Top Ten Design Tips – A Series of 10 Articles

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

---

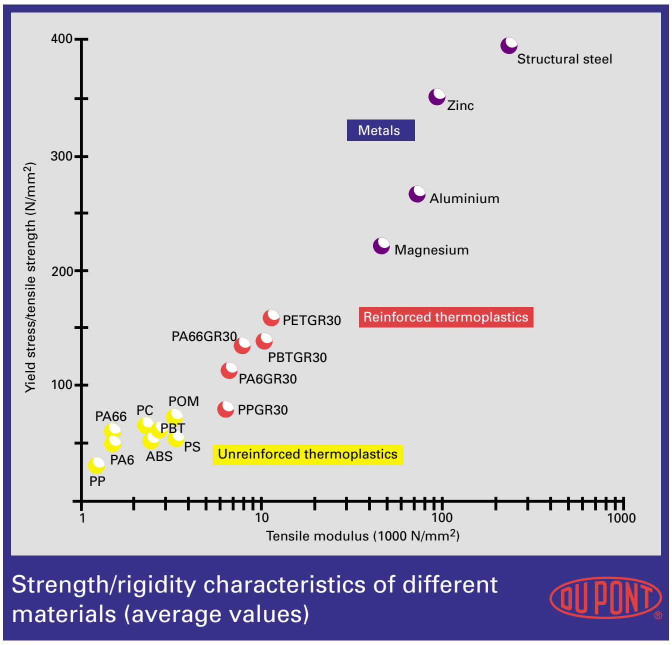
1. Comparison of materials

Plastic is not metal

Comparison of materials – Many plastic designs still continue to be derived from "metal parts". In the series commencing here the authors set out to describe the points that require attention when designing in plastics rather than traditional materials.

Different basic material characteristics

The properties of plastics materials can vary over a far wider range than all other engineering materials. Through the addition of fillers/reinforcing materials and modifiers the property profile of virtually any base polymer can be radically altered. Most basic properties of plastics, however, form a marked contrast to those of metals. For example, in a direct comparison, metals have higher



Strength/rigidity characteristics of different materials (average values)

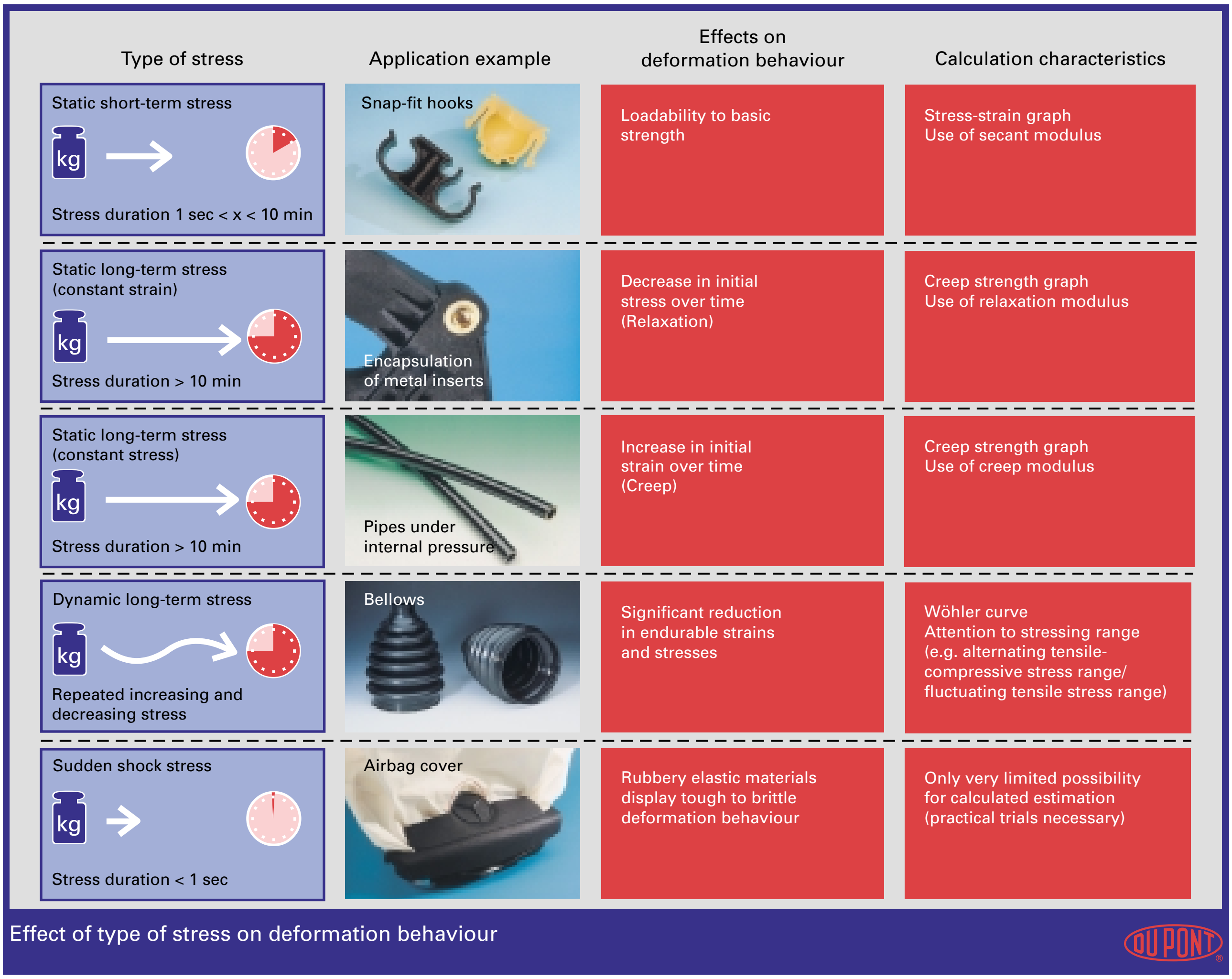
Fig. 1

- density
- maximum service temperature
- rigidity/strength
- thermal conductivity and
- electrical conductivity,

while the

- mechanical damping
- thermal expansion
- elongation at break and
- toughness

of engineering thermoplastics are greater by orders of magnitude (see Fig. 1). To produce functional parts in plastic and at the same time save costs, radical design modification is generally necessary if the plastic is being used to replace metal. This process affords an opportunity for complete redesign of the component with possible integration of functions and geometric simplification.



Type of stress	Application example	Effects on deformation behaviour	Calculation characteristics
Static short-term stress Stress duration 1 sec < x < 10 min	Snap-fit hooks	Loadability to basic strength	Stress-strain graph Use of secant modulus
Static long-term stress (constant strain) Stress duration > 10 min	Encapsulation of metal inserts	Decrease in initial stress over time (Relaxation)	Creep strength graph Use of relaxation modulus
Static long-term stress (constant stress) Stress duration > 10 min	Pipes under internal pressure	Increase in initial strain over time (Creep)	Creep strength graph Use of creep modulus
Dynamic long-term stress Repeated increasing and decreasing stress	Bellows	Significant reduction in endurable strains and stresses	Wöhler curve Attention to stressing range (e.g. alternating tensile-compressive stress range/ fluctuating tensile stress range)
Sudden shock stress Stress duration < 1 sec	Airbag cover	Rubbery elastic materials display tough to brittle deformation behaviour	Only very limited possibility for calculated estimation (practical trials necessary)

Effect of type of stress on deformation behaviour

Fig. 2

Different material behaviour

Plastics sometimes exhibit completely different behaviour to that of metals under the same service conditions. For this reason, a functionally efficient, economic design in cast metal can easily fail if repeated in plastic with excessive haste. Plastics designers must therefore be familiar with the properties of this group of materials.

Temperature and time dependence of deformation characteristics

The nearer the service temperature of a material is to its melting point, the more the material’s deformation behaviour will be temperature- and time-dependent. Most plastics exhibit a change in their basic mechanical properties at room temperature or on exposure to short-term stress. Metals, on the other hand, usually display largely unchanged mechanical behaviour right up to the vicinity of their recrystallization temperature (> 300 °C).
If the service temperature or deformation rate is varied sufficiently, the deformation behaviour of engineering thermoplastics can change from hard and brittle to rubbery-elastic. An airbag cover, for example, in its particular application involving explosive opening, exhibits completely different deformation behaviour from that of a slowly assembled snap-fit element made of the same material (Fig. 2). Similarly, this snap-fit element has to be assembled in a different way according to whether the temperature conditions are hot or cold. The effect of temperature here is significantly greater than the effect of loading rate.

Factors influencing component properties

The characteristics of plastics are not purely material properties. The basic property level of a plastic component can be changed by various factors (e.g. UV radiation, see Fig. 3) right up to the point of unserviceability. A well designed moulded part can easily fail if the material is processed under inappropriate conditions. Similarly, processors cannot generally eliminate moulding design faults during processing. Only through a process of optimization that takes into account all influencing factors (Fig. 4) can a good plastics component be guaranteed.
Since plastics are less tolerant of faulty design than metals, greater attention must be devoted to correct material design in designing plastics components. Every design process must therefore start with a thorough and precise analysis of all requirements and boundary conditions.

Fig. 3

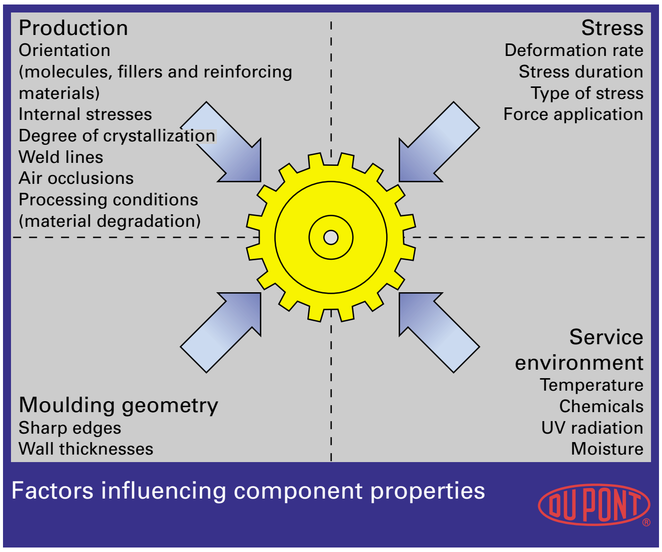


Fig. 4

---

2. Material selection

The right choice

Material selection – There is no such thing as a bad material-just the wrong material for a particular application. It is therefore essential for designers to know the properties of the competing materials inside out and to test them all carefully in relation to the factors affecting the injection moulded part.

Conventional thermoplastics

The materials most frequently used in injection-moulding are thermoplastics. These may be subdivided into amorphous and semi-crystalline plastics (Fig.1).
These two groups differ in molecular structure and in all the properties that are influenced by crystallization (Fig. 2).
As a broad generalization, semi-crystalline thermoplastics are used mainly for components that are exposed to high mechanical stresses, while amorphous thermoplastics are more often employed in housings because of their lower tendency to warp.

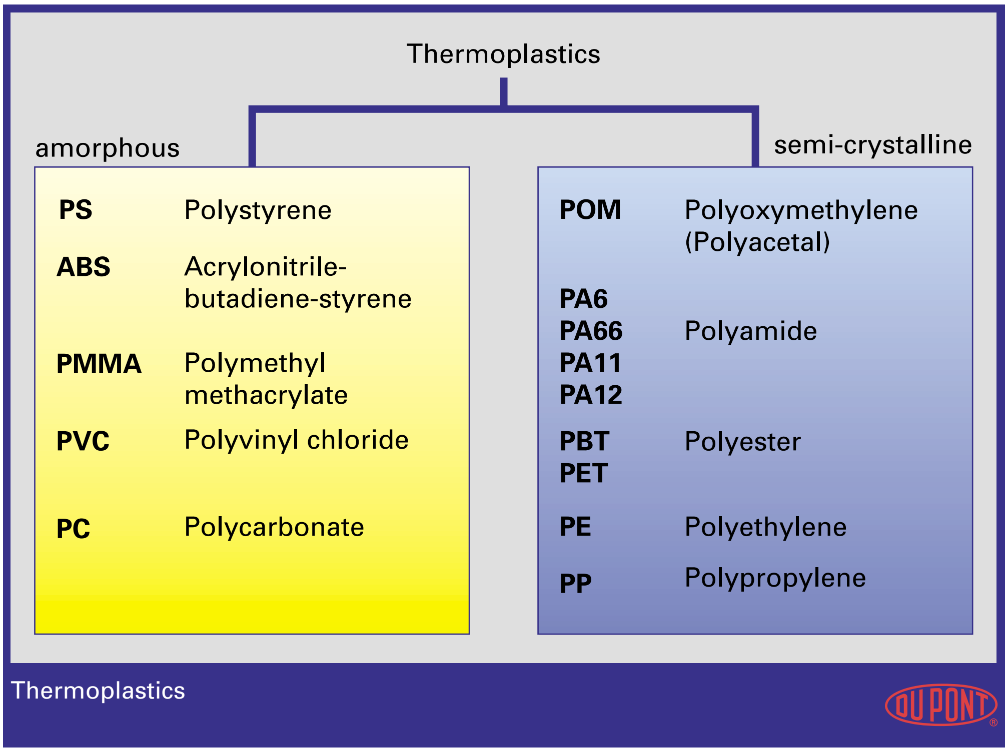


Fig. 1

Fillers and reinforcing materials

Thermoplastics are supplied in unreinforced, glass-fibre-reinforced and mineral- and glass-sphere-filled forms. Glass fibres are used primarily to increase strength, rigidity and service temperature; minerals and glass spheres have a lower reinforcing effect and are employed mainly to reduce warpage.

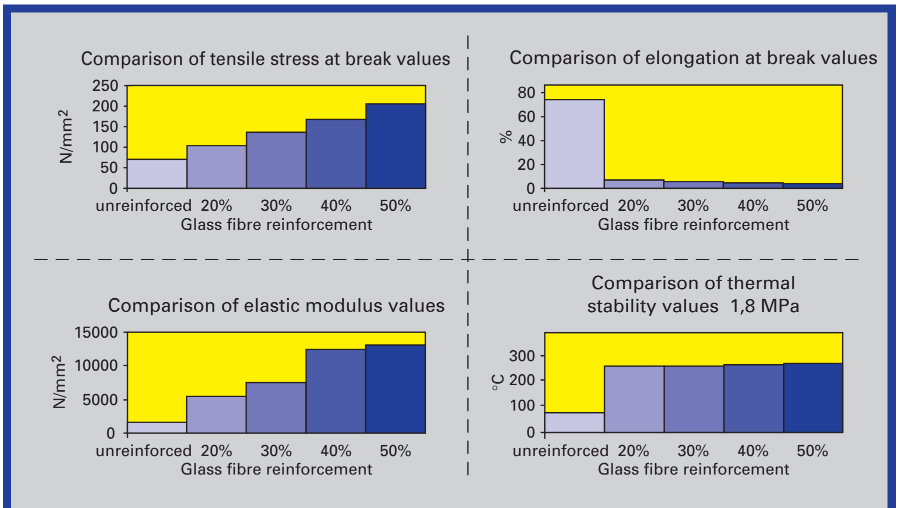
Glass fibres affect processing, particularly a parts shrinkage and warpage behaviour. Fibre-reinforced materials cannot therefore be replaced by unreinforced thermoplastics or materials with low reinforcement content without dimensional changes occurring (Fig. 3). The orientation of the glass fibres is determined by the flow direction. This produces a change in mechanical strength.

	amorphous	semi-crystalline
Mechanical properties	O	+
Tendency to creep	+	O
Chemical resistance	–	+
Flexural fatigue strength	–	+
Critical strain	0,4%-0,8%	0,5%-8%
Notch sensitivity	–	O
Service temperature	O	+
Onset of melting	Softening range	Precise melting point
Shrinkage	0,3% – 0,8%	1,0%-3%

\+ favourable O satisfactory – unsatisfactory

Property comparison of thermoplastics

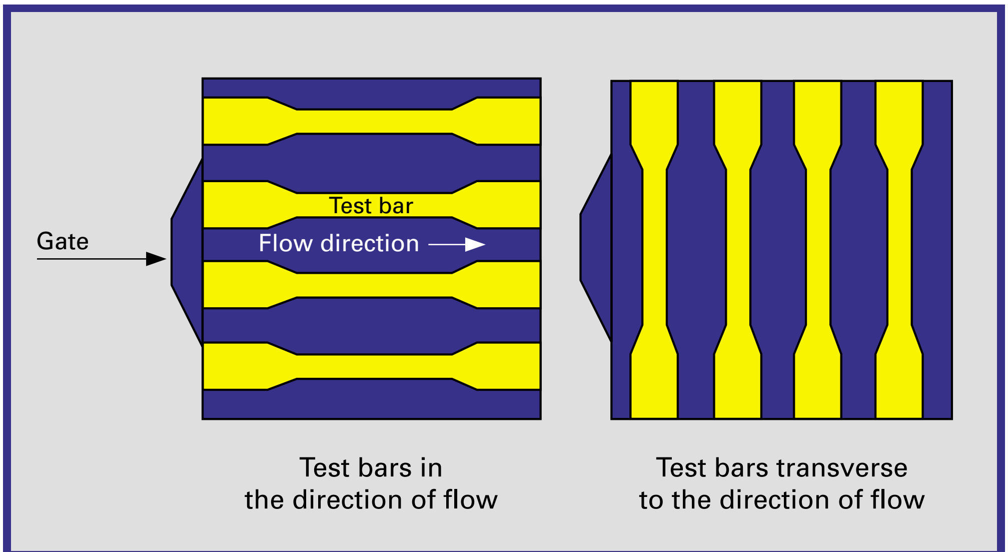
Fig. 2



Change in mechanical property values from unreinforced to glass-fibre-reinforced material (PA 66)

Fig. 3

To demonstrate these effects, test bars were milled from injection moulded sheets in the longitudinal and transverse directions and their mechanical property values were compared in a tensile testing machine (Fig. 4).
In the case of 30% glass-fibre-reinforced PET, there was a strength loss transverse to the direction of flow of 32% for tensile strength, 43% for flexural modulus and 53% for impact strength. These losses must be taken into account in strength calculation by incorporating safety factors.
A wide variety of reinforcing materials, fillers and modifiers are added to many different thermoplastics to alter their property profiles. In material selection, the changes in properties produced by these additives must be checked very carefully in brochures or databases (e.g. Campus) or, better still, technical advice should be sought from specialists employed by the raw material manufacturers (Fig. 5).



Test bars in the flow direction
and transverse to the flow direction

Fig. 4

Additive	Max. content (% w/w)	Elastic modulus	Strain	Impact strength	Dimensional stability	Flame retardancy
Glass fibres	60	↑↑↑	↓↓	↓	↓	↑
Minerals	40	↑	↓	↓	↑↑	↑
Aramid fibres	20	↑	↓	↓	↓	↑
Elastomers	15	↓	↑↑	↑↑↑	↓	↓
UV stabilizers	1	↓	↓	↓	—	—
Flame retardants organic	20	↓	↓↓	↓↓	↑	↑↑↑
inorganic	40	↓	↓↓	↓↓↓	↑	↑↑↑↑
Antistatic agents	5	↓	↓↓	↓↓	—	—

Effects of additives

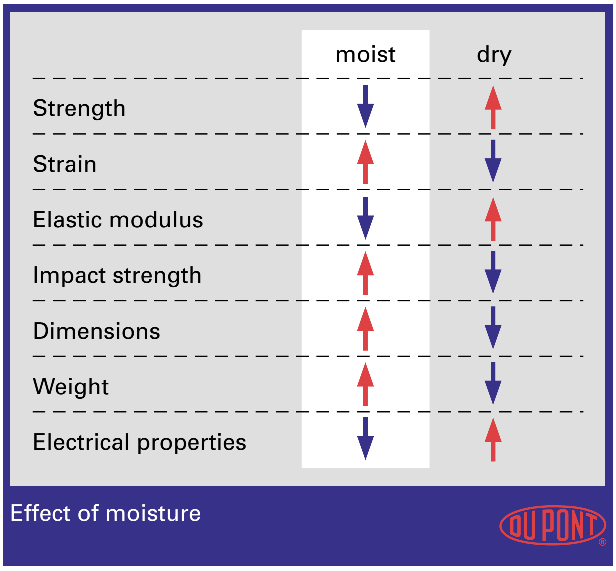
Fig. 5

Effect of moisture

Some thermoplastics, especially PA6 and PA66, absorb moisture. This may have considerable effect on their mechanical properties and dimensional stability. Particular attention should be paid to this property in material selection (Fig. 6 - 7).

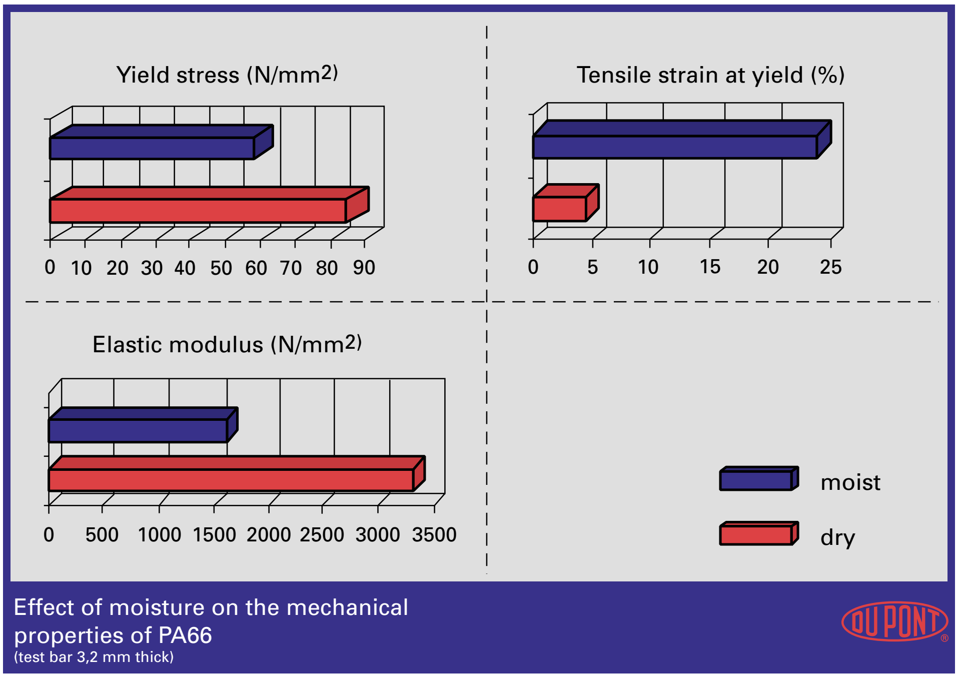
Other selection criteria

Other requirements relate to processing considerations and assembly. It is also important to investigate the possibility of integrating several functions in one component so saving costly assembly operations. This measure can have a very beneficial effect on production costs. It can be seen that in price calculations, it is not only the raw material price that is important. It should also be noted that materials with higher rigidity permit thinner walls and so result in faster cycles.
It is important to list all the criteria for material selection and evaluate them systematically.
A rough material selection flow chart is shown in Fig. 8.



Effect of moisture

Fig. 6



Effect of moisture on the mechanical properties of PA66
(test bar 3,2 mm thick)

Fig. 7

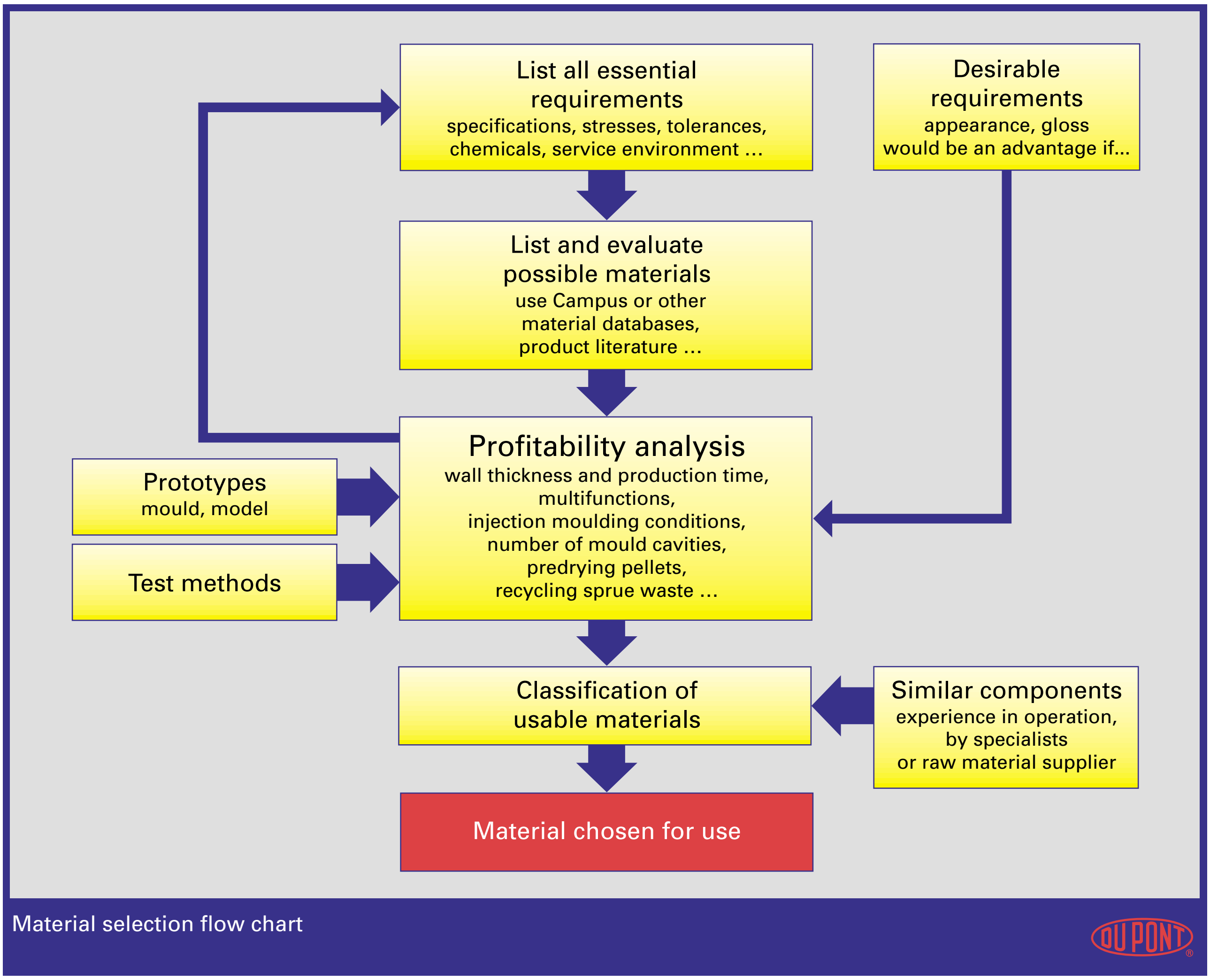

List all essential requirements
specifications, stresses, tolerances, chemicals, service environment ...
Desirable requirements
appearance, gloss would be an advantage if...
List and evaluate possible materials
use Campus or other material databases, product literature ...
Profitability analysis
wall thickness and production time, multifunctions, injection moulding conditions, number of mould cavities, predrying pellets, recycling sprue waste ...
Prototypes
mould, model
Test methods
Classification of usable materials
Similar components
experience in operation, by specialists or raw material supplier
Material chosen for use
Material selection flow chart

Fig. 8

3. Wall thickness

As much as necessary – as little as possible

Wall thickness – In designing components made from engineering plastics, experience has shown that certain design points arise time and again, and can be reduced to simple design guidelines. One such point is wall thickness design, which has an important influence on component quality.

Effect on specific component criteria

Changing the wall thickness of a component has a significant effect on the following key properties:
- component weight
- achievable flow lengths in the mould
- production cycle time of the component
- rigidity of the moulded part
- tolerances
- quality of the component in terms of surface finish, warpage and voids.

Ratio of flow path to wall thickness

At an early design stage, it is important to review the question whether the required wall thicknesses can be achieved with the desired material. The ratio of flow path to wall thickness has a critical influence on mould cavity filling in the injection-moulding process. If long flow paths combined with low wall thickness are to be achieved in an injection mould, only a polymer with relatively low melt viscosity (easy-flowing melt) is suitable. To gain an insight into the flow behaviour of polymer melts, flow lengths can be determined using a special mould (Fig. 1-2).

Flexural modulus as a function of wall thickness

The flexural rigidity of a flat sheet is determined by the material-specific elastic modulus and the moment of inertia of the sheet cross section. If wall thickness is automatically increased to improve the rigidity of plastic components without any thought given to the consequences, this can very often lead to serious problems with partially crystalline materials. In the case of glass-fibre-reinforced materials, changing the wall thickness also influences the orientation of the glass fibres. Close to the mould wall, the fibres are oriented in the direction of flow. On the other hand, in the centre of the wall cross section, random fibre orientation occurs as a result of turbulent flow.
By increasing wall thickness, it is mainly the cross-sectional area of randomly oriented glass fibres

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

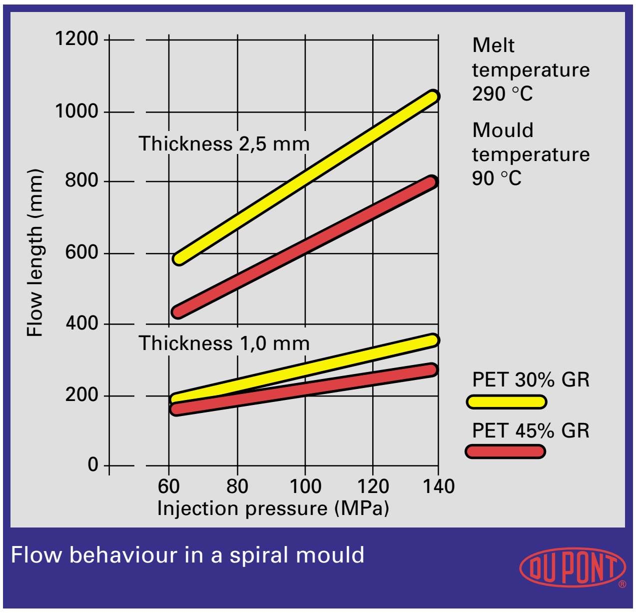


Fig. 1

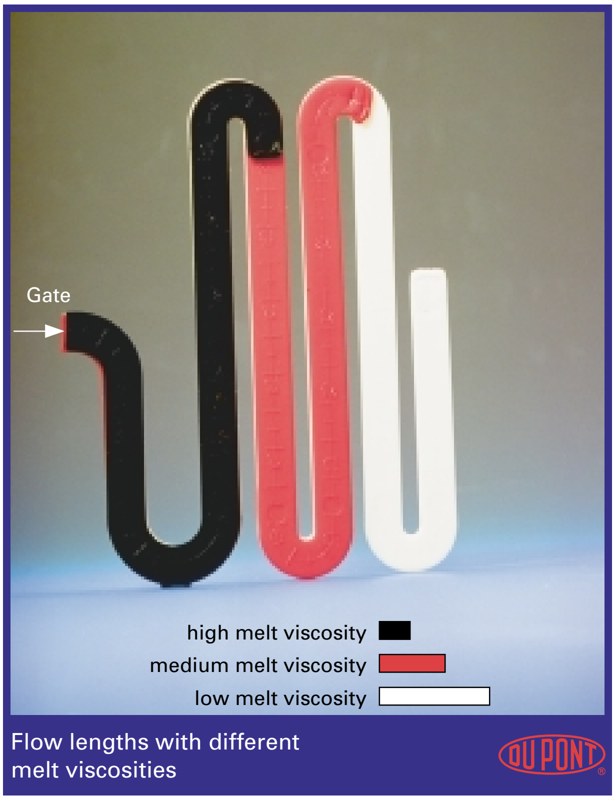


Fig. 2

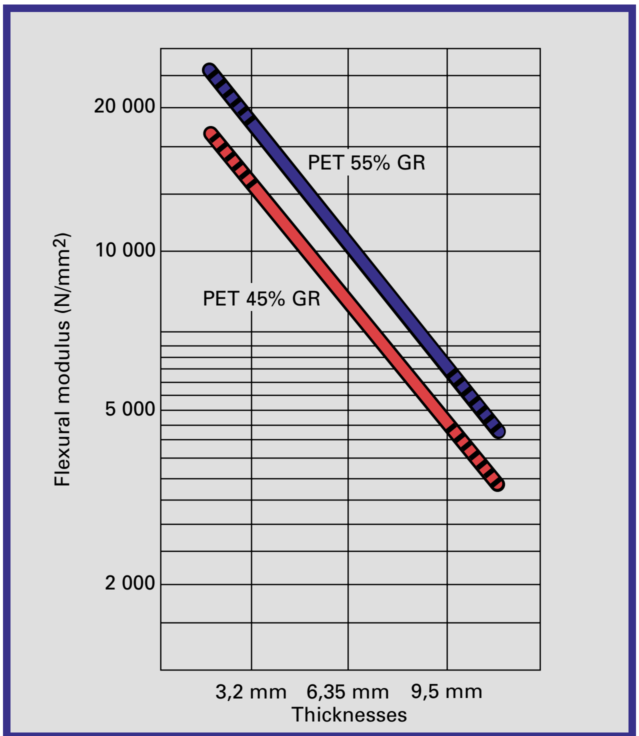
that is enlarged. On the other hand, the thickness of the zone in which the fibres are oriented in the direction of flow remains largely the same (Fig. 3).
This boundary zone, which critically determines component rigidity in the case of glass-fibre-reinforced plastics, is thus reduced in proportion to the overall wall thickness. This explains the decline in the flexural modulus (Fig. 4) when wall thickness is increased. The strength values determined on standard test bars (3,2 mm) are not therefore directly applicable to wall thicknesses deviating from this. To estimate component behaviour, it is essential to make use of safety factors. So by increasing wall thickness without consideration of the consequences, material and production costs are increased without a significant improvement in rigidity.

Increase wall thickness?

An increase in wall thickness not only crucially determines mechanical properties but also the quality of the finished product. In the design of plastics components, it is important to aim for uniform wall thickness. Different wall thicknesses in the same component cause differential shrinkage which, depending on component rigidity, can lead to serious warpage and dimensional accuracy problems (Fig. 6). To attain uniform wall thickness, thick-walled areas of the moulding should be cored (Fig. 5). In this way it is possible to prevent the risk of void formation and reduce internal stresses. Furthermore, the tendency to warp is minimized. Voids and microporosity in the component severely reduce its mechanical properties by cross-sectional narrowing, high internal stresses and in some cases notch effects.

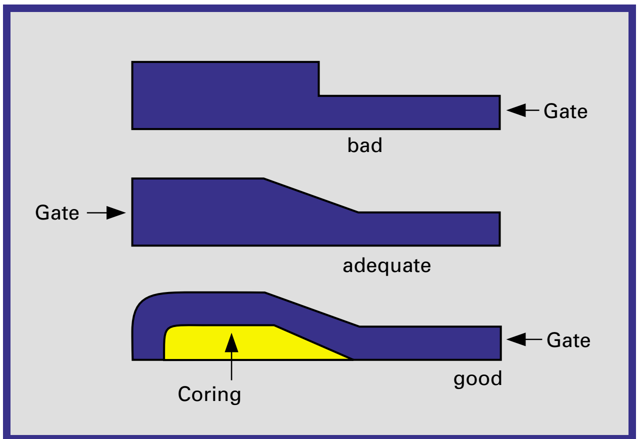
Fibre orientation
Core zone/Edge zone

Fig. 3



Flexural modulus as
a function of wall thickness

Fig. 4



Transition between
different wall thicknesses

Fig. 5

Component warpage as a result
of badly designed wall thickness transitions

Fig. 6

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

4. Ribbing

Optimum rib design

Ribs – To overcome the problems that can arise with thick walls, ribs are an effective means of increasing rigidity while allowing wall thickness to be reduced.

Generally, the rigidity of a component can be increased the following ways:
– increasing the wall thickness
– increasing the elastic modulus (e.g. by increasing reinforcing fibre content)
– incorporating ribs into the design.
If the required rigidity cannot be achieved in a design, the recommended next step is to choose a material with a higher elastic modulus than the original material. A simple way to increase the elastic modulus is to increase the content of reinforcing fibre in a polymer. However, given the same wall thickness, this measure produces only a linear increase in rigidity. A much more efficient solution is to increase rigidity by providing optimally designed ribs. Component rigidity is improved as a result of the increase in the moment of inertia. For optimum dimensioning of ribs, it is generally necessary to take into account not only engineering design considerations as such but also technical factors relating to production and aesthetic aspects.

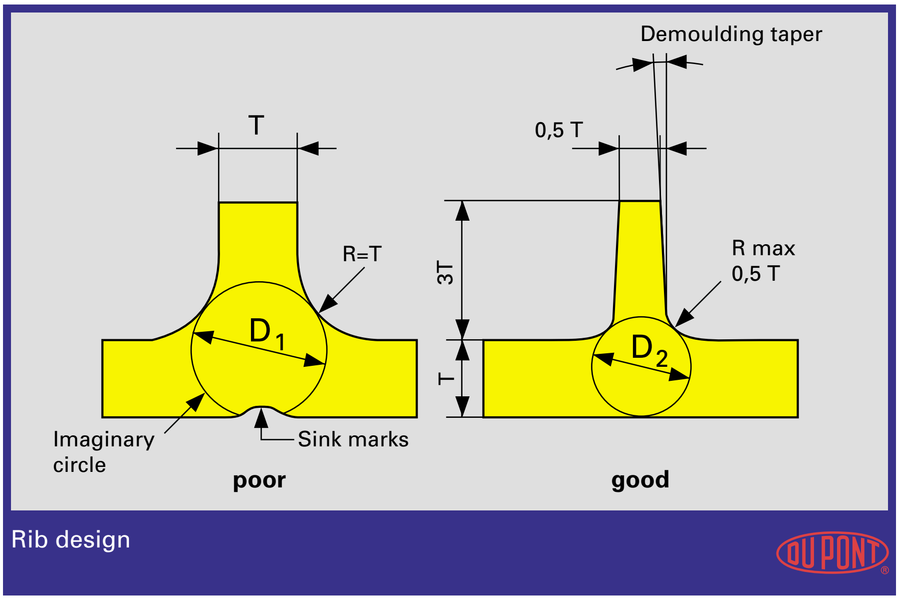


Fig. 1

Top Ten Design Tips

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

Optimum rib dimensions

In rib design, a large moment of inertia can most easily be achieved by providing high, thick ribs. However, with engineering thermoplastics, this approach usually creates serious problems such as sink marks, voids and warpage. Furthermore, if rib height is too great, there is a risk that the rib structure will bulge under load. For this reason, it is absolutely necessary to keep rib dimensions within reasonable proportions (Fig. 1).
To ensure trouble-free ejection of the ribbed component, it is essential to provide a demoulding taper (Fig. 2).

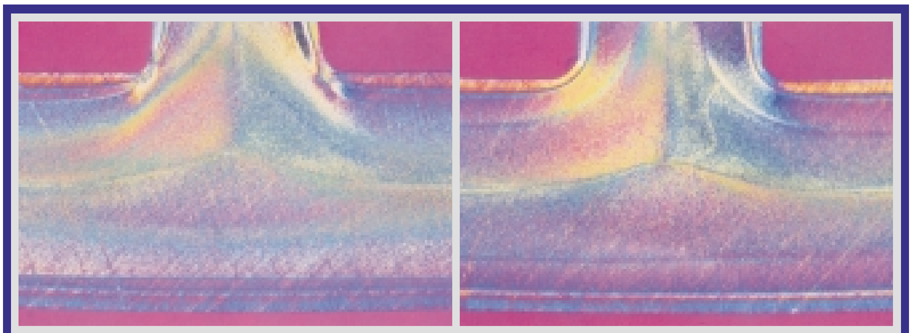
Restricting material accumulation

For components requiring a very high quality surface finish, such as hub caps, rib dimensioning is important. Correct rib design reduces the tendency to form sink marks and thereby increases component quality.
Material accumulation at the rib base is defined by the imaginary circle drawn in Fig. 1. By adhering to the dimensional proportions recommended there, this "circle" can be made as small as possible and sink marks can be avoided or reduced.
If the imaginary circle is too large in this area of material accumulation, voids can be formed and mechanical properties drastically lowered as a result.

	Shallow taper (less than 25 mm deep)	Steep taper (more than 25 mm deep)
POM	0 - 1/4°	1/2°
PA (unreinforced)	0 - 1/8°	1/4° - 1/2°
PA (GR)	0 - 1/2°	1/4° - 1°
PET / PBT (GR)	1/2°	1/2° - 1°

Demoulding tapers

Fig. 2



Stress concentration at sharp corners — Corners well rounded

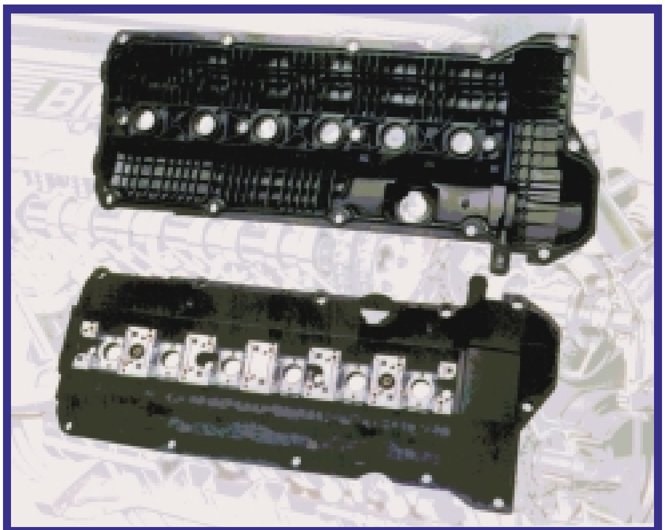
Fig. 3

Stress reduction at the rib base

If a ribbed component is exposed to applied loads, stresses may be created at the rib base. If no fillet radii are provided in this area of the component, very high stress concentration peaks will build up (Fig. 3), which not infrequently lead to cracking and failure of the component. The remedy is to provide a sufficiently large fillet radius (Fig. 1) that will permit better stress distribution at the rib base. Radii which are too large, on the other hand, will also increase the diameter of the imaginary circle, which in turn can lead to the problems already mentioned.

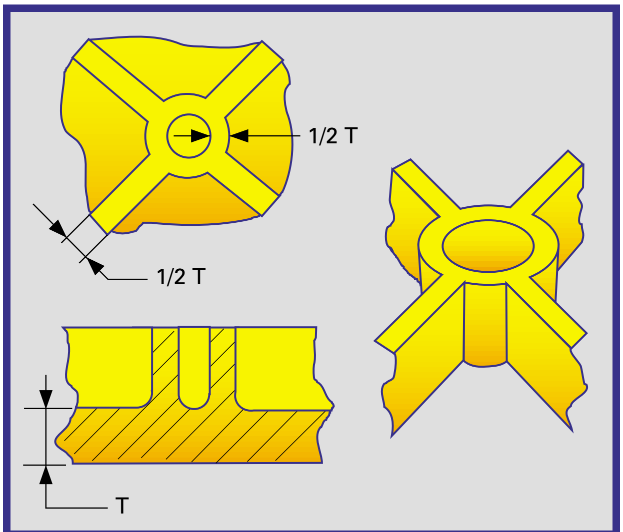
Choice of rib structure

In plastics design, a cross-ribbed structure has proved successful because it can handle many different loading permutations (Fig. 4). A cross-ribbed structure correctly designed for the anticipated stresses ensures uniform stress distribution throughout the moulding. The nodes formed at the rib intersections (Fig. 5) represent material accumulations but can be cored to prevent any problems. Care should also be taken to ensure that undue material accumulation is avoided at the point where the rib joins the edge of the component (Fig. 6)



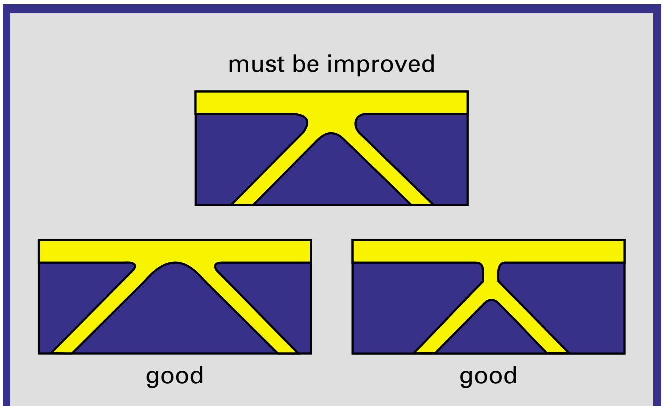
Ribbed rocker cover

Fig. 4



Nodes at rib intersections

Fig. 5



Rib junction with edge of component

Fig. 6

5. Gate positioning

Correct gate location

Gate positioning – Besides causing processing problems, the wrong choice of the type of gating system and gate location can have a considerable effect on the quality of a moulded part. Design departments should, therefore, not underestimate the importance of gate location.

Apart from carrying out design calculations for plastics parts, designers must pay particular attention to mould gating. They have to choose the correct gating system and the number and location of gating points. The different types of gate and gating locations can have a considerable effect on part quality.

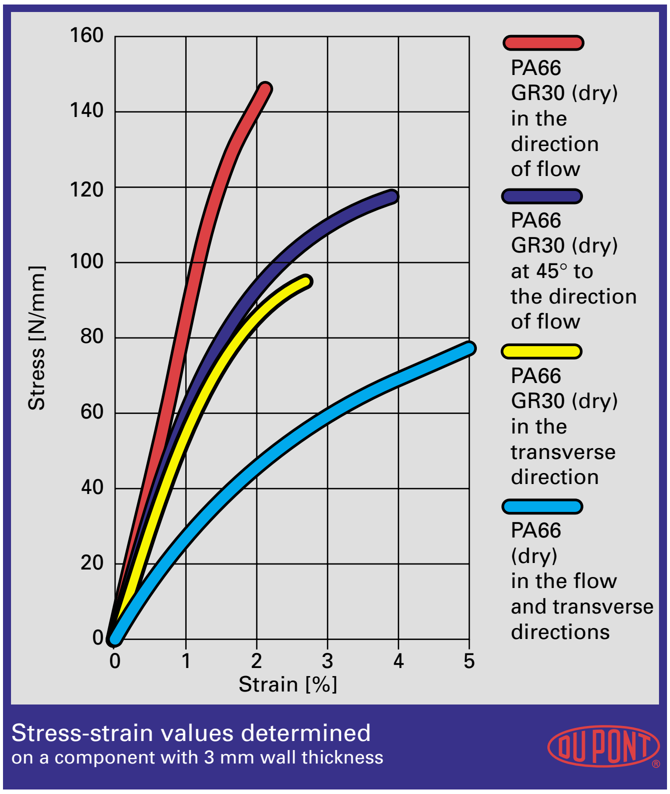


Fig. 1

Fixing the gate location also determines the following characteristics of a plastics part:
– filling behaviour
– final part dimensions (tolerances)
– shrinkage behaviour, warpage
– mechanical property level
– surface quality (aesthetic appearance).

Moulders have little scope to rectify the undesirable consequences of incorrect gating by optimizing processing parameters.

Orientation determines part properties

In the injection moulding process, the long polymer molecules and fibrous filling and reinforcing materials are oriented mainly in the direction of flow of the polymer melt. This results in directional dependency (anisotropy) of the part's properties. For example, strength properties in the flow direction are considerably higher than in the transverse direction (Fig. 1). Here the influence of the reinforcing fibres is significantly greater than the effect on strength of molecular orientation alone. Fibre orientation also causes differential shrinkage in the longitudinal and transverse directions, which can lead to warpage.

Quality reduction as a result of weld lines and trapped air

Weld lines occur when two or more melt streams unite in the mould. This happens, for example, when the melt has to flow around a mould insert or when parts are gated at several points (Fig. 2a+b). In addition, different wall thicknesses in a part can also lead to separation of melt fronts and so cause weld lines. Air entrapment (air bubbles) occurs when air that should be expelled from the mould is enclosed by melt streams and cannot escape. Weld lines and air entrapment are often manifested as surface defects. Apart from the fact that they are ugly, as a rule they also considerably reduce the mechanical properties in the affected areas, particularly impact strength (Fig. 3-4).

Fig. 2a

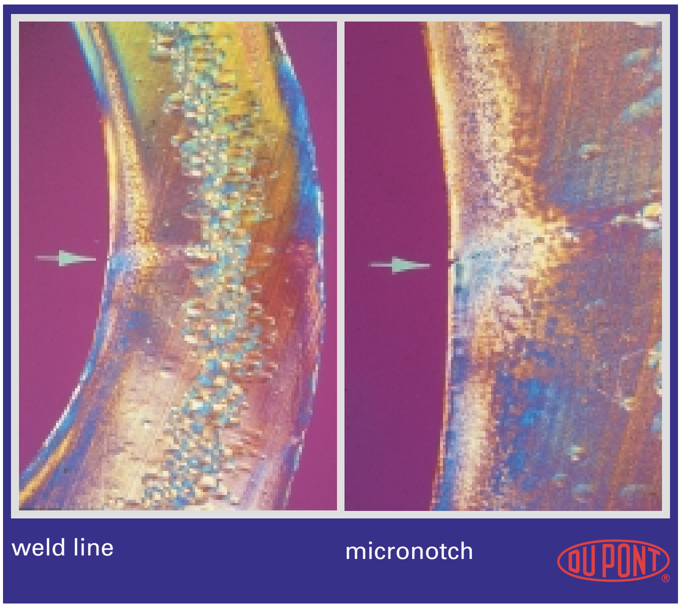
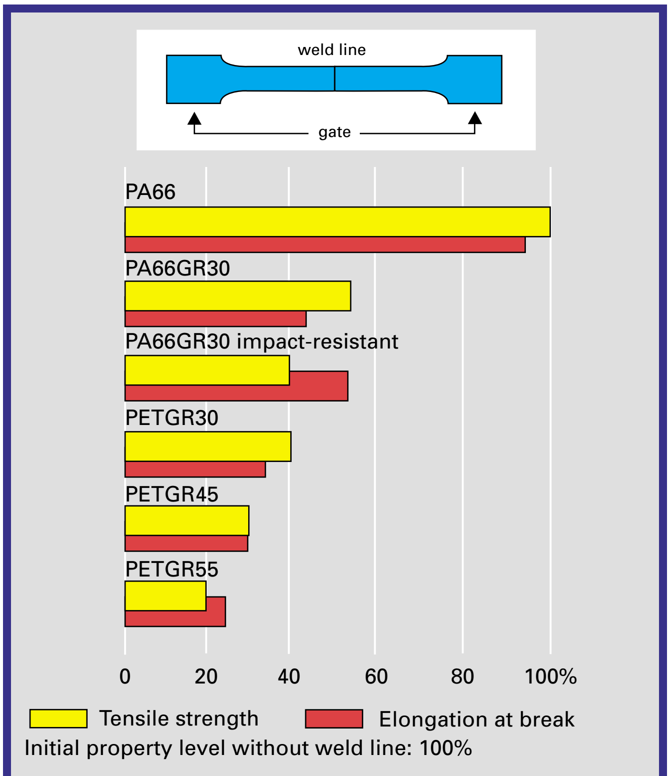


Fig. 2b

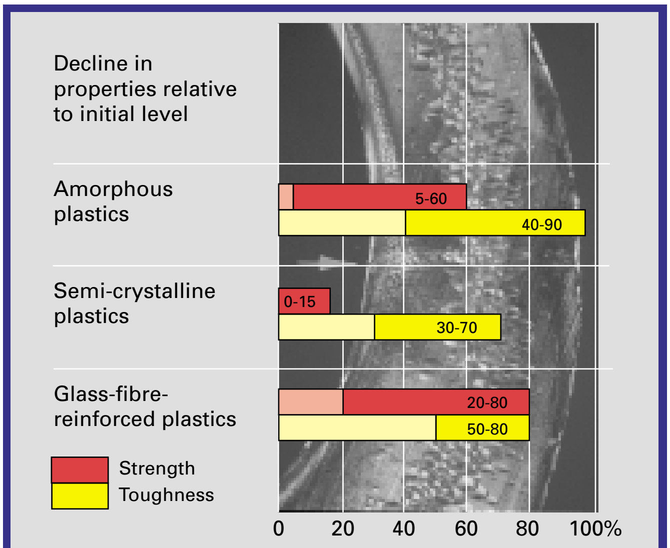
Unsuitable gate positioning has adverse consequences

As gates always leave obvious marks, they should not be placed in areas which should have a high surface quality. In any gating region, high material stress (shear) takes place that considerably reduces the property levels of the plastics resin (Fig. 5). Unreinforced plastics have higher weld line quality than reinforced plastics. The quality-reduction factors in the weld line area are highly dependent on the type and content of filling and reinforcing material. Similarly, additives such as processing aids or flame retardants can have a detrimental effect. It is therefore difficult to estimate how much these factors will affect the part's final strength. In addition, weld line areas with high load-bearing capacity under tensile stress do not show equally good impact strength or fatigue endurance. With fibre-reinforced materials, fibres in the weld line area are aligned transversely to the direction of flow. This significantly lowers the mechanical properties of the part at this point (Fig. 6).



Strength reduction due to the effect of a weld line (average values)

Fig. 3



Reduction factors for weld line areas

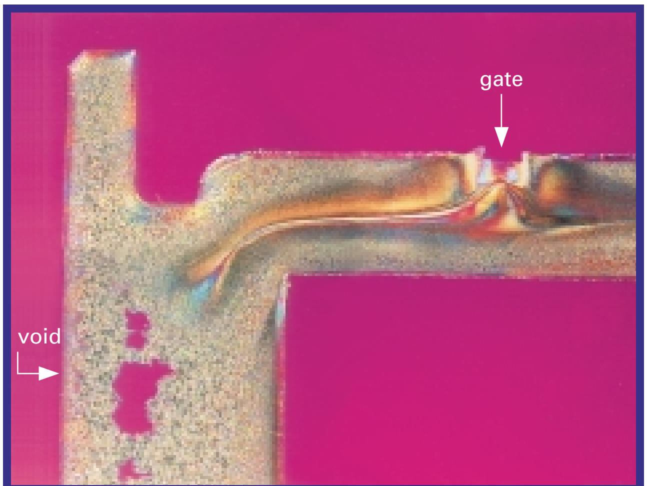
Fig. 4

Correct gate positioning

Complex mouldings usually cannot be produced without weld lines. If the number of weld lines cannot be reduced, they should be placed in non-critical parts of the moulding in terms of surface quality and mechanical strength. This can be done by moving the gate location or by increasing/ reducing part wall thickness.

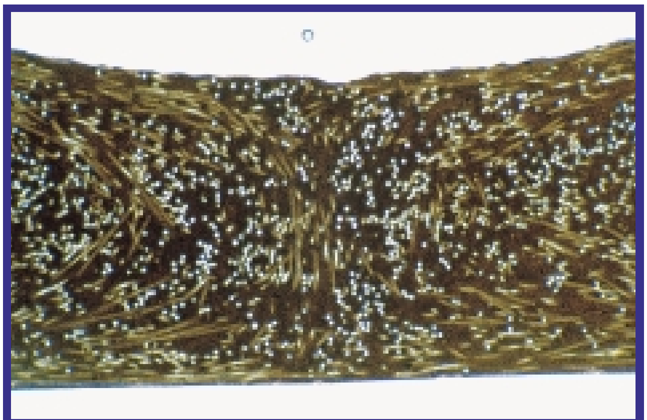
Basic design principles:

- do not gate parts in highly stressed zones
- avoid or minimise weld lines
- avoid leaving weld lines in highly stressed areas
- with reinforced plastics, gate location determines part warpage
- avoid air entrapment by providing adequate vents.



Material defects
in the gate area

Fig. 5



Glass fibre orientation
in the weld line

Fig. 6

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

---

6. Cost-saving designs

Low-cost designs

Price as a Design Factor – The designer of a plastics component bears a large part of the responsibility for its final cost. His decisions essentially predetermine the costs of production, mould-making and assembly. Correction or optimization at a later stage is generally costly or impracticable.

Influencing cost through material properties

Taking full advantage of specific properties of plastics materials can help to save costs in many ways:

Designs with multiple integrated functions
Reduction in the number of individual parts through integration of several functions in one part.

Use of low-cost assembly techniques
Snap-fits, welded assemblies, riveted assemblies, two-component technology, etc.

Exploitation of dry-running properties
Saves the need for additional or subsequent lubrication.

Elimination of surface treatments
Integral colour, chemical and corrosion resistance, electrical and thermal insulation properties.

Nucleation
Materials in the same product family can have different cycle times. The reason for this is a nucleating additive that accelerates crystallization of the melt during the cooling phase.

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

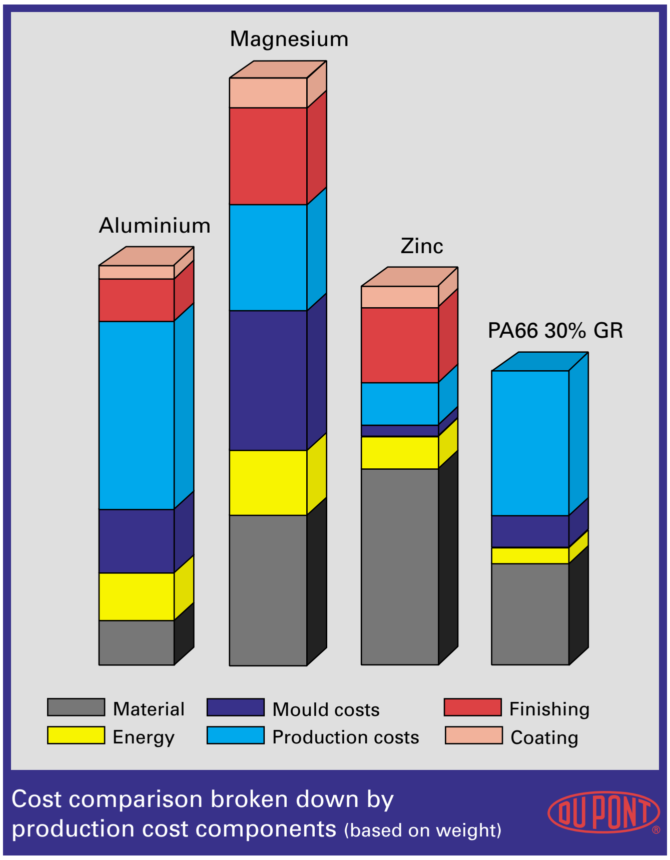


Fig. 1

Influencing cost through finished-part design

Further cost reductions can be achieved, over and above those mentioned above, by observing the following points:

Wall thickness
Optimized wall thickness distribution influences material costs and can reduce production time.

Moulds
Two-plate moulds, reduction in the number of splits, etc.

Tolerances
Excessively high tolerance requirements increase the reject rate and quality control costs.

Materials
Reducing cycle and cooling times through the choice of materials that set up rapidly, minimizing warpage problems by using low-warpage polymers (e.g. optimization of the ratio of mineral to glass-fibre reinforcement).

Cost comparison broken down according to production cost components

Injection-moulded parts should be ready for assembly as soon as they are ejected from the moulding machine, without needing any additional finishing operations. If finishing operations are required, the cost of plastics components often reaches that of metal designs (Fig. 1).

Design determines production costs

A general increase in wall thickness will not always lead to the desired strength increase in a component, but it will certainly mean a steep rise in production and material costs (Fig. 2). Partially crystalline thermoplastics undergo volume shrinkage as they set up. This shrinkage must be compensated for by continuing melt feed during the holding pressure phase. The approximate holding pressure time per mm wall thickness is, for example:

– POM = 8 s
– PA66 unreinforced = 4-5 s
– PA66 reinforced = 2-3 s

(Applies up to wall thickness of 3 mm)

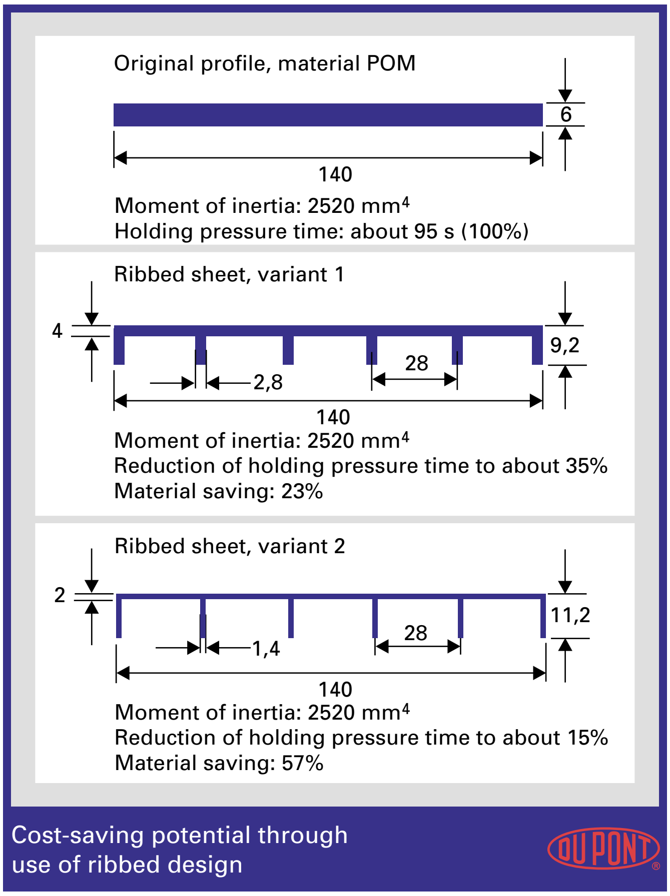


Fig. 2

Examples of typical applications

In contrast to metal designs, which have to be machined and often pass through many assembly stages to turn out a single functional part, plastics technology offers considerable savings potential. In this example (Fig. 3), the guide and drive rods, spring, barbed-leg snap-fit element and bearing arrangement are injection-moulded in one piece. The equivalent metal design would require not only five individual parts that have to be assembled, but the rod would also need lubrication where it comes into contact with the stop. Choice of a POM homopolymer in fact made lubrication unnecessary at this point, too.

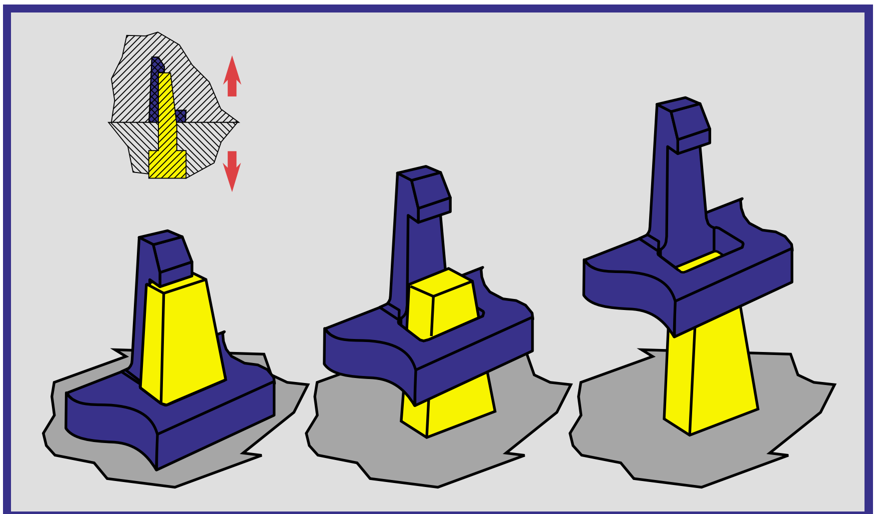
Barbed-leg snap-fit designs in combination with integral hinges reduce the number of individual components, thus making assembly easier and thereby lowering costs. If brittle materials are used, another barbed-leg snap-fit element takes over the locking function if the integral hinge breaks (Fig. 4). In designing the part, the designer also necessarily defines the design of the mould cavity. He therefore determines the ejection system and the number of splits required. By judicious arrangement of undercuts, splits can be replaced by cores (Fig. 5).

Example of functional integration
(guide and drive rod made of POM)

Fig. 3

Example of simplified assembly
(cable clips with integral hinge)

Fig. 4



Low-cost mould design

Fig. 5

---

7. General assembly technology

The best assembly techniques – Part I

General Assembly Technology – Snap-fit, press-fit and threaded assemblies are simple techniques that allow designers to exploit great potential production savings through simple, rapid assembly of components.

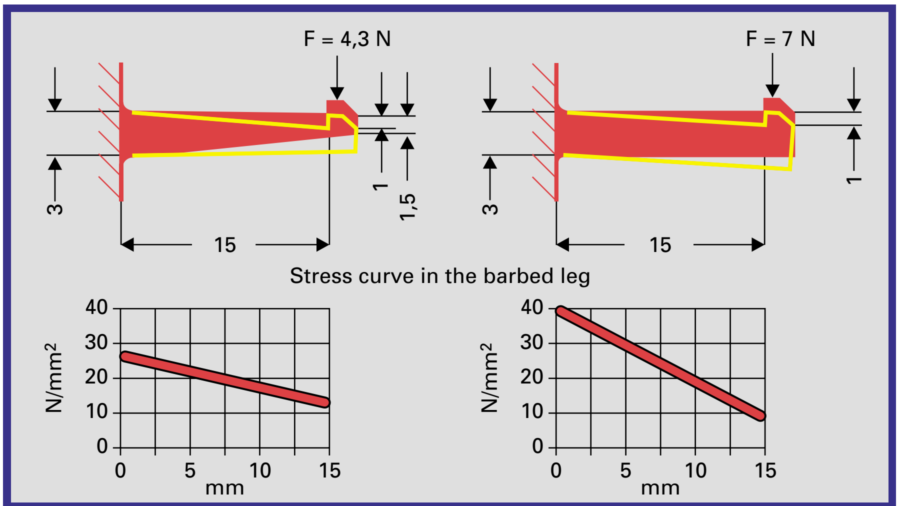
Assembly techniques can be divided into detachable and non-detachable types. The following techniques come under the category of non-detachable assemblies:
– welding
– riveting
– adhesive bonding
– insert technology
– snap-fits with 90° retaining angle.

Detachable assemblies include:
– snap-fits with < 90° retaining angle
– threaded assemblies
– hub assemblies
– press-fit assemblies.

Material	Permissible strain in %
POM homopolymer	about 5-8
PA unreinforced (cond.)	about 4-6
PA unreinforced (dry)	about 3
PA66 GR (conditioned)	about 0,9-1,5
PA66 GR (dry)	about 0,8
PET GR	about 0,5-0,8
PBT GR	about 0,7-1,5

Permissible material strains
(Values are valid only for a single assembly operation)

Fig. 1



Stress distribution with different cross sections

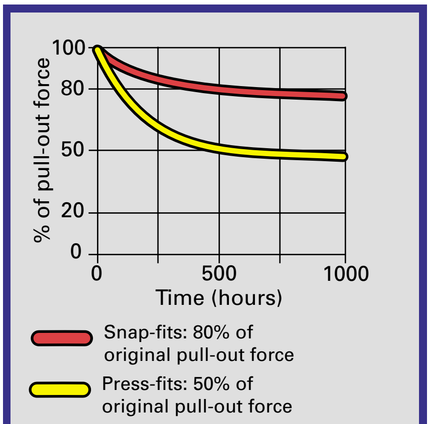
Fig. 2

Snap-fit Assembly Design

The great advantage of snap-fits is that with this technique no additional elements are needed to make the assembly.

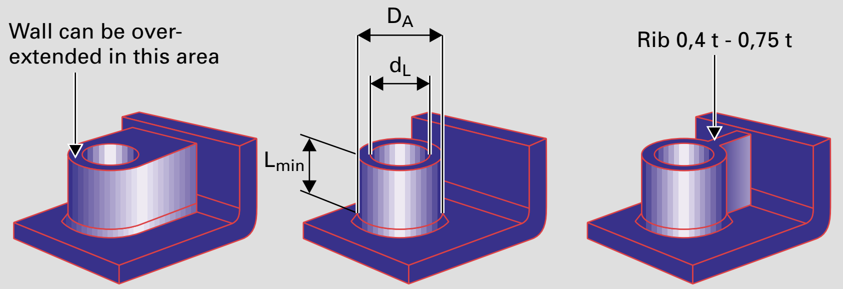
The most commonly used types of snap-fits in plastics technology are:
– barbed-leg-type snap-fits
– cylindrical snap-fits
– ball-and-socket snap-fits.

With all these snap-fit designs, designers must ensure that the geometry of the assembly allows the components to be as stress-free as possible after assembly to avoid stress relaxation, which would loosen the assembly with time.



Effect of time

Fig. 3



Material	d_L (mm)	D_A (mm)	L_{min} (mm)
POM	0,75 d	1,95 d	2,0 d
PET GR30	0,8 d	1,8 d	1,7 d
PBT GR30	0,8 d	1,8 d	1,7 d
PA66 GR30	0,82 d	2,0 d	1,8 d
PA66	0,75 d	1,85 d	1,7 d

d = Nominal screw diameter

Design recommendations for EJOT PT screws

Fig. 4

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

Basic design principles

The design of a snap-fit assembly is determined by the permissible strain of the material to be used. Care should be taken with polyamide, for example, because in the dry state this material generally permits considerably lower strains than in the conditioned state. Glass fibre content also has an important effect on the permissible strain of the material and thus also on the permissible deflection of the barbed leg (Fig. 1).
In a barbed-leg-type snap-fit, tapering of the deflecting leg reduces stress (Fig. 2). This design allows better stress distribution over the entire bending length. Stress concentration peaks at the base of the leg are less and assembly forces are considerably reduced.
Failure to radius the junction between the base of the barbed leg and the main body of the component, or to provide sufficiently large radii in this area, often results in weak points. In principle, a sufficiently large radius should be provided to avoid stress concentration peaks. Cylindrical and ball-and-socket-snap-fits often have to be slotted to facilitate assembly; in this case the slot end must not be designed with a sharp edge.

Press-fit Assemblies

Press-fits enable high-strength assemblies to be made between plastic components at minimal cost. As with snap-fit assemblies, the pull-out force of a press-fit assembly decreases with time as a result of stress relaxation (Fig. 3). Design calculations must take this into account. In addition, tests with the expected service temperature cycles must be carried out to confirm the feasibility of the design.

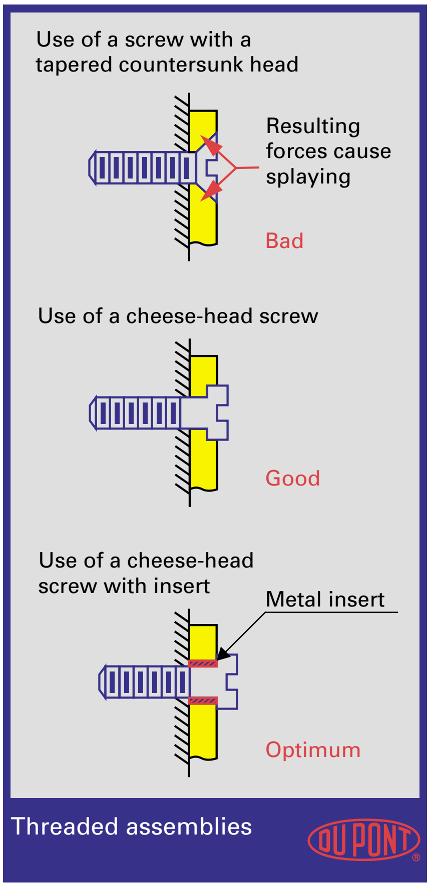


Fig. 5

Threaded Assemblies

Threaded assemblies can be produced with thread-cutting or thread-forming screws, or by the use of integrally moulded threaded inserts. The flexural modulus of the material to be used provides a good guide to the type of threaded assembly that is most appropriate. For example, up to a flexural modulus of about 2800 MPa, thread-forming screws may be used. Metal inserts must be used if metric screws are required or if the threaded assembly is intended to be undone several times. To prevent premature component failure, it is important to ensure correct dimensioning of the boss (Fig. 4). Screw manufacturers give recommendations on this.
Screws with a tapered countersunk head should as a general rule be avoided in plastics assembly technology since the resulting forces (Fig. 5) cause the screw hole to “splay out”. One possible result of such additional stress is that weld lines can easily rupture.

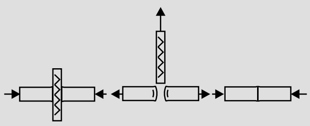
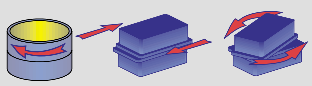
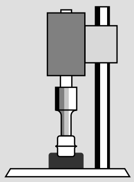
By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

---

8. Welding technology

The Best Assembly Techniques – Part II

Welding technology – In addition to the assembly techniques described in article 7 of this series, many different welding methods can be used to join plastic parts. To ensure low-cost, functionally efficient designs, it is necessary to select a suitable welding method and give careful thought to the required joint geometry at an early stage in the design process.

	Hot-tool	Vibration/Spin	Ultrasonic
Principle			
Welding cycle times	10-20 s	0,2-10 s	0,1-2 s
Advantages	– unevennesses in the joint zone (e.g. distortion) are melted away – good reproducibility of welding results – best weld quality – high degree of automation possible	– suitable for welding medium-sized to large parts – suitable for welding plastics sensitive to oxidation	– different variations possible (riveting, flanging, insertion) – shortest cycle times – method can be readily automated and integrated
Limitations	– oxidation-sensitive plastics – more flash	– position of the parts to be welded relative to each other – minimum rigidity required (material/part geometry) – defined relative movement required	– suitable only for welding small to medium-sized parts – near-field/far-field an additional influencing factor
Examples			

Comparison of different welding methods

Fig. 1

Top Ten Design Tips

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

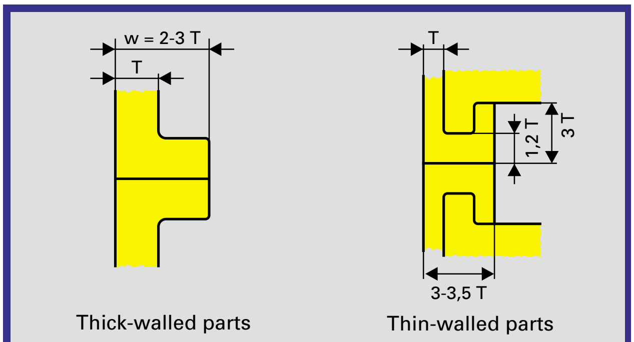
Welded joints are assemblies for permanently connecting plastics parts without additional assembly elements. The choice of welding method depends on several criteria: the geometry of the moulded part and on the materials used, on cost-effectiveness, suitability for integration into the overall production cycle and the mechanical and aesthetic quality requirements for the assembly zone.

Different welding methods

There are many different, cost-effective welding methods suitable for industrial mass production. The methods most frequently used for plastics engineering components are (Fig. 1):
- hot-tool welding
- spin welding
- vibration welding
- ultrasonic welding.

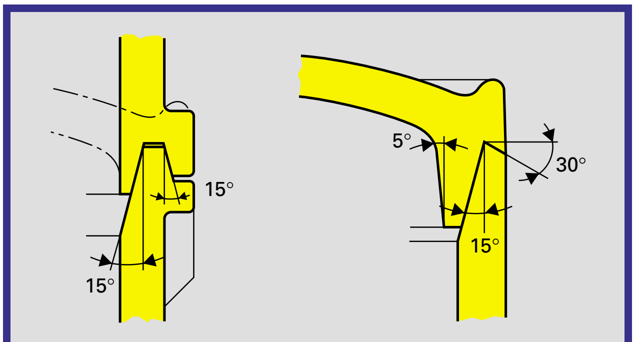
Other methods worth mentioning include:
- high-frequency welding
- induction welding
- hot-gas welding.

New methods are also being developed (e.g. laser welding), but these are not yet widely used in industry.
In all these methods, the assembly operation is carried out by applying heat (melting the surfaces to be joined) and pressure. Heat can be generated directly by contact or radiation, or indirectly by internal or external friction, or by electrical effects.



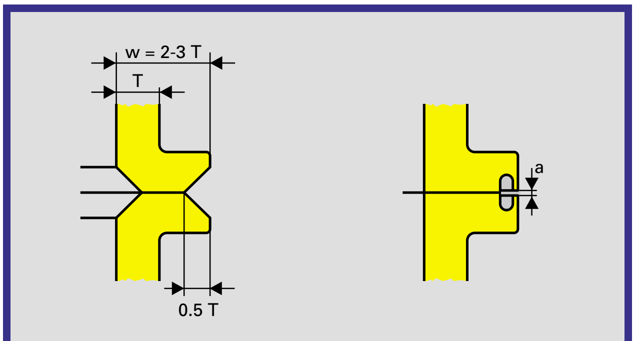
Weld design for vibration welding/hot-tool welding

Fig. 2



Weld design for spin welding

Fig. 3



Examples of recesses for absorbing flash

Fig. 4

Top Ten Design Tips

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

Choosing the right method

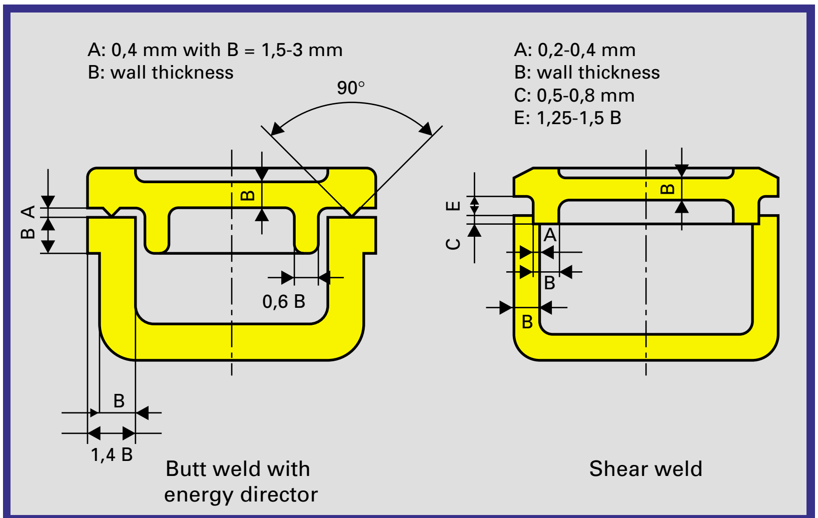
To achieve good, reproducible weld quality, it is necessary to choose a suitable welding method, optimize welding parameters and ensure that the parts to be assembled are correctly designed for the welding method being used. Welding machinery manufacturers supply not only standard equipment but also various special welding units to cater for a wide variety of welding tasks. Before deciding on a welding method, it is advisable to consult the machinery manufacturers or resin suppliers.

Different welding properties

Theoretically, all thermoplastics are weldable, but the welding behaviour of plastics differs considerably in some cases. Amorphous and semi-crystalline polymers cannot be welded together. Plastics that absorb water (e.g. nylon) need to be pre-dried, since moisture leads to poor-quality welds. For best results, nylon parts should either be welded immediately after injection-moulding or kept in a dry state before welding. Resin additives such as glass fibres and stabilizers can also influence welding results. Welded assemblies of unreinforced plastics can attain weld factors close to the strength of the parent material, given suitable process parameters and part design. With glass-fibre-reinforced plastics, loss of strength due to fibre separation or reorientation in the welding zone must be taken into account.

Correct weld design

An essential requirement for high-quality welds is suitable design of the weld profile. The profiles shown in Figures 2 and 3 have proved successful basic designs. If the weld zone additionally has to meet high aesthetic specifications, then special geometry is needed. The diagrams show possible ways of hiding flash by providing recesses to absorb the excess material (Fig. 4). Thin-walled parts need to be designed with a guided fit into each other, so that the necessary welding pressure can be applied without the walls moving out of alignment.



Butt and shear weld designs for ultrasonic welding

Fig. 5

Special features of ultrasonic welding

Semi-crystalline polymers have a sharply defined melting point, i.e. on application of heat they pass abruptly from the solid to the liquid phase. For ultrasonic welding of semi-crystalline plastics, it is therefore preferable to use shear welds (Fig. 5). For welding amorphous plastics, which have a softening range, the weld design is less critical. Fig. 6 shows diagrams of the near-field and far-field welding methods. These differ in the distance between the contact point where the ultrasonic horn transmits vibrations into the workpiece and the faces to be joined. Generally speaking, near-field welding produces the best results with all plastics but it is essential to use the near-field method for plastics with a low elastic modulus.

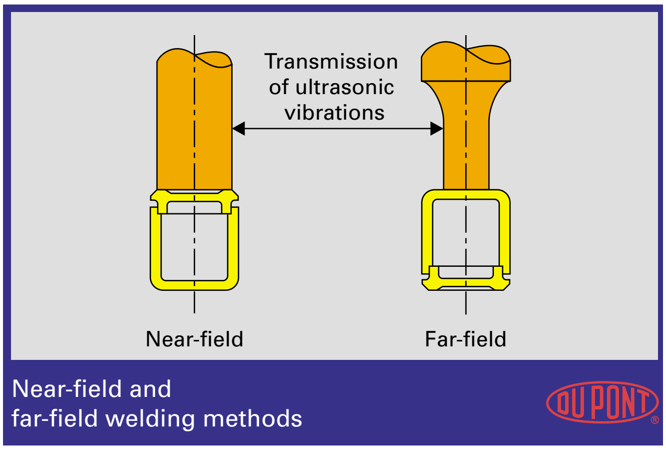


Fig. 6

---

9. Tolerances

Hidden cost factors

Tolerances – Injection mouldings cannot be produced to the same tolerances as machined parts. Although most people are aware of this, tolerances are continually being specified that cannot be attained and/or make cost-efficient production impossible.

Tolerances and their cost implications

A distinction is generally made between three quality classes: general-purpose injection moulding, technical injection-moulding and high-precision injection-moulding. In the DIN 16901 standard, these are specified in terms of general tolerances and dimensions with directly figured allowances (ranges 1 and 2):

– “general-purpose” injection-moulding requires a low level of quality control and is characterised by low reject rates and fast production cycles
– technical injection-moulding is considerably more costly, since it makes higher demands on the mould and the production process, requires frequent quality control checks and is therefore likely to have increased reject rates
– the third group, high-precision injection-moulding, requires precision moulds, optimum production conditions and 100 % production monitoring with continuous quality control. This affects cycle time and-through increased production and quality control costs-on the unit price.

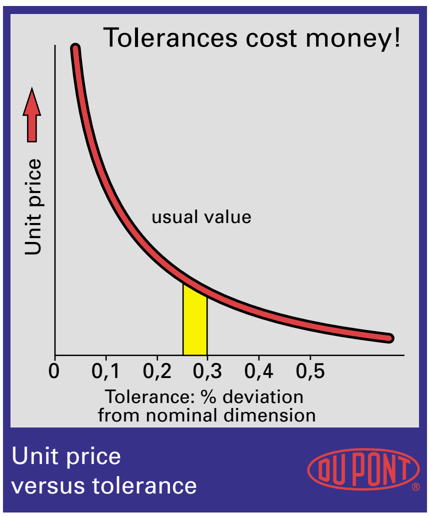


Fig. 1

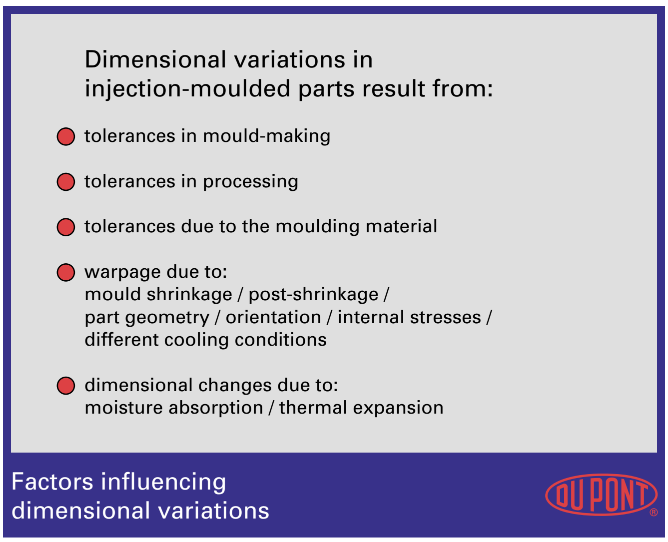


Fig. 2

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

Since designers play a key role in determining the costs of an injection-moulded part, they must also ensure commercially viable tolerancing. The selected tolerances should not be as tight as possible but as tight as necessary.
A commercially acceptable value for a production tolerance would be 0,25 to 0,3 % deviation from the nominal dimension, but this must be checked against application requirements (Fig. 1).
It should be remembered that thermoplastics, which typically have high elongation and elasticity, do not need to have the close tolerances that are specified for metals with their high rigidity, low elongation and low elasticity.

Factors influencing tolerances

To avoid excessively close tolerances for plastics components, the many different factors that influence the dimensional accuracy of an injection-moulded part (Fig. 2) must be kept in mind. Tolerances in tool-making have to be observed relatively closely. Designers should not forget, however, that demoulding tapers for easy, distortion-free ejection from the injection mould are vital (Fig. 3).
Adherence to tolerances is a problem when moulding parts from different materials or with different wall thicknesses. Mould shrinkage values are direction- and thickness-dependent. This behaviour can be seen most clearly with glass-fibre-reinforced materials. Here, the orientation of the glass fibres can produce significant differential shrinkage between the longitudinal and transverse directions, and this can lead to dimensional inaccuracies.
The geometry of the moulded part can also have an effect on shrinkage and hence on tolerances (Fig. 4).
If complex mouldings are to be produced to close tolerances, a prototype mould is essential to obtain accurate information on the actual shrinkage value and warpage behaviour.

Production and operating tolerances

It is important to decide whether only a production tolerance is required or whether an operating tolerance is also necessary, since thermoplastics are affected by their service environment. For example, thermal expansion – which can be ten times more than for metals (Fig. 5) – and the marked tendency of some polymers (e.g. nylons) to absorb moisture play a crucial role in the operational reliability of a part in service.

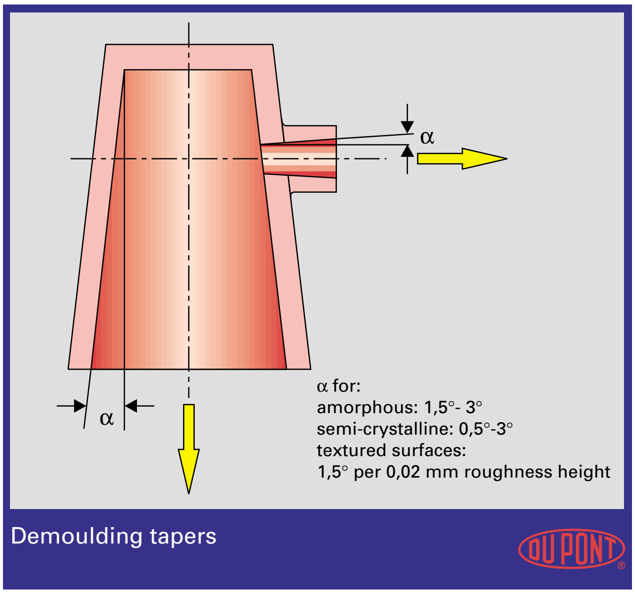
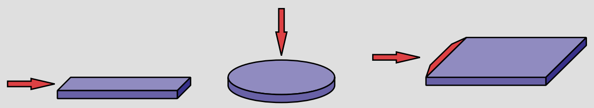


Fig. 3

With semi-crystalline materials, post-shrinkage must also be taken into account. This phenomenon, which is influenced mainly by injection moulding conditions, can lead to dimensional changes in finished parts after demoulding.
Quality control must not be carried out immediately after demoulding. The DIN 16901 standard specifies that quality control should be undertaken only after 16 hours’storage under standard climatic conditions (23 °C, 50 % relative humidity) or after suitable pre-treatment.

Recommendations

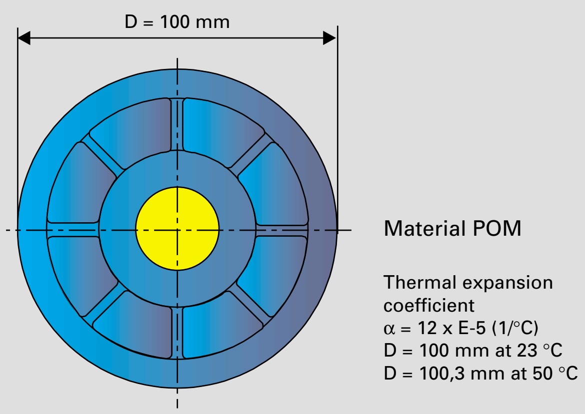
The tolerances specified in DIN 16901 can be used as a starting point for cost-efficient production of moulded parts. However, the improved technology of modern injection moulding machines enables considerably closer tolerances to be attained than the values specified in this standard. For high-precision injection mouldings, individual industry sectors have developed separate tolerance tables because DIN 16901 is no longer adequate.
In any case, however, when close tolerances are needed, it is important to consult with the injection moulder or material supplier to see if the required tolerances are technically feasible and commercially appropriate (Fig. 6).



	Bar 127 x 12,7 x 3,2 mm end gate	Disk 50 x 3,2 mm central gate	Sheet 152 x 76 x 3,2 mm end gate	
Mould shrinkage in:	Length	Diameter	Length	Width
PA66	1,5%	1,7%	1,7%	1,8%
PA66 30% GR	0,1% - 0,2	0,4%	0,4%	1,1%
PA66 43% GR	0,1%	0,2%	0,2%	0,5%

Shrinkage

Fig. 4



Thermal expansion

Fig. 5

- Semi-crystalline thermoplastics have higher post-shrinkage values than amorphous thermoplastics
- Reinforced thermoplastics shrink by different amounts longitudinally (in the direction of the glass-fibre orientation) and in the transverse direction
- Thick walls lead to sink marks, dimensional variations and warpage
- Part design and processing conditions often play a decisive role in meeting specified tolerances
- Temperature fluctuations and moisture absorption result in dimensional changes that must be taken into account for operating tolerances

Tolerance-related factors

Fig. 6

10. Check list

Some Guidelines

Design check list – The aim of new product development or further development of an existing product is to achieve a technically good design that can be produced at an economic cost. The main design tasks involved here are material selection, choice of a suitable production process, strength calculation and moulding design.

A high-quality, commercially viable moulding can be produced only by giving full consideration to each of these design steps and following them through systematically. Design departments often seek only a functional solution. It has to be stressed, however, that the functionality and cost-effectiveness of a plastic component cannot be taken for granted unless designers pay proper attention to developing the right solutions for the material and the production process.

A plastic's properties are not immutable material constants

The property profiles of plastics can be influenced by the service environment, production process, moulding design and operating conditions (Fig. 1). Plastics properties are determined in tests under laboratory conditions. Test bars are produced in highly polished moulds with optimized parameters and tested under standardized conditions with precisely defined stresses. In practice, however, plastic components are never produced exactly under such conditions and are not exposed to precisely the same stresses in service. For these reasons, when setting out on any plastics design project, the exact requirements and boundary conditions must be carefully analysed and listed. A design check list can provide useful assistance here (Fig. 2).

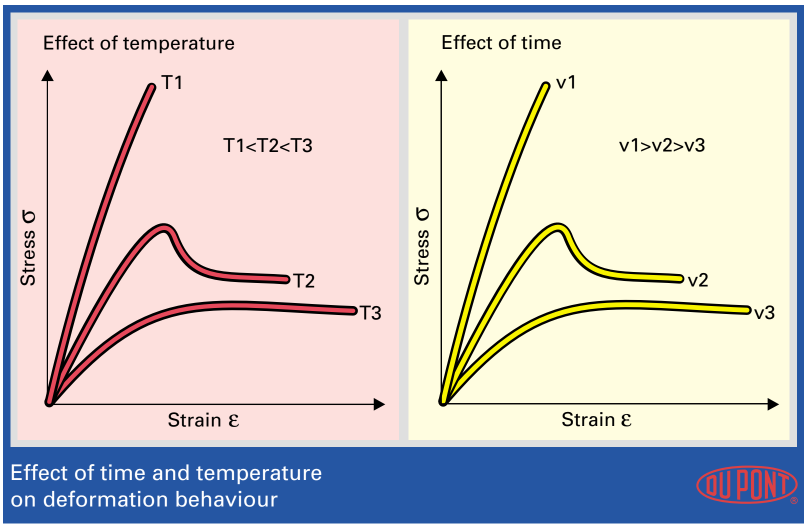


Fig. 1

Production of prototypes

To develop a component from the design phase to market-readiness, it is generally necessary to prepare prototypes for trials and modification. Care should be taken to ensure that the method used to prepare the prototype is broadly similar to the intended full-scale production method. Prototypes for parts that are to be produced by injection moulding should also be prepared by injection moulding. If no mould is available, it is sometimes necessary to resort to machined trial components. However, this is not always without its problems, for the following reasons:

– the effect of weld lines in the injection moulded part cannot be studied
– the grooves produced by machining can sometimes considerably reduce strength properties compared with those of an injection moulded part
– the strength and rigidity of extruded bars and sheets can be higher than those of an injection moulded part on account of higher crystallinity
– the effect of fibre orientation cannot be studied.

A. General
1. Function of the component
2. Possibilities for modification and integration (increase in functionality)

B. Service conditions
1. Stresses: type, duration, level
   - static, dynamic
   - short-term, long-term, intermittent
   - maximum and minimum values
2. Service temperature
   - maximum and minimum values
   - duration of exposure
3. Service environment
   - air – water – humidity
   - chemicals
   - UV stress
   - ...

C. Design requirements
1. Tolerances
2. Maximum permissible moulded-part deformation
3. Assembly – dismantling (joining techniques)
4. Specifications and approvals
   - official regulations
   - company's internal guidelines
5. Surface quality
   - permissible markings

D. Test conditions
All test methods that can be used to determine the performance and assess the quality of the plastic part should be listed in detail.

E. Cost efficiency
1. System or part costs for the old component assembly
2. Production quantity

F. Other
1. Environmental regulations
2. Safety factors
3. All additional information permitting a complete understanding of part functions and the service conditions, mechanical and environmental stresses and possible misuse that the part will have to withstand.

Design check list

Fig. 2

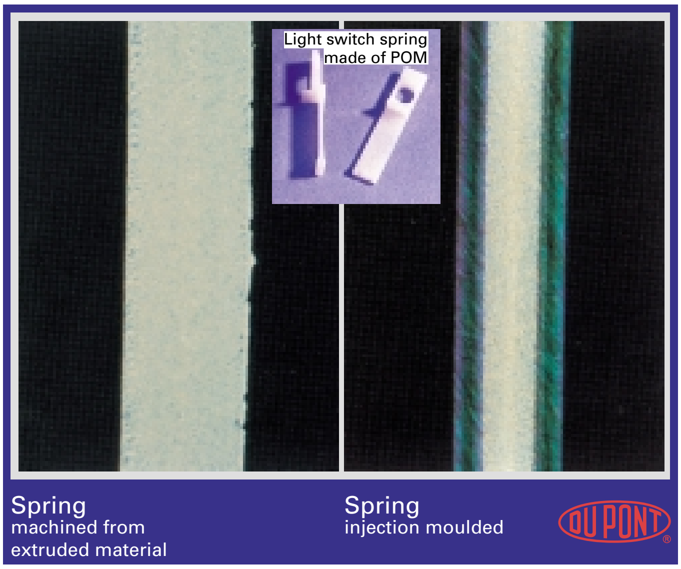


Fig. 3

The machined prototype for a spring in a light switch, produced from an extruded material, withstood 180 000 stress cycles without fatigue. The same part, when injection moulded, showed fatigue fracture after 80 000 stress cycles. The reason for the failure was the different crystalline structure of the injection moulding (Fig. 3).

Prototype moulds

To produce prototypes, existing pressure-diecast moulds or prototype moulds made from easily machinable or low-cost materials such as aluminium or brass are used. It should be kept in mind, however, that important injection-moulding parameters such as temperature and pressure cannot be reproduced with these moulds. In addition, their different cooling characteristics lead to different shrinkage and warpage behaviour. Preliminary production moulds made from hardened steel are recommended. These can be single-cavity moulds or a single mould cavity in a multi-cavity mould.

Testing plastics designs

With modern computer simulation techniques, such as strength analysis and flow analysis, potential weak points in the design or in processing can sometimes be identified at a very early stage.
However, it is not possible to give a 100 per cent guarantee for the quality of the end product and its behaviour under real-life operating conditions. The most reliable information is always obtained by testing prototypes under real operating conditions. This type of testing should never be omitted with engineering parts that have to meet high functional and quality requirements.
If it proves difficult to test under the actual operating conditions, tests under simulated service conditions may also be used. The value of such tests, however, depends very much on how accurately the operating conditions can be simulated.
Time-consuming series of tests to assess long-term behaviour under the effects of mechanical stress or heat are sometimes impracticable or not commercially justifiable. On the other hand, predictions as to long-term behaviour on the basis of accelerated tests under harsher conditions are not always clear-cut and should be treated with extreme caution. The behaviour of a plastic under stress in a long-term test may be completely different from that determined in a short-term, accelerated test.

Top Ten Design Tips

By Jürgen Hasenauer, Dieter Küper, Jost E. Laumeyer and Ian Welsh

Innovating with plastics

Many different applications from all industrial sectors demonstrate that the future belongs to plastics. If the material properties of polymers are intelligently exploited, then multi-functional components can be produced that are commercially and functionally superior to previous designs.
Today's designs require increasingly complex geometries and materials. Plastics can and will solve many different types of problem. It is important, however, to match the plastic to the application very carefully. Raw material (resin) manufacturers have extensive experience of this. Full use must be made of their expertise to translate new plastics design ideas into reality.

- Avoid material accumulations
- Aim for uniform wall thickness
- Design wall thicknesses as thin as possible and only as thick as necessary
- Use ribbing instead of greater wall thickness
- Provide radiusing
- Avoid flat areas
- Provide demoulding tapers
- Avoid undercuts
- Do not design to greater precision than required
- Design multi-functional components
- Use economic assembly techniques
- Gate mouldings on the thickest wall

When replacing metals,
redesign is always necessary.

Rules for designers
of plastics parts

Fig. 4