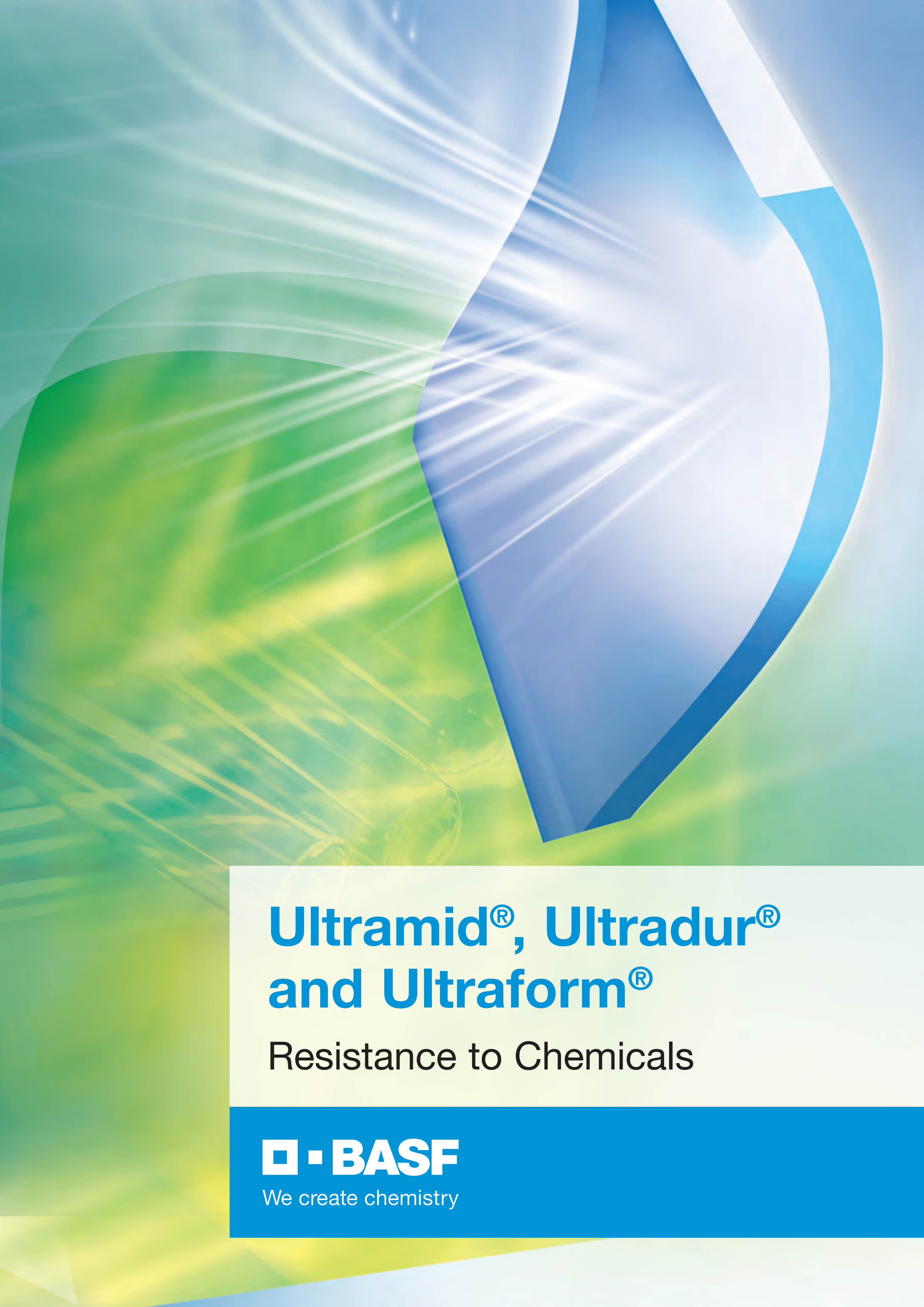

Ultramid®, Ultradur® and Ultraform®

Resistance to Chemicals

BASF
We create chemistry

Ultramid®, Ultradur® and Ultraform®

Basics

The following explanations should give an impression of the phenomena and influencing factors that can be met when thermoplastic components are exposed to chemicals. The statements made here are of a general nature and do not claim being complete or universally valid. Only in individual cases it is possible to adequately take into account all of the relevant factors and to assess the effects.

The consequences of exposing a polymeric material to various types of media can depend on many factors that sometimes interact in a complex way. Consequently, testing a component under realistic circumstances and under typical application conditions always gives the most meaningful results on whether a material is suited for a given application or not. In contrast, when it comes to laboratory tests, simple test specimens are often exposed to a medium under well-defined and constant conditions. Such experiments allow a relative comparison between different materials and thus lay the foundation for pre-selecting potential candidates as the right material for a given application. However, these experiments cannot substitute actual-practice testing.

Influence of processing on the resistance to media

Apart from the environmental conditions to which a component is exposed during its service life, all of the production and processing steps can also affect the quality of a component. Especially if environmental factors can be expected to cause damage to the material during later use, design as well as gentle and expert processing are particularly important aspects. After all, weak structural or qualitative spots usually mean that the material cannot withstand damaging environmental effects for longer, thus needlessly shortening the maximum service life.

Environmental effects

The environmental conditions for a component are essentially defined by the physical factors of temperature and pressure as well as by the chemical nature of the ambient medium. An ambient medium is fundamentally defined by its chemical composition. In fact, technical fluids often consist of one or two main components, together with several additives that are normally present in small concentrations. It can very well be that precisely these additives play a prominent role in the damage potential of a medium. It is not justified to transfer the test results of a medium 1 to a medium 2 that only matches the first one in terms of its main components. In the worst case, even impurities that are unintentionally present in the medium might be the decisive factor. This is especially the case when these compounds are catalytically active and thus could accelerate the damaging reactions.

It goes without saying that, in actual applications or in laboratory testing, not only the component undergoes aging but also the ambient medium. This aging process can be ascribed to chemical reactions in the medium and often goes hand in hand with the formation of chemical compounds that were not previously in the medium at all, or else only in small quantities. The statements made above also apply to the potential effects of these new compounds.

Media can act on a material or part in different ways. The boundary cases involving swelling, dissolution by solvents, reactions and stress crack formation will be briefly touched upon below.

Swelling

Swelling agents are media that a plastic can absorb in fairly large quantities and that then bring about changes in the properties of the part or material. For instance, the dimensions and weight of the component can change and, as a rule, so can the material properties such as stiffness, strength and toughness. The amount of swelling agent that can be absorbed is restricted by the saturation limit and so the plastic stays in solid form (these two factors distinguish swelling agents from solvents). Swelling is a physical process. The swelling agent and the plastic remain chemically unaltered in this process, they are simply present as a mixture. When it comes to partially crystalline polymers, swelling takes place practically only in the amorphous regions. If the ambient conditions change accordingly, then the swollen plastic can partially or completely release the swelling agent back to the surroundings. In this respect, swelling is a reversible process. However, once the swelling has occurred, the plastic will not be able to return completely to its original state. The reason for this is that swelling normally promotes relaxation or re-crystallization processes in the amorphous phase, so that the fine structure of the plastic changes slightly. Contact with swelling agents can be acceptable if the effect of the swelling agent does not jeopardize the functionality of the component.

The above-mentioned relaxation and re-crystallization processes can also be temperature-induced and can take place without the involvement of a medium. Temperatures above the glass-transition temperature promote this to a great extent. In many applications with partially crystalline polymers, the glass-transition temperature of the plastic is at least temporarily exceeded, sometimes even considerably. Here it should be noted that the glass transition temperature is reduced by swelling. Therefore, the tempering effects that occur in this process are fundamentally controllable.

Solvents

Solvents are media which, at a certain temperature, are capable of forming a liquid solution with a plastic. Whether a given medium is a solvent or not is highly dependent on the temperature. In the case of partially crystalline materials, a solvent has to be able to break up the crystalline structures of the polymer. As a rule, the closer this is to the melting temperature of the polymer, the easier this becomes.

In order to dissolve a polymer, especially with weak solvents, there is a need for larger quantities of solvent and a certain amount of time. In other words, brief contact of a component with small amounts of a potential solvent can be acceptable. The consequences are then similar to those described in the section on swelling. In this context, it is advantageous if the solvent is volatile and if the wetted site can easily dry again. Prolonged contact with larger quantities of solvents should be avoided under all circumstances.

Reaction between the ambient medium and the plastic

Whenever reactions occur between the ambient medium and the plastic, the extent of the resultant material changes must not exceed the acceptable limit. This is the case whenever the chemical reactions take place at such a low conversion rate that the part still works, even at the projected end of its service life.

Either directly or indirectly, chemical reactions normally cause splitting of the polymer backbone, that is to say, the polymer chains are shortened. Depending on the duration of these reactions, this can also lead to complete degradation of the polymer. The degradation products range from shorter-chain polymers to low-molecular-weight compounds which no longer have any of the properties of the original polymer.

Many material properties depend on the length of the polymer chains, but the individual properties by no means respond identically or simultaneously to changes in the chain length. Consequently, a universal definition of a limit for the end of the service life of components cannot be given.

Whether chemical reactions with a medium are more likely to occur in a boundary layer near the surface or throughout the entire volume of the part depends largely on how quickly the reactions take place (the reacting medium is consumed in this process) and how quickly fresh medium comes in again through diffusion from the outside. A reaction that is fast in comparison to the rate at which the medium is re-supplied promotes local damage that starts on the surface and can penetrate from there into the material. The damage is then diffusion-controlled. In contrast, a reaction that proceeds slowly in comparison to the rate at which the medium is re-supplied can cause damage that occurs uniformly throughout the entire volume of the part.

The higher the temperature and the higher the concentration of reactants (in other words, the plastic and the medium), the faster simple chemical reactions take place. For this reason, plastics that absorb a given medium in trace quantities or practically not at all can show a relatively high resistance to that medium. This, however, does not prevent possible damaging reactions on the surface.

Stress crack formation

Media that trigger stress crack formation are media that cause cracks to form within a relatively short period of time in a component that is under mechanical stress. As a rule, the media that trigger stress crack formation differ from one class of polymers to another. Partially crystalline polymers are less susceptible to stress crack formation than amorphous polymers are. The resultant cracks can have macroscopic dimensions and can cause the part to break.

Mechanical stresses can be caused by external forces or they can be due to internal stresses. These internal stresses are caused mainly by the local cooling processes, which always vary widely during injection molding since the layers close to the edges cool faster than those far from the edges. Since faster cooling often goes hand in hand with less shrinkage, layers that shrink differently can be formed. They are then under stress with respect to each other (compressive stress in the edge area and tensile stress in the core area).

Crack formation can take place with or without the occurrence of chemical reactions. Stress crack formation can be local and can even occur after exposure to very small quantities of the media in question. Therefore, contact with media that trigger stress crack formation is particularly critical and should be avoided. If such contact with a medium that triggers stress crack formation cannot be completely avoided for specific reasons, then care should already be taken during the design phase to ensure that the components are stress-free. Besides, it is advisable to use specially modified materials that, within their polymer class, are as impervious to stress crack formation as possible.

Viscoelasticity of plastics

Plastics, especially thermoplastics, usually exhibit a viscoelastic behavior that is not negligible for the application, i.e. components that are under an external load (stress) show irreversible time- and temperature-dependent plastic deformation (creep). Figure 1 shows two creep curves for Ultraform® S2320 003. This material shows total strains (sum of elastic and plastic elongation components) below 2 % on air at a temperature of 80 °C and at an external tensile stress of 9 MPa. In contact with fuel FAM-B (DIN 51604), a strongly swelling medium for Ultraform®, the plastic deformation increases several times despite the lower temperature (60 °C). This is usually accompanied by a faster failure of the component. Ultraform® S2320 003 AT shows a similar viscoelastic behavior as shown in Fig. 1.

Thermoplastic materials with reinforcing filler content (e. g. glass fibers, Figure 2), high crystalline content, high molecular weight and a glass temperature above the application temperature are less susceptible to creep.

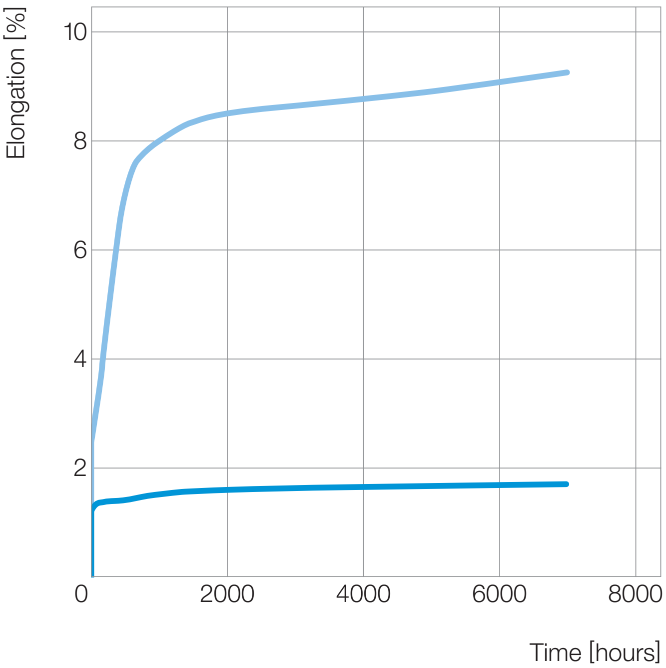

Fig. 1: Tensile creep test for Ultraform® S2320 003 at 80 °C in air (blue curve), and at 60 °C in FAM-B fuel (light blue curve) at a tensile stress of 9 MPa

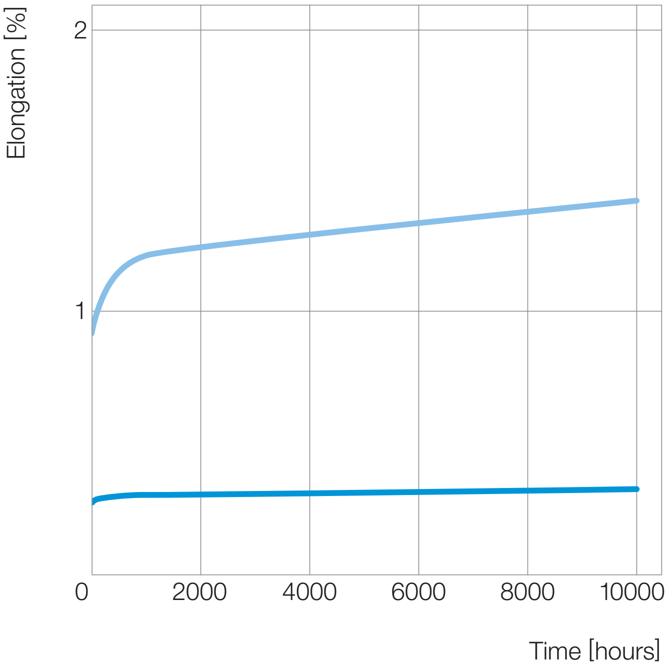

Fig. 2: Tensile creep test for Ultradur® B4300 G6 bk Q16 15007 at 60 °C in air (blue curve), and in FAM-B fuel (light blue curve) at a tensile stress of 15 MPa

Short-term media resistance of Ultramid®, Ultradur® and Ultraform®

The term short-term media resistance generally means that the surface and the properties of a plastic component should not change considerably in response to one-time contact with a chemical for one hour to a few hours at moderate temperatures. For instance, this is simulating the spilling of small amounts of operating fluids such as motor oil or battery acid in the engine compartment of a vehicle during the filling procedure. After a certain exposure time, the part in question is inspected for changes to its surface such as discoloration or cracks. If such changes are not visible, the material is classified as being resistant. The selection of the chemicals and the boundary conditions differ depending on the locationof the plastic part and on the OEM. The following example is typical for these requirements.

- Part: cylinder head cover made of Ultramid® A3WG6 bk 564
- Short-term contact: the surface is wetted with a drop of fluid; after a waiting time of 6 hours in a standard laboratory atmosphere, it is wiped off and inspected
- Typical contact points (Figure 3): area of ribs, radii and inserts

The test results are compiled in Table 1. This example shows that many operating fluids for automobiles (except for acids) are not critical for Ultramid® (Figure 4) during short-term contact.

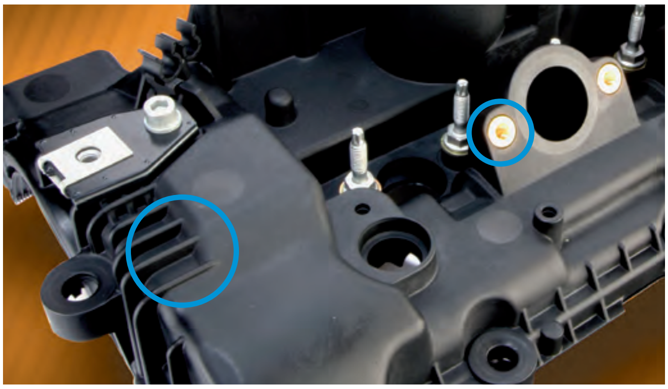

Fig. 3: Typical contact points for testing short-term media resistance.

Fig. 4: Visible surface damage after short-term contact with sulfuric acid (2 %).

Test fluid	Test result
Coolant Glysantin® Protect Plus	No visible surface damage
Brake fluid DOT 4	Brake fluid DOT 4
Windshield cleaning fluid Sonax® AntiFrost & KlarSicht	No visible surface damage
Sulfuric acid (2 %)	Visible surface damage (Figure 4)
Diesel fuel	No visible surface damage

Table 1: Test results for a component made of Ultramid® after short-term contact with various chemicals

Additionally, for purposes of testing the short-term chemical resistance, stress cracking resistance tests are made with the bent strip method, for instance, analogously to DIN EN ISO 22088-3. In this test, tensile bars are clamped onto radius gauges that cause a defined strain of the outer fiber of, for example, 1 % or 2 %. Afterwards the test set-up is wetted with a chemical for several hours and subsequently visually inspected for cracks in case failure due to fracturing has not occurred.

The following example shows a typical result of the stress crack resistance test by means of the bent strip method (Figure 5).

Comparison of the materials: Ultradur® B4300 G6 and Ultradur® B4330 G6 HR. Grade B4330 G6 HR is optimized with special additives for particularly demanding environmental conditions while grade B4300 G6 does not have such additives.

Test procedure: injection-molded test specimens are clamped onto the bending gauge and brushed every 10 minutes with a 10 % sodium hydroxide solution for a period of one hour and, at the same time, they are inspected for cracks. At the end of the hour, test specimens that have not fractured remain clamped without additional wetting with the solution for 24 hours, after which they are once again assessed. The test results are compiled in Table 2.

Fig. 5: Stress crack resistance test by means of the bent strip method, conducted analogously to DIN EN ISO 22088-3; Ultradur® B4300 G6 bk 5110 on the left and Ultradur® B4330 G6 HR bk 15045 on the right.

	Time [minutes]						Time [hours]
Product	**10**	**20**	**30**	**40**	**50**	**60**	**24**
Ultradur® B4330 G6 HR sw 15045	✓	✓	✓	✓	✓	✓	✓
Ultradur® B4300 G6 sw 5110	✓	✓	✓	x	x	x	x*

Table 2: In the bent strip test, Ultradur® B4330 G6 HR shows improved stress crack resistance in contact with sodium hydroxide solution

✓ no stress cracking
x visible stress cracking
x* all specimens fractured before 24 hours had passed

Long-term media resistance of Ultramid®, Ultradur® and Ultraform®

In an evaluation of the long-term media resistance, products made of Ultramid®, Ultradur® and Ultraform® were exposed to the medium in question for at least a few weeks. After the period of exposure, the material was examined for changes. As a rule, exposure to the media was performed as follows:

- Use of standard test specimens: tensile bars of type 1A according to ISO 527-2 and/or flexural impact bars of type 1 according to ISO 179-1/-2.
- The standard test specimens were put in place immediately after having been injection-molded, that is to say, dry, and were then completely surrounded by the liquid medium; the test specimens should be positioned in such a way that they do not touch the vessel walls or each other and are not subjected to any external stress; only test specimens made of the same material must be kept in a given test vessel.
- The test vessel, preferably made of glass, is inert with respect to the medium. It is configured with a reflux condenser with which the atmospheric pressure is equalized; transparent test vessels are covered with aluminum foil to protect them against intense incident light.
- Autoclaves are used if the media temperatures are above the boiling point.
- The test vessels are heated by an adjustable heat source and the temperature of the medium is preferably measured with an internal thermometer.
- The test specimens are removed at room temperature, any media that might still be adhering to them are wiped off with a cloth; the properties are determined immediately after the test specimens have been removed.
- The tensile properties are determined in accordance with ISO 527-1/-2 and the Charpy impact properties according to ISO 170-1/-2 at +23 °C on at least three, preferably five, test specimens per instance of removal.

The figures in chapter 3 show the course over time of the material properties for long-term media contact. Accordingly, the time intervals between two measuring points (= instances of removal) were considerably longer in comparison to those of chapter 2 (evaluation of the short-term media resistance). Whenever a material changes considerably in its properties over a short time span, certain deviations can occur between the actual and the shown course of the properties. This is particularly true of the swelling at the beginning of the exposure period. However, this does not have a negative impact on the quality of the measured curves for the evaluation of the long-term media resistance of the materials.

Aliphatic and aromatic hydrocarbons

Aliphatic hydrocarbons are organic compounds that consist of carbon and hydrogen and that are non-aromatic. The simplest representatives include the alkanes (e.g. methane, ethane, propane), cycloalkanes (e.g. cyclopentane, cyclohexane), alkenes (e.g. ethylene, propylene) and alkines (e.g. acetylene).

The parent and one of the most important representatives of aromatic hydrocarbons is benzene. Other compounds that are derived from this substance and that have the benzene skeletal structure as a structural feature also belong to the aromatic hydrocarbons. Important members of this class are the alkyl-substituted benzenes, for instance, toluene, the various isomeric forms of xylene and the so-called polycyclic aromatic hydrocarbons, for instance, naphthalene.

In technical applications, Ultramid®, Ultradur® and Ultraform® often come into contact with mixtures of aliphatic and aromatic hydrocarbons:

- fuels (Otto fuel, diesel), greases, lubricants, motor oils, non-water based coatings and paints
- natural gas (the main component being methane, along with ethane and higher alkanes)

Ultramid®, Ultradur® and Ultraform® show good resistance to the most common aliphatic and aromatic hydrocarbons and their mixtures, which are often met in technical applications.

Otto fuel

Ultramid® offers good resistance to Otto fuel, which is illustrated in Figure 6 for the example of glass-fiber reinforced Ultramid® A and B. However, it should be noted that ethanol and methanol fractions in gasoline (fluid N) cause severe swelling of polyamide; this is not the case for pure Otto fuel (fluid C), which is extracted from petroleum. Consequently, the aspect of dimensional stability is often more critical than that of chemical resistance. This example uses reference fuels according to DIN ISO 1817, Appendix A.

- Fluid C (mixture of 50 % 2,2,4-trimethyl pentane and 50 % toluene)
- Fluid N (mixture of 90 % Fluid C, 7 % ethanol, 3 % methanol)

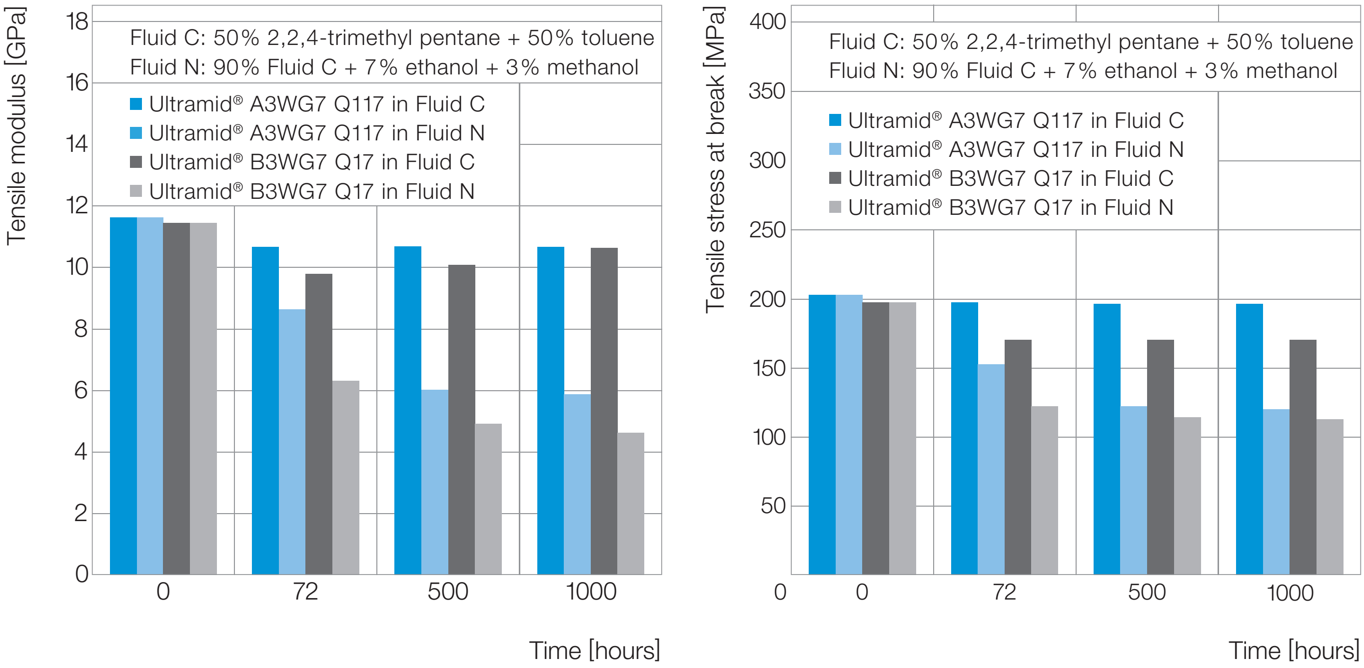

Fig. 6: Resistance of Ultramid® A and B to Otto fuel at 70 °C; the alcohol fractions in the gasoline cause swelling

Ultraform® S1320 003 AT and S2320 003 AT are very resistant in gasoline E10 (summer, 5-10 percent by volume of bioethanol) at 65 °C. The modulus of elasticity and the tensile strength of both materials remain – after swelling at the beginning of the storage associated with 2.5 % fuel consumption – at a consistently high level (Figure 7).

Ultraform® S1320 003 AT has a lower co-monomer content than Ultraform® S2320 003 AT. This results in increased crystallinity and thus greater stiffness and strength.

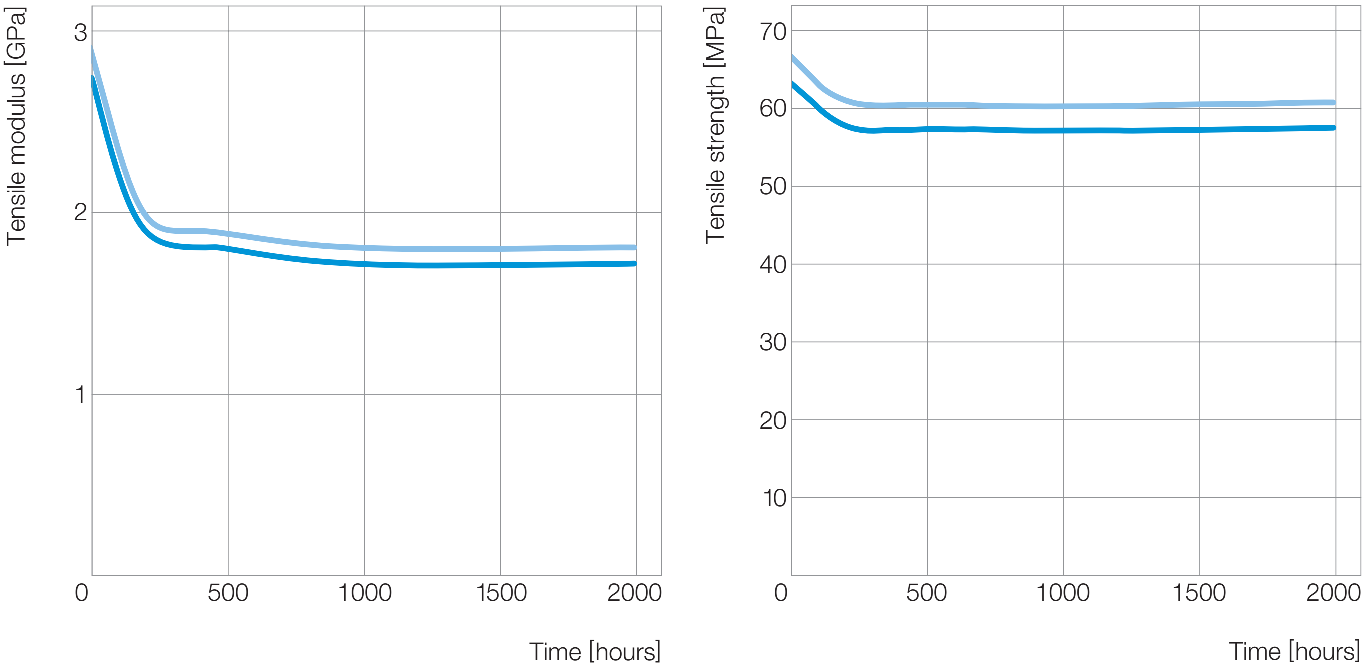

Fig. 7: Storage of Ultraform® S1320 003 AT (ligth blue curve) and S2320 003 AT (blue curve) in E10 at 65 °C

Diesel fuel

Figure 8 shows the storage of Ultraform® S1320 003 AT in a diesel fuel at 100 °C. The swelling in the diesel test fuel used by company Gage is only about 0.8 %. As a result, the tensile modulus of elasticity of the fuel-saturated material decreases only slightly. On the other hand, no loss of strength takes place over the entire test period of 84 days.

The excellent fuel resistance of Ultraform® has led to its longstanding success in the automotive industry, for example, for fuel tank covers, for components of fuel-carrying modules (Figure 9) as well as for tank vents (rollover valves).

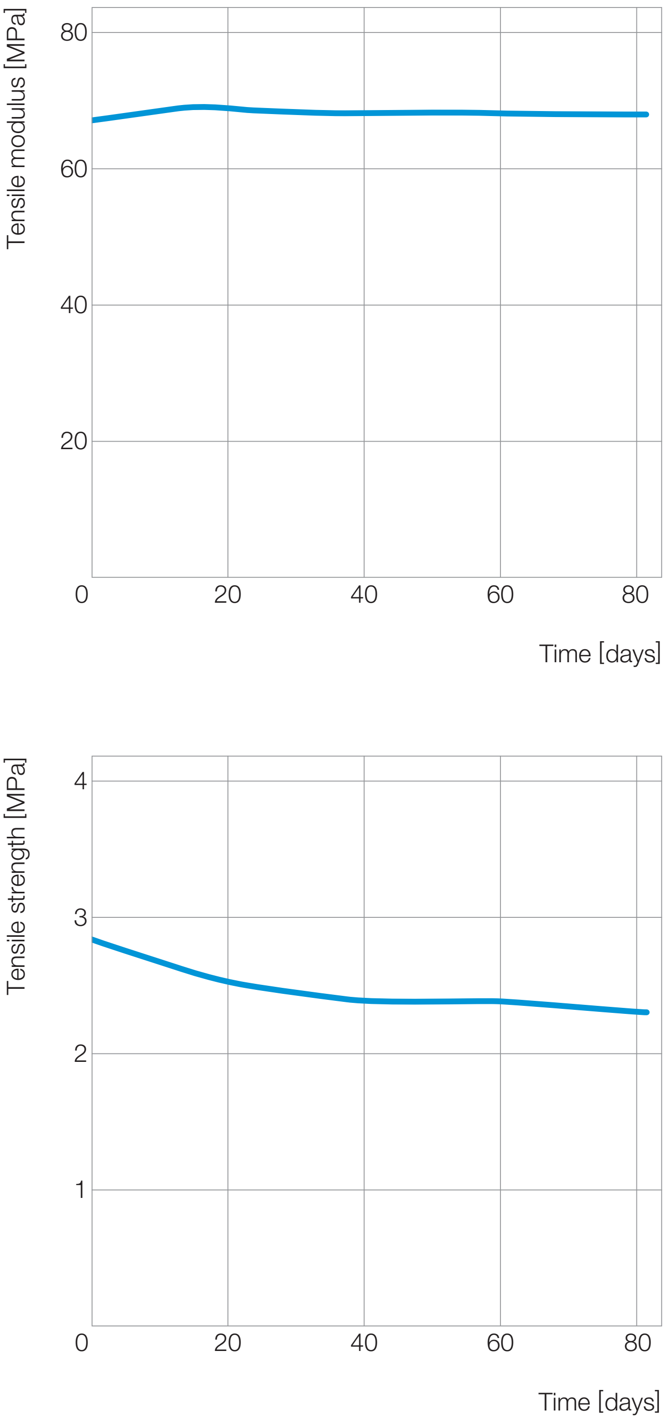

Fig. 8: Storage of Ultraform® S1320 003 AT in Diesel CEC RF-06-03 of company Gage at 100 °C

Fig. 9: Ultraform® fuel delivery module S2320 003 AT

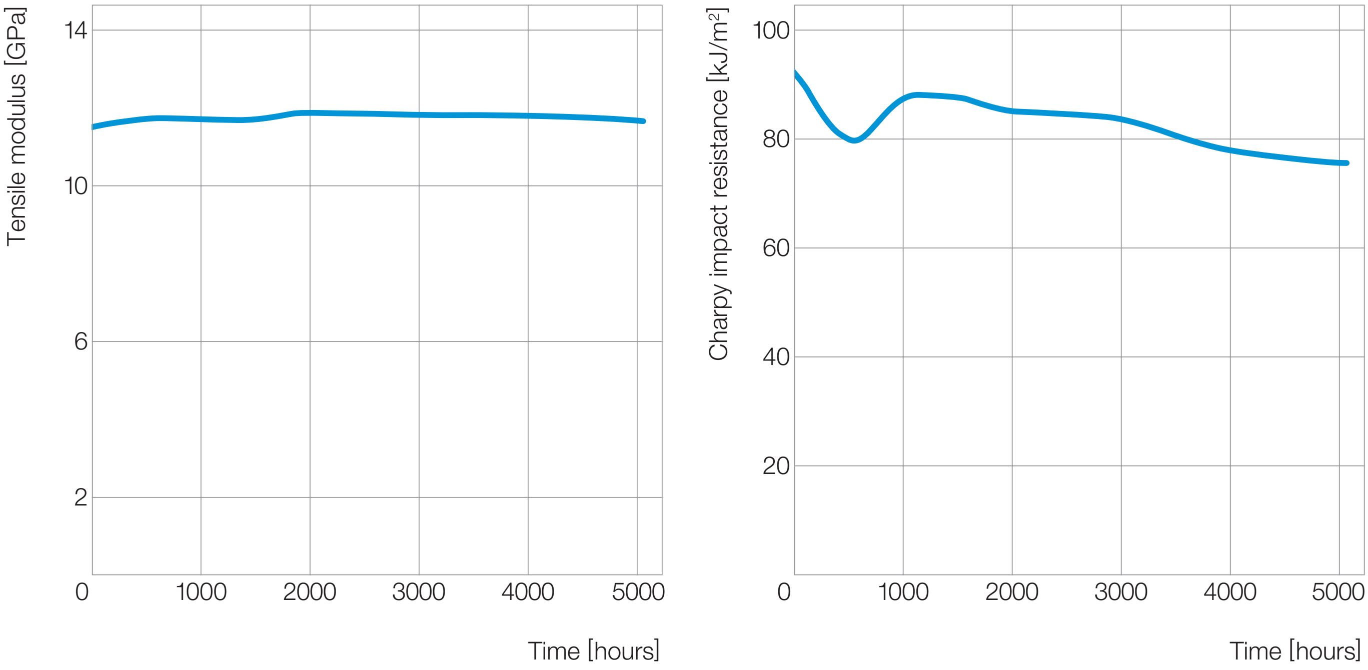

Fig. 10: Exposure of Ultramid® TKR 4355G7 bk 564 to diesel fuel ASTDM D975 2-DS 15 at 100 °C

Thanks to its more polar molecular structure, Ultramid® is generally more resistant to non-polar diesel fuels (without the admixture of biodiesel) than Ultraform® is. The partially aromatic Ultramid® TKR 4355G7 bk 564 in its saturated state absorbs less than 0.1 % of the diesel fuel. The modulus of elasticity, the tensile strength and the tensile strain at break remain practically unchanged over the course of 5,000 hours (Figure 10). Only the Charpy impact strength in the unnotched test bar drops slightly. Ultramid® TKR 4355G7 bk 564 is used, for example, in fuel pressure sensors (Figure 11).

Ultramid® A and B also show similarly good resistance to diesel fuel. This, however, only applies to a limited extent to biodiesel; see the section on esters.

Fig. 11: Fuel pressure sensor made of Ultramid® TKR 4355 G7 bk 564

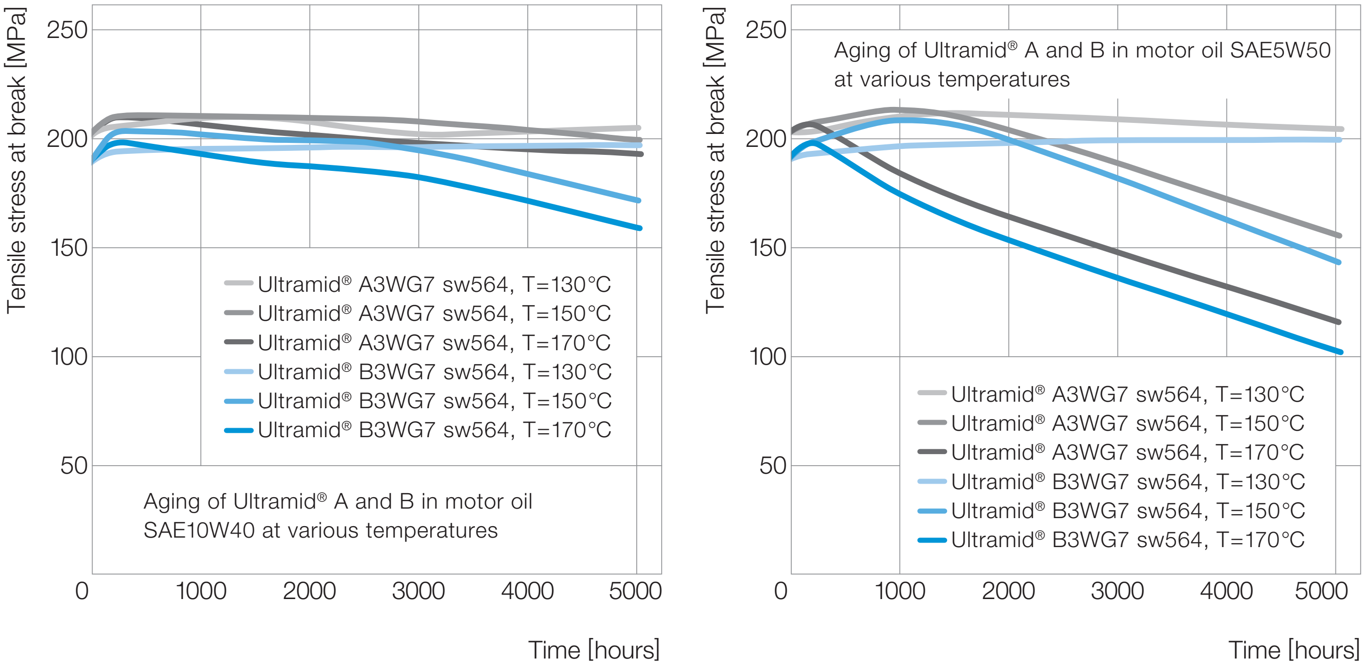

Fig. 12: Resistance of Ultramid® A and B to various types of motor oil at high temperatures; the typical limit of the application range of motor oil is about 150 °C

Motor oil

Generally speaking, Ultramid® has an outstanding resistance to hot motor oil, as can be seen in Figure 12 for Ultramid® A3WG7 and Ultramid® B3WG7 bk 564 for the example of exposure to two different types of oil at high temperatures. The usual exposure temperature is 150 °C at the maximum. Data at higher temperatures is used in order to predict the behavior over prolonged operating times. At the typical exposure temperature of 150 °C, the material still keeps more than 75 % of its initial strength, even after 5,000 hours. The influence exerted by the two types of oil on the behavior of the material differs markedly, which also confirms the need to carry out testing individually. The slight rise in the tensile strength at the beginning of the exposure period is due to post-crystallization of the product. It should be pointed out that the envisaged resistance at such high temperatures can only be achieved by materials that have been sufficiently heat-stabilized (for instance, as given in Figure 12 and 13).

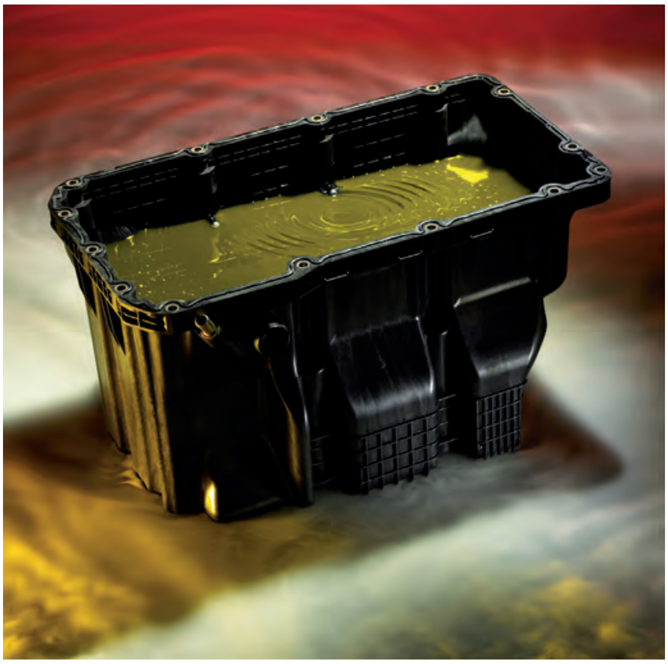

Fig. 13: Motor oil pan made of Ultramid® A3HG7 Q17

Greases and lubricants

Many technical greases and lubricants are based on mineral oil or synthetically manufactured hydrocarbon oils that have been thickened with metal soaps (e.g. calcium stearate, lithium stearate). The Ultradur®, Ultraform® and Ultramid® grades often show good resistance to such greases, even at elevated temperatures. As a rule, the user is not aware of the precise compositions of such lubricants. For this reason, it is recommended that a test be carried out in any case with the greases that are actually going to be used.

The unreinforced Ultramid® A4H has been successfully used in contact with lubricating grease for many years.

The behavior of Ultradur® B4300 G6 bk 5110 at 100 °C with respect to hydrocarbon-based greases is shown in Figure 15.

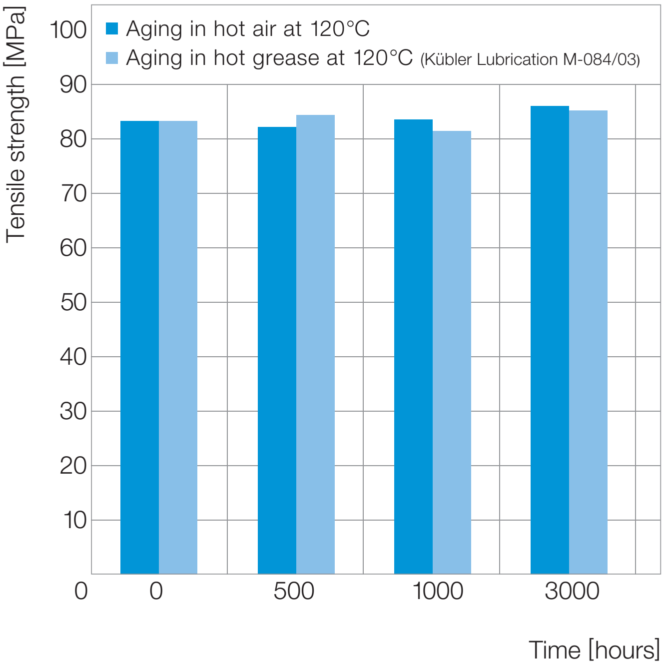

Fig. 14: Resistance of Ultramid® A4H to grease at 120 °C

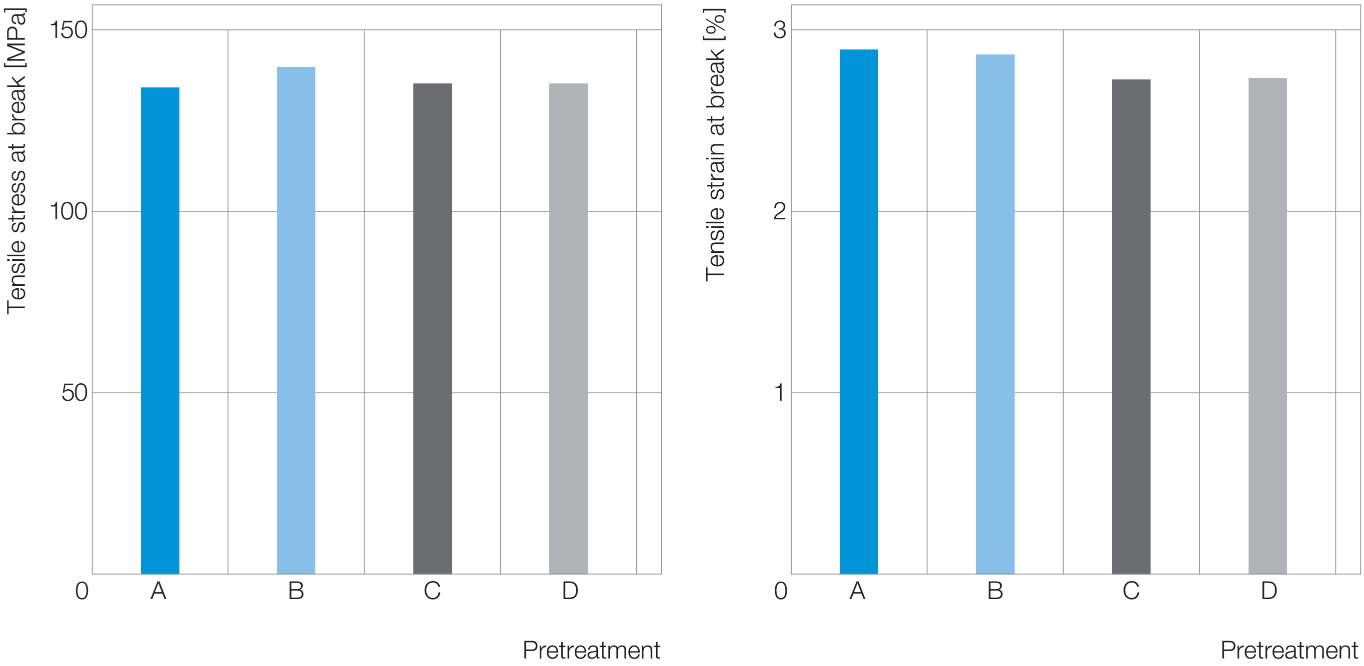

Fig. 15: Mechanical characteristic values of Ultradur® B4300 G6 bk 5110 as a function of the pretreatment
A: initial condition, freshly injection-molded
B: aged for 1,000 hours in hot air at 100 °C
C: aged for 1,000 hours in hot lubricating grease at 100 °C (synthetic oil, thickened with barium soap)
D: aged for 1,000 hours in hot lubricating grease at 100 °C (synthetic oil, thickened with lithium soap)

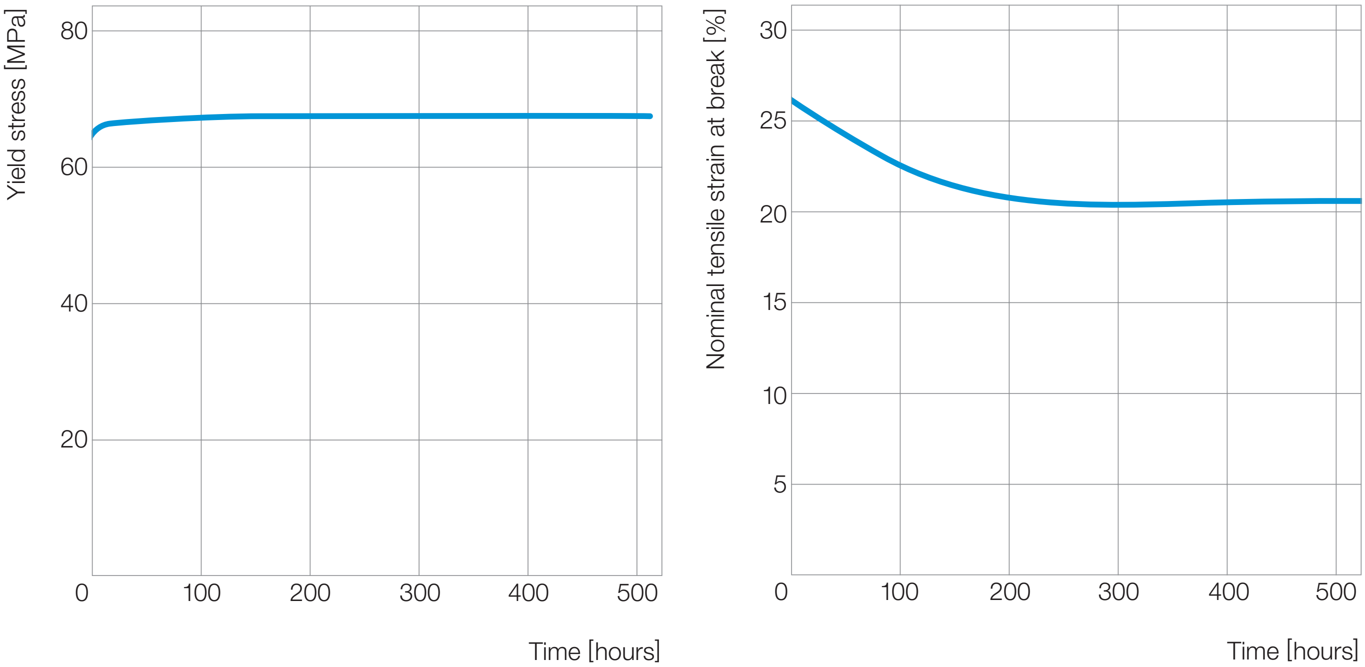

Fig. 16: Resistance of Ultraform® S2320 003 AT to a hydrocarbon-based lubricant at 90 °C

Figure 16 exemplifies the durability of Ultraform® S2320 003 AT vs. hydrocarbon-based lubricant at 90 °C.

Alkalis

Alkalis are substances that form alkaline solutions with a correspondingly high pH value when they come into contact with water.

Ultramid® offers good resistance to alkalis and alkaline solutions, although hydrolytic splitting of the amide groups can occur upon contact. The reaction rate at room temperature, however, is so low that no noteworthy damage occurs to the polymer.

For instance, after the swelling process has ended, Ultramid® A3EG7 in a 10 %-aqueous solution of ammonia shows only a moderate drop in strength within one year at 60 °C (Figure 17).

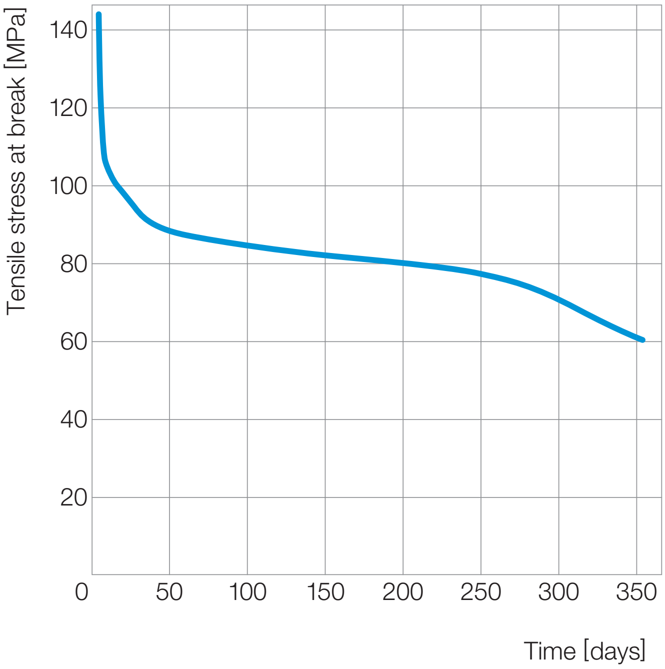

Fig. 17: Exposure of Ultramid® A3EG7 to a 10 %-aqueous solution of ammonia (pH 13) at 60 °C

Examples of applications in which Ultramid® has proven its worth for years include the following:

- plastic wall plugs in contact with concrete
- housings[2] for batteries that are operated with potassium hydroxide solution (Ultramid® B)
- SCR modules[3] in which the materials come into contact with an aqueous urea solution (Ultramid® A)

When glass-fiber reinforced polyamides are used, it should be kept in mind that contact with alkaline media damages the glass fibers and causes a deterioration of the mechanical properties.

Ultraform® has good resistance to alkaline media. The same applies to glass fiber reinforced Ultraform® products, e.g. Ultraform® N2200 G53 (AT) as to glass fiber reinforced Ultramid®.

Figures 18 and 19 exemplify the storage of Ultraform® N2320 U03 AT and Ultraform® N2200 G53 in the alkaline medium AdBlue®, an approximately 33 % aqueous urea solution, at 60 °C.

Figure 20 shows the tensile strength of Ultradur® B4300 G6 when exposed to aqueous sodium hydroxide solutions (caustic soda solution) at room temperature. The change in the tensile strength or the damage to the material depends to a great extent on the pH value. Whereas the material undergoes practically no drop in strength for up to 500 hours at a pH value of 10, the strength already drops after a very short time at a pH value of 14; after 200 hours, the material only exhibits one-fifth of its initial strength.

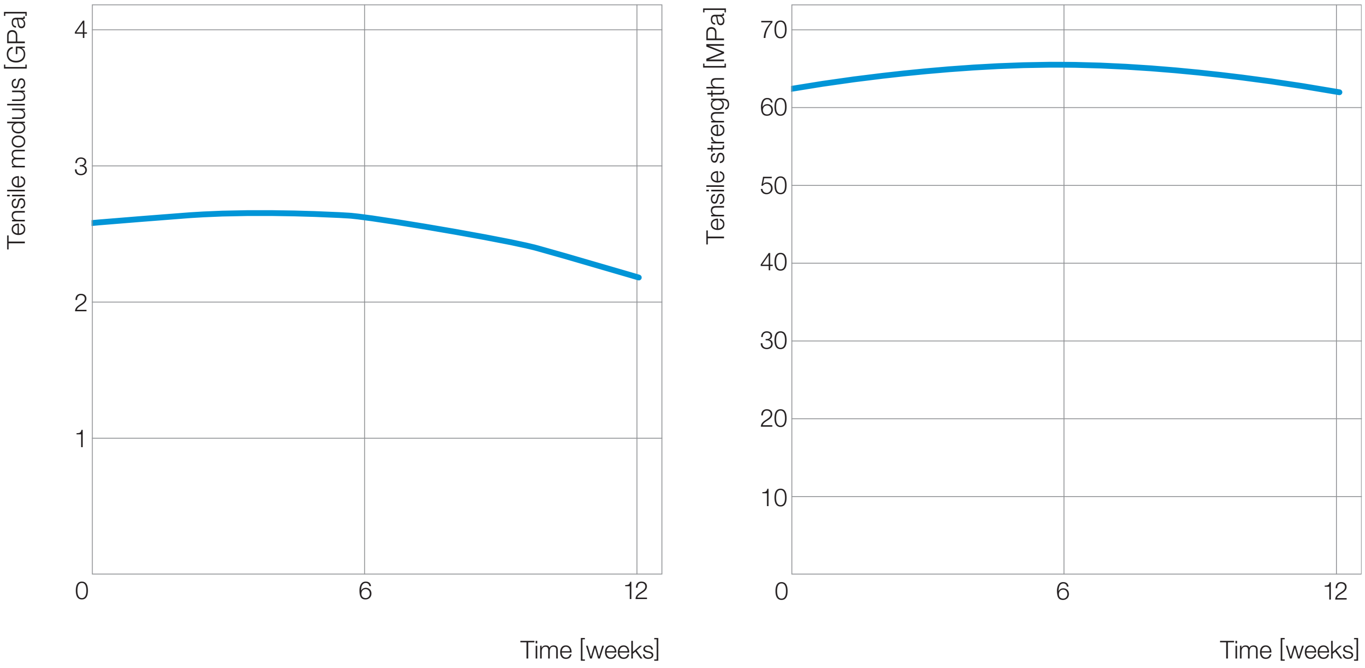

Fig. 18: Storage of Ultraform® N2320 U03 AT in AdBlue® at 60 °C

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[2] Gerhard W. Becker, Dietrich Braun, Ludwig Bottenbruch, Rudolf Binsack, Kunststoff Handbuch [Plastics Manual] Volume 3/4, Technische Thermoplaste-Polyamide [Engineering Thermoplastic Polyamides], page 246, published by Carl Hanser Verlag, 1998.

[3] Wolfgang Sauerer, Tilman Reiner, Materialien für saubere Dieselmotoren [Materials for Clean Diesel Engines], Kunststoffe [Plastics] 3/2007, published by Carl Hanser Verlag.

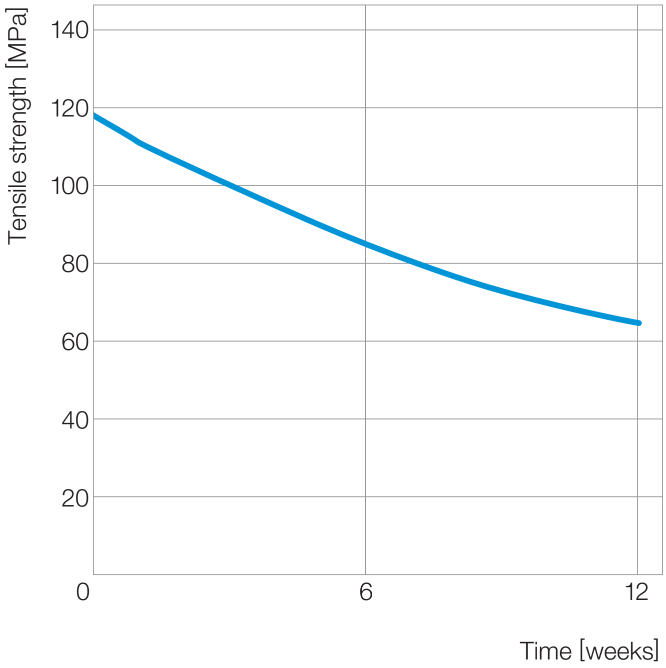

Fig. 19: Exposure of Ultraform® N2200 G53 to AdBlue® at 60 °C

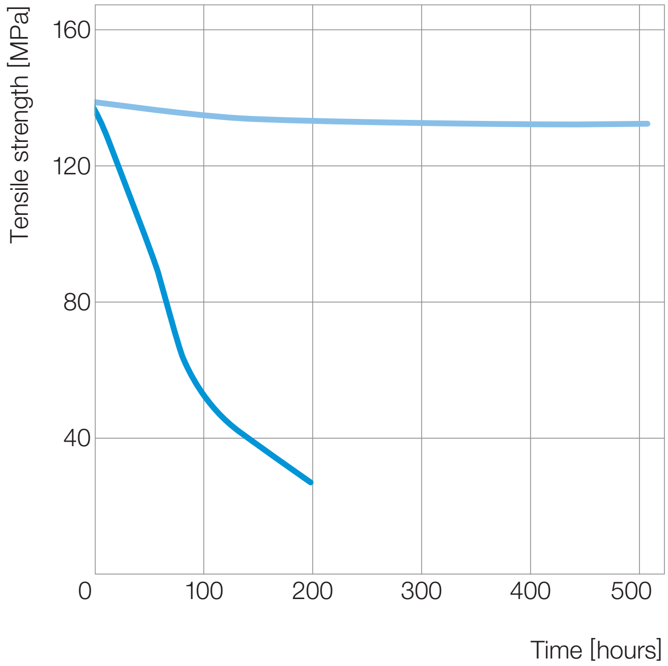

Fig. 20: Exposure of Ultradur® B4300 G6 to sodium hydroxide solution of different concentrations at 23 °C
light blue: 4 ppm of NaOH,
slightly to moderately alkaline, pH 10
blue: 10 % NaOH, highly alkaline, pH 14

Ethylene glycol

Ethylene glycol, also called shortly glycol, is known especially as an anti-freezing agent. For this purpose, it is admixed to the cooling water in automobiles (normally at a mixing ratio of 50:50). On the one hand, this accounts for anti-freezing properties down to about -40 °C and, on the other hand, the vapor pressure of the mixture is lower than that of water, so that coolant temperatures above 100 °C at a slight overpressure are possible.

Resistance in contact with coolant

The typical temperature in the cooling systems of internal-combustion engines in automobiles ranges from 85 °C to 90 °C, with peak values of up to 115 °C. Typical test specifications of the automotive industry are scenarios involving a coolant flow at 2 bar of overpressure and at temperatures of 135 °C for 1,500 hours. These conditions are simulated in laboratory tests by examining tensile bars after 1,000 hours to 3,000 hours of exposure at 120 °C to 135 °C. In this context, it must be pointed out that the stress differs greatly from that found in actual practice (for example, complete versus one-sided wetting with coolant, constant versus cyclically fluctuating temperatures).

When polyamide comes into contact with glycol-water mixtures, it swells markedly. The swelling causes it to soften already after a brief contact (1 to 2 days). After that, the polymer chains begin to degrade, which is highly dependent on the temperature, as is schematically shown in Figure 21. This fundamental behavior takes place in contact with all commercially available coolants, whereas the glycol types used have to be checked individually at the prescribed mixing ratio with water.

Under the conditions in vehicle cooling systems, commercially available Ultramid® B is classified as not being sufficiently resistant. In contrast, Ultramid® A is often used, for example, for coolant expansion tanks, radiator end caps and cooling water pipes. In these applications hydrolysis-stabilized products with the designation HR (hydrolysis-resistant) and HRX are used exclusively. Like Ultramid® A, Ultramid® T is also somewhat resistant, whereas Ultramid® S has a much better resistance, as a comparison of the products in Figure 22 shows.

BASF's polyphthalamide Ultramid® Advanced N offers in the best and longest resistance to this comparison coolant and reaches even at a 135 °C storage in a 1:1 mixture of glycol and water excellent mechanical properties for more than 3,000 hours. For more information on Ultramid® Advanced N on page 44.

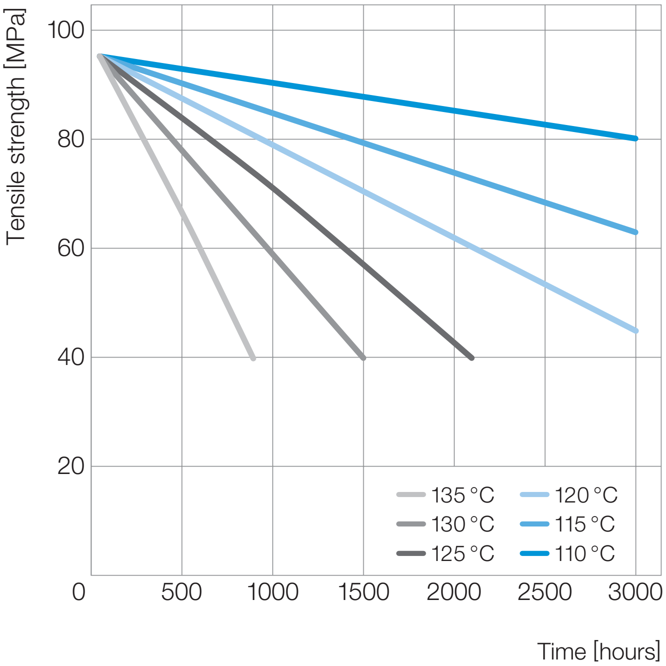

Fig. 21: Resistance of Ultramid® A containing 30 % glass fibers to a coolant consisting of glycol and water, as a function of the exposure temperature (schematically): rapid softening due to swelling, marked loss of residual strength at exposure temperatures > 120 °C. For comparison purposes: the tensile strength is 190 MPa when dry, 120 MPa at 1.7 % moisture, 95 MPa at 5.5 % moisture.

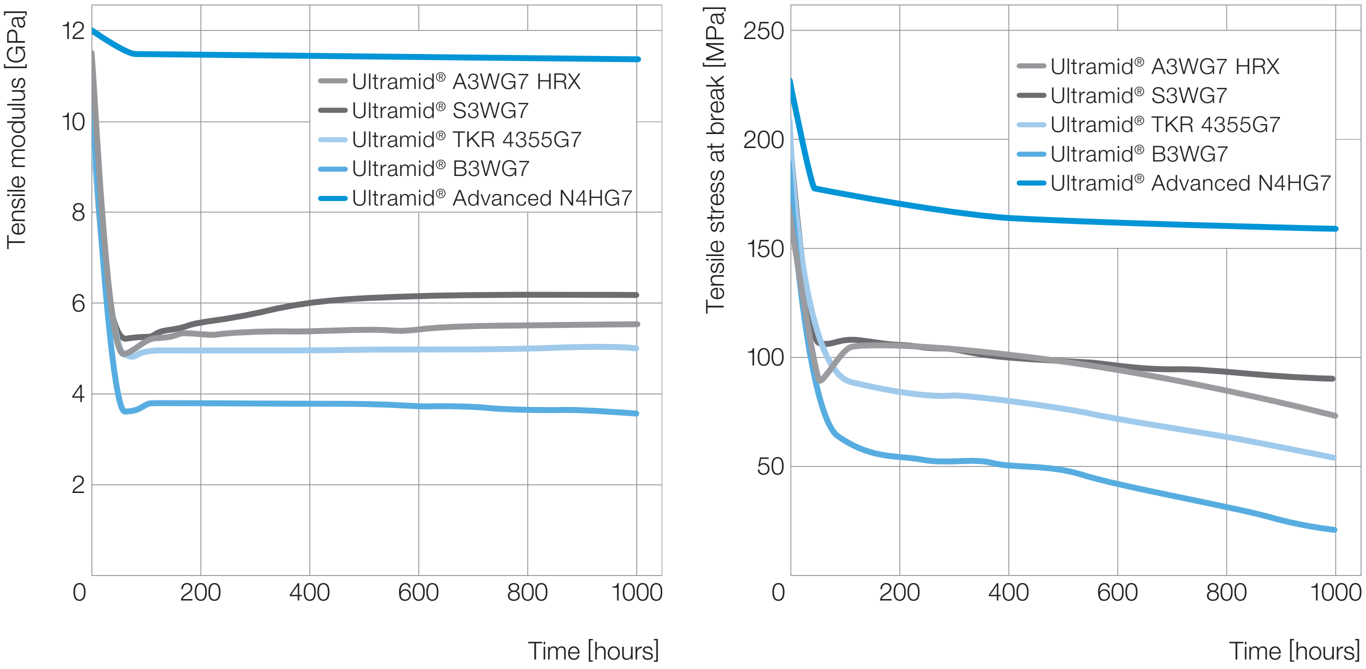

Fig. 22: Comparison of the resistance of Ultramid® A, B, S and T to coolants during exposure to Glysantin® G48/ water (50:50 mixing ratio) at 130 °C.

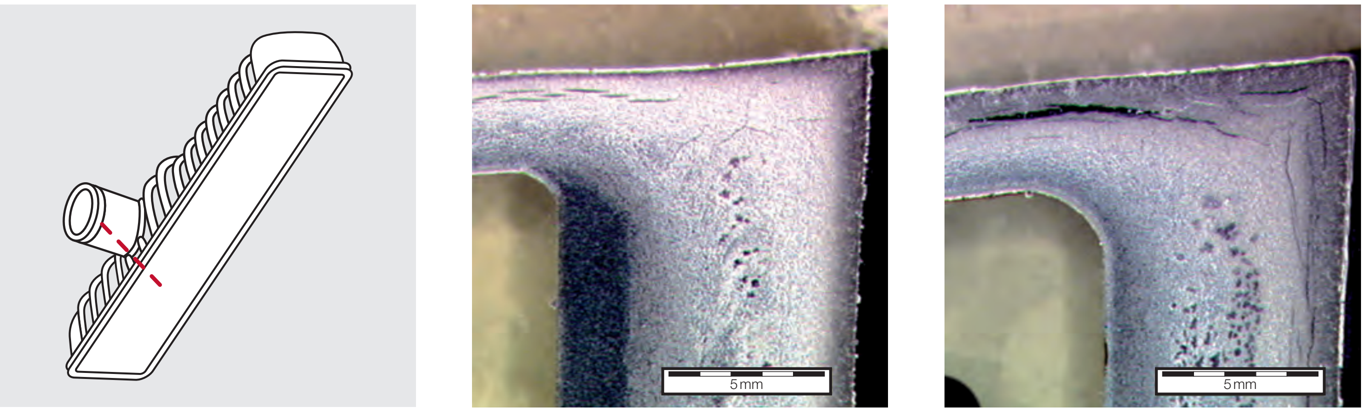

Fig. 23: Section through the connection piece of a radiator end cap following a service-life test; middle: Ultramid® A3WG6 HRX; right: standard PA66 GF30 HR, clearly visible material damage in the form of cracks which have not led to component failure

Aged components sometimes show cracks caused by contact with coolants, as illustrated in Figure 23 for sections of radiator end caps. This is why it is common practice to design the components with a sufficiently thick wall of about 3 mm, in order to take into account the reduced residual strength.

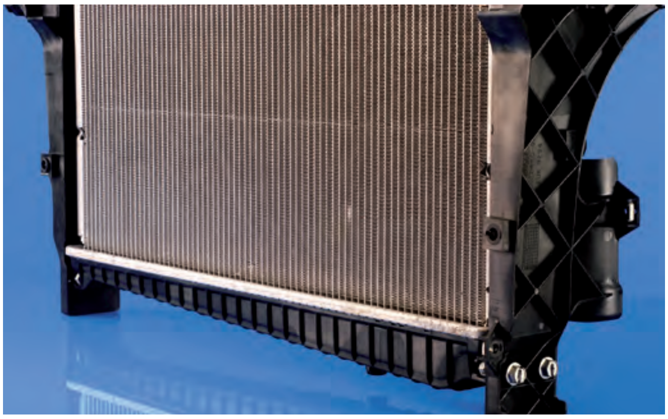

Fig. 24: End caps of vehicle radiators are a typical application for hydrolysis-resistant PA66 types such as Ultramid® A3HG6 HR

Glycol is likewise sometimes used as a heat-conducting medium in solar thermal energy systems. Commercially available Ultramid® is not a suitable material for pressurized systems operating at temperatures of up to 200 °C. In contrast, when it comes to drain-back systems with typical temperatures below 90 °C, Ultramid® can be considered to be resistant to a limited extent, depending on the requirements made of the dimensional stability.

Ultraform® is only partially suitable for applications in the cooling circuit of an automotive combustion engine. Temperature peaks above 110 °C should be avoided.

In the field of battery cooling of electric cars, the maximum temperature requirements for the material are lower due to the system. This opens up application possibilities for the material Ultraform®. Figure 25 shows the storage of Ultraform® N2320 003 AT and Ultraform® N2200 G53 AT in Glysantin® G40/water (50/50 mixture) at 100 °C. After swelling, both materials show a consistently high property level up to 1,900 hours.

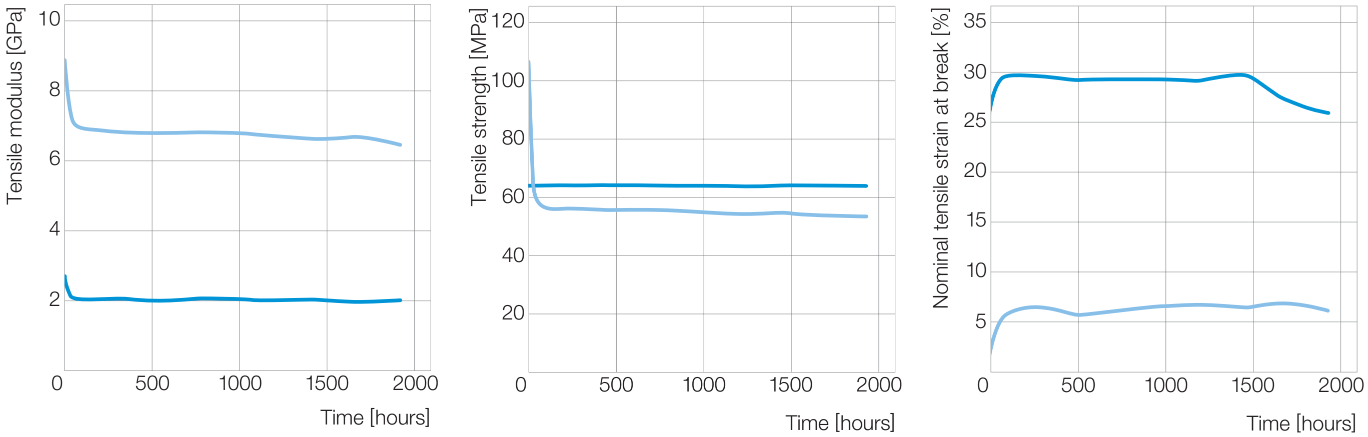

Fig. 25: Storage of Ultraform® N2320 003 AT (blue curve) and Ultraform® N2200 G53 AT (light blue curve) in G40 Glysantin®/ water at 100 °C

Resistance to contact with brake fluids and hydraulic fluids

Derivatives of ethylene glycol, for instance, higher homologues (such as diethylene glycol, triethylene glycol) and its ethers (e.g. triethylene glycol monobutyl ether) are used in conventional brake fluids as well as in special hydraulic fluids.

Ultraform® and Ultramid® are generally resistant to brake and hydraulic fluids containing glycol derivatives.

Figure 26 shows the data for Ultramid® A3HG5 and Ultramid® A3HG7 in DOT 4 brake and hydraulic fluid under typical conditions that are used to simulate the service life of a vehicle. Since brake fluid is hygroscopic[4], water is added to the test fluid, which causes the polyamide to swell.

Polyphthalamide Ultramid® Advanced N offers excellent resistance to brake and hydraulic fluid DOT 4 at temperatures up to 120 °C for more than 3,000 hours. For more information on Ultramid® Advanced N on page 44.

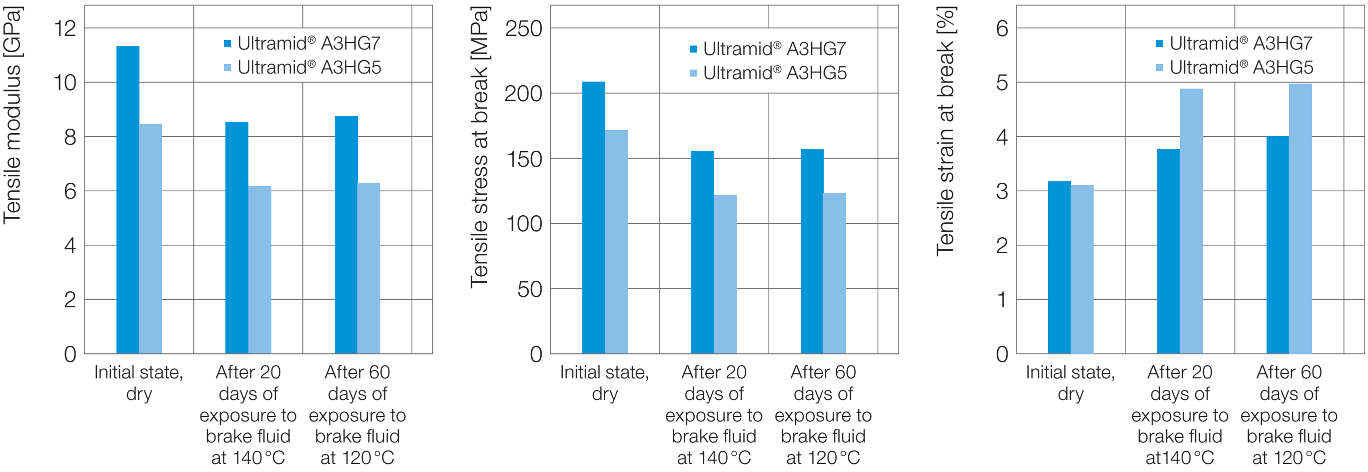

Fig. 26: Exposure of Ultramid® A3HG5 and Ultramid® A3HG7 to ATE Super DOT 4 brake and hydraulic fluid plus 3 % water.

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[4] hygroscopic: absorbs moisture from the air and binds it

Esters

Esters constitute a group of organic compounds that are formed by the reaction of an alcohol and an oxoacid, while splitting off water. Esters on the basis of organic acids must be distinguished from esters on the basis of inorganic acids. The former include, for instance, the carboxylic acid esters. They have the following common structural element: R-COO-R'. They are widespread in nature in the form of greases, oils and even fragrances.

The ultraplastics Ultraform®, Ultramid® and Ultradur® are generally well resistant to greases (e.g. edible oils, lubricating greases), oils (e.g. edible oils, lubricants, engine oils) and surfactants based on carboxylic acid esters. An increased content of free acids must be critically evaluated, as this leads to an accelerated cleavage of the polymer chains. This is especially true for esters based on inorganic acids. If the esters are hydrolytic[5] or are thermally unstable and persistent decomposition in the use phase continuously releases acid, an experimental test of the ultraplastics for their resistance is recommended.

The engineering plastics Ultraform®, Ultramid® and Ultradur® can come into contact with fatty-acid methyl esters in components that carry fuel. Fatty-acid methyl esters constitute the main ingredient of biodiesel. In Europe, this product is usually obtained through transesterification of rapeseed oil with methanol. In the United States, the vegetable oil base is usually soybean oil.

Aside from pure biodiesel (B100), biodiesel fuel is normally used admixed to mineral-oil-based diesel. Depending on the content of biodiesel, a distinction is made, for instance, between B20 (20 % parts by volume of biodiesel), B30 or B50.

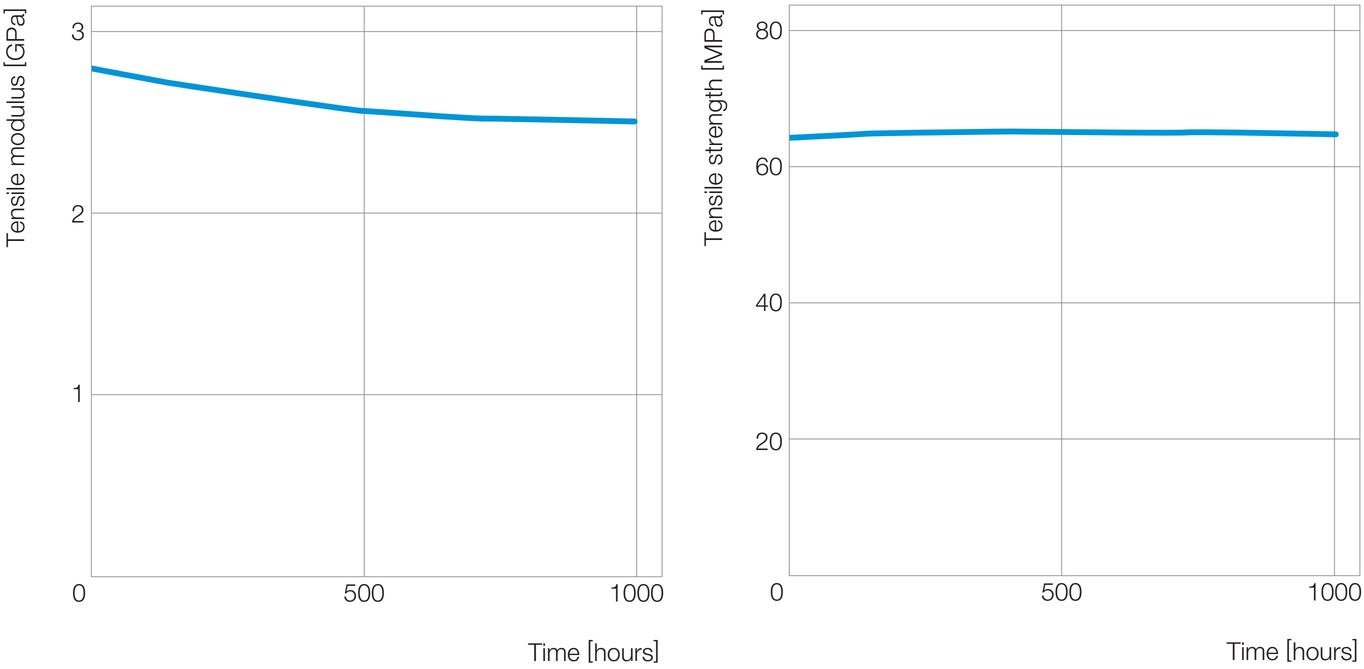

Fig. 27: Storage of Ultraform® N2320 003 AT in FAME (Biodiesel B100 RME) at 90 °C

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[5] hydrolytic: cleavage of chemical compounds through reaction with water

Ultraform® N2320 003 AT shows good resistance to biodiesel B100 (RME, according to DIN EN 14214 from Haltermann). At a storage temperature of 90 °C, no drop in strength can be detected after 1000 hours (Fig 27). The tensile modulus of elasticity decreases slightly, which is due to a slight swelling of the material.

Commercially available Ultramid® is only resistant to biodiesel to a limited extent. Moreover, its resistance is highly dependent on the origin and composition of the biodiesel. The resistance in pure rapeseed methyl ester (RME) is good; see Figure 28. The resistance to biodiesel made on a different basis can be considerably worse. Since the composition of biodiesel is not standardized, each type has to be tested individually, especially those from exotic sources.

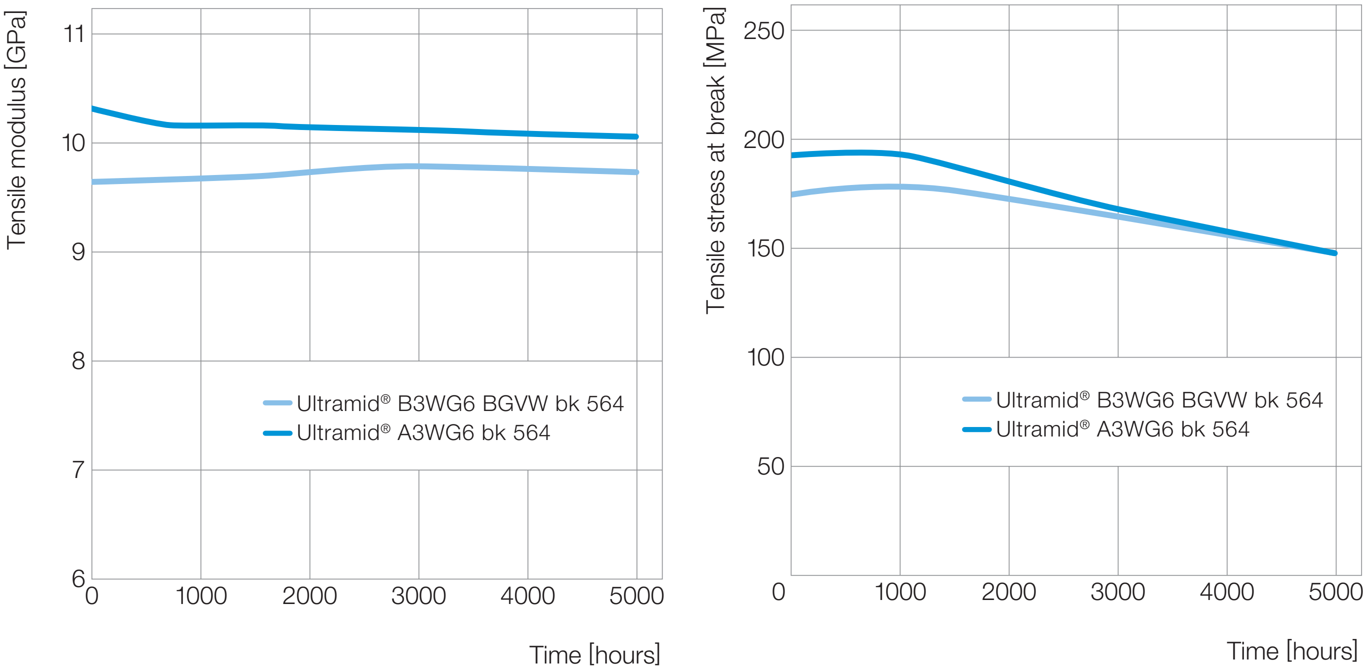

Fig. 28: Resistance of Ultramid® A and B to biodiesel (100 % RME) at 140 °C

Aliphatic alcohols

Aliphatic alcohols (alkanols) are primarily linear aliphatic hydrocarbons having one or more OH groups.

Due to their polar properties and small molecule size, short-chain aliphatic alcohols (for instance, methanol, ethanol) are absorbed by polyamides into the amorphous areas. This causes a change in volume and a reduction in stiffness and strength, since small molecules such as those of water or alkanols have a softening effect on polyamides.

This effect is more pronounced in Ultramid® B than in the higher crystalline Ultramid® A or in the partially aromatic Ultramid® T and Ultramid® Advanced N.

Important applications where polyamides come into contact with alcohols are the fuel systems of cars since alcohols are added to numerous types of fuel, and also components that come into contact with food products containing alcohol.

Fuels and their chemical composition:
Methanol and ethanol are used either in pure form (Brazil: M100, E100) or as a component of conventional fuels. Special bioethanol has become considerably more significant in recent years. Its percentage in the fuel fluctuates regionally and is usually between 5 % or 10 % (Europe: E5 or E10) and 100 % (Brazil: E100).

The mixtures based on Otto fuels are designated in accordance with the percentage of alcohol they contain. M15 or E15 are, for instance, fuels containing 15 % by volume of methanol or ethanol. Moreover, for testing purposes, a wide array of well-defined test fluids are employed so that the test results can be compared. The nomenclature for the unambiguous designation of test fuels and their specific compositions are described extensively in SAE standard J1681.

Fig. 29: Quick connectors for fuel lines using Ultramid® T

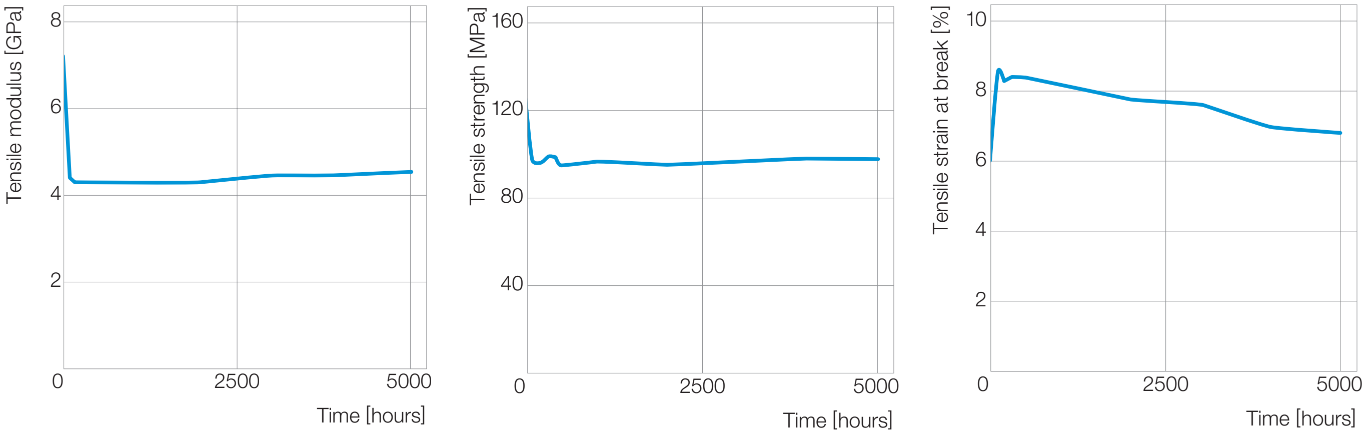

Fig. 30: Exposure of Ultramid® A3WG6 HRX bk 23591 to E50 at 90 °C (zero value = quickly conditioned according to ISO 1110).

Ultramid® A3WG6 HRX bk 23591 shows good resistance to E50[6] at 90 °C for up to 5,000 hours (Figure 30). In its state of equilibrium, this material absorbs approximately 4.5 % of E50.

Ultraform® is very well-suited for use in contact with fuels containing alcohol. This is the reason why it has been used in tank modules (Figure 9) for many years. Figure 31 shows the storage of Ultraform® S2320 003 AT in CM15A at 60 °C. By swelling with approx. 3 % CM15A takes the modulus of elasticity from 2.8 to 1.6 GPa off. Tensile modulus of elasticity and tensile strength remain then up to about 2,000 hours at a constant level.

In E50 at 70°C, the swelling of Ultraform® S2320 003 AT is much slower than in CM15A at 60 °C. The tensile modulus of elasticity decreases continuously from 2.7 to 1.6 GPa over a period of 6 weeks (Fig. 32). The nominal elongation at break increases accordingly from 27 to 43 %. The tensile strength, on the other hand, remains largely constant.

Ultradur® is somewhat resistant to aliphatic alcohols as a component of fuels. Particularly in the case of prolonged contact at high temperatures, it has to be assumed that the fuel components containing alcohol will cause a degradation of the polymer chains. Figures 33 and 34 show the behavior of a glass-fiber reinforced Ultradur® in contact with test fuels containing alcohol. The low-alcohol fluids (CM5[9], CE10[10]) have a high toluene content; the high-alcohol fluids (CM85A[11], CE85A[12]), in contrast, have a low toluene content. Above the glass-transition temperature of about 60 °C, Ultradur® swells considerably more markedly due to toluene than it does due to methanol or ethanol. Owing to this difference in the swelling, the stiffness and strength of the material drop more due to contact with the (low-alcohol) fluids that have a high toluene content. The irreversible material damage due to polymer degradation, however, tends to occur more in fluids that have a high alcohol content. This can be seen in Figure 33 on the basis of the decrease in the tensile stress at break from 750 to 1,000 hours (blue curve).

[6] E50: 50 % bioethanol and 50 % 98-octane premium gasoline.
[7] CM15A: 42.5 % toluene, 42.5 % isooctane, 15 % methanol with aggressive additives.

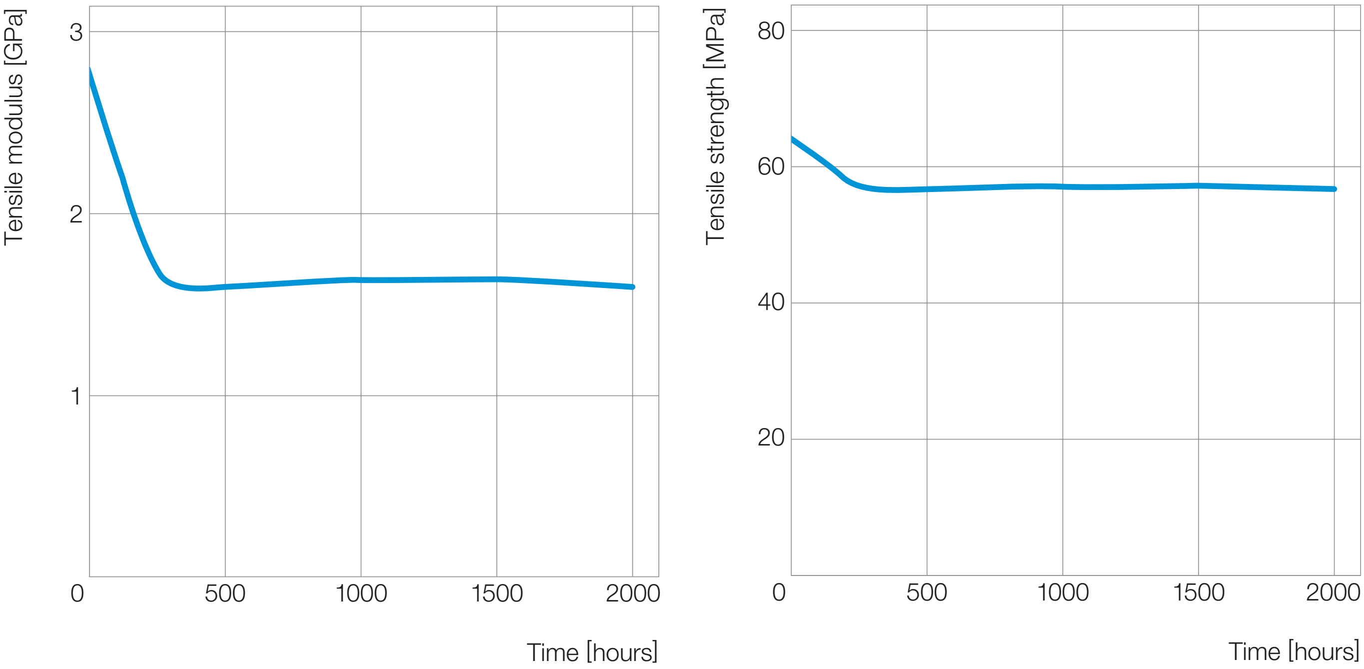

Fig. 31: Storage of Ultraform® S2320 003 AT in CM15A at 60 °C

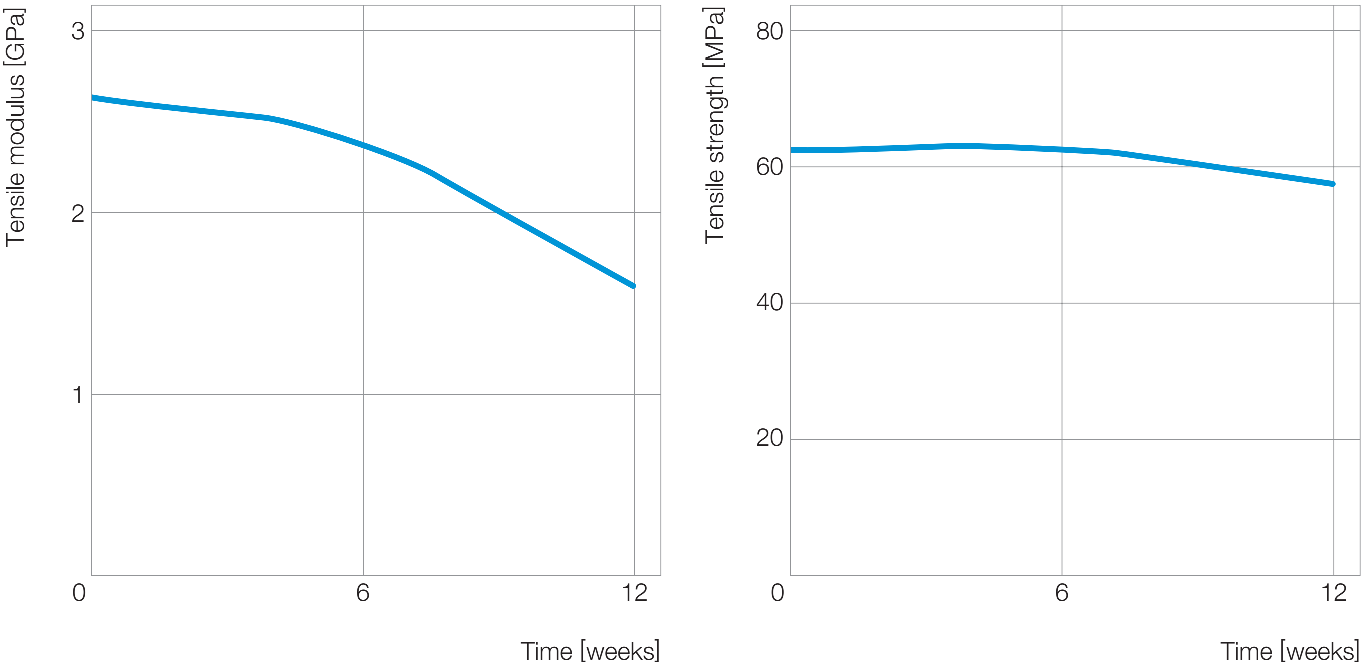

Fig. 32: Storage of Ultraform® S2320 003 AT in E50 at 70 °C

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[8] CE85A: 85 % ethanol with aggressive additives, 7.5 % isooctane and 7.5 % toluene.
[9] CM5: 5 % methanol, 47.5 % isooctane and 47.5 % toluene.
[10] CE10: 10 % ethanol, 45 % isooctane and 45 % toluene.
[11] CM85A: 85 % methanol with aggressive additives, 7.5 % isooctane and 7.5 % toluene.
[12] CE85A: 85 % ethanol with aggressive additives, 7.5 % isooctane and 7.5 % toluene.

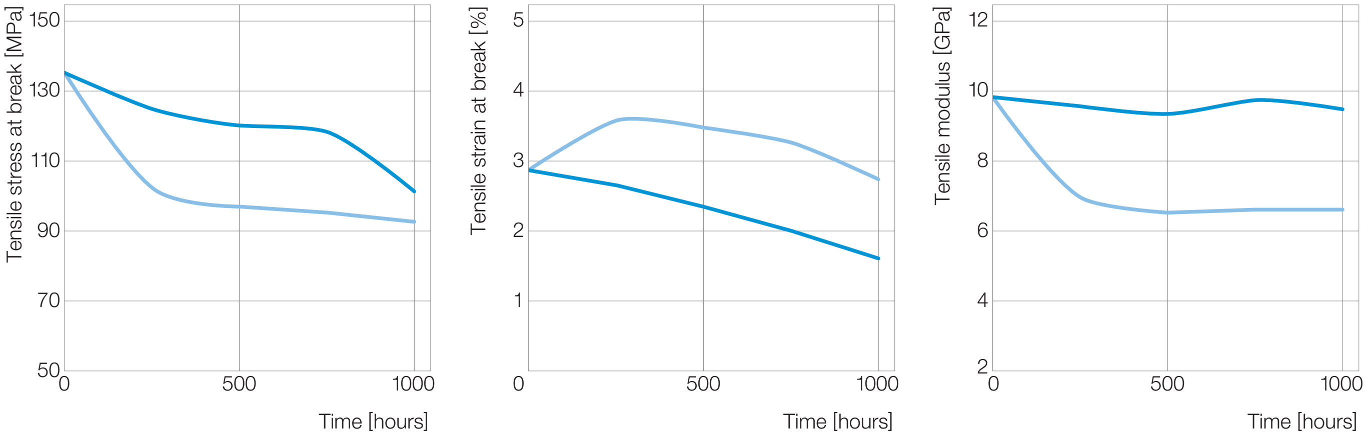

Fig. 33: Exposure of Ultradur® B4300 G6 bk Q16 15007 to fuels containing methanol
light blue: CM59 at 90 °C
blue: CM85A11 at 90 °C

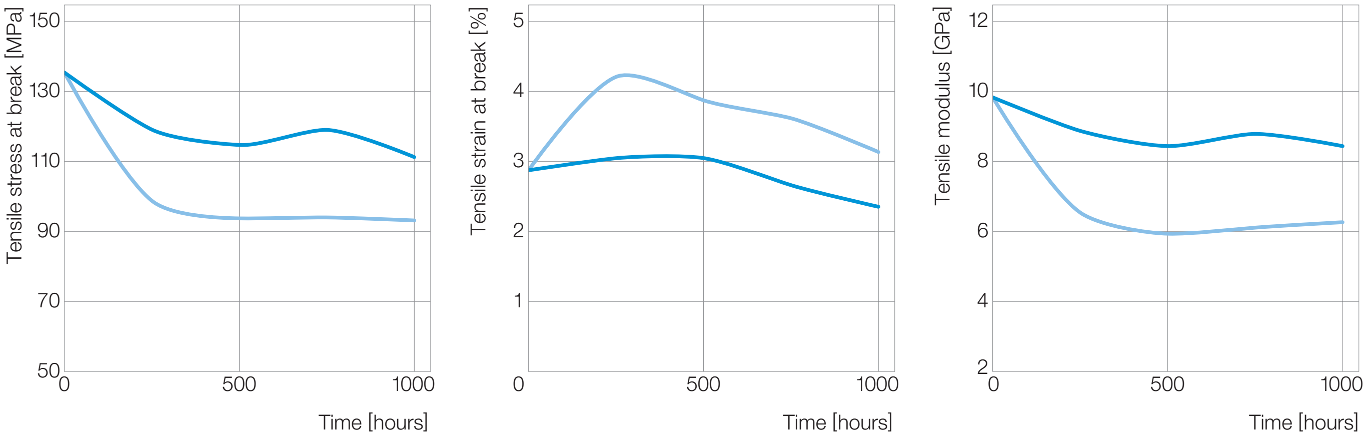

Fig. 34: Exposure of Ultradur® B4300 G6 bk Q16 15007 to fuels containing ethanol
light blue: CE1010 at 90 °C
blue: CE85A12 at 90 °C

Water and aqueous solutions

Water

The general influence of water on Ultramid® in the form of swelling has been described in a number of passages of this publication. Details can also be found in the Ultramid® brochure and in the brochure about the conditioning of finished parts made of Ultramid®. When water swells polyamide, this lowers the glass-transition temperature.

Since the material softens at temperatures above the glass-transition point, the mechanical properties change as follows: the modulus and the strength decrease, while the toughness increases. Figure 35 shows this effect by way of an example for unreinforced and glass-fiber reinforced Ultramid® A. As the water content in the polymer increases, the tensile modulus above the corresponding glass-transition temperature is reduced.

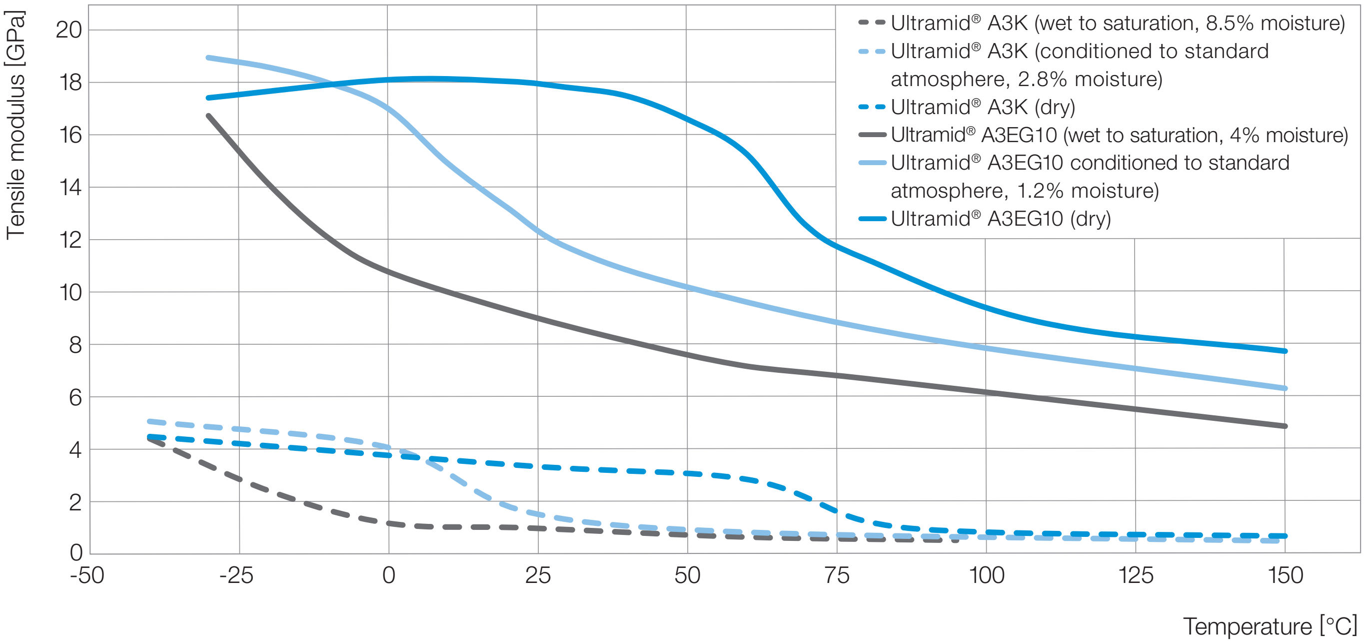

Fig. 35: Tensile modulus of Ultramid® A3K and A3EG10 as a function of the temperature and moisture.

Equilibrium moisture is established depending on the ambient conditions (in humid air or under water, at different temperatures). If, after this moisture level has been reached, the mechanical properties no longer change, as shown in Figure 36, there is no hydrolytic degradation, but only swelling. At very high temperatures, however, water causes severe hydrolytic degradation in Ultramid®: for instance, if the material has not been sufficiently dried before being injection molded, the processing temperatures of about 280 °C cause cracking of the molecule chains.

The hydrolytic aging of Ultradur® depends on several factors, of which the temperature and moisture content in the component are particularly important.

Tensile test bars with a thickness of 1.6 mm (according to ASTM D638) made of Ultradur® B4520 still show a tensile strength that is practically at its initial level (Figure 37), even after being kept in water at 60 °C for more than 300 days. The corresponding elongation at maximum stress increases markedly at the beginning of the exposure since the yield point is shifted from about 3.5 % to about 11 % elongation as a result of the exposure. Test specimens that were exposed for longer than 250 days no longer show a yield point. The drop in the elongation at maximum stress after 250 days is associated with a change from ductile to brittle fracture behavior.

When it comes to hydrolytic aging in humid air, the relative humidity is a crucial parameter that determines the moisture content in the interior of the component. At 100 % relative humidity and under exposure to water in its liquid form, theoretically an equilibrium with the same moisture content is reached.

Figure 38 shows that test bars (1.6 mm according to ASTM D638) made of Ultradur® B4520 still have a high strength level, even after 120 days at 70 °C and 62 % relative humidity. Under more demanding climate conditions (85 °C and 85 % relative humidity), however, a drop in the tensile strength can be observed after about 30 days.

Ultradur®, which can withstand exposure to demanding conditions as 85 °C and 85 % relative humidity for long periods of time, is also offered by BASF in a grade with the suffix HR (= hydrolysis-resistant). Figure 39 shows a comparison between two Ultradur® grades, each with 30 %-glass fiber reinforcement. The HR grade B4330 G6 HR bk 15045 shows a somewhat lower initial strength. This value, however, stays at a high level over the course of 120 days. The comparative grade B4300 G6 bk Q16 15007, in contrast, is already clearly damaged after 40 days.

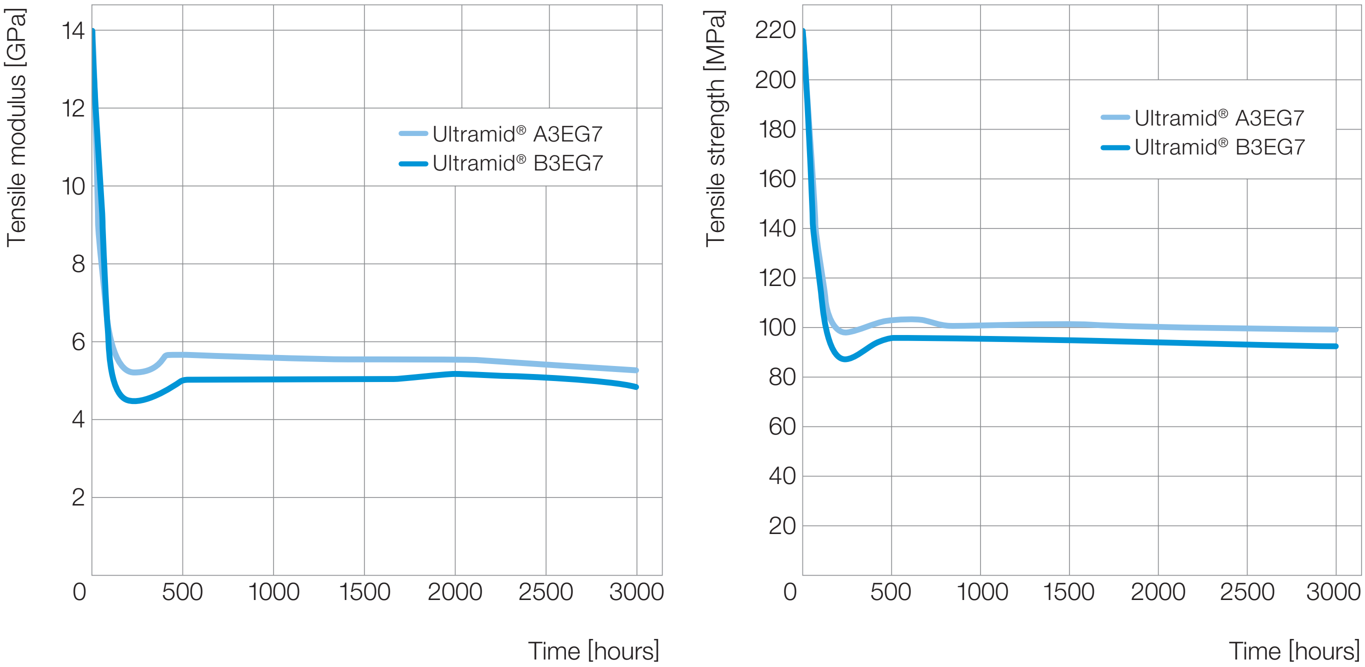

Fig. 36: Exposure of Ultramid® A3EG7 and B3EG7 to demineralized water at 65 °C, with the water being replaced on a weekly basis

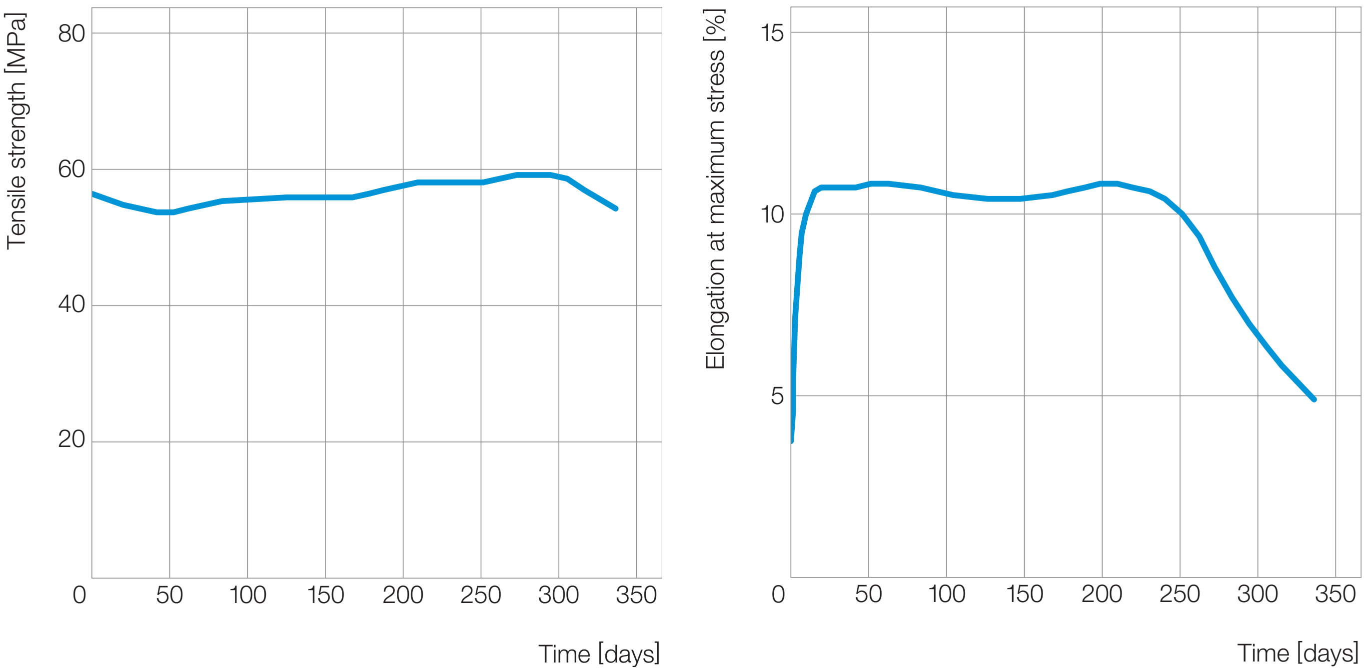

Fig. 37: Exposure of Ultradur® B4520 to hot water at 60 °C

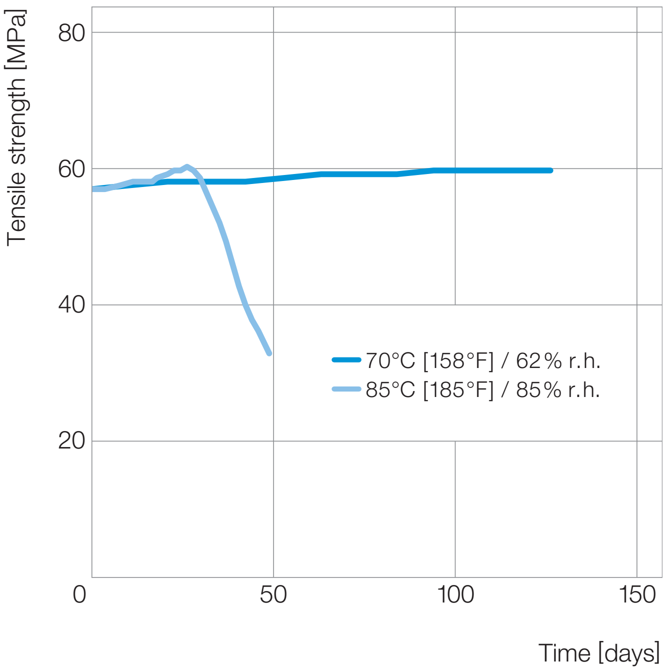

Fig. 38: Tensile strength of Ultradur® B4520 under different climate conditions: 70 °C and 62 % relative humidity as well as 85 °C and 85 % relative humidity

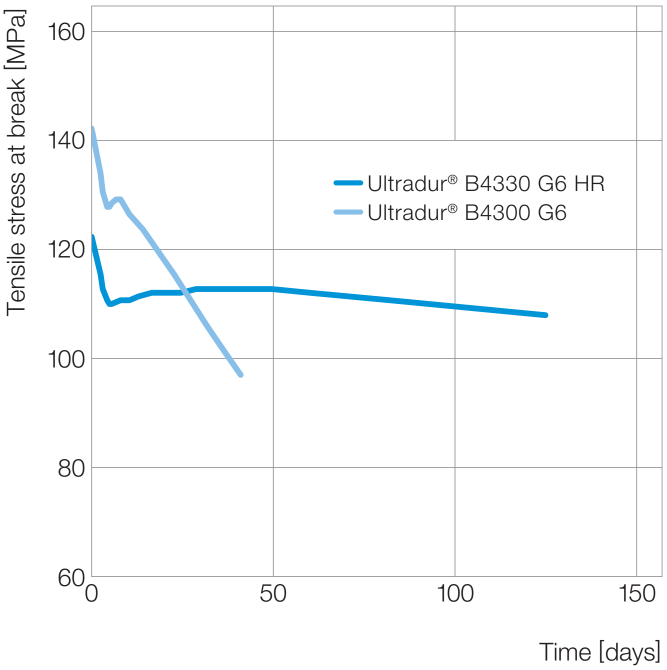

Fig. 39: Tensile stress at break of hydrolysis-stabilized Ultradur® B4330 G6 HR and of non-stabilized Ultradur® B4300 G6 in a hot-moist climate (85 °C and 85 % relative humidity)

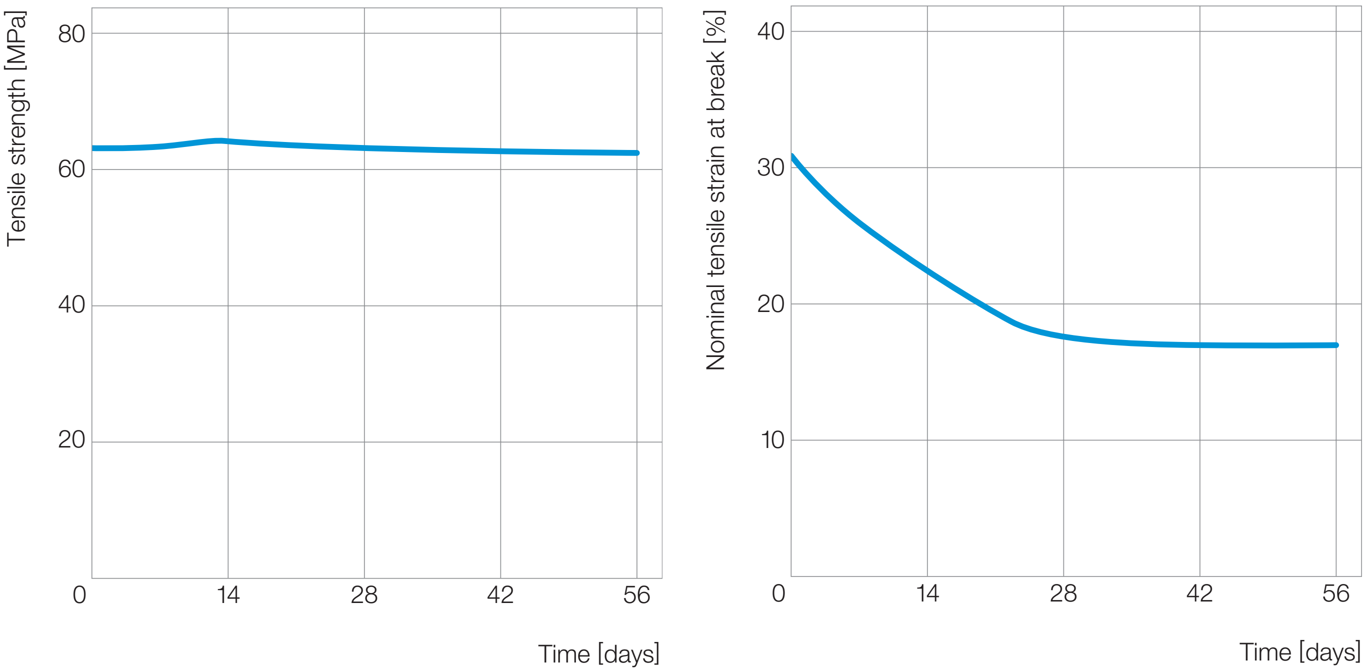

Fig. 40: Storage of Ultraform® N2320 003 AT in fully desalinated water at 100 °C

Unreinforced Ultraform® grades such as the Ultraform® N2320 003 AT injection molding grades have good hot water resistance. At 100 °C, there is no loss of strength after 56 days of storage in fully desalinated water (Fig. 40). Only the nominal elongation at break decreases from about 30 % to about 17 %. Due to the swelling, the tensile modulus of elasticity is reduced from 2.7 to approx. 1.9 GPa.

Glass fiber reinforced products such as Ultraform® N2200 G53 AT suffer a loss of strength of about 50 % in hot water due to hydrolytic attack of the glass fiber in the first 7 days. Subsequently, the strength remains constant up to a total storage period of 84 days.

The suitability of engineering plastics in the drinking water sector is influenced not only by the durability of the materials, but also by various country-specific regulations. For Europe, there are currently no uniform test methods and evaluations for the approval of materials in contact with drinking water, but these are regulated nationally (see e. g. KTW-BWGL[13] guidelines, ACS[14] listing, WRAS[15]). For this reason, each material has to be tested in accordance with the applicable approval method. In the United States, an NSF[16] listing is mandatory.

[13] BWGL: Assessment basis for plastics and other organic materials in contact with drinking water (Germany).
[14] ACS: Attestation de Conformité Sanitaire (France)
[15] WRAS: Water Regulations Approval Scheme (UK)
[16] NSF: National Sanitation Foundation (USA)

A few of the Ultramid® and Ultradur® grades are approved for contact with drinking water in certain application and temperatures ranges. Thus, for instance, glass-fiber reinforced Ultramid® A is found in the housings of water meters, sanitary installations and the brewing units of coffeemakers. Ultradur® is used in the sector of drinking water, for example, in showerheads.

Ultraform® AQUA AT grades are approved for drinking water applications. For example, unreinforced Ultraform® can be found in parts of sanitary fittings, as shower head inserts (Figure 41) or in brewing units of fully automatic coffee machines (Figure 42).

Fig. 41: Ultraform® as a showerhead insert.

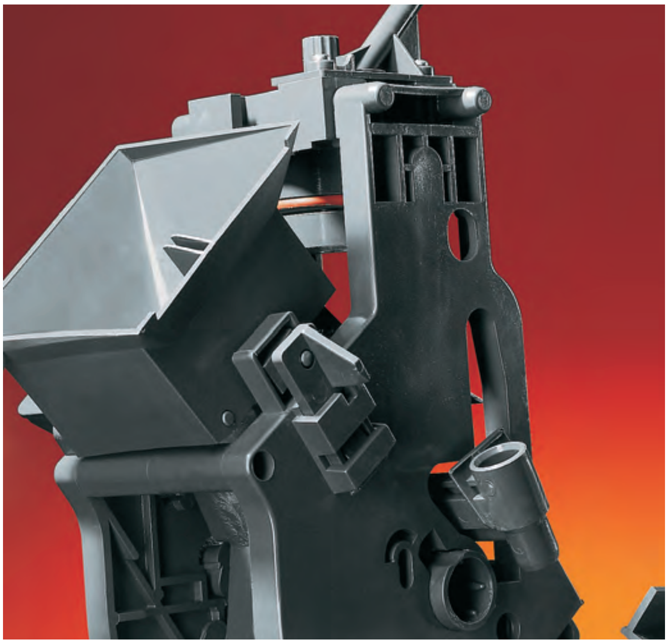

Fig. 42: Ultraform® as a brewing unit of an espresso machine.

Chlorinated water

Chlorine is normally added as the oxidizing chemical for purposes of disinfecting drinking water. The permissible concentration of chlorine in drinking water varies widely from one country to another. For instance, the upper limit in Germany and Austria is 0.3 ppm while it is 0.1 ppm in Switzerland. In Spain, the maximum permissible concentration is 1 ppm. In a few Asian countries and in the United States, even chlorine concentrations of up to 4 ppm are permitted.

Conventional Ultraform® is conditionally resistant to chlorinated drinking water (Fig. 43). In countries with a low free chlorine content (<0,5 ppm) in drinking water, Ultraform® is generally sufficiently resistant for sanitary applications. Starting at a free chlorine content of >0.5 ppm is Ultraform® only partially resistant and an approval test of the component under final operating conditions is therefore essential.

In contrast to this, Ultramid® has excellent resistance to chlorinated water. Even at chlorine concentrations that are several times higher than the concentrations normally used for disinfecting drinking water, no change in the mechanical properties is observed in comparison to exposure to non-chlorinated water.

Figure 44 shows the tensile strength of Ultramid® A3EG7 and Ultramid® B3EG6: both plastics were exposed to chlorinated water (50 ppm) in comparison to exposure to non-chlorinated water.

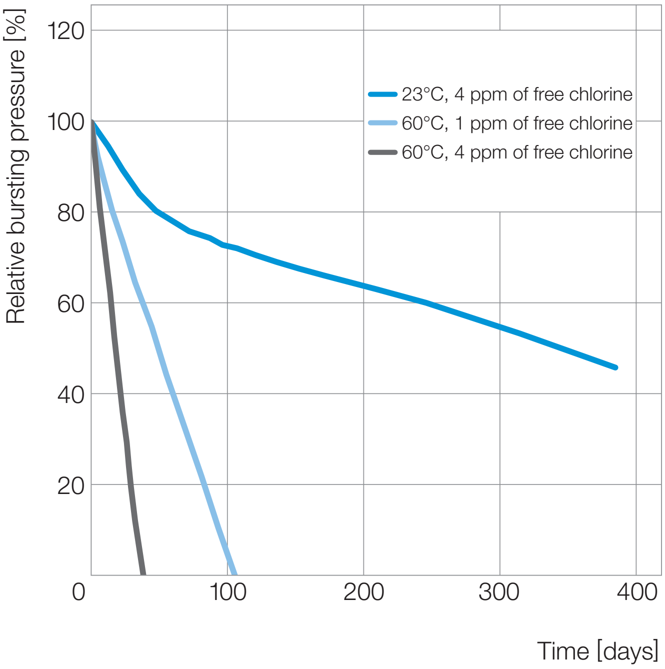

Fig. 43: Resistance of Ultraform® N2320 003 to chlorinated drinking water

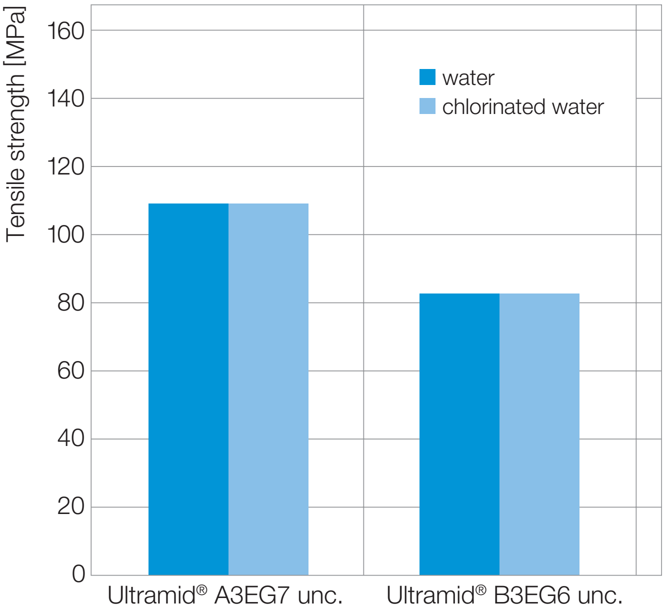

Fig. 44: Tensile strength after exposure of Ultramid® A3EG7 and Ultramid® B3EG6 to chlorinated water (50 ppm) for 7 days at 65 °C

Aqueous salt solutions

Zinc chloride solution

Components made of Ultramid® A and B which are subjected to internal stresses or stresses when subjected to a load already have stress cracks after a brief time of contact with a zinc chloride solution. The damage can occur, for instance, when zinc-plated steel parts come into contact with solutions containing chloride (e.g. road salt).

Ultramid® S has an excellent resistance to aqueous zinc chloride solutions. For instance, Ultramid® S3WG6 bk 564 meets the requirements in terms of $ZnCl_2$ resistance as stipulated in FMVSS 106[17], as can be seen in Figure 45.

Ultramid® T is very resistant to aqueous zinc chloride solutions and it shows no susceptibility to stress cracking in this medium (Figure 46).

The polyphthalamide Ultramid® Advanced N has even better resistance: even prolonged exposure of concentrated zinc chloride solution at 70 °C does not yet lead to damage to the material.

$ZnCl_2$ solutions do not trigger stress cracking in Ultradur®.

Commercially available Ultraform® grades are not resistant to concentrated zinc chloride solutions.

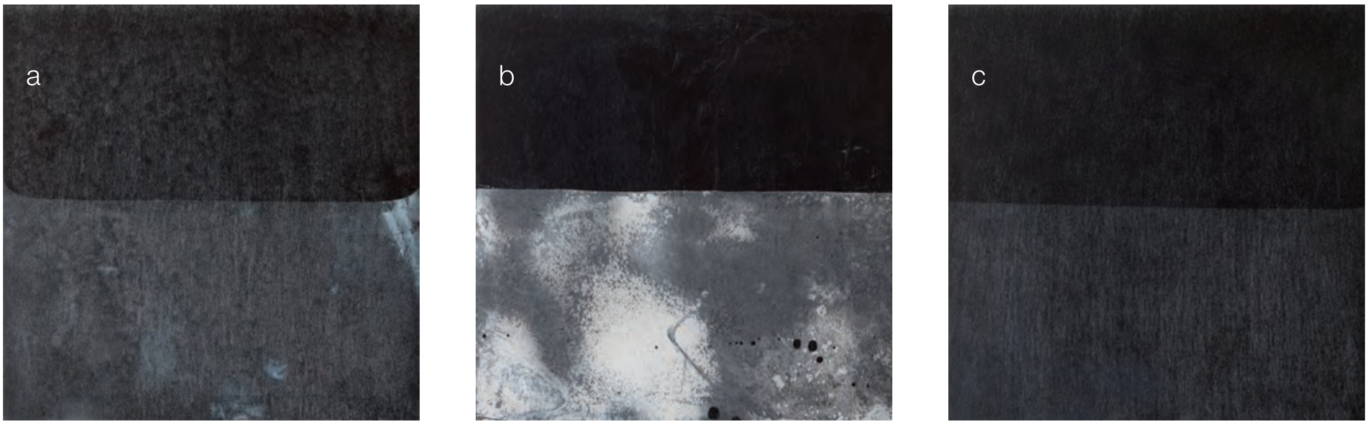

Fig. 45: Surface of test plates made of Ultramid® A3WG6 HRX bk 23591 (a), Ultramid® B3WG6 bk 564 (b) and Ultramid® S3WG6 bk 564 (c) after 200 hours of exposure (half-submerged) to a 50 % aqueous solution of zinc chloride at room temperature.

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[17] No cracks must be visible on the surface after exposure to an aqueous 50 %-solution of $ZnCl_2$ during 200 hours at 23 °C

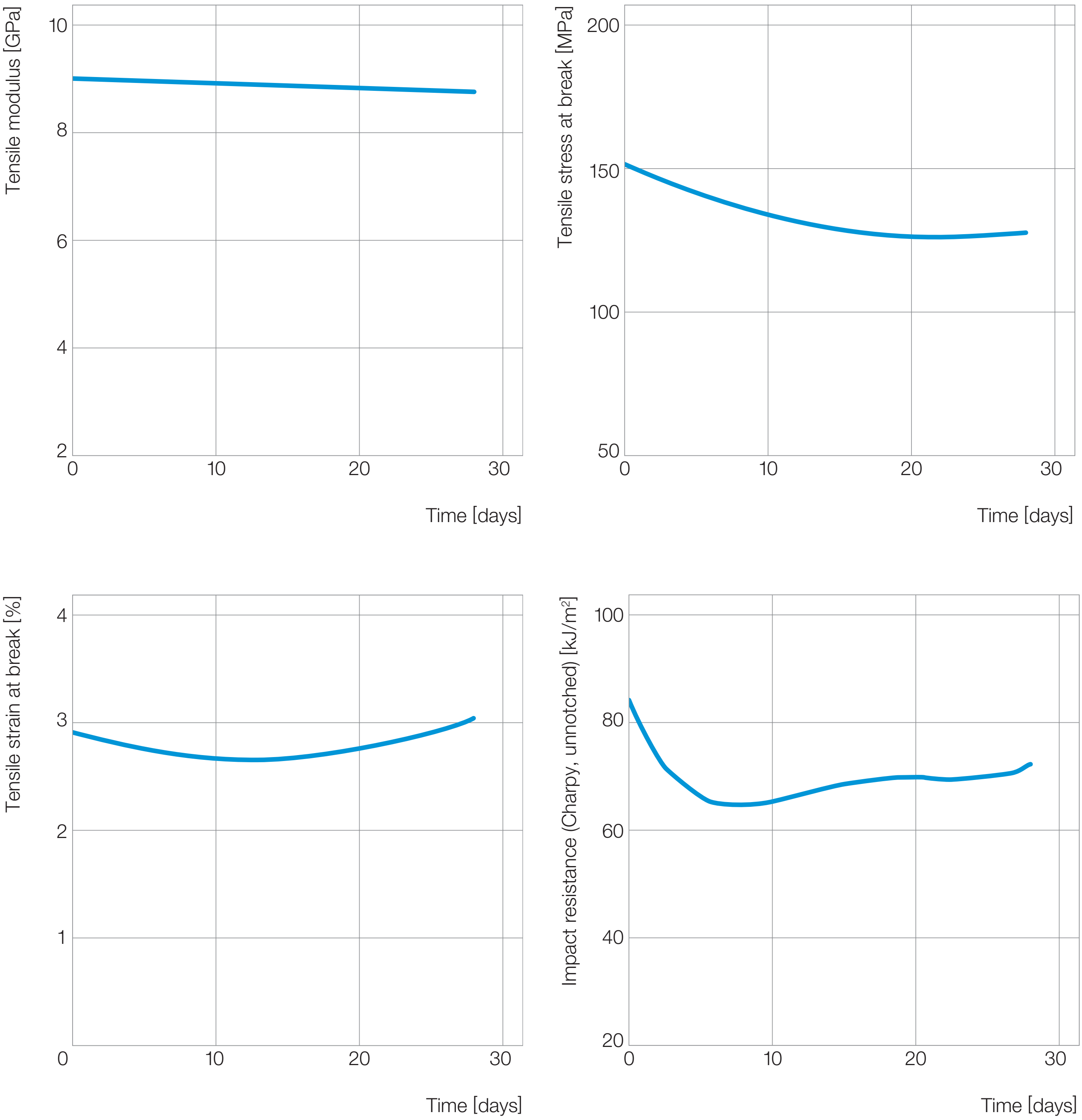

Fig. 46: Exposure of Ultramid® TKR 4357G6 to a 50 %-aqueous solution of zinc chloride at 60 °C

Calcium chloride solutions

Calcium chloride is used as a component of road salt not only in Japan and Russia, for example, but also to an increasing extent in Central Europe. As in the case of contact with a zinc chloride solution, Ultramid® A and B are susceptible to stress cracking when exposed to calcium chloride solutions, whereas Ultramid® S, T, Advanced N and also Ultradur® are considerably less susceptible. The example in Figure 47 shows this on the basis of a resistance test according to an OEM standard. The test plates are exposed to a saturated calcium chloride solution in a mixture consisting of water and ethanol for 30 minutes at room temperature. They are then visually assessed. Ultramid® A and B show clear-cut changes in their surface, while the other materials do not.

Vehicle parts that can come into contact with splashing water should fundamentally be kept free of mechanical stresses.

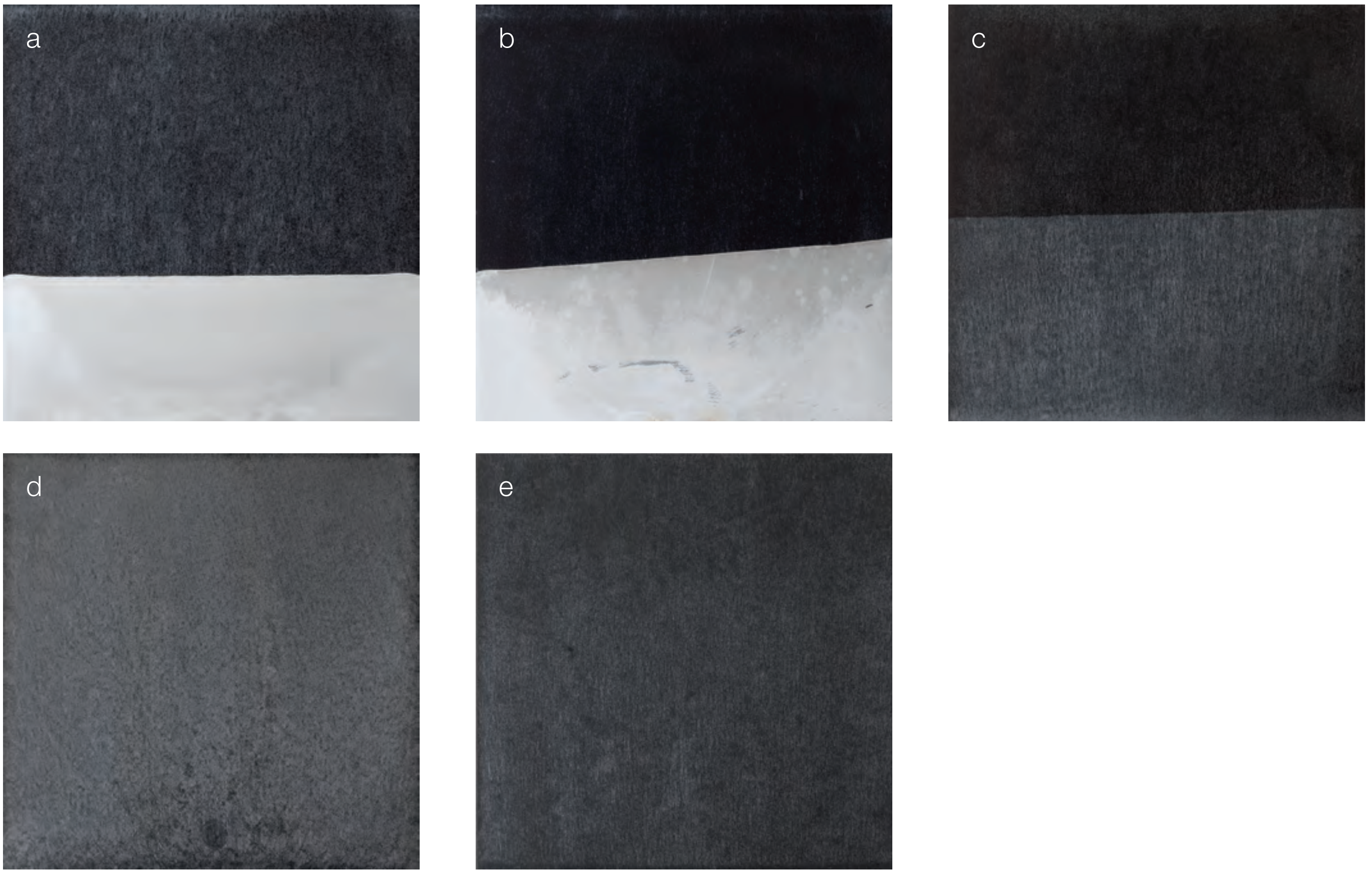

Fig. 47: Surface of test plates made of Ultramid® A (a), B (b), S (c) and T (d) as well as Ultradur® (e) after being exposed (half-submerged) to a saturated calcium chloride solution for 30 minutes at room temperature.

Mineral acids

The general term “mineral acids” is used for strong inorganic acids such as hydrochloric acid (HCl), sulfuric acid (H_2SO_4), nitric acid (HNO_3) and phosphoric acid (H_3PO_4). Mineral acids are present in strongly dissociated form in an aqueous solution, that is to say, in solution, the concentration of the acidic oxonium ions (H_3O+) is in the same order of magnitude as the acid concentration.

At moderate temperatures, Ultramid® A and B are resistant to diluted acids. Depending on the duration of exposure, damage to the material occurs at an elevated acid concentration and at elevated temperatures.

Semi-aromatic polyamides such as Ultramid® T and Ultramid® Advanced N have an even higher resistance to diluted acids; higher concentrations or temperatures can be achieved undamaged.

Figures 48 and 49 show the temperature dependence of the resistance of Ultramid® to diluted acids in an example with Ultramid® B3WG6 GP. After 1,000 hours of exposure to a 0.1-molar mixture consisting of the mineral acids HCl, H_2SO_4, and HNO_3 (mixing ratio of 1:1:1, total acid concentration of 0.1 mol/l, pH value of 1) at 90 °C, a drop in tensile strength by about 30 % was observed after re-drying. The re-drying of the test specimens allows the material damage to be examined independently of the softening effect of the swelling with water, since during exposure to diluted acid, most of the drop in tensile strength is caused by the swelling. At an elevated temperature (150 °C), a decrease in the tensile strength by 80 % can be already observed in the re-dried state after 180 hours in the mixture in question, and this is equivalent to a failure of the material.

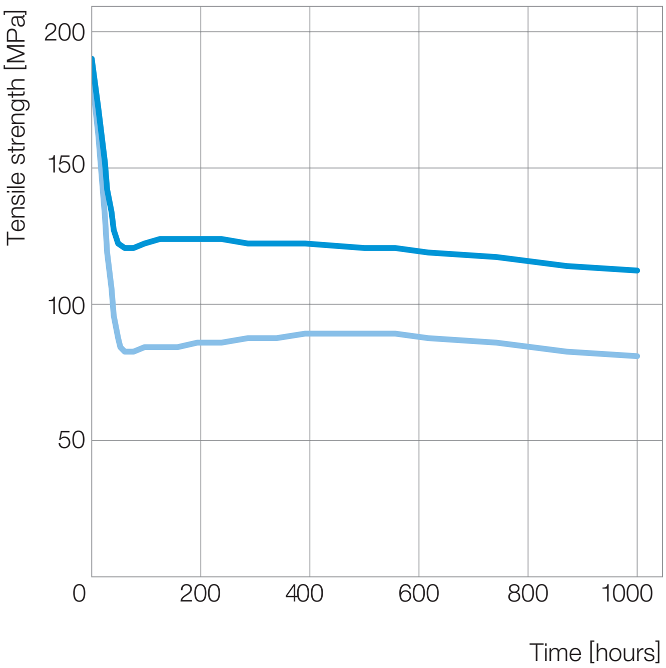

Fig. 48: Tensile strength of Ultramid® B3WG6 GP bk 23210 after exposure to a mixture of HCl, H2SO4, and HNO3 (pH 1) at 90 °C
light blue: testing immediately after exposure
blue: testing after re-drying

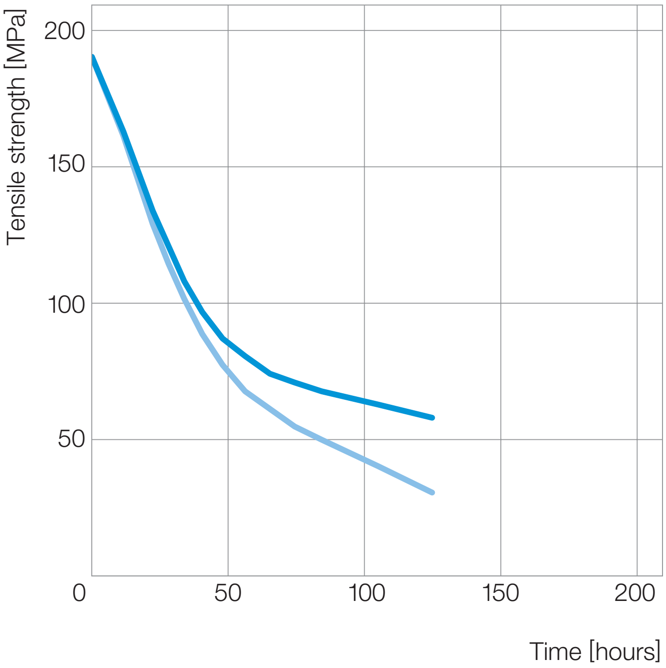

Fig. 49: Tensile strength of Ultramid® B3WG6 GP bk 23210 after exposure to a mixture of HCl, H2SO4, and HNO3 (pH 1) at 150 °C
light blue: testing immediately after exposure
blue: testing after re-drying

Ultraform® is against diluted mineral acids at room temperature short-term resistant. However, at elevated temperature or at concentrated acids a significant damage to the material occurs after a short period of time.

In approx. 7 % amidosulfuric acid (pH 1.1) at 80 °C, the 4 mm thick test specimens made of Ultraform® S2320 003 AT suffer a weight loss of approx. 20 % after only 15 days (Fig. 50). The strength values remain almost constant over the test period, while the tensile modulus of elasticity drops to about 80 % of the initial value. In 20 % sulfuric acid at 50 °C, Ultraform N2320 003 AT is significantly damaged, which is accompanied by a loss of strength (Fig. 51).

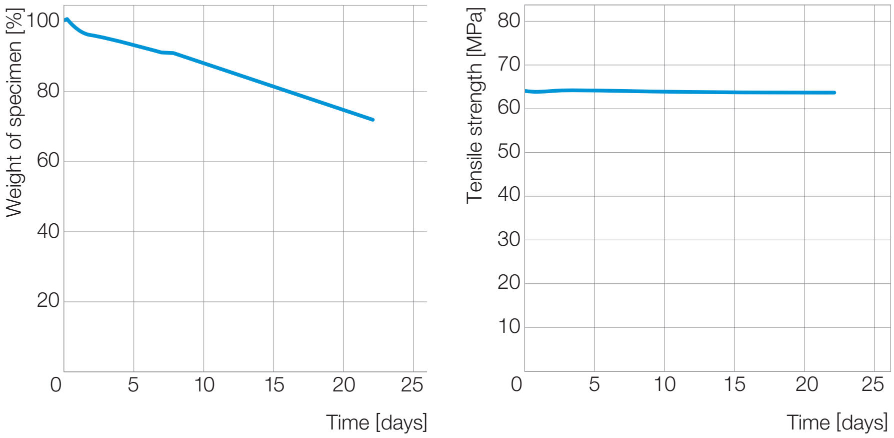

Fig. 50: Storage of Ultraform® S2320 003 AT in approx. 7 % amidosulfuric acid (pH 1.1) at 80 °C

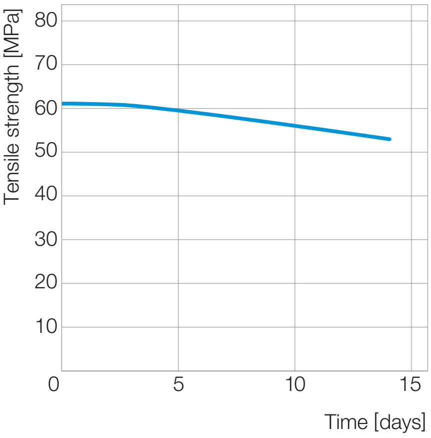

Fig. 51: Decrease in tensile strength of Ultraform® N2320 003 AT after storage in 20 % sulfuric acid at 50 °C

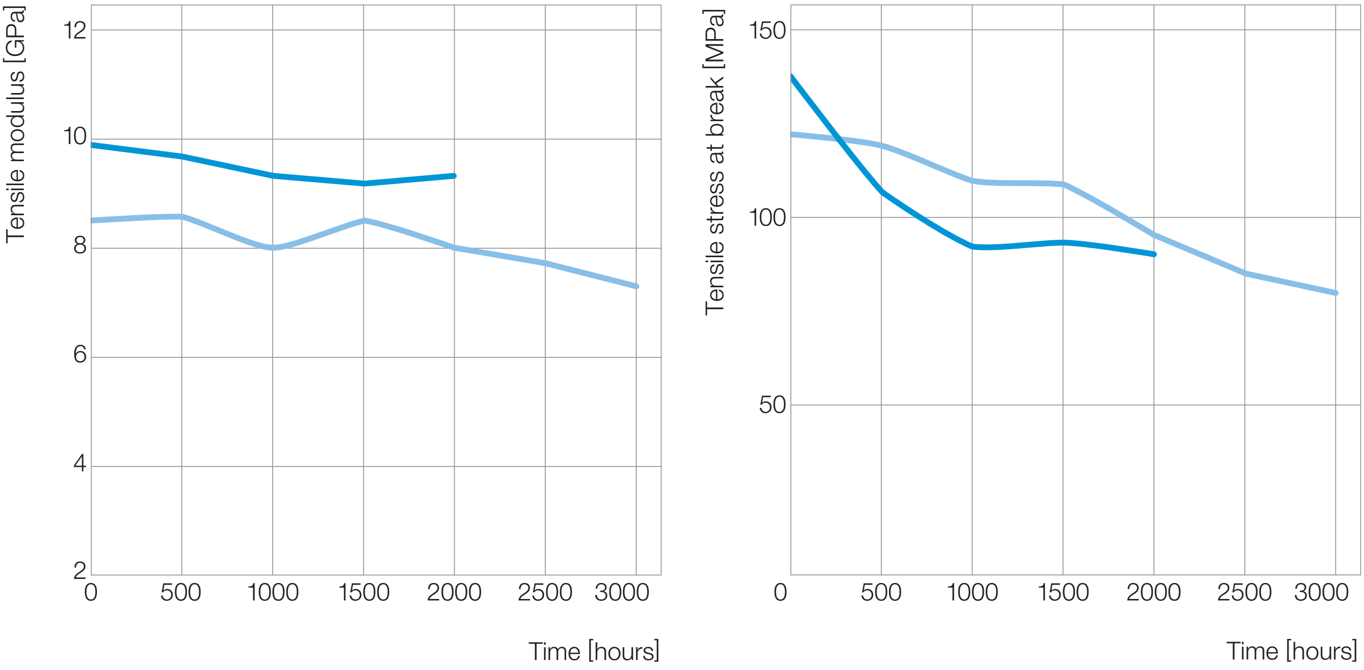

Fig. 52: Exposure of Ultradur® B4300 G6 bk Q16 15007 (blue) and Ultradur® B4330 G6 HR bk 15045 (light blue) to an acidic test exhaust gas (5,000 ppm NOx, 50 ppm SO2, 10 % by volume of O_2, H_2O, CO_2 each, and the rest N_2, pH value of about 1.7); the testing was conducted in test cycles of 168 hours each (24 hours at 80 °C, 48 hours at 20 °C, 24 hours at 80 °C, 72 hours at 20 °C

Ultradur® shows excellent resistance to diluted mineral acids at room temperature. At an elevated temperature or in contact with concentrated acids, however, considerable damage can occur already after just a brief exposure.

As an important example that is relevant for actual practice, Figure 52 shows the exposure to Ultradur® B4300 G6 and Ultradur® B4330 G6 HR to an acidic test exhaust gas. Under the given conditions, both Ultradur® B4300 G6 and Ultradur® B4330 G6 HR show an acceptable drop in tear strength. After 3,000 hours, Ultradur® B4330 G6 HR still has a tensile stress at break of 70 % of the initial value.

Commercially available Ultraform® and Ultramid® grades are not resistant to nitrous gases and sulfur dioxide when moisture is in the air. Nevertheless, there are applications in which Ultramid® comes into contact with nitrous gases, for example, in charge air tubes and intake manifolds with exhaust-gas return.

Here, although local damage occurs to the surface, this often does not lead to failure of the component because the cracks are only a few micrometers deep. In individual cases, the suitability depends on the composition of the exhaust gases and on the local geometrical conditions.

Figure 53 shows the surface of the inside of a charge air tube made of Ultramid® A3W2G6. One specimen of this component was subjected to a service-life test on an engine test stand, while another specimen was pre-damaged by thermal aging and subsequently exposed to exhaust gas condensate in a process similar to that of VDA 230-214 of the German Automotive Industry Association. On the basis of this test, it can be assumed that especially condensed exhaust gas that collects as puddles at the bottom of the component will damage the surface.

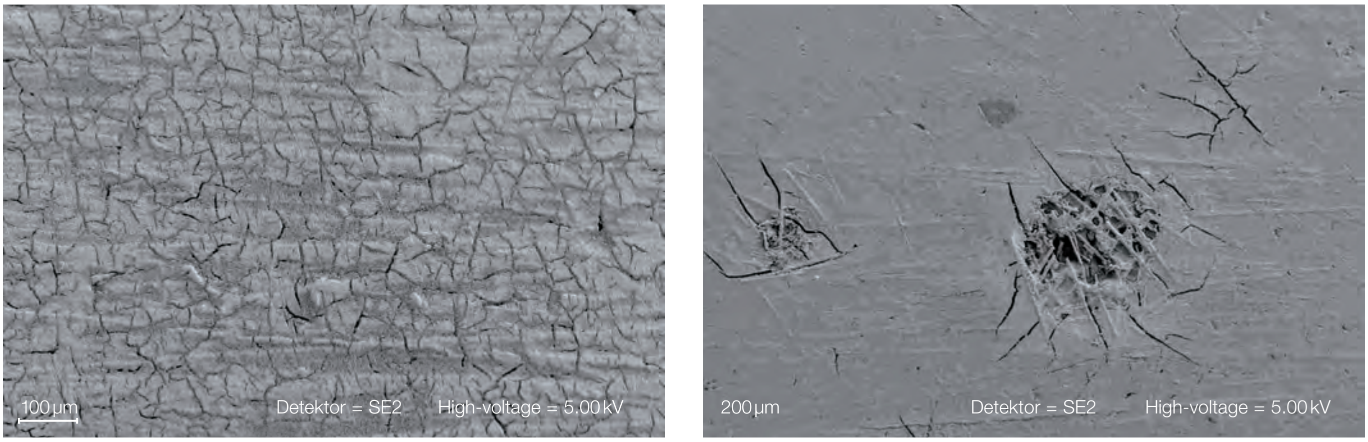

Fig. 53: Surface of the inside of a charge air tube made of Ultramid® A3W2G6. On the left: after a service-life test on an engine test stand, cracks having a depth of approximately 10 µm appear. On the right: the component was aged for 2,000 hours at 140 °C and subsequently subjected to a corrosion test in a process similar to that of VDA 230-214. In this process, exhaust gas condensate can concentrate in individual places. In these areas, the material is visibly damaged by cracks having a depth of about 100 µm

Organic acids

The term “organic acids” refers to those organic compounds that release protons (H+) through dissociation, and can thus react acidically. If the solvent is water (H_2O), this causes the concentration of oxonium ions (H_3O+) to increase significantly while the pH value decreases (pH <7). Examples of organic compounds that fall under this general definition include the carboxylic acids (e. g. formic acid, acetic acid, citric acid, benzoic acid, etc.), sulfonic acids, phosphonic acids, phenols.

For the most part, the term organic acids is equal to carboxylic acid or a weak acid. In this section, the term organic acid will refer to a weak acid. Weak acids, unlike mineral acids (strong acids), are weakly dissociated in water and thus lower the pH value by several units less than mineral acids do. This will be shown on the basis of the following example: a 0.1-molar (mol/l) aqueous solution of acetic acid has a pH value of about 3 at room temperature; the acetic acid is present with a degree of dissociation of only about 1 %; an equally concentrated hydrochloric acid, in contrast, has a pH value of about 1 (100 times more acidic) and is present with a degree of dissociation of practically 100 %.

In the solid state, weak organic acids such as, for instance, benzoic acid or citric acid are not critical for Ultramid®, Ultradur® and Ultraform®. Damage occurs at the most on the surface of the material and does not normally lead to failure of the component.

If, on the other hand, the weak organic acids are present in aqueous solution, a differentiated picture emerges with regard to resistance, depending on the acid concentration, temperature and contact time: For example Ultraform® S1320 003 in 5 % aqueous formic acid at room temperature has a sufficient short-term resistance (up to about 40 days of media contact) for many applications. We expect comparable resistance for Ultraform® S1320 003 AT.

In 20 % lactic acid (pH 2.4) at 80 °C, Ultraform® S2320 003 AT is massively damaged after a relatively short time (Figure 54).

Ultramid® and Ultradur® show against aqueous organic Acids a similarly differentiated behavior.

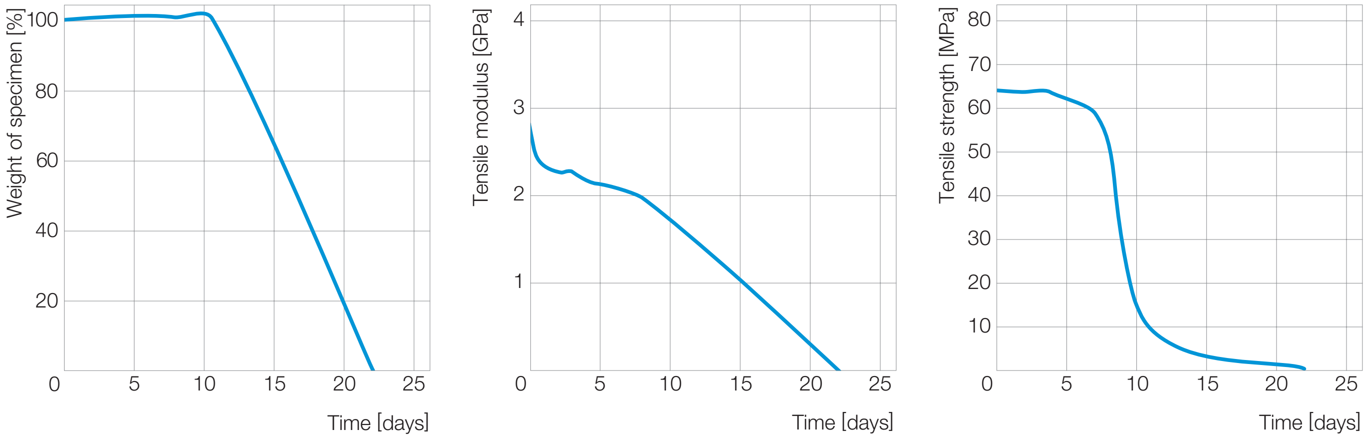

Fig. 54: Storage of Ultraform® S2320 003 AT in 20 % lactic acid (pH 2.4) at 80 °C

Oxidants

Generally speaking, oxidants are chemical compounds that, in chemical reactions, have a greater electron affinity than their reactants. Consequently, the bonding electrons in the reaction product are more strongly localized in the reactant stemming from the oxidant. The boundary case of a complete electron transition to the oxidant causes the formation of a salt. Whether a certain compound acts in a chemical reaction as an oxidant or as a reducing agent always depends on the relationship of the electron affinities of the two reactants. Owing to their great electron affinity, the elementary halogens (fluorine, chlorine, bromine, iodine), for example, take on the role of the oxidant in a reaction in the overwhelming majority of cases. The same applies to elementary oxygen, ozone (O_3) and peroxides such as hydrogen peroxide (H_2O_2).

Strictly speaking, oxidants are compounds that contain oxygen and that transfer oxygen to the reactant during a reaction. Typical examples of this class of substances are elemental oxygen (O_2), ozone (O_3), oxygen compounds of the halogens (for instance, hypochlorites -OCl, chlorites -OClO, chlorates -$OClO_2$, perchlorates -$OClO_3$) or other oxygen-rich compounds, for example, concentrated nitric acid, nitrates, hydrogen peroxide or potassium permanganate. Atmospheric oxygen (O_2) itself only shows a low level of reactivity under normal conditions. Gas mixtures that have a higher oxygen content than air can cause considerably faster and stronger reactions than air can.

Dry salt-like oxidants (for example, sodium nitrate, potassium permanganate) can be kept at room temperature in plastic containers for a longer period of time. Contact with highly reactive liquid (e. g. elementary bromine) or gaseous (e. g. elementary chlorine) oxidants should be fundamentally avoided.

Commercially available Ultraform® grades are not resistant to oxidants such as ozone or elementary chlorine (halogens) that, in the presence of air or water, release strong acids. In this context, there is reason to assume that the degradation reaction takes place to a substantial degree via acid-catalyzed acetal cleavage.

If, on the other hand, the oxidation takes place under alkaline conditions, e. g. when using an aqueous sodium hypochlorite solution (caustic soda bleach), Ultraform® is much more resistant. For example Ultraform® S1320 003 can be stored for more than 20 days in a 12.5 % aqueous caustic soda bleach at room temperature – without significant losses in mechanical properties. We expect a similar behavior in aqueous caustic soda bleach for Ultraform® S1320 003 AT.

At 50 °C, in contrast, the test specimen measuring 80 × 10 × 4 mm shows a loss in mass of about 30 % already after 3 days.

Ultramid® TKR 4355 G7 bk 564 that was exposed to ozone (2 ppm in the air) for 72 hours at 38 °C shows a slight fading of its color (Figure 55). The mechanical properties listed in Table 3, however, are largely retained. A concentration of 2 ppm of ozone corresponds to approximately 18 times the alarm threshold value of 240 µg/m³ stipulated in the European Union.

Property	**Initial value**	**After exposure to ozone**
Tensile modulus [GPa]	11.6	11
Tensile stress at break [MPa]	195	185
Tensile strain at break [%]	2.7	2.6

Table 3: Properties of Ultramid® TKR 4355 GT7 bk 564

Fig. 55: Test specimens made of Ultramid® TKR 4355 G7 bk 564 before and after exposure to ozone. The color of the test bars faded slightly due to ozone exposure but the material properties remained largely unchanged

Ultramid® Advanced (PPA) for excellent chemical resistance

Ultramid® Advanced is a compound portfolio based on polyphthalamides (PPA). The portfolio includes Ultramid® Advanced N (PA9T), Ultramid® Advanced T1000 (PA6T/6I) and Ultramid Advanced® T2000 (PA6T/66). Based on their chemical structure, these polymers offer excellent mechanical mechanical properties at elevated temperatures. In addition, thanks to their hydrophobic properties, they are resistant to moisture and aggressive media, with only a slight loss of strength. Due to their low water absorption, the materials achieve dimensional stability in humid environments, which is among the highest of all polyamides.

Within the Ultramid® Advanced portfolio, Ultramid® Advanced N has the highest chemical resistance. In addition to its performance under normal conditions, Ultramid® Advanced N extends the application possibilities of Ultramid® to areas where in which an extremely high resistance to moisture and chemicals – also in combination with higher temperatures – is required. Ultramid® Advanced N is resistant to aggressive media such as:

- Coolant fluids, e.g. glycol/water at up to 135 °C for >3,000 h (Fig. 56)
- Aggressive fuels, e. g. with high ethanol or methanol content (Fig. 57)
- Engine and transmission oils, brake fluids (Fig. 58 and 59)
- Various acids such as acetic acid or mixtures of hydrogen chloride, nitrogen and sulfuric acid (Fig. 60)
- Calcium or zinc chloride solutions

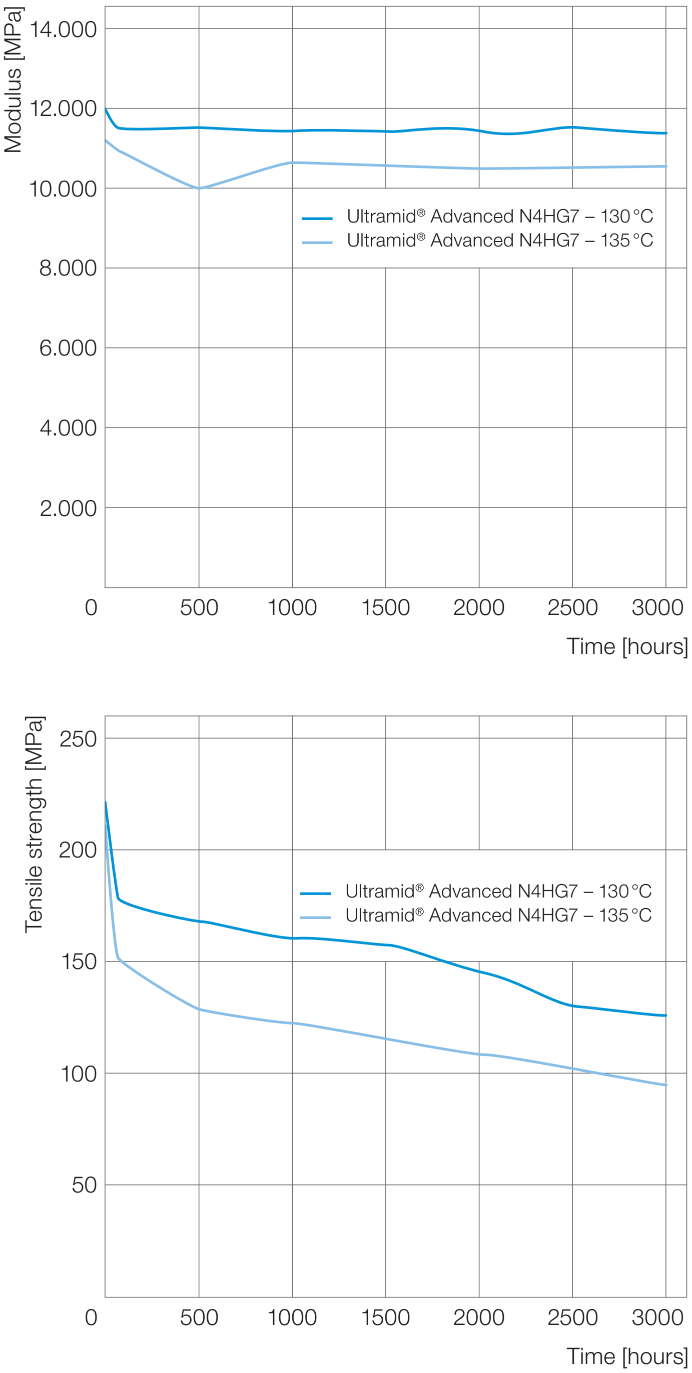

Fig. 56: Storage of Ultramid® Advanced N4HG7 (35 % GF) in glycol/water at 130 °C and 135 °C (G48, 1:1): More than 50 % of the original conditioned strength is retained after 3,000 hours of storage

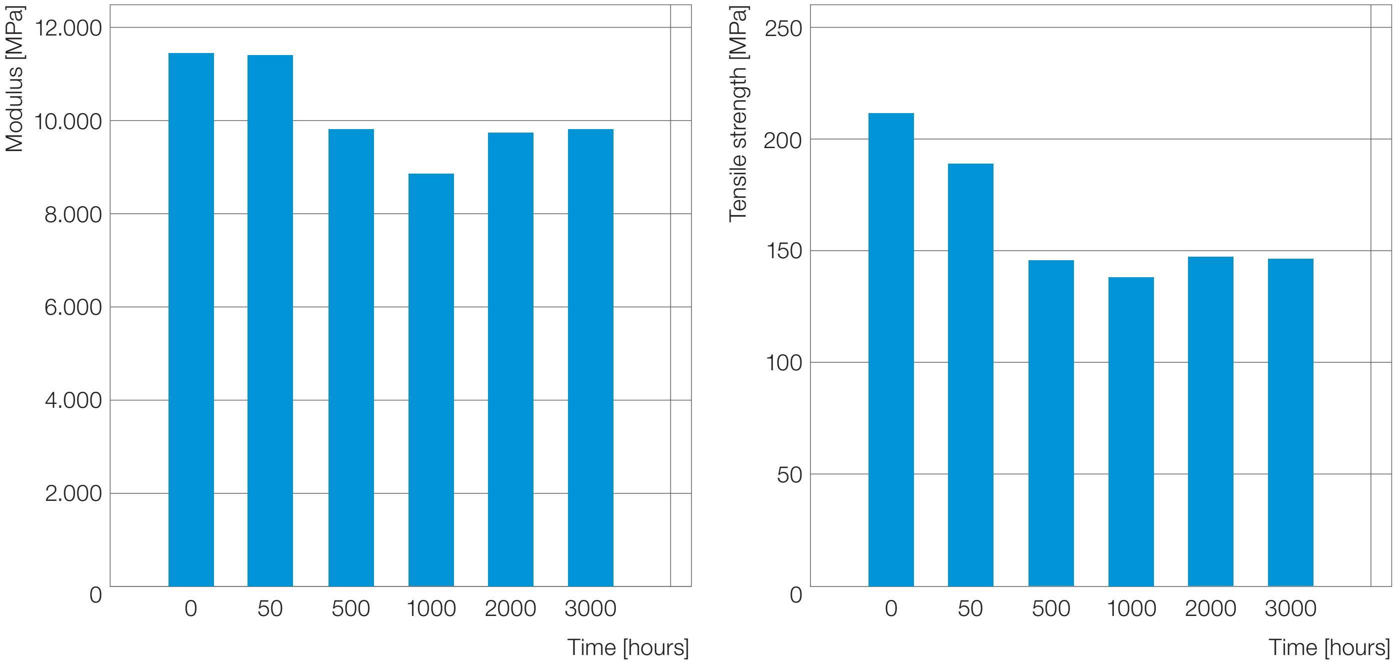

Fig. 57: Modulus and tensile strength of Ultramid® Advanced N4HG7 (35 % GF) after fuel storage in E50 at 90 °C (50 % ethanol, 50 % gasoline)

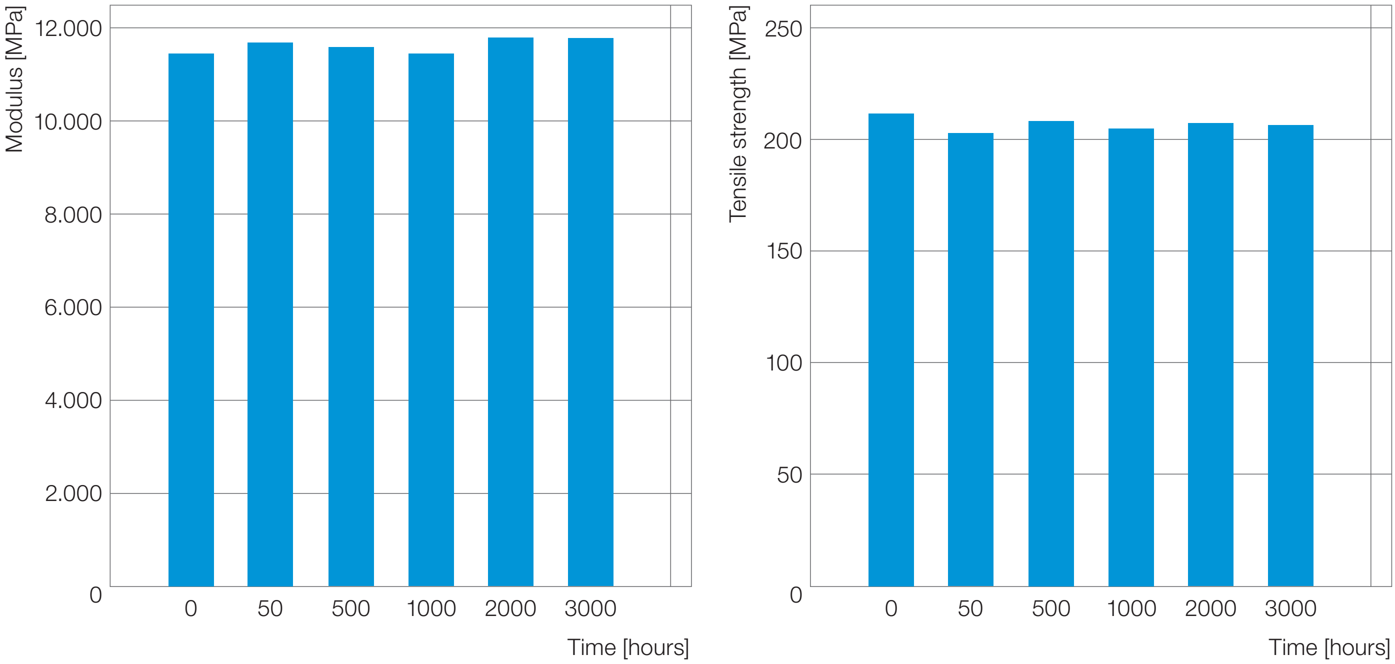

Fig. 58: Modulus and tensile strength of Ultramid® Advanced N4HG7 (35 % GF) after storage in brake fluid at 120 °C (DOT4)

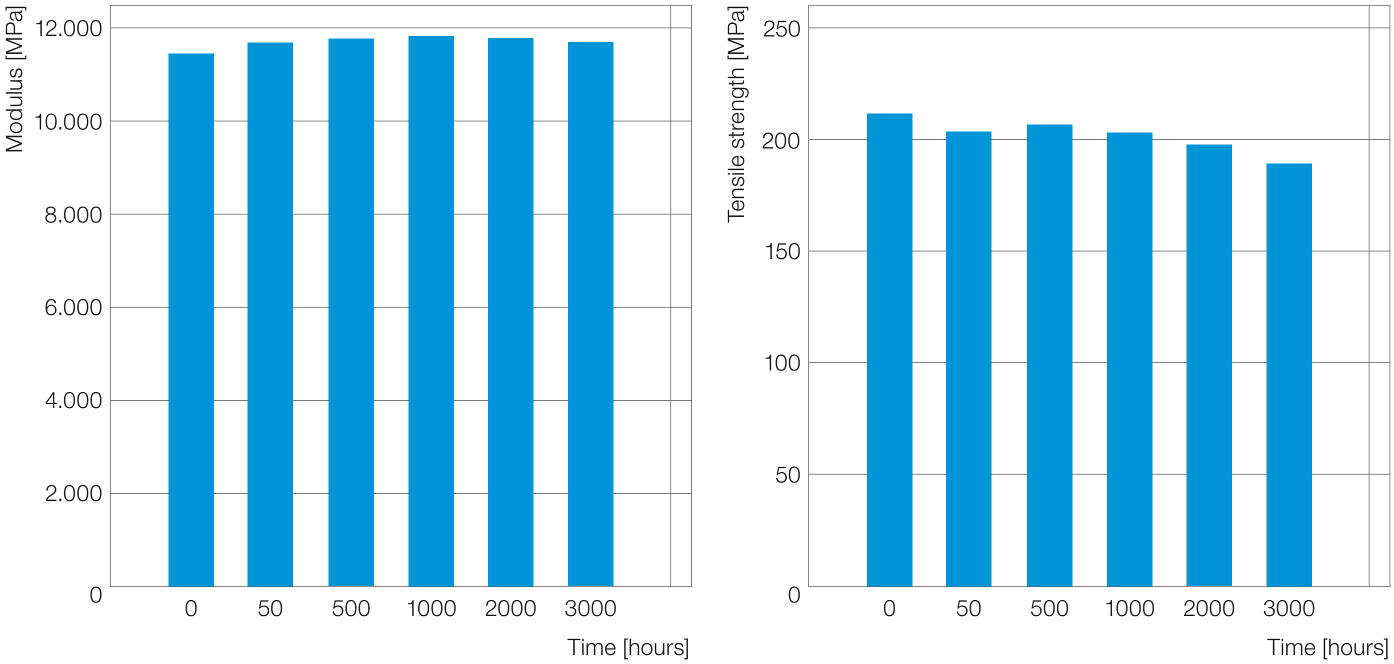

Fig. 59: Modulus and tensile strength of Ultramid® Advanced N4HG7 (35 % GF) after storage in gear oil at 150 °C (Dextron 6 ATF2)

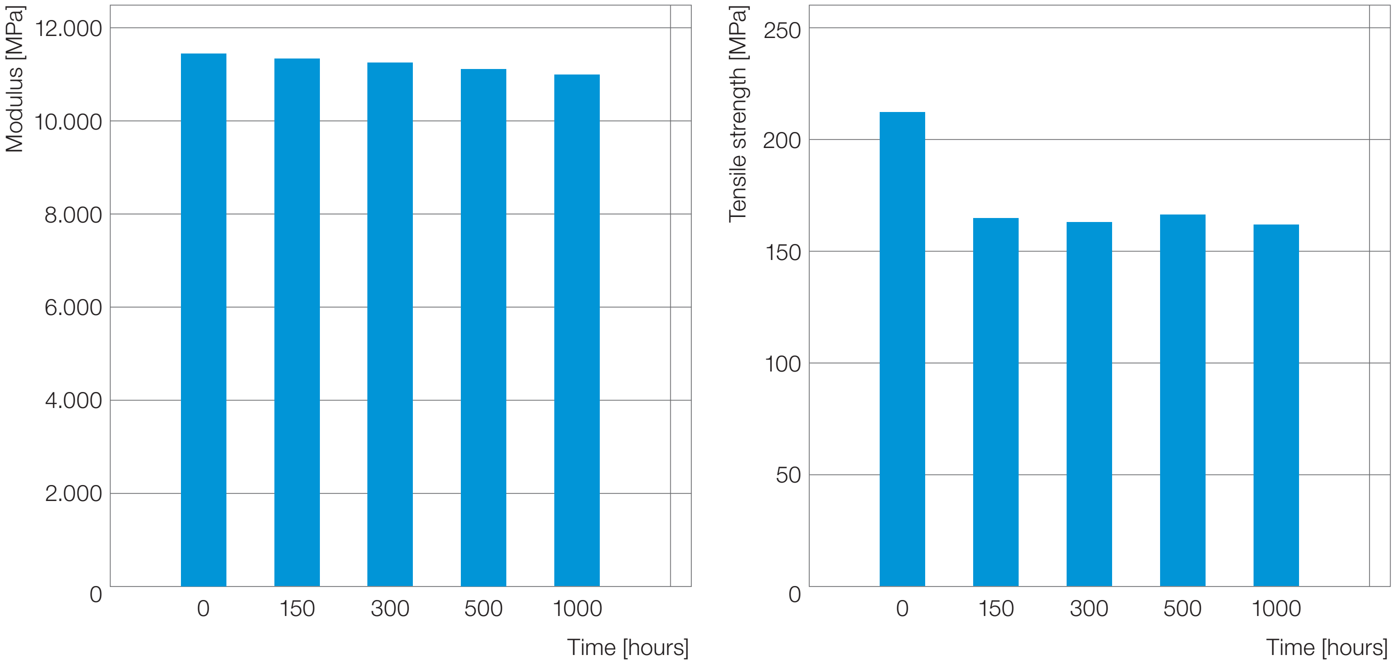

Fig. 60: Storage of Ultramid® Advanced N (35 % GF) in the acid mix of hydrochloric acid, nitric acid and sulfuric acid at 100 °C. (1:1:1, pH 2): Young's Modulus and tensile strength of Ultramid® Advanced N (35 % GF).

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Reference works

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- Gerhard W. Becker, Dietrich Braun, Ludwig Bottenbruch, Kunststoff Handbuch [Plastics Manual], Volume 3/1, Technische Thermoplaste – Polycarbonate, Polyacetale, Polyester, Celluloseester [Engineering thermoplastics – Polyacetals, Polyesters, Cellulose Esters], published by Carl Hanser Verlag, 1992

- Gerhard W. Becker, Dietrich Braun, Ludwig Bottenbruch, Rudolf Binsack, Kunststoff Handbuch [Plastics Manual], Volume 3/4, Technische Thermoplaste – Polyamide [Engineering thermoplastics – Polyamides], published by Carl Hanser Verlag, 1998

Test standards

Determination of mechanical characteristic values

- ISO 527-1: Plastics – Determination of tensile properties – Part 1: General principles

- ISO 527-2: Plastics – Determination of tensile properties – Part 2: Test conditions for molding and extrusion plastics

- ISO 179-1: Plastics – Determination of Charpy impact properties – Part 1: Non-instrumented impact test

- ISO 179-2: Plastics – Determination of Charpy impact properties – Part 2: Instrumented impact test

Testing for stress cracking resistance

- ISO 22088-3: Plastics – Determination of resistance to environmental stress cracking (ESC) – Part 3: Bent strip method

Corrosion testing

- VDA 230-214: Beständigkeit metallischer Werkstoffe gegen Kondensat-Korrosion in abgasführenden Bauteilen – Prüfmethode [Resistance of metallic materials to condensate corrosion in exhaust gas-carrying components – Testing methods]

Test fuels

- ISO 1817: Rubber, vulcanized or thermoplastic – Determination of the effect of liquids

- SAE J1681: Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing

Conditioning of polyamides

- ISO 1110: Plastics – Polyamides – Accelerated conditioning of test specimens

BASF brochures

- Ultramid® main brochure, 2010
- Conditioning of prefabricated parts from Ultramid®, 2010
- Ultradur® main brochure, 2010
- Ultraform® main brochure, 2016
- Ultramid® Advanced N
- Ultramid® Advanced T1000
- Ultramid® Advanced T2000

More information regarding the chemical behavior of Ultrason® (PSU, PESU, PPSU) can be found in the BASF brochure “Ultrason® – Resistance to Chemicals”, 2010.

Overview

Ultramid® A	Examples	Ultramid® B	Examples	Ultramid® S	Examples	Ultramid® T
Highly resistant: empirical value from numerous applications under their typical conditions						
aliphatic hydrocarbons	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**
aromatic hydrocarbons	benzene, toluene	**aromatic hydrocarbons**	benzene, toluene	**aromatic hydrocarbons**	benzene, toluene	**aromatic hydrocarbons**
alkalis	ordinary soap, washing solutions, alkaline concrete	**alkalis**	ordinary soap, washing solutions, alkaline concrete	**alkalis**	ordinary soap, washing solutions, alkaline concrete	**alkalis**
ethylene glycol	brake fluids, hydraulic fluids			**ethylene glycol**	brake fluids, hydraulic fluids	**ethylene glycol**
ethers	THF, antiknock agents for fuels (TBME, ETBE)	**ethers**	THF, antiknock agents for fuels (TBME, ETBE)	**ethers**	THF, antiknock agents for fuels (TBME, ETBE)	**ethers**
esters	greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate)	**esters**	greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate)	**esters**	greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate)	**esters**
aliphatic alcohols	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**
water and aqueous solutions	drinking water, seawater, beverages	**water and aqueous solutions**	drinking water, seawater, beverages	**water and aqueous solutions**	drinking water, seawater, beverages, road salt, calcium chloride and zinc chloride solutions	**water and aqueous solutions**
organic acids	in the solid state: citric acid, benzoic acid	**organic acids**	in the solid state: citric acid, benzoic acid	**organic acids**	in the solid state: citric acid, benzoic acid	**organic acids**
oxidants	ozone as a component of air	**oxidants**	ozone as a component of air	**oxidants**	ozone as a component of air	**oxidants**

Table 4: Overview of the media resistance of Ultramid®, Ultradur® and Ultraform®

Examples	Ultramid® Advanced	Examples	Ultradur®	Examples	Ultraform®	Examples
natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants	**aliphatic hydrocarbons**	natural gas, fuels (Otto, diesel), paraffin oil, motor oils, technical greases and lubricants
benzene, toluene	**aromatic hydrocarbons**	benzene, toluene	**aromatic hydrocarbons**	benzene, toluene (severe swelling possible at elevated temperatures)	**aromatic hydrocarbons**	benzene, toluene
ordinary soap, washing solutions, alkaline concrete	**alkalis**	ordinary soap, washing solutions, alkaline concrete			**alkalis**	ordinary soap, washing solutions, alkaline concrete
brake fluids, hydraulic fluids	**ethylene glycol**	brake fluids, hydraulic fluids			**ethylene glycol**	<100 °C brake fluids, hydraulic fluids
THF, antiknock agents for fuels (TBME, ETBE)	**ethers**	THF, antiknock agents for fuels (TBME, ETBE)			**ethers**	THF, antiknock agents for fuels (TBME, ETBE)
greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate)	**esters**	greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate)	**esters**	greases, cooking oils, motor oils	**esters**	greases, cooking oils, motor oils, surfactants (e.g. sodium dodecyl sulfate), biodiesel
<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)	**aliphatic alcohols**	<60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels (E10, E50, E90)
drinking water, seawater, beverages, road salt, calcium chloride and zinc chloride solutions	**water and aqueous solutions**	drinking water, seawater, beverages, road salt, calcium chloride and zinc chloride solutions	**water and aqueous solutions**	<40 °C drinking water, seawater, beverages, road salt, calcium chloride and zinc chloride solutions, moist climate	**water and aqueous solutions**	drinking water, seawater, beverages
in the solid state: citric acid, benzoic acid	**organic acids**	in the solid state: citric acid, benzoic acid	**organic acids**	in the solid state: citric acid, benzoic acid	**organic acids**	in the solid state: citric acid, benzoic acid
ozone as a component of air	**oxidants**	ozone as a component of air	**oxidants**	ozone as a component of air	**oxidants**	ozone as a component of air

Note: Discoloration of the test specimens is not taken into consideration during the evaluation of the resistance.

Ultramid® A	Examples	Ultramid® B	Examples	Ultramid® S	Examples	Ultramid® T
Somewhat resistant: known applications, thorough testing and case-to-case evaluations necessary						
alkalis	sodium hydroxide solution, ammonia solution, urea solution, amines	**alkalis**	sodium hydroxide solution, ammonia solution, urea solution, amines	**alkalis**	sodium hydroxide solution, ammonia solution, urea solution, amines	**alkalis**
ethylene glycol	coolants			**ethylene glycol**	coolants	**ethylene glycol**
esters	transmission oils, biodiesel	**esters**	transmission oils, biodiesel	**esters**	transmission oils, biodiesel	**esters**
aliphatic alcohols	>60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels	**aliphatic alcohols**	>60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels	**aliphatic alcohols**	>60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels	**aliphatic alcohols**
water and aqueous solutions	chlorinated drinking water	**water and aqueous solutions**	chlorinated drinking water	**water and aqueous solutions**	chlorinated drinking water	**water and aqueous solutions**
organic acids	as an aqueous solution: acetic acid, citric acid, formic acid, benzoic acid	**organic acids**	as an aqueous solution: acetic acid, citric acid, formic acid, benzoic acid	**organic acids**	as an aqueous solution: acetic acid, citric acid, formic acid, benzoic acid	**organic acids**
oxidants	traces of ozone, chlorine or nitrous gases	**oxidants**	traces of ozone, chlorine or nitrous gases	**oxidants**	traces of ozone, chlorine or nitrous gases	**oxidants**

Table 4: Overview of the media resistance of Ultramid®, Ultradur® and Ultraform®

Examples	Ultramid® Advanced	Examples	Examples	Examples	Ultraform®	Examples
sodium hydroxide solution, ammonia solution, urea solution, amines	**alkalis**	sodium hydroxide solution, ammonia solution, urea solution, amines	**alkalis**	weakly alkaline media: urea solution, sodium hydroxide solution pH 10	**alkalis**	sodium hydroxide solution, ammonia solution, urea solution, amines
coolants	**ethylene glycol**	coolants			**ethylene glycol**	> 100 °C coolants
					ethers	tetrahydrofurane (THF)
transmission oils, biodiesel	**esters**	transmission oils, biodiesel	**esters**	transmission oils		
> 60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels	**aliphatic alcohols**	> 60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels			**aliphatic alcohols**	> 60 °C ethanol, methanol, isopropanol, anti-freeze agents for windshield washing systems, spirits, fuels
chlorinated drinking water	**water and aqueous solutions**	chlorinated drinking water	**water and aqueous solutions**	40 °C to 90 °C moist climate	**water and aqueous solutions**	chlorinated drinking water, aqueous zinc chloride solutions
as an aqueous solution: acetic acid, citric acid, formic acid, benzoic acid	**organic acids**	as an aqueous solution: acetic acid, citric acid, formic acid, benzoic acid			**organic acids**	as a diluted aqueous solution: acetic acid, citric acid, formic acid, benzoic acid, lactic acid
traces of ozone, chlorine or nitrous gases	**oxidants**	traces of ozone, chlorine or nitrous gases				

Note: Discoloration of the test specimens is not taken into consideration during the evaluation of the resistance.

Ultramid® A	Examples	Ultramid® B	Examples	Ultramid® S	Examples	Ultramid® T
Not resistant						
mineral acids	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**
oxidants	halogens, oleum, hydrogen peroxide, ozone, hypochlorite	**oxidants**	halogens, oleum, hydrogen peroxide, ozone, hypochlorite	**oxidants**	halogens, oleum, hydrogen peroxide, ozone, hypochlorite	**oxidants**
Triggers stress cracking						
aqueous calcium chloride solutions	road salt	**aqueous calcium chloride solutions**	road salt			
aqueous zinc chloride solutions	road salt solution in contact with zinc-plated components	**aqueous zinc chloride solutions**	road salt solution in contact with zinc-plated components			
Solvents						
	concentrated sulfuric acid		concentrated sulfuric acid		concentrated sulfuric acid	
	formic acid 90 %		formic acid 90 %		formic acid 90 %	
	hexafluoroisopropanol (HFIP)		hexafluoroisopropanol (HFIP)		hexafluoroisopropanol (HFIP)	

Table 4: Overview of the media resistance of Ultramid®, Ultradur® and Ultraform®

Examples	Ultramid® Advanced	Examples	Ultradur®	Examples	Ultraform®	Examples
			water and aqueous solutions	>90 °C moist climate		
			alkalis	strongly alkaline media: sodium hydroxide solution pH 14, concrete/concrete liquor		
					sulfur dioxide	
					nitrous gases	
concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid	**mineral acids**	concentrated hydrochloric acid, battery acid, sulfuric acid, nitric acid
					organic acids	concentrated solution: acetic acid, formic acid
halogens, oleum, hydrogen peroxide, ozone, hypochlorite	**oxidants**	halogens, oleum, hydrogen peroxide, ozone, hypochlorite	**oxidants**	halogens, oleum, hydrogen peroxide, ozone, sodium hypochlorite at an elevated temperature	**oxidants**	halogens, oleum, hydrogen peroxide, ozone, sodium hypochlorite at an elevated temperature
			sodium hydroxide solution	10 %-solution		
concentrated sulfuric acid						
formic acid 90 %						
hexafluoroisopropanol (HFIP)				hexafluoroisopropanol (HFIP)		hexafluoroisopropanol (HFIP)
				dichlorobenzene/phenol (50/50)		
						N-methyl-pyrrolidone (NMP) at an elevated temperature
						dimethyl formamide (DMF) at an elevated temperature

Note: Discoloration of the test specimens is not taken into consideration during the evaluation of the resistance.

For your notes

Selected Product Literature:

- Ultramid® – Product Brochure
- Ultramid® – Product Range
- Ultradur® – Product Brochure
- Ultradur® – Product Range
- Ultraform® – Product Brochure
- Ultraform® – Product Range AT
- Ultramid®, Ultradur® und Ultraform® – Resistance to Chemicals
- Ultramid® Advanced PPA brochures and flyers

Note

The data contained in this publication are based on our current knowledge and experience. In view of the many factors that may affect processing and application of our product, these data do not relieve processors from carrying out own investigations and tests; neither do these data imply any guarantee of certain properties, nor the suitability of the product for a specific purpose. Any descriptions, drawings, photographs, data, proportions, weights etc. given herein may change without prior information and do not constitute the agreed contractual quality of the product. It is the responsibility of the recipient of our products to ensure that any proprietary rights and existing laws and legislation are observed. (March 2022)

Further information on Ultramid®, Ultradur® und Ultraform® can be found on the internet:
ultramid.basf.com
ultradur.basf.com
ultraform.basf.com

Please visit our websites:
www.plastics.basf.com

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