Licharz
engineering plastics

STRUCTURE AND PROPERTIES OF PLASTICS

The competitive edge through engineered components made of plastic

1. Fundamentals

In general terms, plastics are macromolecular compounds manufactured from existing natural substances by chemical conversion or by synthesising products from the chemical decomposition of coal, petroleum or natural gas. The raw materials produced by conversion or synthesis are usually converted into semi-finished or finished products by applying temperature and pressure.
These processes include, among others, injection moulding and extrusion. Exceptions to this are the polyamide semi-finished products manufactured by Licharz in static and centrifugal moulding processes, as these methods are done without pressure.

2. Structure

2.1 Classification

Usually plastics are classified in two main groups – thermoplastics and duroplastics.

- When they are heated to an adequate degree, **thermoplastics** soften until they are melted and then harden again on cooling. Forming and reforming thermoplastics is based on this repeatable process. Provided the heating does not cause excess thermal stress leading to chemical degradation, there is no change to the macromolecules.
- Because of their molecular structure, **duroplastics** cannot be reformed after they have been originally formed, not even at high temperatures. The original formation is based on a chemical reaction of intermediates, most of which are not macromolecular, to closely cross-linked macromolecules.

In DIN 7724, plastics are classified according to their behaviour when subjected to different temperatures. This leads to the following classification:

- **Plastomers** (= thermoplastics) are non-cross-linked plastics that react energy-elastically (metal elastically) within their service temperature range, and which soften and melt from a material specific temperature onwards.
- **Thermoplastic** elastomers are physically or chemically coarse-meshed, cross-linked plastics or plastic mixtures. In their normal service temperature range they behave entropy-elastically (rubber-elastically) but at high temperatures they soften to the point of melting.
- **Elastomers** are coarse-grained, temperature-stable, cross-linked plastics which are entropyelastic (rubber-elastic) in their service temperature range. They can be formed reversibly and do not flow until they reach their decomposition temperature range.
- **Duromers** (= duroplastics) are close-meshed, cross-linked plastics, which react energy-elastically (metal-elastically) in their service temperature range and which do not flow until they reach their decomposition temperature range.

2.2 Structure and form of the macromolecules

Apart from a few exceptions, the plastics that are produced today are generally based on the ability of carbon to form long chains through atomic bonds. As opposed to ion bonds, the outer shell of the carbon atom fills to the noble-gas configuration with eight electrons. Bond partners can be complete atom groups or single atoms such as hydrogen, oxygen, nitrogen, sulphur or carbon.

Through synthesis many individual small molecules (= **mono**mers) of one or more starting products are bonded together chemically into macromolecules (= **poly**mers). As a rule, the resulting chains are between 10^{-6} and 10^{-3} mm long. The size of the macromolecules is expressed by the degree of polymerisation n or by the molecular weight. As it is not possible to achieve a homogeneous distribution of the chain length in polymerisation, the values are given as averages. It is normal to give a measure of the viscosity (e.g. melt index, M.F.I.) instead of the degree of polymerisation or the molecular weight. The higher n is, the higher the viscosity.

In the formation of macromolecules a distinction is made between linear, branched and cross-linked molecule structures:

- If the monomers are bonded with one another at two points (bifunctional) this forms a threadlike, linear macromolecule.
- If the individual monomers are bonded at more than two points this produces molecule branches.
- If monomers are mainly bonded with one another at three points (trifunctional) this forms a spatial, weakly or strongly cross-linked macromolecule.
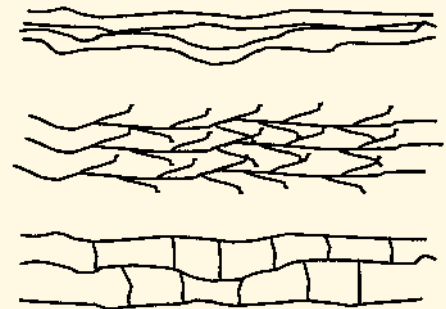
Linear or branched macromolecules produce thermoplastics, weak cross-linked ones produce elastomers and strongly cross-linked macromolecules produce duromers.

As Licharz has specialised in the manufacture and marketing of semi-finished products and finished parts from thermoplastics (plastomers), we will only consider the thermoplastic group and its various sub-groups in the following. There is adequate literature available that deals with the other groups of plastics.

2.3 Molecular bonding force

The coherence of macromolecules is based on chemical and physical bonding forces.

For polymer materials these are:
- the primary valency forces as a chemical bonding force
- the secondary valency force (van der Waals forces) as a physical bonding force

The primary valency forces are essentially responsible for the chemical properties of the plastic, while the secondary valency forces are responsible for the physical properties and the alignment of the macromolecules.

2.3.1 Primary valency forces

The primary valency forces that are generated by the bond distance and the bonding energy come from the atomic bond of the polymers. The smaller the bond distance between the individual atoms in the polymer chain the higher the bonding energy. The bonding energy is also increased with the number of bonds of the individual atoms.

**2.3.2 Secondary valency forces (Secondary bonding forces)**
The secondary valency forces come from the intermolecular bonds. They consist of three forces:

1.) Dispersion forces are the forces of attraction between the individual molecules in the substance. These are greater the closer the molecules are to one another. In the crystalline ranges of the semi-crystalline plastics, these forces are especially high because of this. This explains their mechanical superiority compared to amorphous plastics.

Increasing the distances between the molecules drastically reduces the forces. One reason for increasing distances could be vibration caused by heating the polymer material. But intercalating foreign atoms between the molecules (e.g. solvent or water) can also increase the distance.

By intercalating plasticisers in the molecule chain, this effect can be used to produce plastics that are rubber-elastic at room temperature.

2.) Dipole forces are not found in all plastics. They only occur if the atomic bond has a strong overweighting to one side due to the alignment of the atoms in the galvanic series. This can only happen if dissimilar partners form a bond. The more electronegative atom of a bond draws the electron pair towards itself (➜ polarisation) and a dipole is formed. The neighbouring polarised groups attract one another because of the unequal electrical charges.
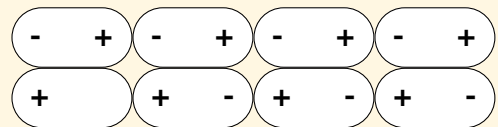
Polymer materials with a dipole character are generally less soluble (with the exception of strong polar solvents) and soften at higher temperatures than polymer materials without a dipole character. PVC is the most significant polymer material with a dipole character.

3.) Hydrogen bridges are bonds of opposite oxygen and hydrogen molecules of different molecule chains due to their high affinity to one another. This type of bond is the most stable of all secondary valency bonds. The hydrogen bridges are only dissolved with very strong forces and immediately reform themselves as soon as the displacement forces cease, rather like Velcro. The excellent properties, like a high melting point or extraordinary toughness, of various polymer materials such as polyamides are due to hydrogen bridges.

Other purely physical intermolecular bonds are entanglement, looping of chains or bonding in the semi-crystalline ranges. These are described as network points that allow molecule interlocking power transmission.

In very thin and symmetrical molecule chains, the secondary valency powers are generally not so pronounced, apart from molecule parts in the semi-crystalline ranges. The molecule chains of polymer materials such as this can easily slide past one another if they are subject to mechanical load. These materials have very good sliding properties, but at the same time they are subject to high wear due to abrasion, and they have a high tendency to creep. Examples of this are PE-UHMW and PTFE.

2.4 Order of the macromolecules

Thermoplastics are classified in two groups according to the order of their macromolecules. A distinction is made between:

- amorphous thermoplastics with completely disordered macromolecules (wadding-like structure) due to the form of the basic units and /or the alignment of any side groups that exist. Amorphous thermoplastics are hard, brittle and transparent.
- semi-crystalline thermoplastics with some highly ordered, parallel positioned macromolecule chains that form crystallites. A large number of crystallites form so-called spherulites. Complete crystallisation (➜ semi-crystalline plastic) is not possible because of chain looping during polymerisation. Semi-crystalline plastics are tough and opaque to white.
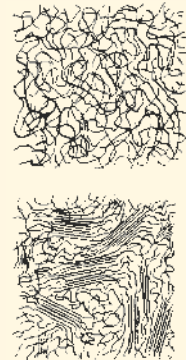
Semi-crystalline plastics have different properties than amorphous plastics due to the higher secondary valency forces. They soften later, can be subjected to more mechanical load, are more resistant to abrasion, are tough-elastic rather than brittle and are generally more resistant to chemicals. Because of this, the semi-crystalline thermoplastics are more significant for engineering plastics.

2.5 Alignment of the molecules in the macromolecule

Basically there are three different alignment possibilities of the substitute "R" in the molecule chain.
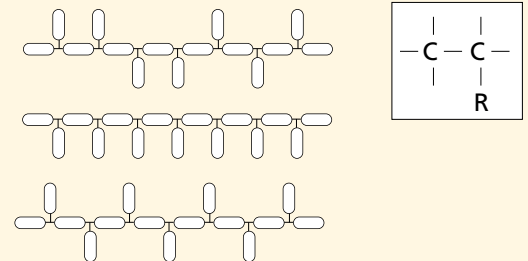
1.) Atactic
Random alignment in the chain

2.) Isotactic
Regular, one-sided alignment in the chain

3.) Syndiotactic
Regularly changing alignment in the chain

The polymer material can only have a crystalline structure if a regular chain alignment exists for a specific length of the complete sequence. As a result of this, the molecule alignment has a direct influence on the mechanical properties.

2.6 Homopolymers/copolymers

Plastics that are polymerised from the same monomer units are called homopolymers. Plastics that consist of two or more monomer units are described as copolymers. When copolymers are being produced, the monomer units are not just mixed, but chemically integrated into the molecule chain. With copolymerisation it is possible to improve specific material properties in a targeted manner.

Essentially, a distinction is made between four different types of copolymers:

1.) Statistic chain structure (random distribution of the different monomer units)
2.) Alternating chain structure (regular change of the different individual monomer units)
3.) Block-like chain structure (regularly changing blocks of the different monomer units)
4.) Graft polymers (homogeneous chain of one unit with grafted side chains of a different unit)

Another alternative to change the properties is to (physically) mix two polymers. The materials produced from this are known as polyblends.

3. Properties
The above-described molecular structure of the plastics produces a range of special properties and unique characteristics. In the following, several of these will be introduced and described in more detail.

3.1 Mechanical properties
The mechanical properties of plastics are primarily determined by the secondary bonding forces. The more pronounced these are, the better the mechanical properties.

Because of the morphological structure of plastics, the properties are dependent on factors such as
• time
• temperature
• moisture
• chemical influences
and fluctuate strongly depending on the influence of one of more factors.

3.1.1 Visco-elastic behaviour
All plastics have a more or less pronounced visco-elasticity. Mechanical load dissolves the secondary bonds in the molecule structure, and the molecule chains slide past one another. The longer the load is applied, the further the chains move away from each other.

This means that compared to metallic materials, plastics deform when subjected to high load over a long period (➜ cold flow). When maximum expansion has been reached, the plastic solidifies again and expansion is reduced. The weaker the secondary bonds in the macromolecule are, the more pronounced these properties are.

A simple molecule structure with no entangled side-groups, or a low degree of crystallinity in the plastic, encourages the chains to glide past one another.
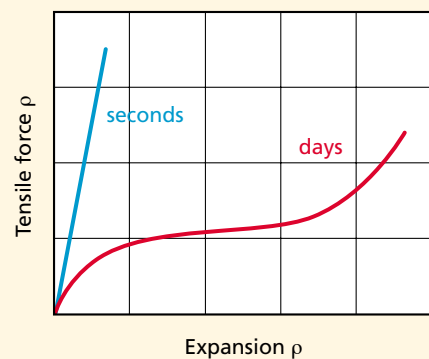
This deformation is further promoted by thermal influences. The molecules are stimulated to vibrate which leads to greater distances between the chains and consequently to weaker secondary bonds. Hence, stability values for dimensioning component parts cannot be used as a single point value, but rather they must be included in the static calculation in relation to load time and thermal effects.

3.1.2 Moisture absorption
In particular plastics produced by polycondensation (➜ polymerisation with the cleavage of water for example) have a tendency to absorb water from the surroundings via inward diffusion. This process is a reversible balanced reaction in which the more water which is available, the more the plastics absorb. The intercalated water molecules increase the distance between the molecule chains and weaken the secondary bonds.

The chains become more mobile, which results in a reduction in mechanical values and an increase in elasticity as well as swelling. In the case of polyamides the hydrogen bridges do not just ensure excellent mechanical properties such as good abrasion resistance, mechanical stability and toughness, they also lead to intercalation of water in the molecule chains. As both water and the polyamide molecules are capable of forming hydrogen bridges when the water has diffused into the molecule chain, it separates the existing hydrogen bridge and occupies the free valences. The water molecules make the polymer chain slightly more mobile which gives room for more water molecules. This process continues until the saturation point has been reached. When the water concentration in the surroundings falls again, the process is reversed. Water absorption is favoured by increasing temperatures and high ambient moisture. By absorbing water, the polyamides become more tough-elastic and less solid and rigid.

Water content ρ

Water content ρ

For applications in which these properties are required, it is possible to increase the water concentration by storing the materials in hot water (➜ conditioning).

For water absorption through atmospheric moisture, it should be noted that the process in thick-walled component parts only takes place close to the surface and that generally no water absorption, with the described effects, should be expected in the inner area of the component part.

3.1.3 Influence of chemicals
Chemicals can attack and separate the primary and secondary bonds of the molecule chains, which can be seen by swelling or decomposition of the plastic. Swelling of the plastic is caused by the chemical diffusing into the molecule structure, leading to a loss of stability. In a purely chemical attack, the loss of stability can occur with no noticeable increase in volume or weight.
The inward diffusion of the foreign molecules reduces the secondary valency powers to such an extent that the internal stresses in the material or external forces can cause (stress) cracking (➜ stress corrosion cracking).

3.2 Chemical resistance
Compared to metallic materials, plastics have a high resistance to chemicals. This can be attributed to the fact that the molecules are linked through atomic bonding. Because of their physical nature, the secondary valency powers only play a subordinate role. Most plastics are resistant to many acids and alkaline solutions as well as aqueous salt solutions and solvents. However, oxidising acids and organic solvents can be a problem in many cases, but this problem can be resolved by using special plastics. Resistance to chemicals decreases as the temperature and exposure time increase. This can be seen by an increase in weight and volume as well as a decline in mechanical values. A lack of resistance to a specific medium can generally be seen by a swelling of the plastic with no appreciable chemical attack, or in a chemical attack with medium to severe swelling.
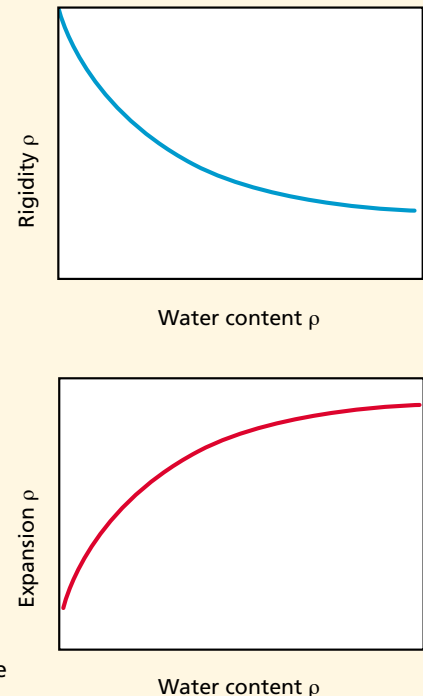
3.3 Electrical properties

Because of the atomic bonding of their molecules, plastics, unlike metallic materials with ion bonds, do not have free electrons and are thus classified as non-conductors. However, the insulation properties can be greatly reduced or even completely negated through water absorption and/or the addition of metallic fillers, graphite or carbon black.

Many plastics are suitable for use in high-frequency areas as their dielectric losses are very low and they only heat up a little.

Losses in the area of application should be
- for high frequency insulators $\quad \epsilon_r \cdot \tan \partial < 10^{-3}$
- for high frequency heating $\quad \epsilon_r \cdot \tan \partial > 10^{-2}$

Plastics generally have a surface resistance of $> 10^8 \ \Omega$. In the event of friction with a second non-conductor, this leads to electrostatic charging due to electron transfer at the boundary surface. Plastics without any conductance additives are not suitable for use in explosion protected areas as sparks can be caused when they touch grounded objects.

3.4 Dimensional stability

Increasing heat or intercalation of foreign molecules (e.g. water or solvent) in the chain compound of the molecule chains increases the distance between the chains. This causes the volume of the plastic components to change, resulting in a change in its dimensions. Vice versa, as the surroundings become colder, or when the water concentration decreases, the volume is reduced and is accompanied by the corresponding shrinking and size reduction.

Plastics are generally formed or reformed to semi-finished products from the melt. As a rule, the semi-finished products we manufacture are thick-walled products with large volumes, such as solid rods, slabs and blocks. As plastics are poor heat conductors, the edges of the products cool much quicker than the core. However, because of heat expansion, this has greater volume than the edges. The outer area has already solidified with a loss of volume and the associated shrinking. The shrinking of the core causes inner stresses that "freeze" as the product cools. These stresses can be minimised by heat treatment (➜ annealing, similar to stress-free annealing of steel). However, some residual stress can remain. These decrease over a period of time due to the visco-elastic behaviour of the plastics (➜ relaxation).

Warm core

Solidified jacket
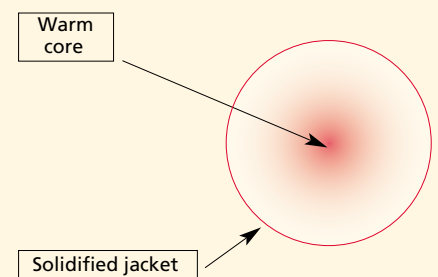
These residual stresses can be released by one-sided machining or heating and can become obvious through dimensional changes or distortion.

The properties of the plastics described above are more or less pronounced and can be compensated and kept under control relatively easily with proper design. The following chapters deal with special issues such as behaviour in fire, storage, material-compliant tolerances in components and many other factors.

1. Behaviour of plastics in fire and fire ratings

Generally, plastics are organic substances or modifications of organic substances, which, like other organic substances are threatened by chain breakage, cleavage of substitutes and oxidation at high temperatures. Therefore, apart from a few exceptions, plastics are more or less combustible, which is something that can be a serious technical problem in the specific use of plastics.

1.1 Combustibility

If plastics are heated locally or over large surfaces to above their specific decomposition temperature, they release volatile, low molecular constituents. In many cases together with the ambient oxygen, these form a flammable gas mixture which can ignite if an ignition source is added and an adequate supply of oxygen is available.

The amount of heat that is fed in and the volume of the combustible surface that this can affect are both very significant for the evolution of a fire and the course of the fire. Another decisive factor is the atmospheric oxygen concentration.

For instance, it is possible that a large quantity of heat which affects a large volume with a large surface area but a lack of oxygen only leads to pyrolytic cleavage in the beginning (➜ release of highly flammable, volatile and low molecular constituents). If one adds oxygen in the right concentration, under unfavourable conditions this can result in a deflagration or an explosion.

However, with the same volumes and a lower heat input, as well as an adequately high oxygen concentration, the same substance only burns slowly. Because of this behaviour, it is very difficult, if not impossible, to make any fire-technical forecasts.

1.2 Conflagration gases

As with the combustion of other substances, when plastics burn they produce various conflagration gases. As a rule, these are said to be highly toxic. This is not absolutely correct as, on the one hand, the toxicity depends on the type and quantity of the plastic involved in the fire and, on the other, all conflagration gases resulting from a (substance-independent) fire should be regarded as toxic.

One example is the conflagration gases resulting from the incineration of polyethylene, which, in addition to small quantities of soot and low molecular plastic constituents, almost exclusively contain carbon monoxide, carbon dioxide and water. This is comparable with the conflagration gases that occur when wood or stearine are burned.

In contrast, when polyvinyl chloride is burned, there is a danger of chlorine being released, which in combination with atmospheric moisture or extinguishing water forms to hydrochloric acid.

Many plastics produce a lot of soot when they burn, which makes it difficult for the fire brigades to reach the source of the fire. These plastics include the polyolefins PE and PP as well as styrene plastics such as PS and ABS.

This must be considered for designs in fire-critical areas.

1.3 Behaviour in fire

Almost all plastics are combustible. Exceptions to this are PTFE and silicones, which are virtually non-combustible. Most plastics continue to burn after they have been ignited and the source of ignition has been removed. Several extinguish when the ignition source is removed, while others cannot be ignited. In many cases, the plastic melts due to the heat of combustion and forms burning droplets which can promote the spread of the fire. The degree of combustibility can be reduced by adding the corresponding additives. Additives based on the following mechanisms are used:

- **Endothermy**
  The temperature of the plastic is reduced by the decomposition or vaporisation of the additive. This is possible for example with water stores (aluminium hydroxide) or phosphorous compounds being added to the plastic.
- **Radical bonding**
  The radicals that form during the fire are bonded by the additive, which slows down the thermal decomposition and consequently the release of flammable, volatile constituents.
- **Formation of heavy gases**
  Heavy gases are formed through the thermal effects on the additive, preferably halogens, which shield the plastic from atmospheric oxygen and thus prevent oxidation.

But the use of fire retarding additives does not make plastics non-combustible. Only plastics that are regarded as being non-flammable are suitable for applications that demand non-combustibility of the plastic.

1.4 Fire ratings

Often, to assess how plastics behave in fire, imprecise terms such as "highly flammable" or "fire resistant" or "non-combustible" are used. These terms inadequately reflect the actual behaviour of the plastics and only provide a limited inference for the usability of a plastic for a specific application. To assess how plastics behave in fire in the areas of electro-technology, traffic, building, etc. there are currently approximately 700 national and international test methods. In the electrical sector the method UL 94 HB or UL 94 V from Underwriters Laboratories (USA) has become the most widely accepted. These tests refer to the burning time and the burning behaviour of plastics. In test UL 94 V a distinction is made between classifications V0 to V2, V0 being the most favourable rating.

However, some test methods, such as the UL tests from Underwriters Laboratories (USA), have now obtained worldwide recognition for fire protection rating. Originally intended for electrical engineering, the methods UL 94 HB and UL 94 V are being applied as the most significant. In the meantime, however, other industries are increasingly moving towards test results obtained with this method. Principles for tests in accordance with UL 94 are the flash duration and the burning behaviour of plastics. These are calculated using two different test setups.

Behaviour in fire

Horizontal flame test (UL 94 HB)

The samples are horizontally clamped to a 45° incline to the horizontal transverse axis in the sample holder and ignited with a Bunsen burner at the free end. Marks are made on the sample at a distance of 25.4 mm and 101.6 mm from the end exposed to the flame. The sample material then corresponds to the classification, if the burning rate between the two measuring marks at sample thicknesses of ≤ 3.05 mm is maximum 76.2 mm/min and a thickness > 3.05 mm is maximum 38.1 mm/min. In addition, the samples must self-extinguish before reaching the 101.6 mm mark.
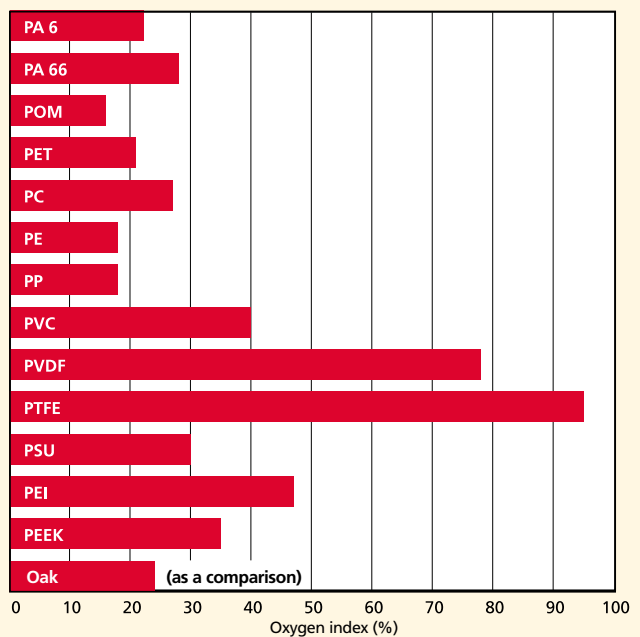
Vertical flame test (UL 94 V)

The samples are suspended vertically clamped in the sample holder. A piece of cotton wool is placed at a defined distance below the clamped test specimen. A Bunsen burner is placed vertically under the sample and ignites the free end. The flame is applied per sample twice for 10 seconds. The test criterion for classification is the amount of time that elapses between the removal of the burner and the self-extinguishing of the sample. As an additional criterion for the classification it is observed whether parts of the burning sample drip off and ignite the cotton wool placed below. Details to the individual requirements of the different classifications can be found in the table below.

	Classification according to UL 94		
	V0	V1	V2
Number of test pieces	5	5	5
Permissible burning time, per sample, with flame impingement	≤ 10 s	≤ 30 s	≤ 30 s
Total permissible burning time of 5 tests and 2 flame impingements	≤ 50 s	≤ 250 s	≤ 250 s
Permissible formation of burning droplets/ignition of the cotton wool	no	no	yes

Another possibility of comparing the flammability of plastics is the oxygen index. In a controllable O_2/N_2 mixture a vertical plastic sample is ignited and the minimum volume of O_2 required to burn the plastic is measured. This test also allows the effects of flame retardants to be observed. The diagram opposite contains several oxygen indices for comparison. Index values ≤ 21% can lead to continued burning after the source of ignition has been removed. Information regarding other technology standards and test methods applied are available on request.

PA 6
PA 66
POM
PET
PC
PE
PP
PVC
PVDF
PTFE
PSU
PEI
PEEK
Oak (as a comparison)

0 10 20 30 40 50 60 70 80 90 100
Oxygen index (%)

Resistance to radiation and weathering

1. Plastics' resistance to radiation and weathering

Changes in plastics due to weathering effects and high-energy rays are often described as "aging", with reference to the process of biological degradation. This is quite an accurate description since plastics, as organic materials, do not just have an analogy to natural substances in their constituents but also in their macromolecular structure. The parallels are also obvious by the fact that we often speak of the "life" of a plastic product. The duration is determined by the decomposition of the plastic. It may be relatively long compared to other natural substances, but it is still limited.

1.1 Radiation

The majority of plastics are subject to decomposition or a cross-linking of the macromolecular structure when affected by high-energy radiation. The changes in the molecular structure that actually occur depend on the atmospheric oxygen.

When oxygen is present, generally oxidative decomposition of the plastic occurs. This is especially the case when the dose of radiation is small, the surface area of the product is large and the walls are thin. Under these prerequisites, the atmospheric oxygen has sufficient time to diffuse into the plastic and to occupy the valences that are made free by the radiation.

In the absence of oxygen, the plastic is partially degraded by the main chains breaking up and partially cross-linked. Generally degradation and cross-linking reactions happen at the same time, although one of the reactions is stronger.

In any case, the changes in the plastics caused by radiation are accompanied by a loss of mechanical properties such as mechanical stability, rigidity and hardness or brittleness. Plastics that are subject to cross-linking can experience a change in properties even leading to a rubber-elastic condition. Besides this, during both the cross-linking and decomposition of the plastics, small amounts of gaseous substances such as carbon monoxide or carbon dioxide are released.

Attention should be paid to the fact that the described changes are very gradual and that there is no sudden, unannounced change in properties. The effects of radiation on plastics depend on the geometry of the component, dosage, mechanical load, temperature and the surrounding medium. Therefore, it is not possible to make a generalised statement about the damaging doses for individual plastics.

1.2 Weathering effects

Weathering resistance is mainly evaluated by the visual change of the surface. However, this leaves the question unanswered as to how the mechanical values change. On the one hand, it cannot be ruled out that plastics which are not subject to any great visual changes have a serious loss of mechanical properties and, on the other hand, plastics with considerable visual changes suffer no great loss of mechanical properties. But to evaluate weathering resistance correctly, the mechanical properties must be a measured. Some results of weathering are a decline in stability and hardness as well as an increase in elasticity or brittleness. The surface of the plastic can appear bleached or oxidatively degraded or stress cracks can form.

The changes in plastics as a result of weathering are mainly caused by thermal and photo-oxidative reactions as well as by the intercalation of water molecules in the plastic's chain structure.

UV rays and warming by direct sunlight lead to chain decomposition and free valences that are saturated by oxygen diffusing inwards. The surface becomes yellow or bleached.

In the case of semi-crystalline plastics there could be secondary crystallisation resulting in increased hardness and rigidity. Consequently these plastics are also more brittle and lose a large part of their elasticity. Frozen residual stresses from the manufacturing process can relax and cause deformation through the effects of warming – similar to an annealing process. This is especially serious for thin-walled finished parts.

By absorbing water, the plastics become tough-elastic and stability and rigidity decline, which can also be a problem with thin-walled finished parts. Weathering resistance can be improved with additives – in a similar way that fire retardant additives are used. However, it is not possible to provide a complete protection against degradation caused by the effects of weathering. Unfortunately no valid testing standard or standard parameters are defined regarding artificial weathering and its variables that could be used to compare resistances. However it can be said that plastics that have been coloured with carbon black or stabilised against UV rays with additives are more stable against light and weathering effects than light coloured or natural coloured grades. Exceptions to this are PVDF and PTFE, which have outstanding resistance to light and weathering effects even without colouring or additives.

However, due to their chemical structure even polyamides do not absorb UV radiation and are therefore in principle classified as a weather-resistant plastic. This assessment applies to thick-walled components (wall thickness > 5 mm). Changes in the material characteristics (e.g. embrittlement) are often only observed in extremely thin products (e.g. films and foils) – especially with double-sided weathering. However, changes are also observed in thick-walled components where they are exposed to high-energy radiation (UV rays or similar) whilst being exposed to the effects of oxygen at the same time. Under these conditions surface oxidation may occur which can lead to discoloration of the surface. However, as polyamides also act as an oxygen barrier, the effect of the surface damage remains limited to a depth of 0.2 to 0.3 mm. It forms a "rind" under which the core of the part is well protected against further oxidative attack. The effects of UV radiation on the material characteristics of the core material are therefore normally not observed. The phenomenon of rind formation is also valid for thick-walled parts made of polyamides used for water storage. Here, effects on the material characteristics of the core material, (an increase in elasticity with a simultaneous decrease in strength), are generally only observed when the part has reached the end of its service life due to mechanical influences (e.g. wear).

In the evaluation of weather resistance it is clear that not only the type of plastic used is significant, but also the geometry of the part. Changes that are caused by weathering are usually only reflected in the regions near the surface of the products. In general deep-lying layers are not attacked, so that thick-walled parts are less affected by changes than thin-walled parts. Nevertheless, for parts that are used in weather conditions or that are exposed to high-energy rays, it is recommended that resistant materials are used and that the resistance is verified by experimentation (if possible carried out under operating conditions).

Storage information

Information for material-related handling of plastics at receipt and in storage

The material properties and special features of plastics described in the previous sections clearly illustrate that plastic products can suffer unwanted quality losses due to environmental effects.

Therefore to maintain the high quality and functionality of our products – also over longer periods – several factors should be considered when handling and storing them:

1. Plastics become brittle at low temperatures and become hard, less elastic and sensitive to impact. In this condition the danger of breaking or splitting through external forces is very high – especially for finished products. Cold plastic products should never be thrown, shaken or dropped.
2. The properties of plastics can change due to weathering effects. The material properties can suffer irreversible negative effects through sunlight, atmospheric oxygen and moisture (e.g. bleaching and/or oxidation of the surface, water absorption, etc.). If the products are subject to direct sunlight or one-sided heat, there is a danger of permanent deformation through heat expansion and released internal residual stresses. Therefore finished products should not be stored outdoors and semi-finished products should be stored outdoors for as short a period as possible.
3. Plastics have scratch sensitive surfaces. Sharp edges on shelves, nails in pallets, large dirt particles between the products and other sharp objects can cause scratches and/or grooves, which in turn can cause breakage and notching. When transporting and storing plastic products it should be ensured that the surface remains scratch and groove free and that no rough particles are allowed to adhere to the surface.
4. Not all plastics are equally resistant to chemicals, solvents, oils or fats. Several are attacked by these substances, which can lead to surface opacity, swelling, decomposition and permanent changes in the mechanical properties. Therefore, substances that can attack and damage plastics must be kept away from the products during storage.
5. Plastics are subject to reversible dimensional changes when affected by extreme temperature fluctuations due to shrinking or expansion. Dimension checks can only be carried out immediately on receipt of the goods if the products are at room temperature ($\approx$ +23 °C). Products with a higher or lower temperature could produce incorrect measured values due to shrinkage or expansion of the plastic. Too warm/cold products must be stored temporarily in a dry place and be brought up/down to room temperature before dimensions are checked.
6. Because of the production process, plastics, and finished products manufactured from them, can have residual stresses, in spite of annealing. These have a tendency to relax when the products are stored for long periods and subjected to temperature effects (e.g. direct sunlight). Polyamides also tend to absorb water when the humidity is high, which in turn causes the volume to increase. These processes are generally accompanied by dimensional and shape changes due to deformation.

Therefore for long-term storage we recommend closed boxes and constant conditions ($\approx$ standard climate +23 °C/50% RH). The expected dimensional and shape changes are thus kept to a minimum and generally have no effect on the function of the product.

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