TPEs

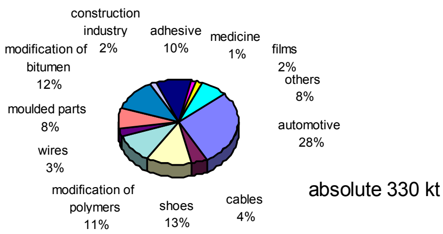

table 7: TPE-consumption in western europe (1995)

We hope that we have brought the thermoplastic elastomers to your attention and created your interest.

If there are any further questions, our process engineering staff are always at your disposal for a discussion or evaluation.