DuPont™ Minlon® and Zytel®

nylon resins

Design Information – Module II

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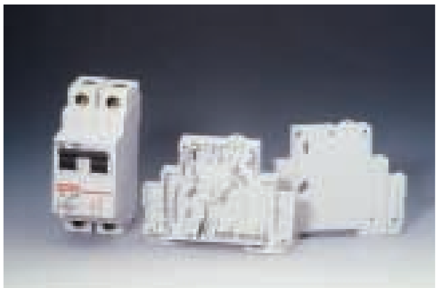
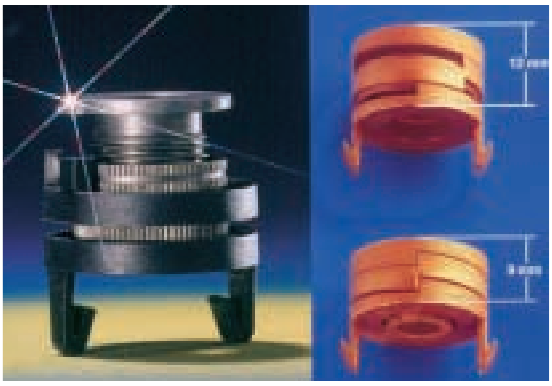




3

4

The miracles of science™

Design information on MINLON® and ZYTEL®

Table of contents

1 – General

Introduction

The invention of nylon by DuPont in the early 30's, and its introduction in 1938, was a major breakthrough in polymer chemistry. No resin has yet been introduced that can begin to match the unique combination of properties which has made nylon the most versatile and broadly applied plastic material. Its use as an injection moulding resin to produce a wide variety of engineering plastic parts used in every industry has grown, by some estimates, to the existence of more than a half million different parts, and the diversity and growth continues as the DuPont nylon resin product line expands through the results of ongoing extensive research and market development. Nylon has also found wide and varied uses as an extrusion resin for film, filament and proprietary oriented products. Finally, nylon is widely known for its multitude of uses in the textile fibre industry.

The information that follows is intended to help designers and engineers become familiar with the unique characteristics of the DuPont nylon family of ZYTEL® and MINLON® engineering thermoplastic resins, and how these characteristics are affected by environment and stress. With this knowledge, the information provided by the Design Handbook – Module I, it is hoped that correct resin selection coupled with good design practice will result in the development of a successful part in the shortest possible time.

The data contained in this module falls outside the scope of CAMPUS and should not be used to establish specification limits or used alone as the basis for design. Since DuPont can make no guarantee of results and therefore assumes no liability in connection with the use of this information, confirmation of its validity and suitability should be obtained independently.

Do not use DuPont plastics in medical applications involving permanent implantation in the human body. For other medical applications, see "DuPont Medical Caution Statement", H-50102.

Product overview

Basic DuPont nylon resins

The "basic" nylon resins include the unmodified nylon homopolymers and modifications produced by the addition of heat stabilizers, lubricants, ultraviolet screens, nucleating agents, etc. The majority of resins have molecular weights suited for injection moulding and some are used for filaments, wire jacketing, film, and extruded shapes including rod, slab and sheet stock.

Many grades of DuPont nylon resin meet European and/or non-European requirements for food contact applications and for potable water uses. Many are rated by Underwriters' Laboratories, Inc. for use in electrical and electronic equipment. Many are certifiable to a long list of customer, ISO and ASTM specifications.

Compositions of DuPont nylon resins and their description are shown in the Table on page 1.3.

66 Nylons

The most important of the nylon resins are ZYTEL® lubricated versions 101L and 101F. These are 66 nylons made by the polymerization of hexamethylenediamine and adipic acid, each of which contain six carbon atoms. They possess an outstanding balance of properties – combining strength, moderate stiffness, high service temperature and a high level of toughness. They are particularly resistant to repeated impact, have low coefficients of friction and excellent resistance to abrasion. They resist fuels, lubricants and most chemicals, but are attacked by phenols, strong acids and oxidizing agents.

The 66 nylons are easily injection moulded. The general purpose moulding resins readily fill thin section moulds due to low melt viscosity. These crystalline polymers set up rapidly, especially the nucleated and lubricated ZYTEL® 135F.

The combination of easy fill and fast set up allows very fast moulding cycles.

Nylons absorb moisture from the air and 66 nylon equilibrates at about 2,8% water at 50% RH and at about 8,5% at 100% RH. This plasticizes the nylon, lowering its strength and stiffness but increasing its toughness and elongation. Moisture absorption increases dimensions of 66 nylons by 0,6% at 50% RH and about 2,6% at 100% RH. The process is reversible, that is, the strength and stiffness increase and dimensions decrease as moisture content decreases. Absorption and desorption are slow processes. For example, it takes about 125 days for a 1,5 mm thick dry specimen to reach equilibrium moisture content when exposed to 50% relative humidity.

Nylon resins are not considered primary electrical insulators but their high temperature properties, their toughness and abrasion resistance, and their chemical resistance, combined with electrical properties adequate for most power frequencies and voltages, have made them the choice for a wide variety of electrical applications.

Toughened DuPont nylon resins

DuPont has developed a series of toughened nylon resins that further extends the usefulness of nylon into areas where very high toughness is desired. They may be divided into two groups, both involving the uniform dispersion of modifiers which interfere with the initiation and propagation of cracks. The effect is seen most dramatically in the Charpy impact strength, which is raised from about 5 kJ/m^2 for ZYTEL® 101L (dry-as-moulded, 23°C) to over 20 kJ/m^2 for ZYTEL® Toughened nylons.

The first of the series to be introduced was ZYTEL® 408 and related resins. These are modified 66 nylons with the Charpy raised to about 25 kJ/m^2 and the strength and stiffness lowered about 25%. They mould very well.

Supertough DuPont nylon resins

The second series, the "Supertough" nylons resulted from a significant breakthrough in nylon polymer chemistry. The "Supertough" technology has been applied to the 66 nylon moulding resins, increasing notched Charpy impact values to over 100 kJ/m^2, with ductile rather than brittle breaks.

In addition to extremely low notch sensitivity, the super-tough nylons exhibit exceptionally high energy absorption characteristics even in special high speed impact tests. While strength and stiffness are reduced, the outstanding toughness of these resins commends their consideration whenever the ultimate in toughness is needed.

612 nylons

The 612 nylons, such as ZYTEL® 151L, have lower melting points, strength, and stiffness than 66 nylons. They absorb less water, only about 1,3% at 50% RH and 3,0% at 100% RH, and therefore have better dimensional stability and electrical properties. 612 nylons have better chemical resistance than 66 nylons. As in the case of 66 nylons, heat and weather stabilized grades are available.

Glass reinforced DuPont nylon resins

The glass reinforced DuPont nylon resin families extend the usefulness of nylon to applications requiring an elastic modulus of up to 11000 MPa and a tensile strength of up to 200 MPa. By using various nylon matrices, essential characteristics such as dimensional stability, toughness, chemical resistance, etc., can be maximized to meet the requirements of a wide range of applications.

Property enhancement is maximized by the uniform dispersion of specially treated glass fibres into the nylon. Treatment of the glass fibres produces a tightly adhering chemical bond between the nylon and the glass that enhances both tensile strength and stiffness over a wide range of environmental conditions. Glass levels of up to 60% (weight) are available in the different matrices. The highest loadings, of course, provide the highest strength and stiffness.

- Nylon 66 matrix based resins
  ZYTEL® 70G, in different glass loadings has a lubricant added for improved machine feed and mould release properties. These have the highest strength, stiffness, creep resistance and melting point. They may be pigmented and stabilized against the effects of long term high temperature exposure (HSL) and hot glycol/water mixtures (HSLR).
  ZYTEL® 79G is an impact modified resin, which combines high stiffness with higher toughness.
  ZYTEL® 80G is based on a supertough resin for getting highest toughness with relatively minor sacrifices in strength and stiffness.

- Nylon 66/6 matrix based resins
  ZYTEL® 74G30 is a PA66/6 blend, with improved properties related to impact resistance and surface appearance compared to 70G types

- Nylon 6 matrix based resins
  ZYTEL® 73G grades are available in glass loadings varying from 15% to 50%. These materials are more sensitive to moisture than PA66; they therefore generally have a higher toughness combined with a lower stiffness and strength. The surface appearance of PA6 is excellent. Instead of glass fibres, several grades are also available with mineral fillers, or mixtures of both.

- Nylon 612 matrix based resins
  ZYTEL® 77G grades are available with 33 or 43% glass loadings, giving excellent dimensional stability, also at higher temperatures because of their low moisture absorption.
  In addition the 77G grades have a better chemical resistance.

MINLON®

MINLON® engineering thermoplastic resins are mineral and mineral/glass reinforced 66 nylons with stiffness and heat deflecton temperatures approaching those of glass reinforced nylons – but which are lower in cost and exhibit substantially less warpage.

The reinforcing materials – either mineral alone or mineral/glass combinations – are chemically bonded to the nylon. Strength and stiffness are increased with some loss of toughness and elongation.

MINLON® resins also exhibit greater dimensional stability and creep resistance than unreinforced nylon.

Various grades of MINLON® have been formulated to meet specific end use requirements.

Speciality ZYTEL® resins

- ZYTEL® FN
  ZYTEL® FN flexible nylon alloys are a new family of plasticizer-free thermoplastics which offer a unique combination of properties. These flexible resins exhibit high end-use properties, good low temperature toughness and good chemical resistance. ZYTEL® FN nylon alloys can be processed on typical thermoplastic equipment. Service temperatures range from –40 to 150°C.
- Flame retardent ZYTEL® grades
- Transparent ZYTEL® 330
- ZYTEL®-KEVLAR® SFC

Fabrication

Injection moulding is the most common method for producing parts of DuPont nylon resins. For specific processing conditions and safe handling, separate literature is available.

ZYTEL® nylons can also be extruded into tubing, rods, slabs, sheeting and film.

Blow moulding can be used for making bottles, reservoirs, and similar parts.

Rods, tubes and other semi-finished extruded shapes of ZYTEL® can be fabricated into small parts by automatic screw machining. Prototypes and small-run items can be machined from rod or slab stock.

Designing with DuPont nylon resins

Many of the same design considerations apply to ZYTEL® and MINLON® as to metals and other engineering materials. It is common practice to use standard engineering equations for designing. However, since all engineering materials are affected to some extent by temperature, moisture and other environmental service conditions, it is necessary to determine the extreme operating conditions and to design a part so that it will perform satisfactorily under all these conditions.

Compositions

Designation	Description
Unreinforced	
Zytel® 101L	Lubricated PA66
Zytel® 103HSL	Heat stabilised lubricated PA66
Zytel® 105F	Lubricated UV resistant PA66 (Black)
Zytel® 122L	Hydrolisis resistant lubricated PA66
Zytel® 135F	Nucleated lubricated PA66
Zytel® 7300	Lubricated PA6
Zytel® 7335F	Nucleated lubricated PA6
Zytel® 151L	Lubricated PA612
Toughened	
Zytel® 114L	Impact modified PA66 (Black)
Zytel® 408	Toughened PA66
Zytel® 450	Toughened PA66
Zytel® 490	Toughened PA66
Zytel® 7300T	Toughened PA6
Supertough	
Zytel® ST801	Supertough PA66
Zytel® ST7301	Supertough PA6
Glass reinforced	
Zytel® 70G20HSL	20% glass reinforced heat stabilised PA66
Zytel® 70G25HSL	25% glass reinforced heat stabilised PA66
Zytel® 70G30HSL	30% glass reinforced heat stabilised PA66
Zytel® 70G35HSL	35% glass reinforced heat stabilised PA66
Zytel® 70G43L	43% glass reinforced PA66
Zytel® 70G50HSL	50% glass reinforced heat stabilised PA66
Zytel® 70G60HSL	60% glass reinforced heat stabilised PA66 (Black)
Zytel® 73G15L	15% glass reinforced PA6
Zytel® 73G25L	25% glass reinforced PA6
Zytel® 73G30L	30% glass reinforced PA6
Zytel® 73G35L	35% glass reinforced PA6
Zytel® 73G40	40% glass reinforced PA6
Zytel® 73G45L	45% glass reinforced PA6
Zytel® 73G50L	50% glass reinforced PA6
Glass reinforced (Speciality)	
Zytel® 70G30HSLR	30% glass reinforced heat stabilised hydrolysis resistant PA66
Zytel® 70G35HSLX	35% glass reinforced hot oil and grease resistant PA66
Zytel® 70GB40HSL	40% glass bead reinforced heat stabilised PA66
Zytel® 74G30L	30% glass reinforced PA66/6 blend
Zytel® 77G33L	33% glass reinforced PA612
Zytel® 77G43L	43% glass reinforced PA612
Toughened glass reinforced	
Zytel® 73G15T	Toughened 15% glass reinforced PA6
Zytel® 73G30T	Toughened 30% glass reinforced PA6
Zytel® 79G13L	Toughened 13% glass reinforced PA66
Zytel® 80G14	Toughened 14% glass reinforced PA66
Zytel® 80G25	Toughened 25% glass reinforced PA66
Zytel® 80G33HS1L	Toughened 33% glass reinforced heat stabilised PA66

Designation	Description
Flame retardant	
Zytel® FR7026 V0F	Unreinforced PA66 UL94 V0 (0,8 mm)
Zytel® FR7200 V0F	Unreinforced PA66/6 copolymer, UL94 V0 (0,5 mm) halogen and phosphorous free
Zytel® FR70G25 V0	25% glass reinforced PA66, UL94 V0 (0,5 mm)
Zytel® FR72G25 V0	25% glass reinforced PA66/6, copolymer UL94 V0 (0,5 mm)
Zytel® FR70M30 V0	30% mineral reinforced PA66, UL94 V0 (1,6 mm)
Zytel® FR70M40GW	40% mineral reinforced PA66, glow wire 960°C
High viscosity / Extrusion	
Zytel® E40	High viscosity PA66 (RV = 95–150)
Zytel® E42A	High viscosity PA66 (RV = 180–310)
Zytel® E50	High viscosity PA66 (RV = 240–470)
Zytel® E51HSB	High viscosity heat stabilised PA66 (RV = 240–470)
Zytel® E53	High viscosity PA66 (RV = 470–600)
Zytel® 158	High viscosity PA612
Specialities	
Zytel® 330	Transparent amorphous nylon
Zytel® FN714	PA66 based flexible nylon alloy
Zytel® FN718	PA66 based flexible nylon alloy
Zytel® FN727	PA6 based flexible nylon alloy
Zytel®-Kevlar® SFC 70K20HSL	20% Kevlar® short fibre reinforced, heat stabilised PA66
Mineral reinforced grades	
Minlon® 10B140	40% mineral reinforced PA66
Minlon® 11C140	40% mineral reinforced PA66/6 blend. Toughened and heat stabilised
Minlon® 13T2	30% mineral reinforced PA66. Toughened and heat stabilised
Minlon® 13MMGY	16% mineral reinforced PA66. Toughened and heat stabilised
Minlon® 14D1	26% mineral reinforced PA66. Toughened and UV stabilised (black)
Minlon® 73M30	30% mineral reinforced PA6
Minlon® 73M40	40% mineral reinforced PA6
Mineral/glass reinforced grades	
Minlon® 21B1	39% mineral-glass reinforced PA66 (34% mineral and 5% glass)
Minlon® 23B1	37% mineral-glass reinforced PA66 (28% mineral and 9% glass)
Minlon® EFE6053	40% mineral-glass reinforced PA66 (16% mineral and 24% glass)
Minlon® 73GM30HSL	30% mineral-glass reinforced PA6 (20% mineral and 10% glass)
Minlon® 73GM30T	30% mineral-glass reinforced PA6, toughened (20% mineral and 10% glass)
Minlon® 73GM40	40% mineral-glass reinforced PA6 (25% mineral and 15% glass)

For characteristics of special grades: contact your local DuPont representative.

The selection of the best material for any application requires a knowledge of the properties of all candidate materials and how they satisfy the requirements of the application.

Much of the engineering data needed in designing with DuPont nylons are given in the following pages and should be helpful to the designer. However, it is always good practice to test prototypes of a proposed design and material under realistic conditions before making production commitments.

Another responsibility for designers is to keep the impact on the environment as low as possible. This can be done by optimal designs, using the right materials, including the possibilites to design for disassembly. By selecting the best colourants and other additives, given the knowledge of the impact on the environment of these additives today, DuPont tries to minimise or avoid any effect on the environment.

For designs, including disassembly possibilities, see DuPont "Design Handbook", module I: General Design Principles.

Standards

In principle all new material information, obtained in Europe, is measured according ISO standards. The data in the "Product and properties guide (H-53823 for ZYTEL® and H-53824 for MINLON®)" and CAMPUS are examples.

Because of the long usage of nylons, there is much historical information available, measured according to other standards. Where such information is considered to be useful for designers, it is included in this manual; data obtained according to old or former standards is still considered to be better than no data at all.

Users of any of the data in this handbook are, however, strongly recommended to check the validity of the given values for end-use applications.

The technical information in TRG 14 compares ASTM, DIN, BS and ISO standards and test methods.

All ZYTEL® and MINLON® grades are subject to possible changes and DuPont can not accept any liability for any damage caused by the wrong use of properties in designs of plastic parts.

2 – Value engineering

Introduction

ZYTEL® and MINLON® nylon resins are converted into useful parts by a number of processing techniques, with injection moulding being the most prevalent. Other methods include extrusion, machining, nonmelt forming processes and blow moulding.

There are two important but quite different aspects of the cost estimated in considering nylons for a new component, or replacement of a metal or other material of construction. The first portion of the estimate includes the aggregate of costs for the tool, material, moulding and postmoulding operations. This is a cost that can be reliably estimated, using standard and accepted procedures.

Less easy to determine, although frequently more important, are the cost savings that may be effected through lower wear, superior performance, or the possibility of combining several component parts into one structural piece. The wide range of properties available in the DuPont nylon range frequently permit novel and imaginative design approaches with savings in performance and assembly that may even exceed production costs. These cost savings represent the economic incentives for using ZYTEL® or MINLON® and should be considered separately from the cost of manufacture or purchase price of the item.

Economic incentives for using DuPont nylons

A few potential savings – or economic incentives – that are frequently important in cost considerations are given below.

- *Elimination or reduction of parts associated with assemblies of traditional design.* One moulded part may serve the function of an assembly of individual parts, as for example, a single moulded part performing the functions of both a gear and a cam.
- *Elimination of mechanical finishing operations.* In most cases, plastic parts can be produced fully finished and ready for use as ejected from the mould.
- *Rapid assembly of parts.* The resilience and strength of plastics permit the use of assembly techniques such as snap fitting, press fitting, cold heading, spin welding, sonic welding, angular and linear welding.
- *Lower maintenance and service costs.* Unreinforced ZYTEL® has exceptionally good frictional properties and is frequently used in combination with metal and other plastic parts without additional lubrication.
- *Excellent stress crack resistance.* ZYTEL® is resistant to stress cracking during cleaning in solvents and detergents. Accordingly, it in TV tuners, switches and power tools. ZYTEL® will remain unharmed by many solvents and chemi cals that plasticize or stress crack other plastic materials.
- *Longer service life.* DuPont nylons have been selected for many demanding applications because of superior repeated impact strength and high fatigue endurance level under severe environmental conditions.
- *Lower decorative finishing costs.* Most colour effects can be obtained by using coloured moulding resins. This avoids the need for painting.
- *Production of colour-coded parts.* Colours can be added during moulding in order to produce easily identifiable components. Parts can also be readily dyed.
- *Avoidance of corrosion.* Several problems with metals, including rusting and de-zincification, can be avoided by designing parts in DuPont nylon resins.
- *Weight savings where substituted for metal construction.* Strong, lightweight parts are used to reduce the weight of the overall assembly. Easier handling and reduced shipping costs can be obtained.

Cost of producing assemblies by injection moulding

As already indicated, the cost of moulded parts (in contrast to potential in-use savings) can be accurately estimated. These costs are broken down into five elements:

Material

For a general guide, the material cost is usually between 30 and 50% of the moulded part cost, although this may increase to 80% for large parts. The cost is partly dependent upon the amount of material purchased, the specific composition used and colour.

To minimize rework, the size of runners and sprues should be kept to a practical minimum by proper mould design. The reduction of rework material can sometimes be affected through the use of runnerless moulds. In this case, sprues and runners are not removed from the mould with the parts during the cycle. The runnerless moulding technique, however, is not suitable for all moulds, especially when temperature control within the mould is difficult.

Runners and sprues can be ground up and reused without significant loss in physical properties, providing care is taken to avoid contamination of, or moisture pick up by, the regrind.

Adequate quality control should be applied to parts as they are produced to improve the overall efficiency of moulding and to reduce the generation of rework to a minimum

Contribution of tool cost to part cost

Tool costs are largely dependent on the size and complexity of the mould, which in turn is determined by part design and production requirements.

Because mould costs can contribute significantly to overall cost, the design of injection moulds for production should be left to an experienced mould designer. It is advisable to consult the mould designer before part design is finalized, since even seemingly insignificant changes in part geometry may greatly influence the cost of producing the tool and the part. Figure 2.01 illustrates the factors which should be considered in designing economical injection moulds. Part shape, tolerances and wall dimensions are all-important factors.

Cost of the moulding operation

The moulding operation usually constitutes 40–60% of the moulded part cost. Variations in this range depend on the size of machine employed, cavities in a mould, the extent to which the machine is utilized in production and part geometry. Factors associated with the size of the moulding machine are usually in the hands of the moulder. However, the designer can contribute towards reducing the cost of moulding by designing components that can be moulded with short cycles. The productivity and, hence, the cost of moulding, depends on four factors: moulding cycle, parts per cycle, product quality and run length.

The moulding cycle depends on many factors. Most important is the maximum section thickness. Moulding is essentially a heat transfer process. Once the mould has been filled with resin, it is necessary to reduce the temperature of the piece to a level where it may be removed and yield a part of the desired quality. Thicker sections usually require longer moulding cycles. The composition chosen for the part may also affect the cycle. Most DuPont nylon resins are semi-crystalline with high transition temperatures, allowing fast moulding cycles.

The cycle is also dependent on the part specifications. For example, where stringent dimensional tolerances must be held, moulding conditions may be needed which would lengthen the cycle.

The number of parts per cycle or the number of cavities in a mould determines output, the size of moulding machine required and the type of operation used. Usually the number of cavities increases as the required annual volume of parts increases. There are limitations on this number of cavities depending on part size and complexity, type of mould, runner length, dimensional tolerances and machine design. Automated operation, as compared to manual or semi-automatic, will usually result in the design of a tool with fewer cavities.

The number of cavities in a mould may be influenced by the anticipated size of a production order or the annual production volume. Thus, an economic balance should be reached between the tool cost and the cost of setting up and running an order.

Cost of post-moulding operations

Most parts made of DuPont nylon resins are moulded as fully finished parts. However, sometimes it may be necessary to carry out operations such as conditioning, annealing, machining and decorating. Annealing costs will depend on the cost of labour and on the annealing medium employed. Costs for machining will depend on the precision and extent of the machining operations involved.

When requirements for moulded parts go beyond the usual dimensional tolerances, and include specifications for such properties as relative viscosity or a specified degree of toughness, laboratory testing must be done. Costs will vary according to the tests and sampling required.

Other charges and part cost

Special operating, handling or packaging of moulded parts or short moulding runs may cause supplementary charges.

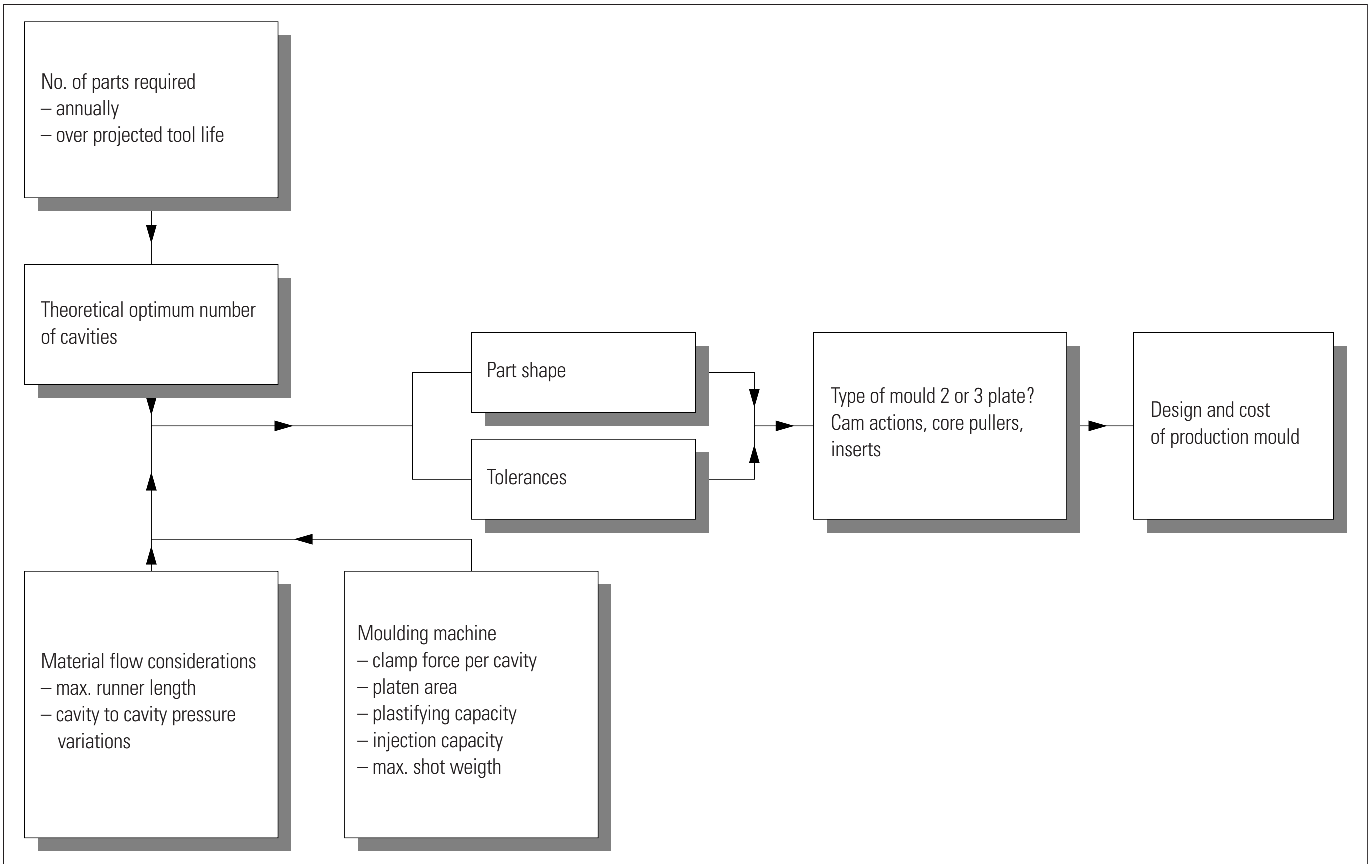


Figure 2.01 **Guide to factors important in mould design**

Cost of other processing methods

The injection moulding process has been discussed in some detail. However, ZYTEL® non reinforced nylons also may be converted into useful objects by extrusion, by thermoforming of extruded and cast sheet, blow moulding, powder sintering and various nonmelt techniques.

- *Extrusion.* Extrusion is a continuous process used in the production of sheet, rods, tubes or shapes from resin. With extrusion, it is possible to produce these items economically in large volume with a low tooling cost.
- *Thermoforming.* Thermoforming is a process for the manufacture of shapes from sheet. Material costs for making parts from sheet will normally be higher than those for injection moulding. However, considerably lower tooling costs can give this process an economic advantage over moulding where production volume is low.
- *Blow moulding.* In the blow moulding process a "parison" is produced, by extrusion or injection moulding, from which the finished article is blown. Blow moulding allows the production items such as bottles and tanks economically in large volumes with low tooling cost.

3 – Properties of DuPont nylons

Material properties

Introduction

It is important for the designer to realize, that DuPont nylon resins have strength and stiffness properties considerably different from some of the older engineering materials, particularly most metals. In general the strength and stiffness properties of nylon resins are more sensitive to environmental changes of moisture and temperature.

However with adequate knowledge of the effects of the environment the designer is better able to get the best out of the potentials of DuPont nylon resins.

This handbook contains properties of DuPont nylon resins shown in tables and graphs. Standard graphical information about general grades, like stress-strain curves, viscosity versus shear rate, are included in CAMPUS (version 2.4 and subsequent issues) and not repeated in this handbook; see also Table 3.01.

For a copy of the DuPont materials in the CAMPUS database, contact your DuPont representative.

Later on in this handbook several references are made to "ZYTEL® 101". This implies the generic name for the grades: ZYTEL® 101L, ZYTEL® 101F and ZYTEL® 103HSL all of which have similar values for the applicable properties.

In those cases where graphs do not include a reference to the source of the data, they are copied from the original version of this handbook: "The DuPont ZYTEL® Nylon Resin Design Handbook".

Strength and stiffness

When pulling a moulded test bar in a tensile test machine, one registres the pulling force versus the elongation. Dividing the force by the original cross sectional area of the test bar and the elongation by the original length, one obtains the stress-strain curve.

From the stress strain curve, several interesting material parameters can be derived:

- (tensile) strength, the stress at which the test bar breaks
- yield strength, the first maximum in the stress-strain curve (only applicable to high toughness materials)
- modulus of elasticity, slope of curve at 0% strain, ($E = 100\ \sigma/\varepsilon$; ε in%). The tensile modulus is obtained with tensile test bars, a flexural modulus is derived using bending tests.
- elongation-at-break, the strain at which the test bar breaks.

Stress-strain behaviour of ZYTEL® and MINLON® resins

Humidity and temperature are two environmental factors important for nylon resins. The effects of moisture on ZYTEL® 101 are shown in Figure 3.01, in which complete stress-strain curves are shown for dry as moulded and also for 50 and 100% relative humidities. Increasing humidity results in greater flexibility (lower modulus of elasticity) and toughness but also in lower yield and tensile strengths. Higher temperatures result in lower tensile and yield values.

For stress-strain curves of ZYTEL® 77G43L, see Figure 3.02. More stress-strain curves of ZYTEL® and MINLON® resins (details) are included in CAMPUS, as indicated in Table 3.01.

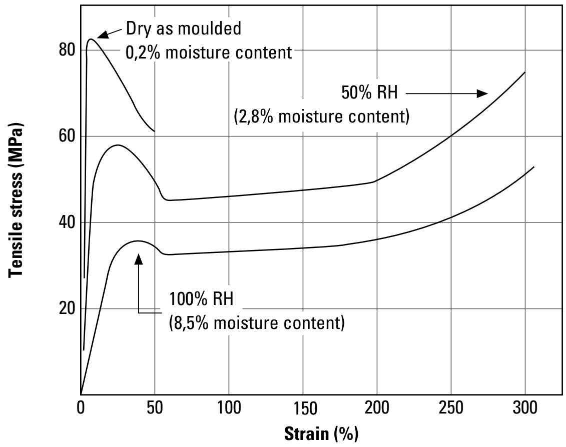


Figure 3.01 **Tensile stress-strain data for ZYTEL® 101 (PA66) at 23°C at various moisture contents**

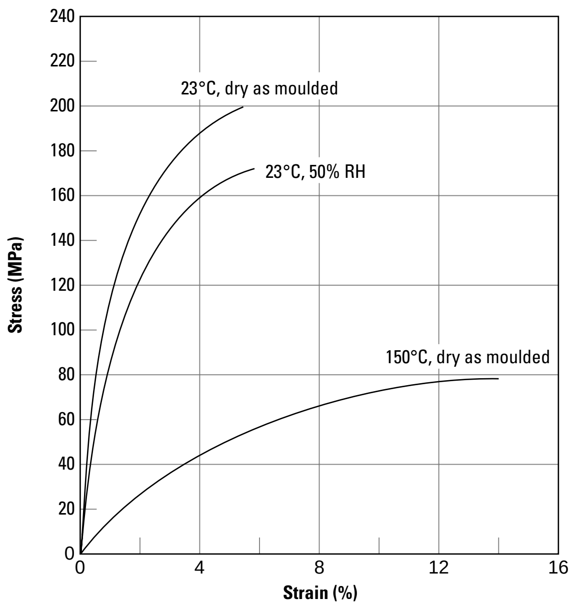


Figure 3.02 **Stress vs. strain at two temperatures and humidities, ZYTEL® 77G43L (PA612, 43% GR)**

Tension and compression

In some calculations, it is important for the designer to know the stress-strain curves in both tension and compression. Figure 3.03 shows these data for ZYTEL® 101 nylon resin at 23°C.

Table 3.01 ZYTEL® and MINLON® resins that are included in CAMPUS, version 3.0 (Dec. 1994)

Grade	Stress-strain curve[1] Secant modulus / strain	Viscosity / shear rate[2] at 3 temperatures	Shear modulus[3] versus temperature	Creep data[4]
Unreinforced PA66				
ZYTEL® 101F NC010	4/4	+	–	–
ZYTEL® 101L NC010	6/7	+	DAM / 50% RH	23, 60°C
ZYTEL® 103HSL NC010	4/4	+	DAM / 50% RH	23°C
ZYTEL® 105 BK010A	7/7	+	–	23°C
ZYTEL® 135F NC010	7/7	+	–	23°C
ZYTEL® 408 NC010	7/7	+	DAM	23°C
ZYTEL® 450 NC010	7/7	+	DAM	–
ZYTEL® 490 NC010	7/7	+	50% RH	–
ZYTEL® E42 NC010	7/7	+	DAM	–
ZYTEL® ST801 NC010	5/7	+	50% RH	23, 60°C
ZYTEL® ST811 NC010	7/7	–	–	–
Reinforced PA66[5]				
ZYTEL® 70G20HSL NC010	5/7	–	–	–
ZYTEL® 70G25HSL NC010	6/7	–	50% RH	–
ZYTEL® 70G30HSL NC010	1/1	+	DAM / 50% RH	–
ZYTEL® 70G30HSLR NC010	6/6	+	DAM / 50% RH	23, 80, 120°C
ZYTEL® 70G35HSL NC010	5/7	+	–	–
ZYTEL® 70G43L NC010	5/7	+	–	23°C
ZYTEL® 79G13L NC010	7/6	+	50% RH	23, 80°C
ZYTEL® 80G33HSIL NC010	6/7	–	DAM / 50% RH	–
Unreinforced PA612				
ZYTEL® 158 NC010	6/7	–	–	–
Reinforced PA612[5]				
ZYTEL® 77G33L NC010	6/7	–	–	–
PA 66/6 copolymers				
ZYTEL® FR10 NC010	7/7	–	–	–
ZYTEL® FR51 NC010	7/7	–	–	–
Reinforced PA6[5]				
ZYTEL® 73G20 NC010	6/5	–	–	–
ZYTEL® 73G30 NC010	7/6	–	–	–
Mineral reinforced PA66				
MINLON® 10B140 NC010	7/7	+	50% RH	23°C
MINLON® 11C140 NC010	7/7	+	DAM	23, 80°C
MINLON® 13T2 GY282	7/7	+	–	23°C
MINLON® 14D1 BK113	6/7	–	–	–
MINLON® 21B1 BK143	7/7	–	–	–
MINLON® 23B1 NC010	7/7	+	–	–
MINLON® EFE6052 NC010	5/7	+	–	–
MINLON® EFE6053 NC010	7/7	+	–	–
MINLON® FR60 NC010	6/7	–	–	–

Notes:
1 The indicated number refers to the number of different temperatures at which stress-strain curves have been measured for DAM and 50% RH.
2 Viscosities are for Dry-As-Moulded (DAM) materials.
3 Conditions as specified.
4 At temperature(s) as indicated.
5 Short glass-fibre reinforcement.

For relatively large strains, the compressive stress is higher than the corresponding tensile stress. This indicates that the yield stress in compression is greater than the yield stress in tension. For all practical purposes, the tensile and compressive stress-strain curves are identical at low strain levels. Therefore, at low strain, the compressive modulus is equal to the tensile modulus.

Tensile strength

The tensile strength of nylon resins is dependent of environmental factors like humidity and temperature.

Figures 3.04 to 3.06 show the effect of different moisture contents on the tensile strength of ZYTEL® 70G30HSL, ZYTEL® 77G33L and several MINLON® grades respectively.

The indications in these figures have the following meaning:

- *Dry as moulded:* moisture content of ≤0,2%.
- *50% RH:* 50% relative humidity of the air or 2,8% moisture content.
- *100% RH:* 100% relative humidity of the air or 8,5% moisture content.

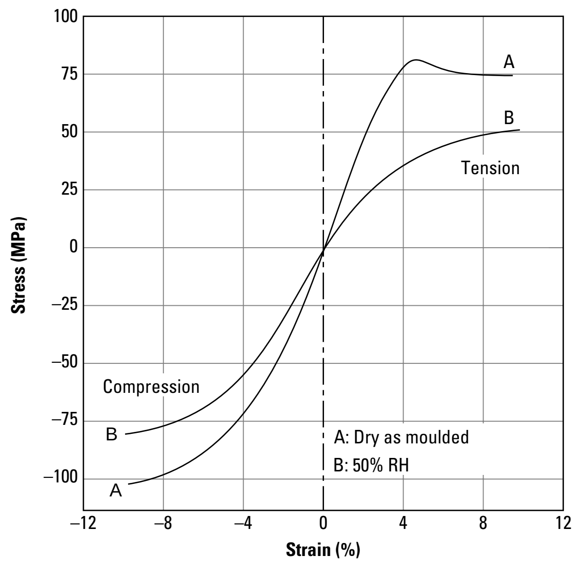


Figure 3.03 **Stress-strain curves in tension and compression of ZYTEL® 101 (PA66), 23°C**

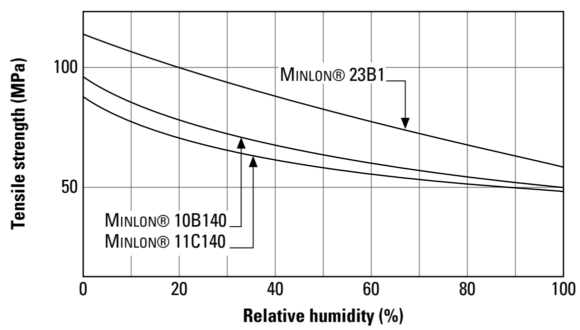


Figure 3.05 **Tensile strength of MINLON® vs. humidity at 23°C**

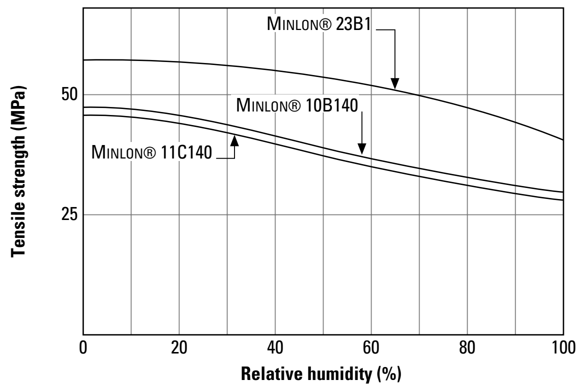


Figure 3.06 **Tensile strength of MINLON® vs. humidity at 90°C**

The effect of the temperature on the tensile strength is shown for ZYTEL® 70G30HSL, ZYTEL® 73G30 and ZYTEL® 77G33L in Figures 3.07–3.08.

Figure 3.09 shows this for several MINLON® grades.

For glass-fibre reinforced nylon, the fibre content also has a big influence on the tensile strength, which is demonstrated in Figure 3.10.

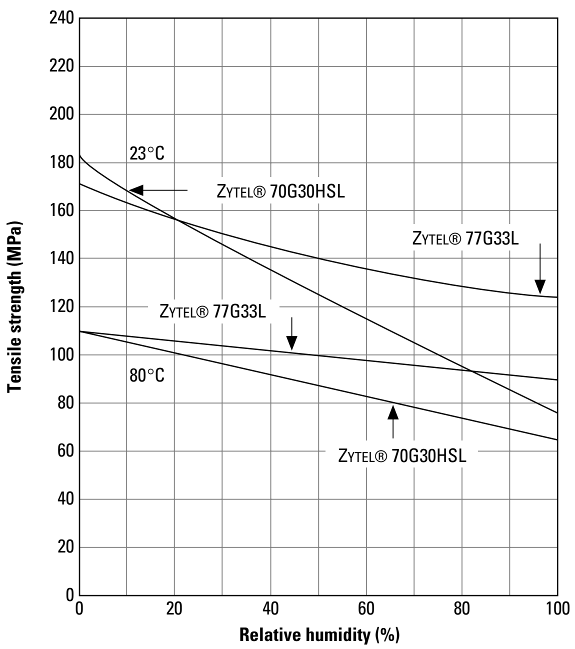


Figure 3.04 **Tensile strength vs. humidity. ZYTEL® 70G30HSL (PA66), ZYTEL® 77G33L (PA612)**

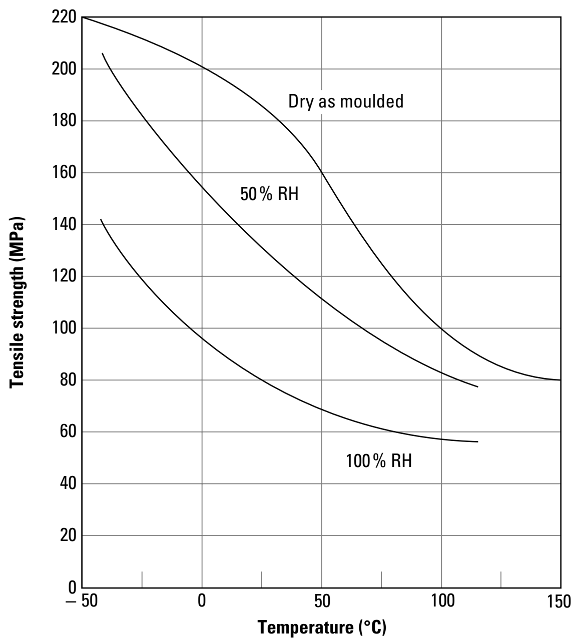


Figure 3.07 **Tensile strength vs. temperature and moisture content of ZYTEL® 70G30HSL, cross-head speed 5 mm/min**

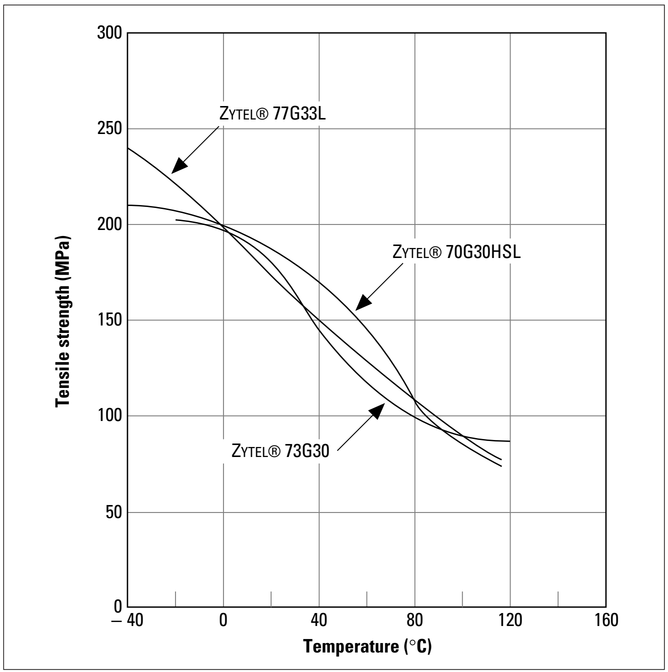


Figure 3.08 **Tensile strength vs. temperature of ZYTEL® 70G30HSL, 73G30, 77G33L (dry-as-moulded)**

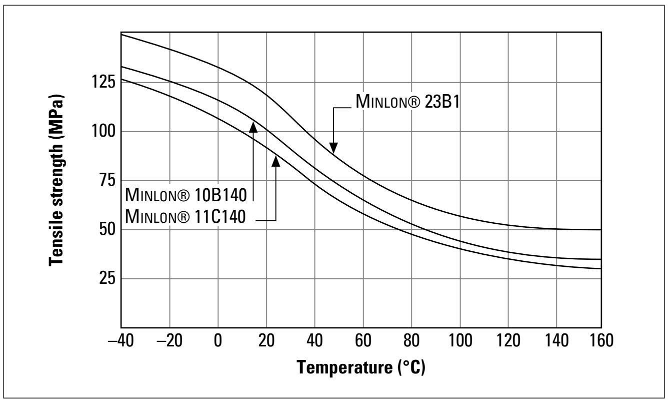


Figure 3.09 **Tensile strength of MINLON® vs. temperature, dry-as-moulded**

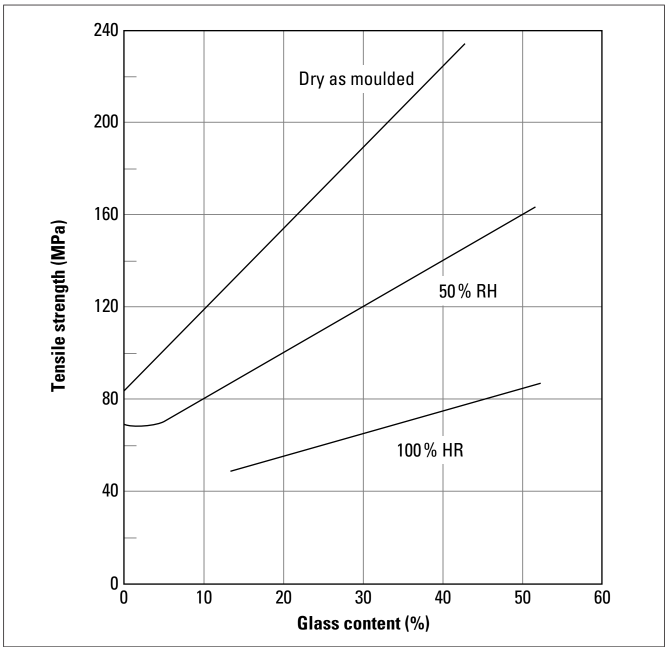


Figure 3.10 **Tensile strength vs. glass content, 23° C. ZYTEL® 70G(XX)HSL (in flow direction)**

Shear strength

When a plastic part is subjected mainly to shear forces, it is not the tensile strength which is decisive for the allowable load, but the shear strength.

According the Von Mises equivalent stress theory the following statement can be used:
Allowable shear stress = allowable tensile stress / $\sqrt{3}$.

Yield strength

For tough materials yield stress is of greater importance in design than is tensile strength… once a part undergoes permanent deformation, failure is usually implied. The effects of temperature and humidity on the yield point of ZYTEL® 101 are shown in Figure 3.11 and of ZYTEL® 158 in Figure 3.12.

The rate at which a plastic is stressed may have a significant effect upon its strength.

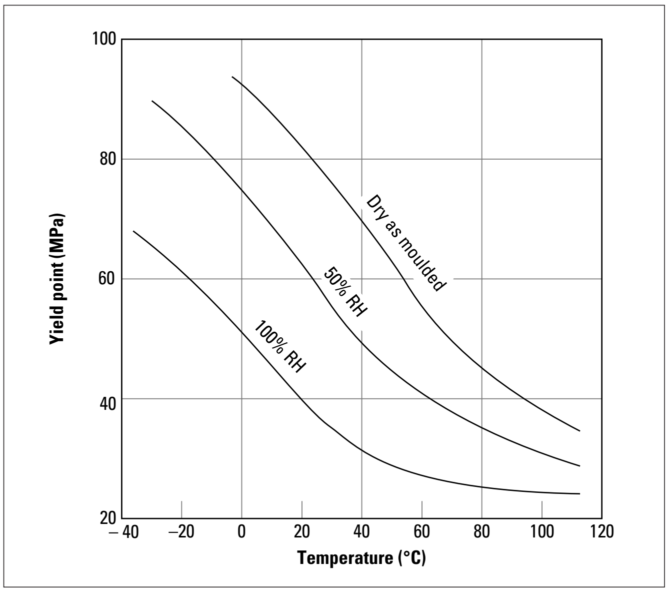


Figure 3.11 **Yield point of ZYTEL® 101 (PA66) vs. temperature and moisture content**

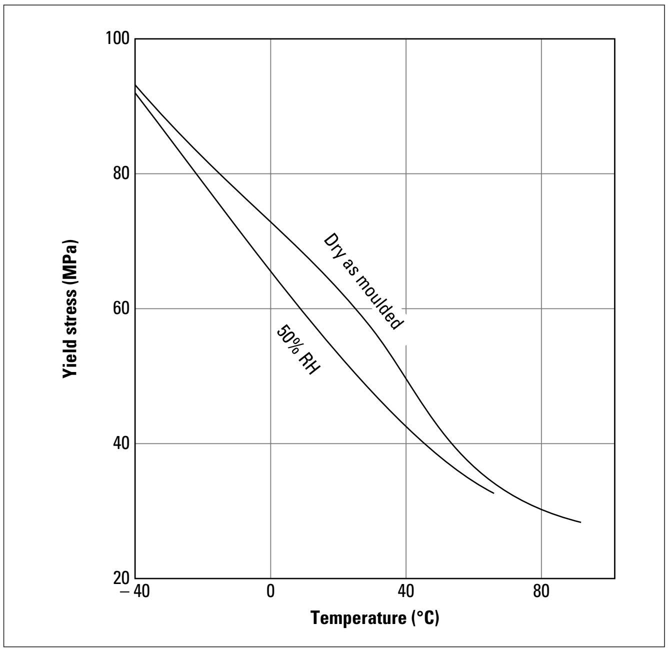


Figure 3.12 **Yield point of ZYTEL® 158 (PA612) vs. temperature and moisture content**

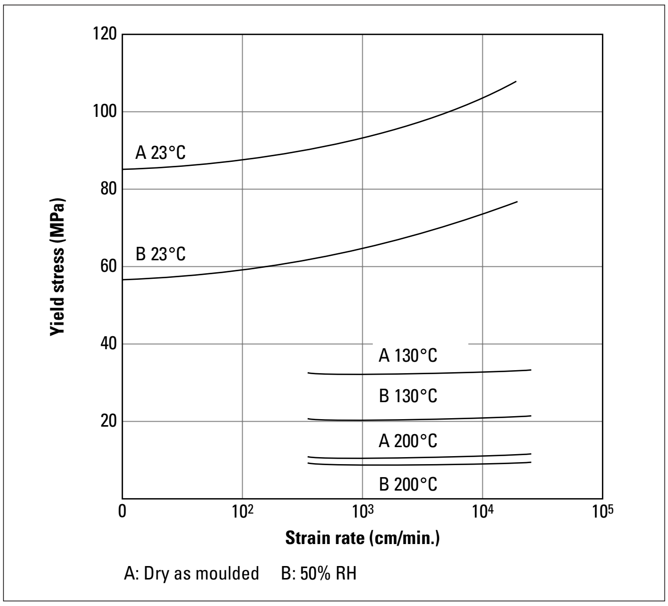


Figure 3.13 **Yield stress data for ZYTEL® 101, dry as moulded and 50% RH vs. strain rate and temperature**

Figure 3.13 shows that the yield strength of ZYTEL® 101 increases with the rate of loading.

Modulus of elasticity / flexural modulus

The value of the modulus of elasticity under specific environmental conditions such as moisture and temperature are shown in Figure 3.14 for ZYTEL® 101, in Figure 3.15 for ZYTEL® 158 and in Figure 3.16 for ZYTEL® 408. This information may be used to calculate initial deflection under load. For deformation with time under load, reference should be made to Creep and Stress Relaxation.

For the flexural modulus of ZYTEL® ST801 as function of temperature, see Figure 3.17. For several MINLON® grades, this property is shown in Figure 3.18.

Picture 3.19 shows the flexural modulus at 1% strain (= apparent modulus) as function of temperature for ZYTEL® 70G30 and ZYTEL® 70G43.

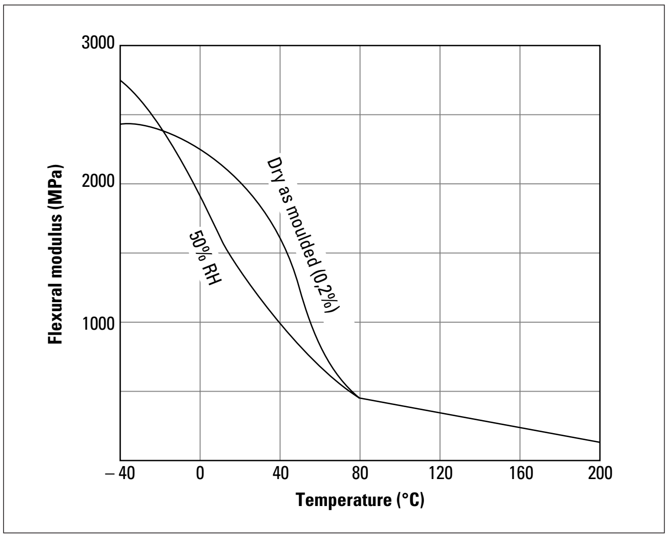


Figure 3.15 **Flexural modulus of ZYTEL® 158 (PA612) vs. temperature at two moisture contents**

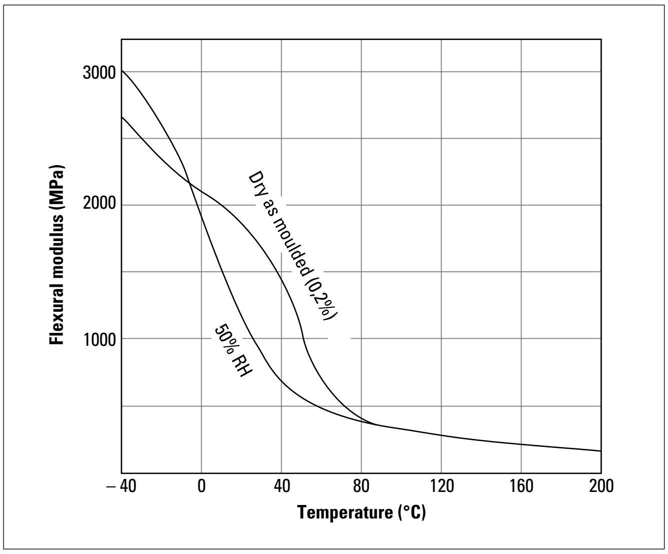


Figure 3.16 **Flexural modulus of ZYTEL® 408 (PA66, toughened) vs. temperature at two moisture contents**

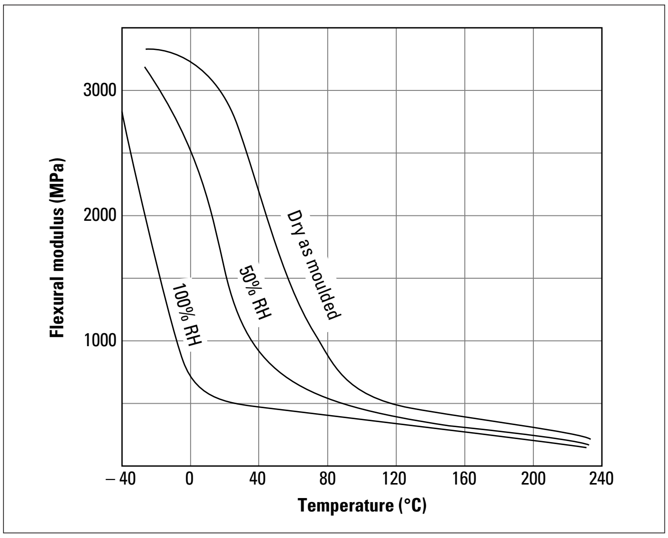


Figure 3.14 **Flexural modulus of ZYTEL® 101 (PA66) vs. temperature at various moisture contents**

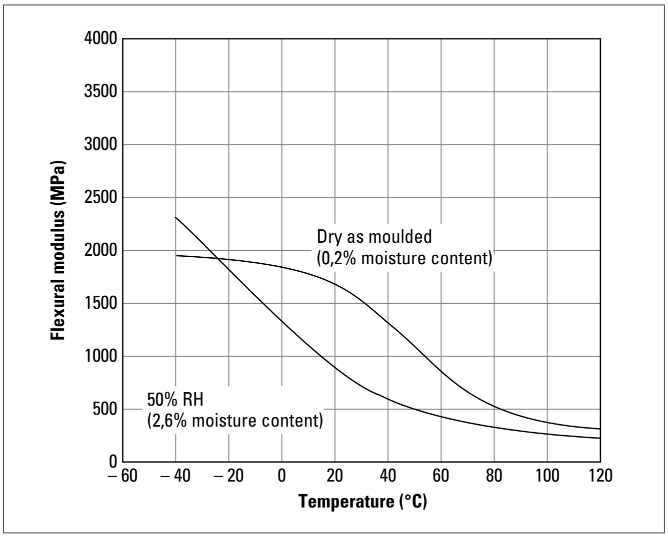


Figure 3.17 **Flexural modulus of ZYTEL® ST801 (PA66, supertough) vs. temperature at two moisture contents**

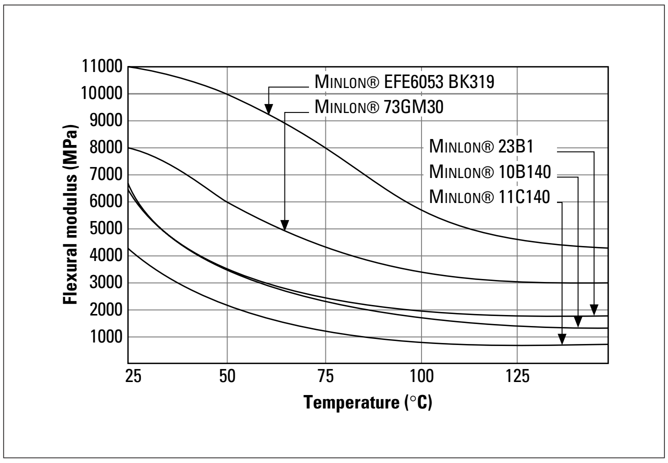


Figure 3.18 **Flexural modulus of MINLON® vs. temperature, dry-as-moulded**

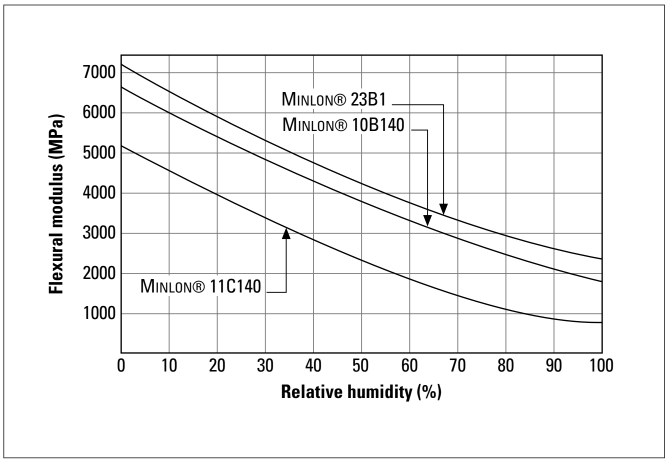


Figure 3.21 **Flexural modulus of MINLON® vs. humidity at 23°C**

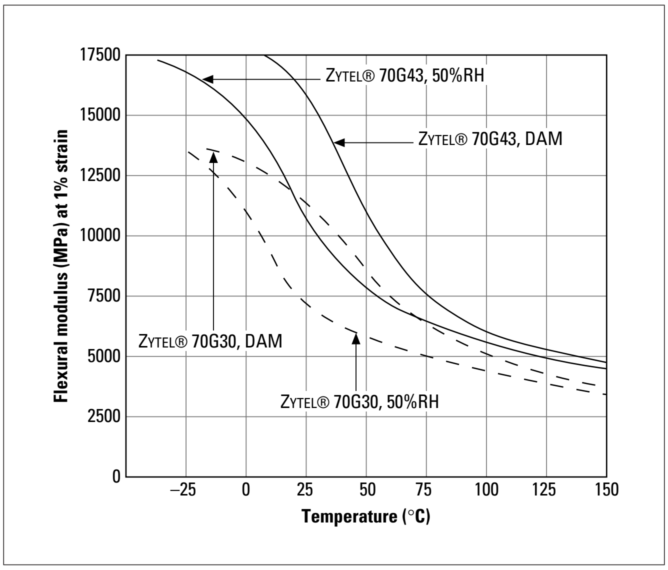


Figure 3.19 **Flexural modulus at 1% strain (= apparent modulus) vs. temperature for ZYTEL® 70G30 and ZYTEL® 70G43**

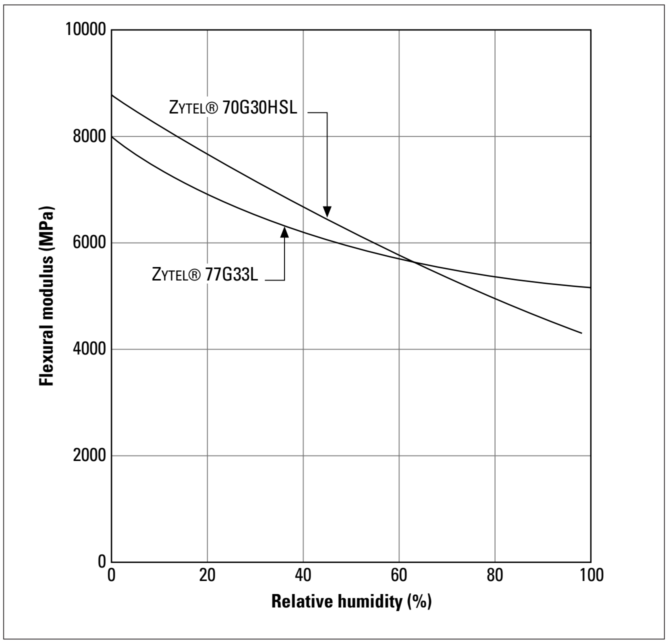


Figure 3.20 **Flexural modulus vs. humidity at 23°C**
ZYTEL® 70G30HSL (PA66, 30% GR)
ZYTEL® 77G33L (PA612, 33% GR)

The effect of humidity on the flexural modulus of ZYTEL® 70G30HSL, 77G33L and several MINLON® grades is shown in Figures 3.20 and 3.21.

Likewise for the tensile strength, the amount of glass in a glass fibre reinforced nylon is very important for the flexural modulus, as demonstrated by Figure 3.22.

Poisson ratio

Though the Poisson ratio is not very important in the design of plastic parts, it is a required input for finite element analyses.

The following values can be used for ZYTEL® and MINLON® resins:

$500 < E < 1500$; $\upsilon = 0{,}40$
$1500 < E < 10\,000$; $\upsilon = 0{,}35$
E = modulus of elasticity in MPa

Creep, long-term loads and recovery

Long-term loads in air

As with all plastics, the long-term behaviour of ZYTEL® under load is characterized by the phenomenon usually called creep. Upon loading, a plastic part shows an initial deformation or strain roughly predicted by its modulus of elasticity. This is followed by a slow but steady increase in strain with time until eventual rupture. This increase in strain with time is referred to as creep.

The creep rate of ZYTEL® will vary markedly with composition, ambient temperature, stress level and moisture content. Consequently, design must be based on a consideration of estimated creep behaviour of the particular resin under the environmental conditions expected.

Creep data are presented as the sum of the initial strain plus the incremental strain with time. In the past, this has been termed the sum of elastic deformation and plastic flow. No effort is made to separate the effects of initial strain and creep strain.

Creep data may be graphed in a variety of ways. A useful form is isochronous (equal time) stress vs. strain, for a selected number of time periods. The apparent (creep) modulus can be derived from these curves from the strain data at any point in time.

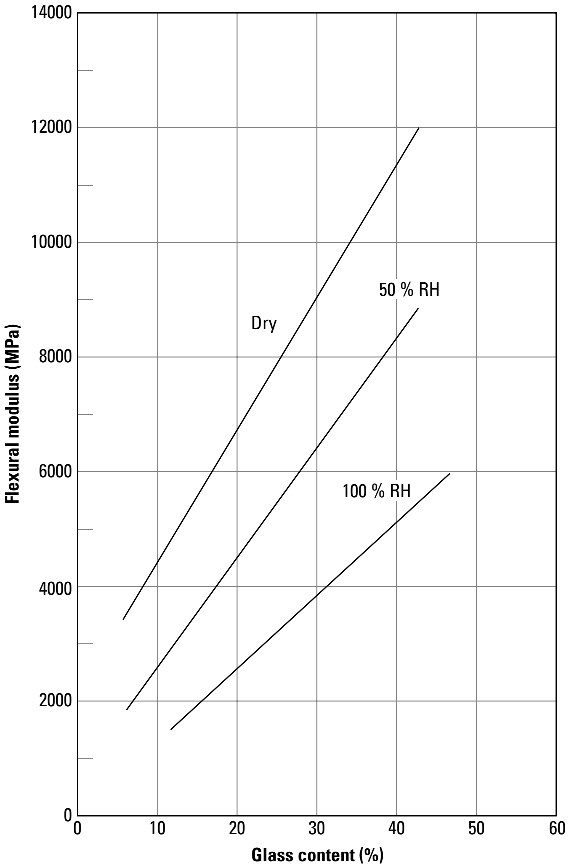


Figure 3.22 **Flexural modulus vs. glass content, 23°C. ZYTEL® 70G % HSL (in flow direction)**

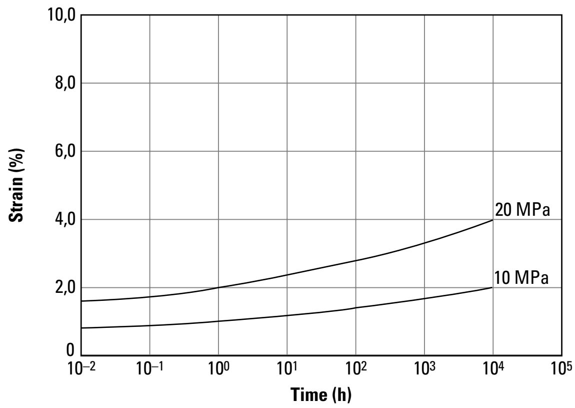


Figure 3.23 **Creep in flexure for ZYTEL® 101F, at different stress levels, 23°C and 50% RH**

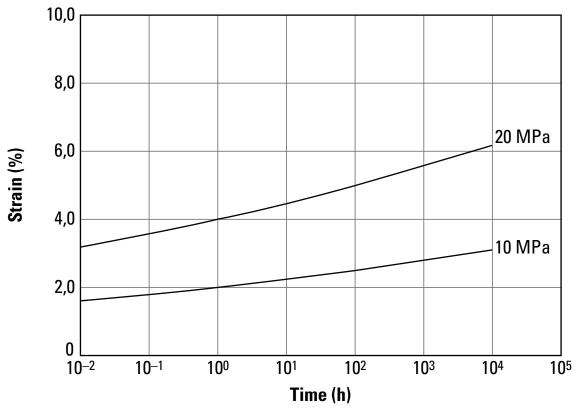


Figure 3.24 **Creep in flexure for ZYTEL® 101F, at different stress levels, 60°C and 50% RH**

Table 3.02 Materials for which creep information is given in this handbook (for other creep data, see Table 3.01/CAMPUS

Figure	Material	Temperature °C	Relative humidity %	Creep presentations	Reference
3.24	ZYTEL® 101F NC010	125	Dry	Creep in flexure	EMPA tests
3.25	ZYTEL® 103HSL	125	Dry	Isochronous stress vs. strain	
3.26	ZYTEL® 151L	23	50	Isochronous stress vs. strain	
3.27	ZYTEL® 158	23	50	Isochronous stress vs. strain	
3.28	ZYTEL® 158	60	50	Isochronous stress vs. strain	
3.29	ZYTEL® 153HSL	125	Dry	Isochronous stress vs. strain	
3.30	ZYTEL® 408HSL	23	50	Isochronous stress vs. strain	
3.31	ZYTEL® 408HSL	125	Dry	Isochronous stress vs. strain	
3.32	ZYTEL® 70G43L	60	50	Isochronous stress vs. strain	
3.33	ZYTEL® 70G43L	125	Dry	Isochronous stress vs. strain	
3.34	ZYTEL® 70G60HSL	23	50	Creep in flexure	
3.35	ZYTEL® 70G60HSL	80	Dry	Creep in flexure	
3.36	ZYTEL® 70G60HSL	120	Dry	Creep in flexure	
3.37	ZYTEL® 79G13L	125	Dry	Creep in flexure	EMPA tests
3.38	ZYTEL® 80G14	23	50	Creep in flexure	EMPA tests
3.39	ZYTEL® 80G14	125	Dry	Creep in flexure	EMPA tests
3.40	ZYTEL® 77G43	23	50	Isochronous stress vs. strain	
3.41	ZYTEL® 77G43	125	Dry	Isochronous stress vs. strain	
3.42	MINLON® 11C140	125	Dry	Creep in flexure	EMPA tests
3.43	MINLON® 23B1	23	50	Creep in flexure	
3.44	MINLON® 23B1	125	Dry	Creep in flexure	

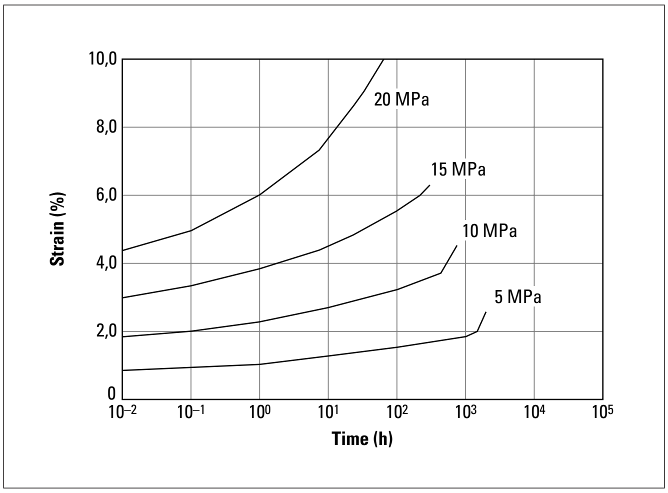


Figure 3.25 **Creep in flexure for ZYTEL® 101F, at different stress levels, 125°C, dry as moulded**

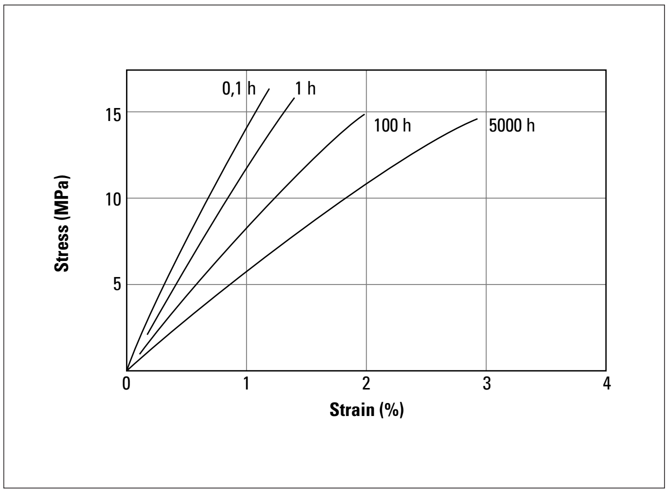


Figure 3.28 **Isochronous stress vs. strain in flexure of ZYTEL® 158 at 23°C and 50% RH**

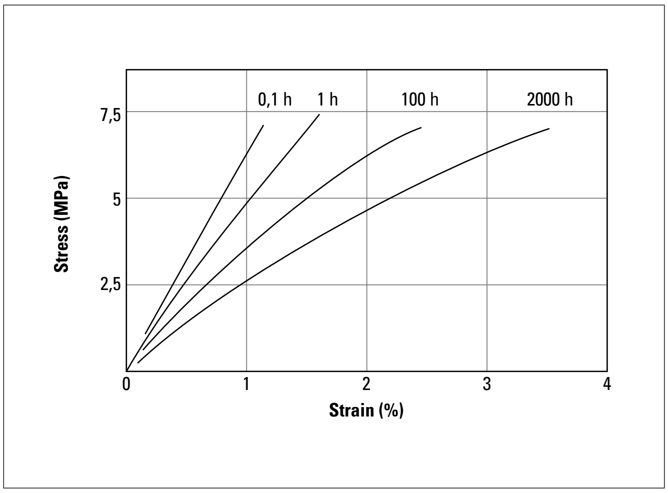


Figure 3.26 **Isochronous stress vs. strain in flexure of ZYTEL® 103HSL at 125°C, and dry as moulded**

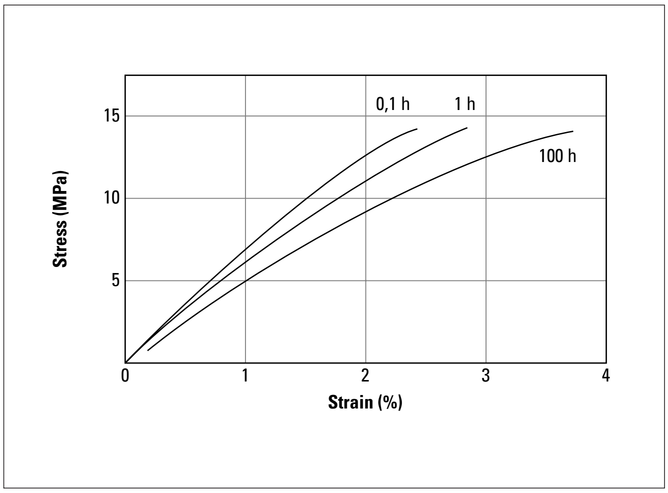


Figure 3.29 **Isochronous stress vs. strain in flexure of ZYTEL® 158 at 60°C and 50% RH**

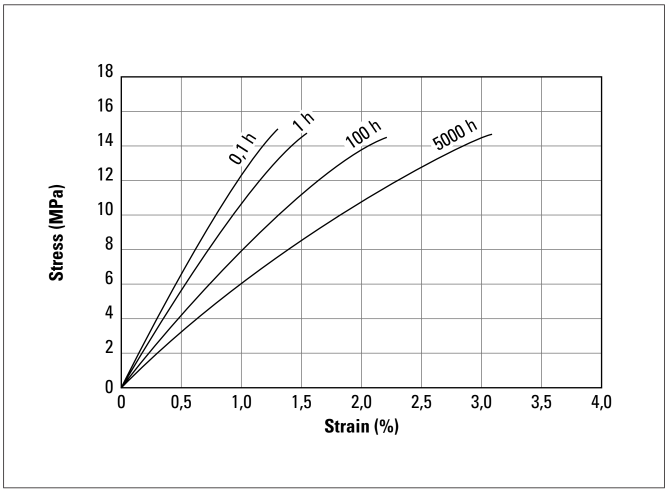


Figure 3.27 **Isochronous stress vs. strain in flexure of ZYTEL® 151L, 23°C, 50% RH**

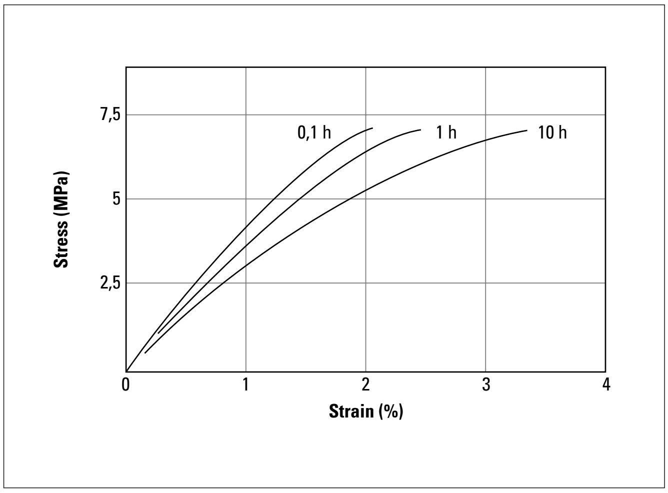


Figure 3.30 **Isochronous stress vs. strain in flexure of ZYTEL® 153HSL at 125°C, and dry as moulded**

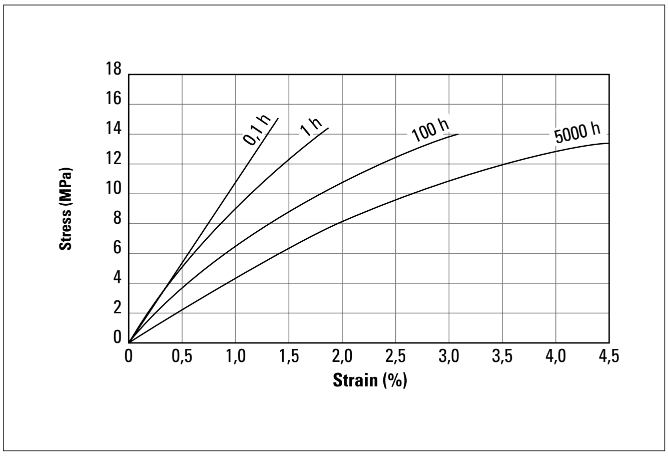


Figure 3.31 **Isochronous stress vs. strain in flexure of ZYTEL® 408HSL, 23°C, 50% RH**

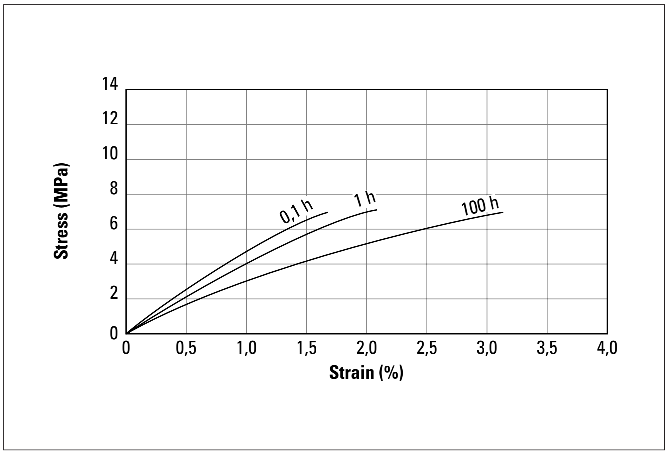


Figure 3.32 **Isochronous stress vs. strain in flexure of ZYTEL® 408HSL, 125°C, dry**

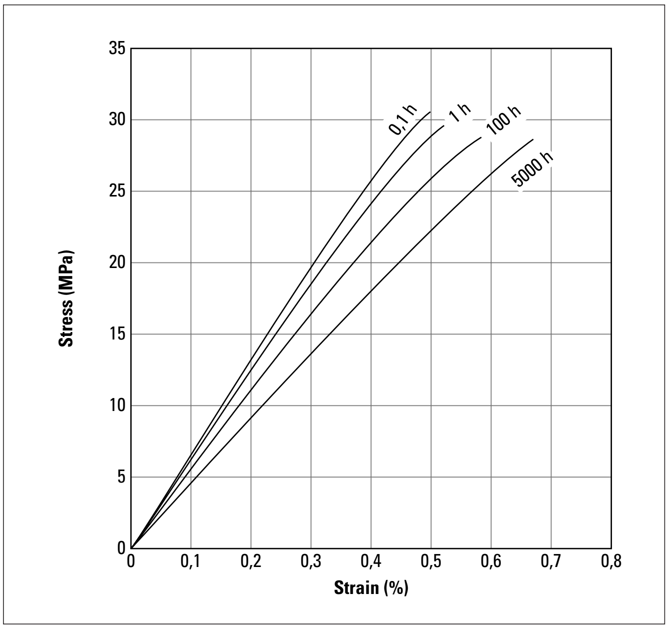


Figure 3.33 **Isochronous stress vs. strain ZYTEL® 70G43L at 60°C, 50% RH**

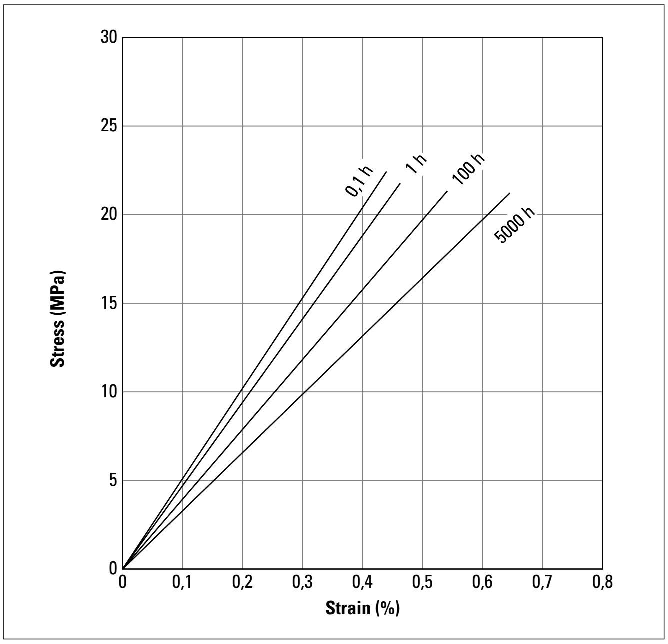


Figure 3.34 **Isochronous stress vs. strain ZYTEL® 70G43L at 125°C, dry**

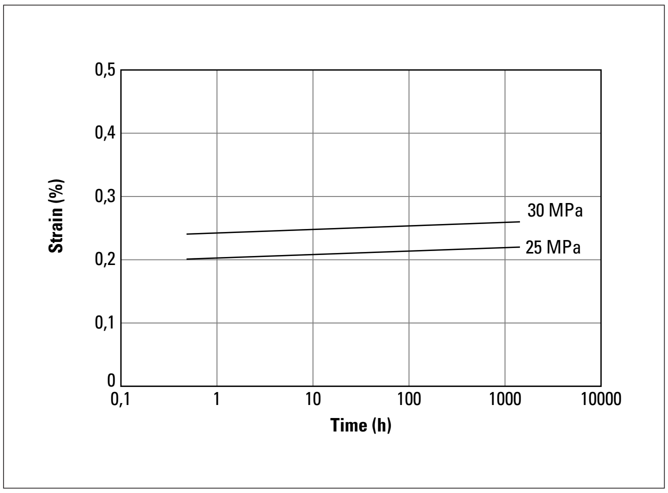


Figure 3.35 **Creep in flexure of ZYTEL® 70G60HSL (PA66, 60% GR) at 25 and 30 MPa, 23°C, 50% RH**

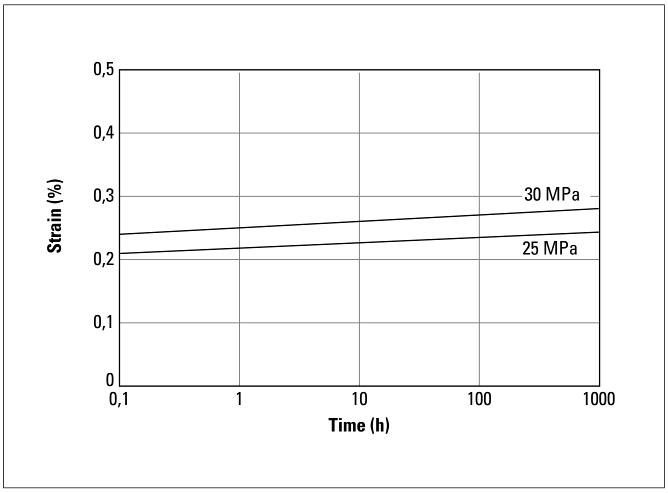


Figure 3.36 **Creep in flexure of ZYTEL® 70G60HSL (PA66, 60% GR) at 25 and 30 MPa, 80°C, dry as moulded**

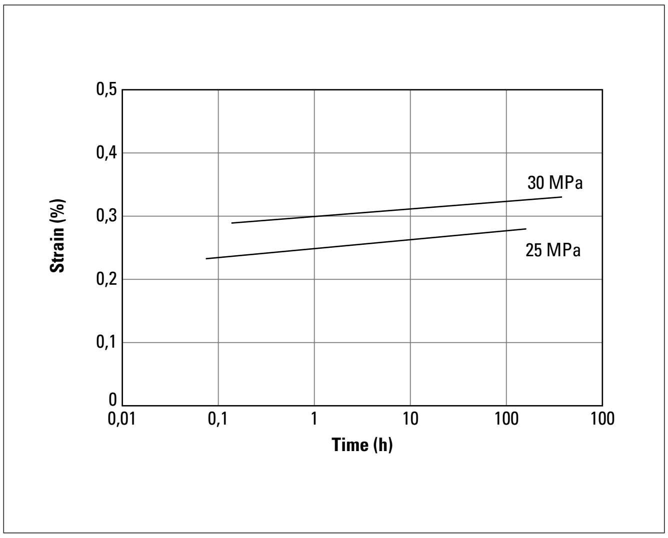


Figure 3.37 **Creep in flexure of ZYTEL® 70G60HSL (PA66, 60% GR) at 25 and 30 MPa, 120°C, dry as moulded**

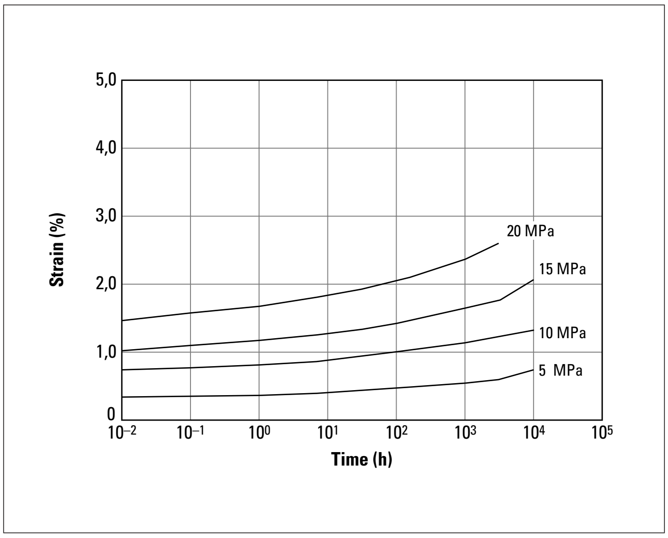


Figure 3.38 **Creep in flexure of ZYTEL® 79G13L at different stress levels, 125°C, dry as moulded**

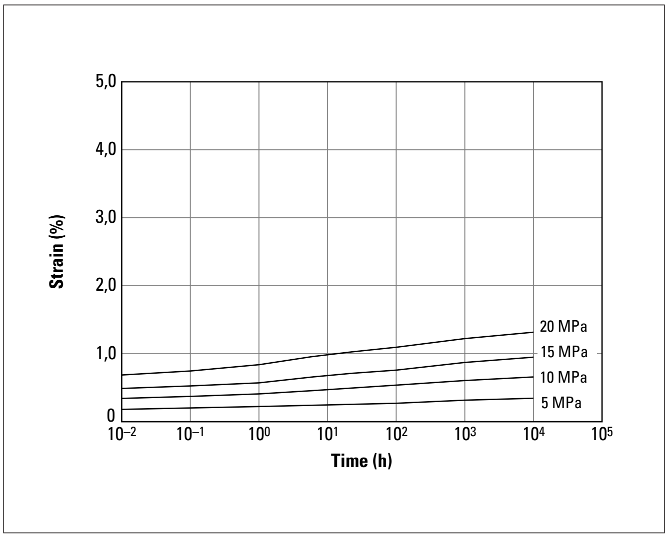


Figure 3.39 **Creep in flexure of ZYTEL® 80G14 (PA66 toughened, 14% GR) at different stress levels, 23°C, 50% RH**

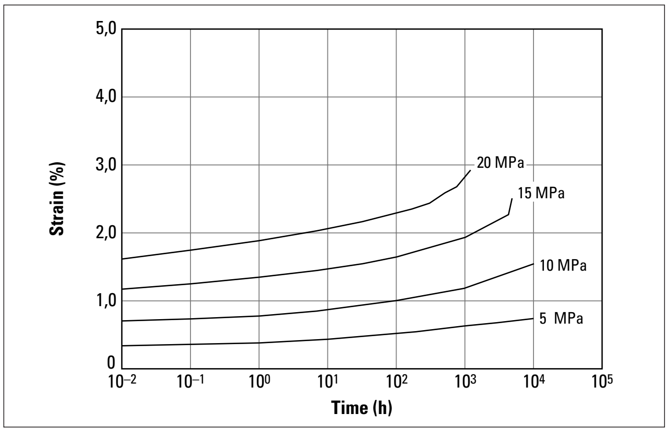


Figure 3.40 **Creep in flexure of ZYTEL® 80G14 (PA66, toughened, 14% GR) at different stress levels, 125°C, dry as moulded**

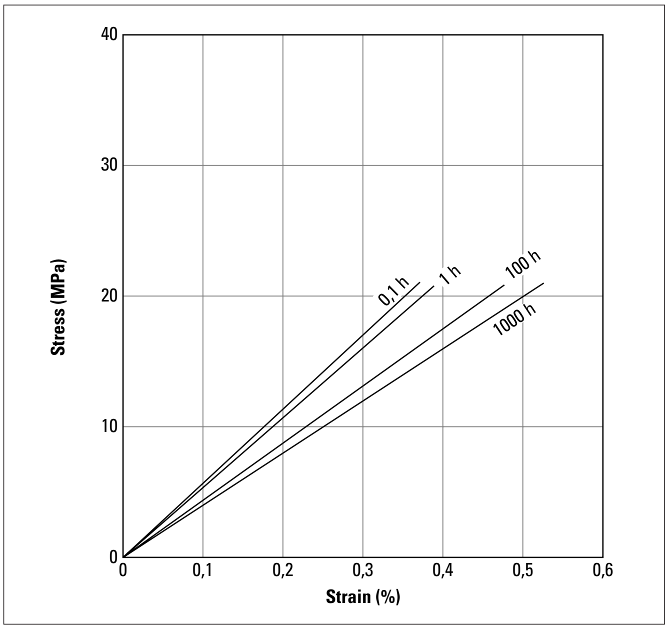


Figure 3.41 **Isochronous stress vs. strain in flexure of ZYTEL® 77G43 (PA612), 125°C, dry**

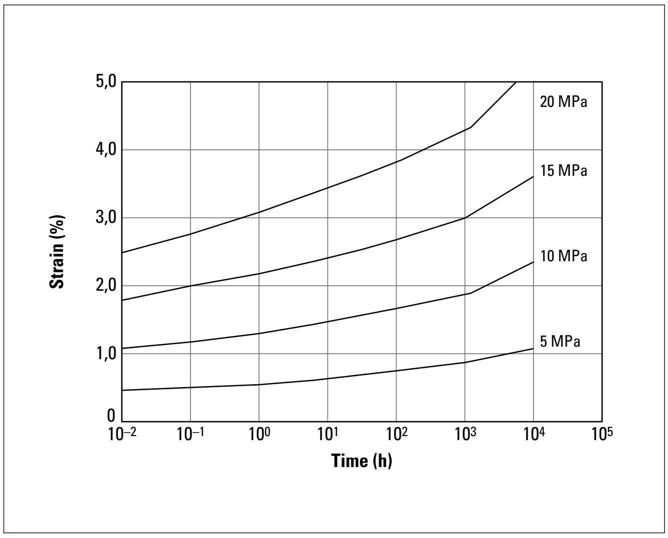


Figure 3.42 **Creep in flexure of MINLON® 11C140 at different stress levels, 125°C, dry as moulded**

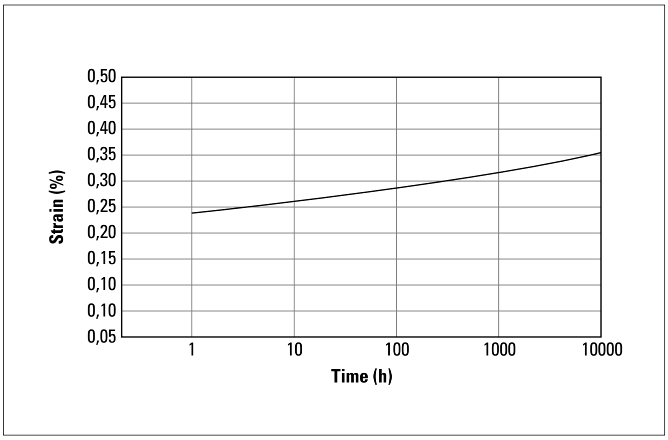


Figure 3.43 **Creep in flexure of MINLON® 23B1 at 6,9 MPa, 23°C, 50% RH**

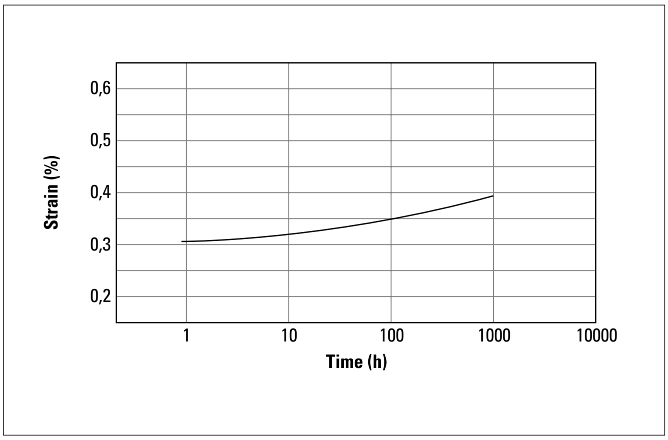


Figure 3.44 **Creep in flexure of MINLON® 23B1 at 6,9 MPa, 125°C, dry as moulded**

Another form is shown in graphs presenting the amount of total strain vs. time for a selected number of stresses. This is a clearer representation of experiments and fits better with the needs of computer aided analyses.

From the Isochronous stress vs. strain curves, the "Creep in flexure" for a given stress level (see Figures 3.23–3.25), can be constructed vice versa, if desired.

All creep data presented in this Section were determined on test specimens 12,7 mm wide by 3,2 mm thick, freely supported at the ends on a 100 mm span and loaded in flexure at the centre of the span.

Creep data at selected conditions of temperature and relative humidity equilibrium for a number of ZYTEL® compositions are shown in the Figures 3.23–3.44

For glass-fibre reinforced nylon 66 grades, ZYTEL® 70Gxx, it has shown to be possible to express the total strain as:

$$\varepsilon_{total} = \varepsilon_{elastic} + \varepsilon_{creep} = \frac{\sigma}{E} + 0{,}1\,\frac{\sigma}{E}\,t^{0,2} = \frac{\sigma}{E}\,(1 + 0{,}1\,t^{0,2})$$

with: σ = stress (MPa);
E = modulus of elasticity at given temperature (MPa);
t = time (h).

For other nylon family grades similar formulae can be derived.

Creep (Apparent) Modulus

In parts with a uniform stress distribution, the deformations can be computed using the creep modulus. This property can be obtained from the isochronous creep curves, using the right time / stress / temperature, with:

$$E_{creep} = 100\ \sigma/\varepsilon_{total},\ (\varepsilon_{total}\ \text{in\%})$$

Long-term loads in water

Data for hoop stress vs. time to failure for pipes of ZYTEL® 42 and 101 nylon resin exposed to internal water pressure in water baths at indicated temperatures are shown in Figures 3.45 and 3.46. It is suggested these data be used in conjunction with the creep curves to formulate designs for items subject to internal pressure. The design should be thoroughly evaluated by realistic testing.

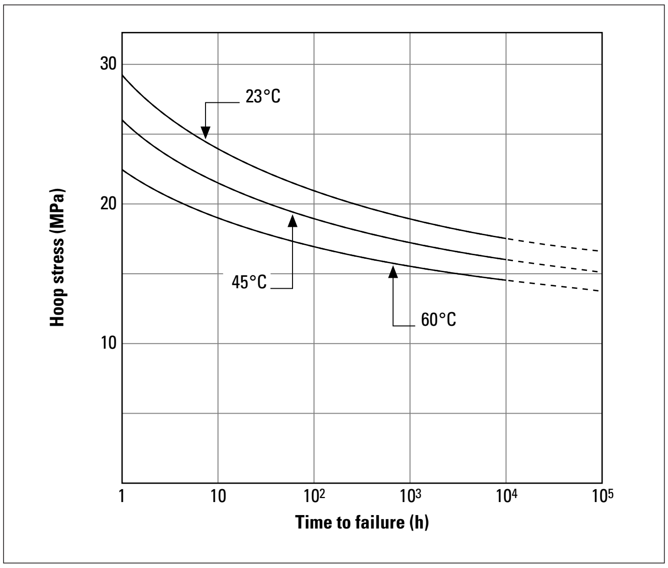


Figure 3.45 **Hoop stress vs. time to failure for ZYTEL® 42 at different temperatures. Pipe saturated with 8,5% moisture (100% RH)**

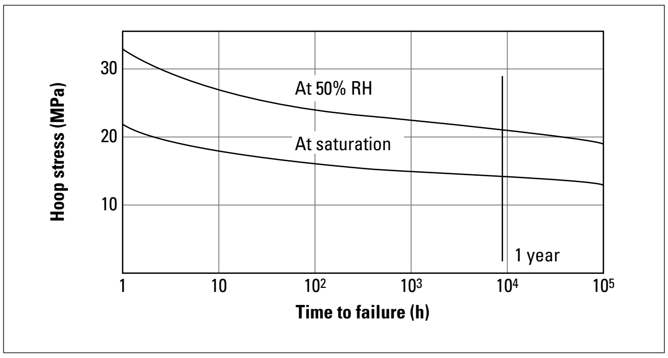


Figure 3.46 **Hoop stress vs. time to failure, ZYTEL® 101 at 50% RH and saturated, 66°C**

Recovery from cyclic loading in air

Figures 3.47–3.48 show the behaviour of ZYTEL® 101 under cyclic loads at room temperature. Upon removal of stress, there is an immediate elastic recovery followed by a time dependent recovery. Time under load is an important factor influencing extent of recovery when stresses are well below the yield stress. In general, the amount of recovery after removal of static loads will depend on the duration of stress, the stress level, temperature, nature of the environment, the time allowed for recovery and most important, the shape of the tested sample.

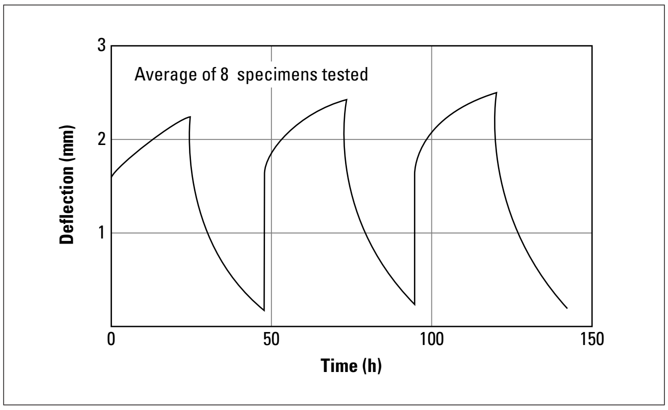


Figure 3.47 **Cyclic loading and recovery of ZYTEL® 101, short term, 6,9 MPa, 23°C. Test bar 95 × 12,7 × 3,2 mm; loaded at one end**

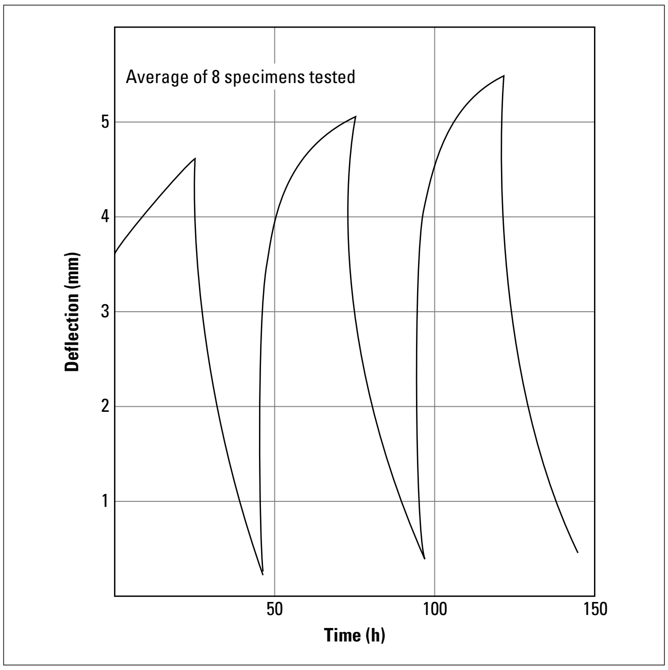


Figure 3.48 **Cyclic loading and recovery of ZYTEL® 101, short term, 13,8 MPa, 23°C. Test bar 89 × 12,7 × 3,2 mm; loaded at one end**

Stress relaxation in air

Figure 3.49 shows the long-term decay of stress due to creep in a beam subjected to a fixed deflection. This behaviour must be considered in applications such as preloaded springs, self-tapping screws and press fits.

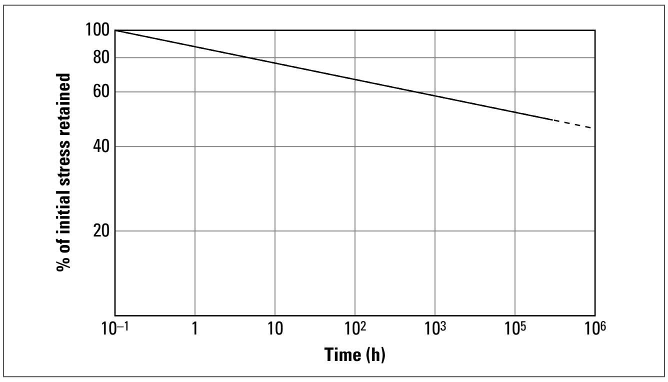


Figure 3.49 **Stress relaxation in deflected cantilever beams of ZYTEL® 101 nylon resins. Outer fibre strain 2%; initial stress (0,1 hour after loading), 13,8 MPa**

Impact

Impact resistance – single blow

Impact resistance, or the ability of a part to absorb a blow, is difficult to predict in a moulded part because shape has a major effect on performance. Consequently, good design is important in helping parts resist impact, especially in terms of applying generous radii for all sharp corners. The energy of an impact must be absorbed within the part. Hence, designing flexibility into the part greatly improves resistance to impact. Thin-walled flexible pieces like round coil forms are difficult to break on impact. On the other hand, rigid corners are less tough because they absorb less impact energy.

A variety of test procedures is used to measure the impact resistance of plastic materials. This is necessary because factors such as rate of loading, design (notch effect) and other factors have important effects on impact resistance. No single test procedure can be used to predict how a part will perform under diverse service conditions.

The Tensile Impact Energy-to-Break Test is described in ASTM D1822. This determines the energy to break a flat test specimen using a calibrated pendulum and subjecting the test specimen to a tensile stress at a high strain rate. Either a short specimen (for greater reproducibility), or a long specimen (for better material differentiation) can be used. A possible problem with the procedure is that results from differently built test machines may provide different answers.

Temperature and moisture can affect the impact resistance of ZYTEL® nylons, as measured by service tests, lzod and tensile impact. Moisture makes the nylon part more flexible; consequently, the conditioned part will absorb more energy before breaking. Heat, like moisture, will increase the impact resistance of ZYTEL®. This effect is most noticeable in the thermal range from room temperature to 66°C.

Tensile impact values of both long and short specimens are shown in Table 3.03 for a number of ZYTEL® compositions.

The Brittleness Temperature, ASTM D746, establishes the temperature at which 50% of test specimens fail when subjected to a specified type of impact. The procedure points out that the brittleness temperature of this test does not necessarily measure the lowest temperature at which the material may be used. The test has been used extensively for elastomers, polyethylenes and other flexible materials.

The brittleness temperatures of representative ZYTEL® compositions are shown in both the dry-as-moulded state and in moisture-conditioned specimens in Table 3.04. The Izod Impact, ISO 180, measures the energy to break a specimen in which a notch with a 0,25 mm radius has been machined. During impacting, the notched side is under tension. The Izod impact value is indicative of the reduction in toughness that can result from part design as, for example, failure to provide a generous fillet for a corner. Although this test has been one of the common physical tests used in the plastics industry, its value for actually measuring impact toughness has frequently been questioned. Because notched specimens are used, the test mainly measures notch sensitivity rather than ability to withstand impact.

Table 3.03 Tensile impact of ZYTEL® nylon resins, ASTM D1822 at 23°C in kJ/m²

Specimen	DAM	50% RH
ZYTEL® 42 (long)	535	no break
ZYTEL® 101 (long)	504	1470
ZYTEL® 101 (short)	158	23
ZYTEL® 103 (long)	462	1180
ZYTEL® 158 (long)	611	945
ZYTEL® 158 (short)	153	218
ZYTEL® 408 (long)	550	1680
ZYTEL® 408 (short)	189	265

Table 3.04 Brittleness temperature of ZYTEL®, ASTM D746

	Low temperature brittleness	
Material	Dry as moulded	50% RH
ZYTEL® 101	–80°C	–65°C
ZYTEL® 105	–52°C	–52°C
ZYTEL® 42	–100°C	–85°C
ZYTEL® 91HS	–72°C	–40°C
ZYTEL® 151L	–120°C	–118°C
ZYTEL® 158L	–126°C	–110°C

Table 3.05 Izod impact of ZYTEL® 23°C, ASTM D256

	J/m	
Material	DAM	50% RH
ZYTEL® 101	53	112
ZYTEL® 42	69	134
ZYTEL® 105	43	107
ZYTEL® 408	166	240
ZYTEL® 91HS	No break	800
ZYTEL® 151	43	69
ZYTEL® 158	53	75
ZYTEL® ST801	910	910–1330

Table 3.06 Repeated impact test on ZYTEL® 101 and cellulose acetate butyrate

	Distance of fall in mm		
Material	One blow	Repeated	Izod impact
	mm	mm	J/m
ZYTEL® 101	900	760	112
Cellulose acetate butyrate	1000	180	32C

Roller 17,8 mm O.D. × 8,9 mm I.D. hit on outer surface by free falling 1,2 kg weight.
Height of fall required to cause a visible crack in one blow or ten blows for repeated test.
Run in room at 50% RH but actual moisture content of nylon 0,35%.

Izod impact values of representative ZYTEL® compositions for both dry-as-moulded and for conditioned bars are shown in Table 3.05.

The effect of the notch radius on the Izod impact value of some unreinforced ZYTEL® grades is given in Figure 3.50. This figure illustrates the importance of avoiding sharp notches in end-use parts. Generally the impact resistance increases with relative humidity and temperature.

Impact resistance – repeated blows

Resistance to repeated impacts is more meaningful than single impact strength in selecting materials for many end-uses. Striker plates in automobiles and appliances, ladies' shoe

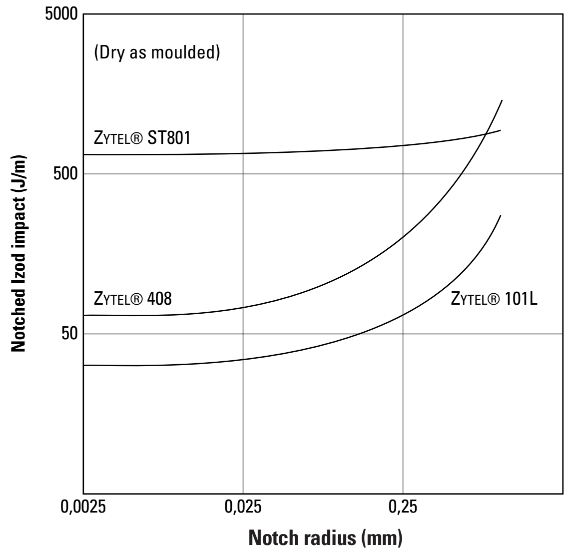


Figure 3.50 **Effect of notch radius on Izod impact strength**

heels, cams, gear teeth in gear reduction units are a few of the many applications where resistance to a number of light impacts is more important than resistance to a single heavy impact.

Repeated impact data are frequently more useful for predicting how well a part will stand up under actual service conditions than are data from the single impact type of test, such as the Izod. In Table 3.06, cellulose acetate butyrate is shown to have a high Izod value and good toughness in the single impact roller test and, thus, compares favourably with ZYTEL® 101 nylon resin. Under repeated impact, however, ZYTEL® 101 is markedly superior to cellulose acetate butyrate.

Repeated impact with a pendulum has also been used for comparing the repeated impact resistance of ZYTEL® 101 with other materials as shown in Table 3.07. ZYTEL® 101 has unusually high resistance to repeated blows.

Table 3.07 Repeated impact resistance on a cylindrical specimen 2,16 m/s*

Material	Impacts to failure**
ZYTEL® 101 nylon	250
DELRIN® 500*** acetal	185
Polycarbonate	37
Die-cast zinc	7
Die-cast aluminium	5

* Modern Plastics, May, 1964.
** Failure defined as fracture on a maximum of 20% decrease in cross-sectional area due to creep.
*** DuPont registered trademark for its acetal resin.

Fatigue resistance

When materials are stressed cyclically, they frequently fail at stress levels below their tensile strengths. The phenomenon is termed ''fatigue failure''. In metals, fatigue failures have been known and studied for many years. With plastics, examples of this type of failure are seen in gears or in parts subjected to vibration, repeated loading or flexure while under stress.

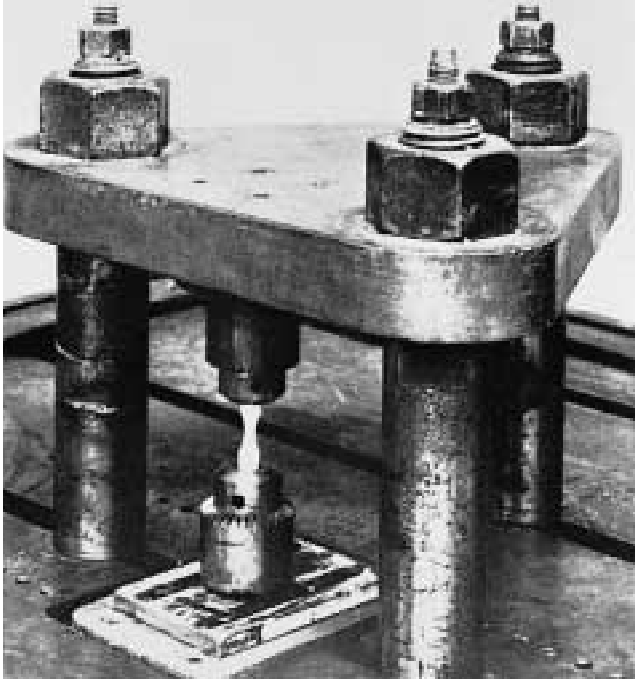


Figure 3.51 **Close-up of sample in testing apparatus**

Fatigue data obtained from standard specimens are helpful to the designers as a guide. Fatigue data are dependent upon environmental conditions. Thus, in design calculations, proper consideration must be given to these conditions and also to the effect of stress concentrations. *Realistic actual or simulated end-use testing of a part in service is the best method of evaluating material performance for a specific application.*

Fatigue data for plastics can be obtained by using a Sonntag-Universal machine at constant stress levels. In these tests, a stress is applied repeatedly at 1800 cycles per minute to a test specimen until failure occurs. Specimens may be stressed in tension only, compression only or in both tension and compression, which is generally considered the most severe situation. In addition, fixtures can be used with this machine for producing flexure stresses. The picture in Figure 3.51 illustrates how the test specimen is placed in the apparatus for fatigue stressing.

Fatigue endurance relates to the useful life expected for a material subjected to repeated loading. It is generally

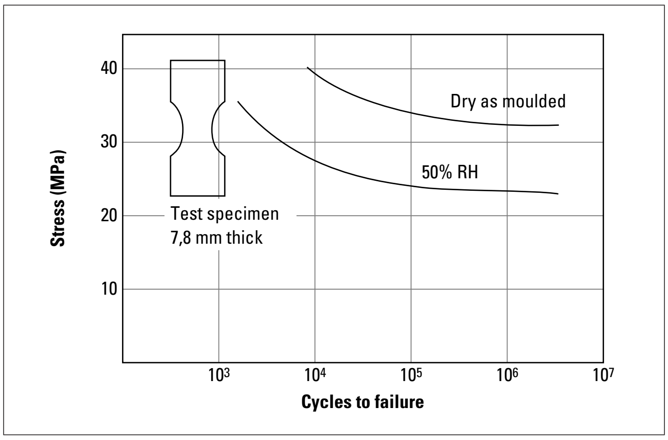


Figure 3.52 **Flexural fatigue data for ZYTEL® 101 using Sonntag machine. Constant maximum stress and 1800 cycles per minute at 23°C**

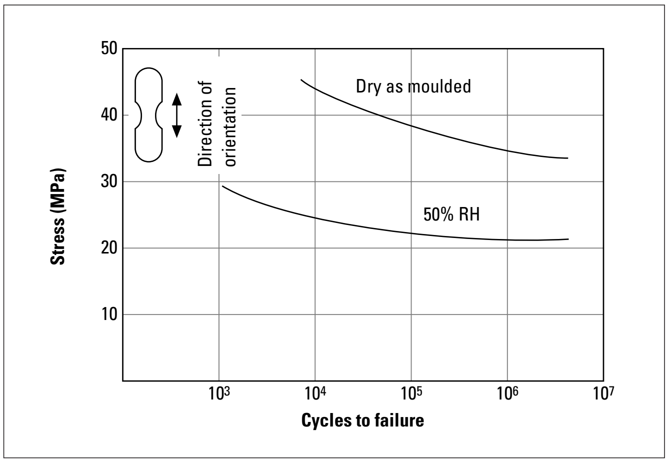


Figure 3.53 **Sonntag axial fatigue for ZYTEL® 101 with alternate tension and compression. 1800 cycles per minute. Tests at 23°C (longitudinal orientation of the test bars)**

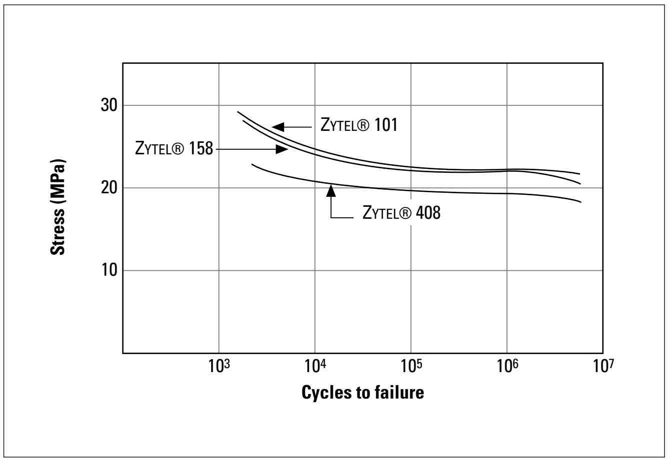


Figure 3.54 **Sonntag axial fatigue for ZYTEL® 101, ZYTEL® 408 and ZYTEL® 158. With alternate tension and compression at 1800 cycles per minute. Equilibrated to and run in 50% RH condition at 23°C**

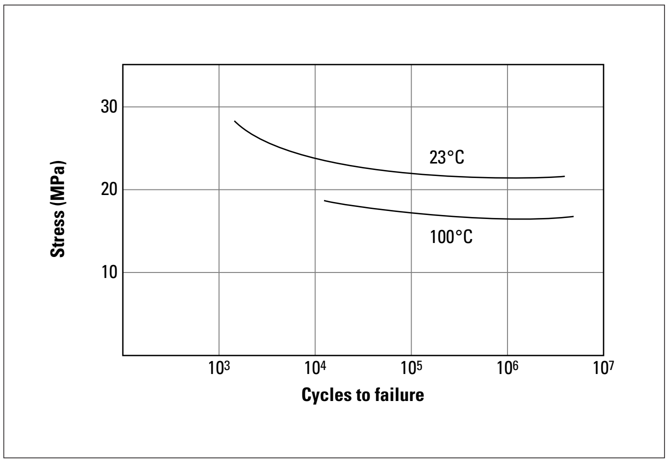


Figure 3.55 **Effect of temperature on Sonntag axial fatigue of ZYTEL® 101 with alternate tension and compression, 1800 cycles per minute. Tests at 23°C and 100°C**

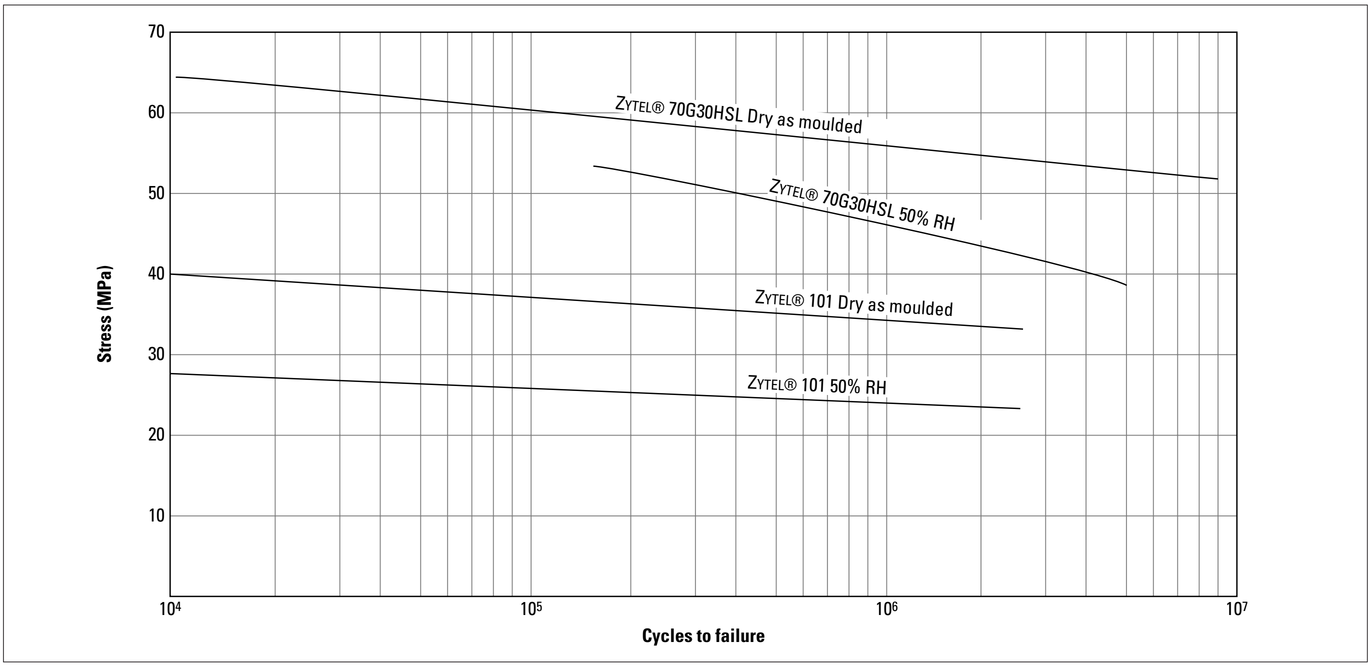


Figure 3.56 **Fatigue resistance, tension-compression 1800 cycles/min, glass reinforced ZYTEL® 70G30HSL vs. ZYTEL® 101**

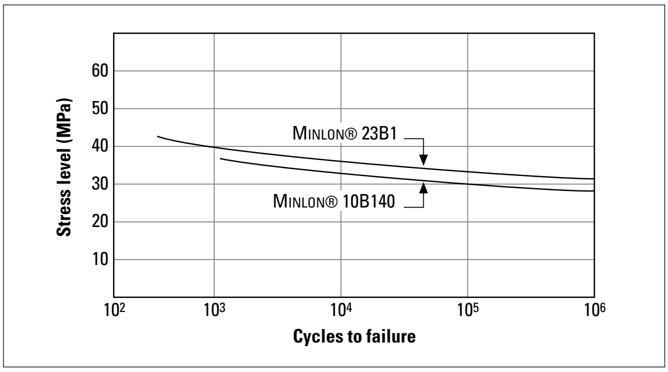


Figure 3.57 **Flex fatigue stress vs. cycles to failure for MINLON® 23B1 and 10B140, dry-as-moulded**

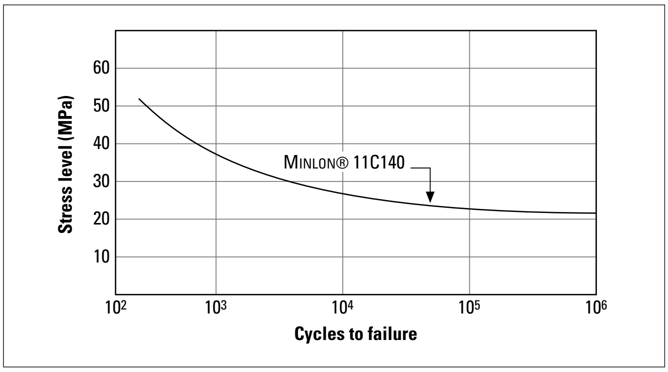


Figure 3.58 **Flex fatigue stress vs. cycles to failure for MINLON® 11C140, dry-as-moulded, 23°C**

expressed for plastics as the stress level at which test parts will undergo one million cycles without breaking. By extrapolating the curves obtained, corollary information may be determined on the number of cycles that can be withstood at any given stress level.

The response of ZYTEL® 101 to repeated flexural type stress is shown in Figure 3.52. The fatigue endurance limit for dry ZYTEL® 101 is higher than for specimens equilibrated to a 50% relative humidity. Figure 3.53 provides information on ZYTEL® 101 nylon resin with axial stress with alternate tension and compression.

Figure 3.54 provides comparative Sonntag fatigue data on ZYTEL® 101, 158 and 408.

Many automotive, appliance and machinery service conditions require good fatigue endurance behaviour both at elevated temperatures and in the presence of such materials as oils, greases, gasolines and detergents.

It has been found, that gasoline vapours have no influence on the fatigue resistance of ZYTEL® 101.

Temperatures ranging from 23–100°C have only slight effects on the fatigue endurance limits of ZYTEL® 101, as shown in Figure 3.55.

Tests on samples of ZYTEL® 101 conditioned in a variety of detergents showed that no loss in fatigue endurance resulted from these exposures.

Fatigue curves, obtained with testbars in the Sonntag-Universal machine, for ZYTEL® 70G30HSL and some MINLON® grades are given in Figures 3.56–3.58.

Experimental work has revealed that below 1800 cycles per minute, the rate of stress application has little effect on the fatigue properties of ZYTEL®. At higher rates or at higher stress levels than those indicated in the previously referred Figures, heat generated from the energy loss in the material might raise the temperature sufficiently to cause a change in properties.

The fatigue properties of ZYTEL® are most advantageous where vibrations are involved. Metals can withstand higher repeated stresses. However, because metals are stiffer, and lack a degree of yielding, failure can occur at very small repeated strains. Under the same conditions, ZYTEL®, at a much lower stress level, will perform satisfactorily. The fatigue resistance of ZYTEL® therefore, is particularly valuable in gears, tubing, and in parts on vibrating machinery.

Hardness, abrasion resistance, friction and wear

Hardness

The Rockwell hardness is the measure of surface penetration with a 12,5 mm diameter ball under a specified load. This measurement is closely related to tensile modulus and is the hardness value most frequently used to describe nylon resins. Another measure of hardness, sometimes reported, is Durometer, which is a measure of the indention with a hardened steel indenter. Both types of hardness for nylons are shown in Table 3.08.

Table 3.08 Hardness values for ZYTEL® nylon resin at 23°C (Rockwell hardness, ASTM D785-51; Durometer hardness D676-49T)

	Rockwell hardness		Durometer hardness	
Material	Dry	50% RH	Dry	50% RH
ZYTEL® 101	R121	R108	89	82
ZYTEL® 105	R121	R109	91	85
ZYTEL® 151	R114	R103	–	–
ZYTEL® 42	R121	R108	90	82
ZYTEL® 91HS	R70	R65	–	–
ZYTEL® 408	R115	R102	83	76

Values are given for samples, dry-as-moulded and for samples conditioned to equilibrium at 50% RH. The moisture-containing specimens possess the lower hardness values.

All of the nylon hardness values were made on samples that had come to thermal equilibrium in a room at 23°C. Hardness of nylon decreases with increased temperature.

Abrasion resistance

Experience in a variety of applications proves that ZYTEL® has outstanding abrasion resistance. A resilient material like ZYTEL® can deform under load and return to its original dimensions without wear. For example, worm gears used on paint mixers have operated for more than 18 months with little or no wear; whereas, metal gears in the same equipment had the teeth worn to knife edges in three to six months.

A wide variety of physical tests has been used for measuring the resistance to abrasion of plastic materials. In all of these tests, ZYTEL® shows superior resistance to wear.

Taber abrasion tests showed that ZYTEL® does not lose as much material as do a number of other commercial plastics under comparable test conditions (see Table 3.09). The material loss is only one-half to one-tenth as great. Ballmill tumbling tests resulted in a weight loss of less than one-tenth that of hard rubber, cast aluminium or mild steel.

In wire drag tests, ZYTEL® showed a resistance to wear that is superior to that of polyethylene by a factor of 35. In caster wheel tests, ZYTEL® exhibited its ability to outperform a thermoset material, phenol formaldehyde.

In the street marker tests, disks of ZYTEL® subjected to street traffic performed up to 25–60 times better than similar disks made from either the styrene butadiene and acrylonitrile terpolymer or from cellulose acetate butyrate.

Frictional properties

ZYTEL® nylon resins find many applications in bearings, gears, and sliding parts because of their excellent frictional and wear characteristics. ZYTEL® resins can be used in dry, frictional applications where many other materials would not work. Initial lubrication of the bearing surface extends the opportunities for dry, frictional applications for ZYTEL®.

The measured coefficient of friction depends upon many variables, including equipment used, the test temperature and the cleanliness and surface finish of the material being tested. The values are also dependent on the load and speed.

Table 3.09 Comparing the weight loss of various materials relative to ZYTEL® in different abrasion tests

Material	Taber	Ball mill	Wire drag	Caster wheel	Street marker
ZYTEL® 101	1	1	1	1	1
DELRIN® 500 NC010 acetal resin	2–5	4–6	5–6	3–4	2–3
Polystyrene (several types)	9–26	15–20	35	–	–
Terpolymer of styrene, butadiene & acrylonitrile	9	10–20	–	–	–
Copolymer of styrene & acrylonitrile	–	–	–	–	25
Cellulose acetate	9–10	–	–	–	–
Cellulose acetate butyrate	9–15	10–20	15	–	60
Methyl methacrylate	2–5	10–20	20	–	–
Melamine formaldehyde (moulded)	–	15–20	–	–	–
Phenol formaldehyde (mouldings)	4–12	–	–	16–50	–
Hard rubber	–	10	–	–	–
Die cast aluminium	–	11	–	–	–
Mild steel	–	15–20	–	–	–

Test descriptions

A. Taber abrasion tests were made with a CS-17 wheel and a 10N load at 23°C. Except where otherwise noted, the pieces were conditioned at 23°C and 50% RH.

B. Ball-mill abrasion tests were made by rolling 50 × 38 × 3 mm bars in a 125 mm ball mill with 25 "Carborundum" balls and 500 cm³ of water. In various instances, moulded objects were substituted for test bars, the "Carborundum" balls were replaced by steel balls, and the water was omitted without substantial changing the relative results.

C. Wire-drag abrasion tests were conducted by pulling a continuous loop of fine resistance wire (spirally wrapped on a cord) over a cylindrical test piece. The cord was held at a constant tension and pulled over the test piece at about 0,3 m/s. The depth of the groove was measured after 30 minutes.

D. Caster wheels 38 mm in diameter with an 8,7 mm tread were moulded and mounted in pairs in standard chair caster frames. The phenolic wheels were the wheels normally supplied with the casters. The chairs in which the test wheels were mounted were used on cement floors and tests carried out over a period of months.

E. Street marker disks 50 mm in diameter by 3,2 mm thick were secured by a center bolt in a traffic lane. Much of the abrasion was between the street and the disk.

Data on coefficients of friction have been obtained at several conditions as shown in Tables 3.10 and 3.11. Tests have indicated that there is little variation in the coefficient of friction over a temperature range of 23–120°C and speed changes from 0,05 to 2,0 m/s. In any application where friction is critical, it is recommended that measurements be made under simulated operating conditions.

Table 3.10 Range of coefficients of friction of ZYTEL® 101F

	Coefficient of friction	
	Static	**Dynamic**
ZYTEL® on ZYTEL®		
no lubricant		
maximum	0,46	0,19
minimum	0,36	0,11
ZYTEL® on DELRIN®		
no lubricant		
maximum	0,20	0,11
minimum	0,13	0,08
ZYTEL® on steel		
no lubricant		
maximum	0,74	0,43
minimum	0,31	0,17

Normal pressure: 0,14 MPa
Sliding speed: 0,5 m/s
Temperature: 23°C
Test method: Thrust washer
ZYTEL® at 2,5% moisture

Table 3.11 Coefficients of friction of ZYTEL® 101 Battelle Memorial Institute; Neely, or boundary film, testing machine; surface speed 0,75 m/s

Lubricant	Other surface	Load MPa	Coefficient of friction
Dry	ZYTEL®	7,2	0,04 to 0,13
Water	ZYTEL®	7,2	0,08 to 0,14
Oil	ZYTEL®	7,2	0,07 to 0,08
Water	Steel	7,2	0,3 to 0,5
Oil	Steel	10,7	0,02 to 0,11
Water	Brass	7,2	0,3 to 0,5
Oil	Brass	10,7	0,08 to 0,14

Wear

Most wear of plastics is a combination of adhesive and abrasive wear. The relative contribution of either type of wear and the rate of wear in any given application, depends on a large number of factors and is impossible to predict.

A traditional method for calculating wear, based on short-term wear data, involves the following equation:

$$W = kFVt$$

where: W = volume of wear particles, removed in time t
k = wear factor
F = load supported
V = sliding velocity

It must be recognized, however, that, as for any other plastic material, the wear factor can not be used to make realistic calculations of wear in practical applications.

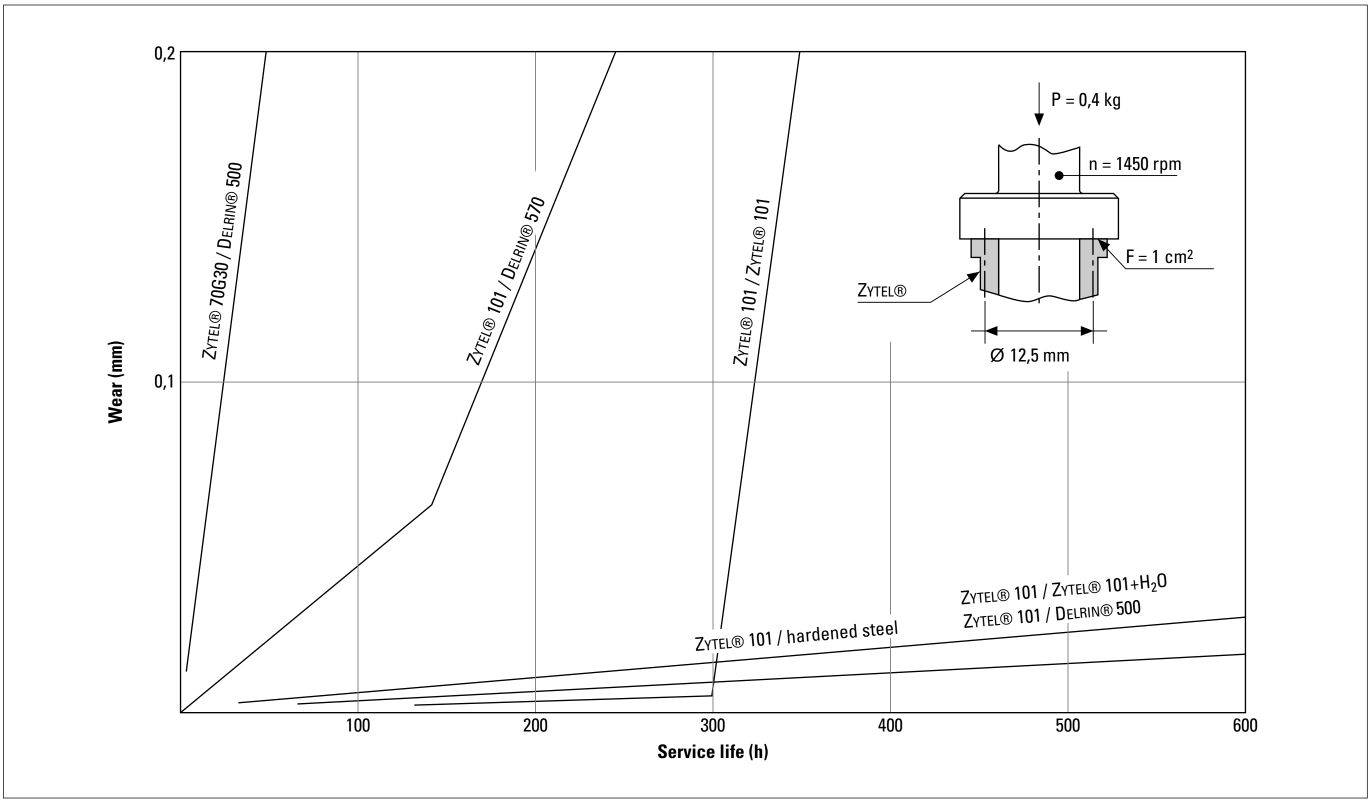


Figure 3.59 **Wear on axial bearings at room temperature part machined, conditioned at 2,5% water and washed in tricloroethylene**

More reliable tests have been carried out on axial bearings of ZYTEL® against various materials. The results of some of these tests are shown in Figure 3.59. Again these data should be used mainly for comparative purposes.

As for any plastic material, the geometric shape of the wear surface is of the utmost importance as far as wear is concerned. Particular care must thus be taken in obtaining good moulded parts; in this respect it must be noted that an incorrectly designed part will be impossible to mould correctly even by the best of processors. Also dimensional variations must be taken into account.

The maximum PV limit value for ZYTEL® 101 on a hardened steel shaft is 0,1 MPa × m/s. This value should be taken only as a rough estimate of the behaviour of a ZYTEL® bearing. An accurate and complete testing on *moulded* parts in the *actual* service conditions should always be done and any extrapolation or accelerated test should be avoided.

The excellent abrasion and wear characteristics of ZYTEL® is further enhanced by the addition of KEVLAR® para-aramid fibres. ZYTEL®-KEVLAR® SFC70K20 is a short fibre composite containing 20% KEVLAR® fibre which is at least five times more wear resistant than unreinforced nylon and virtually eliminates abrasion of the counter surface.

4 – Other properties of polyamide resins

Electrical properties

ZYTEL® nylon resins are widely used in electromechanical parts because of their excellent mechanical properties, chemical resistance, heat resistance and self-extinguishing characteristics. This combination of properties permits ZYTEL® to be used in coil forms, connectors, strain relief grommets, terminal blocks and tough overcoatings on wire insulation.

Parts made of ZYTEL® are generally used in electrical applications requiring 600 volts or less and frequencies of 400 cycles per second or lower. Power losses increase with increasing temperature, frequency and moisture.

Some electronic applications, such as large microwave transmitters, experience high electrical losses because of the high frequencies and the high heat sometimes encountered.

Moisture and temperature affect the volume resistivity, dielectric strength and dissipation factor for ZYTEL®. The effect of moisture can be minimized by using ZYTEL® 151 or 158 which are 612 nylons with lower moisture absorption than 66 nylons.

The short-time dielectric strength, as measured by ASTM D149, changes with thickness, moisture content and temperature. As the thickness and moisture content increase, the dielectric strength decreases (Figure 4.01). As the temperature increases, the dielectric strength decreases (Figure 4.02a), and the volume resistivity decreases (Figure 4.02b). Increasing moisture content causes decreased volume resistivity (Figure 4.03). Note that ZYTEL® 151 a 612 nylon, reaches moisture saturation at a lower level than ZYTEL® 101, a 66 nylon, and retains higher volume resistivity. Volume resistivity measurements were made according to ASTM D257.

The dielectric constant increases rapidly with increasing temperature or moisture content as shown in Figures 4.04–4.05. Dielectric constant measurements were made in accordance with ASTM D150. Since maintaining constant moisture and temperature conditions over the test period is difficult, the curves represent only general values for these conditions.

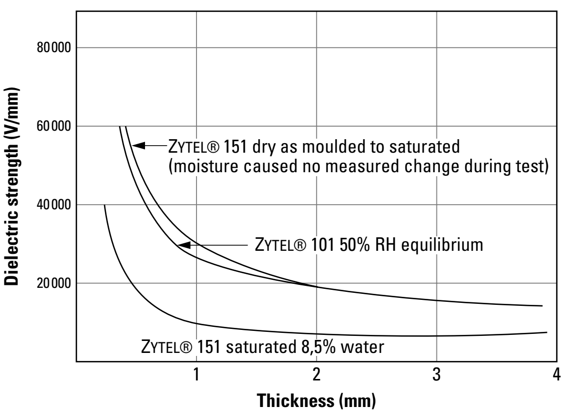


Figure 4.01 **Short time dielectric strength of ZYTEL® vs. thickness measured at 23°C**

The dissipation factor increases with increasing temperature and moisture. Measurements of change were made using ASTM D150 and are shown in Figures 4.06–4.07.

Many compositions of ZYTEL® nylon have been rated by Underwriters' Laboratories (UL) in its Component Recognition Program for polymeric materials. The UL ratings of ZYTEL® nylons are discussed in Section 8.

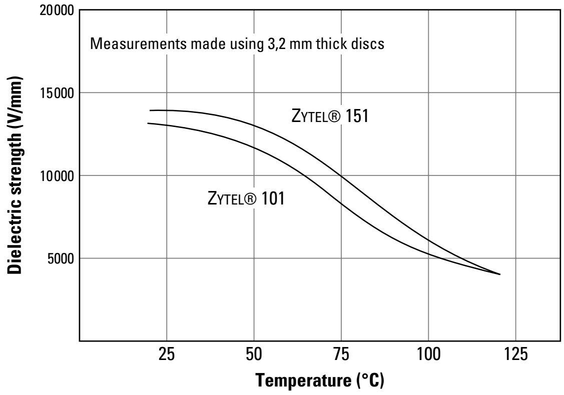


Figure 4.02a **Effect of temperature on dielectric strength of ZYTEL®**

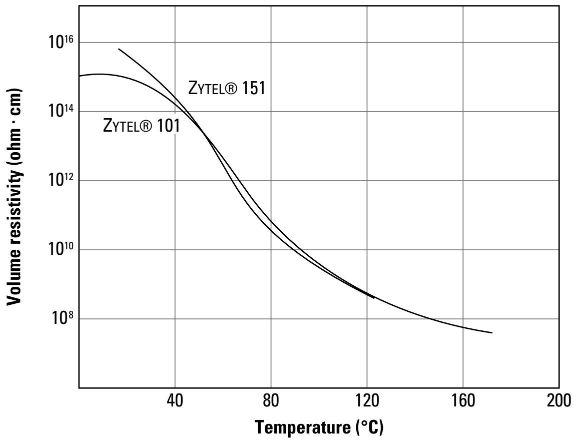


Figure 4.02b **Volume resistivity vs. temperature, dry as moulded**

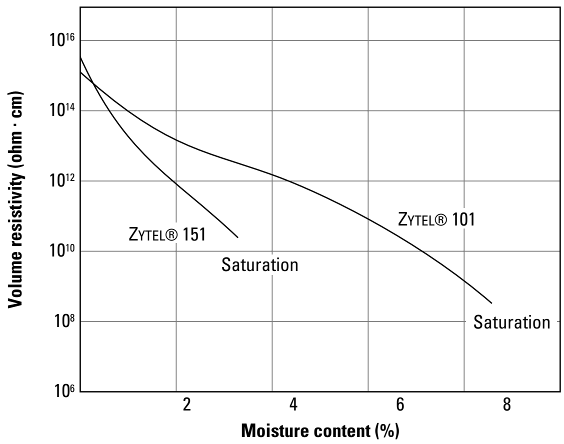


Figure 4.03 **Effect on moisture content on volume resistivity at 23°C**

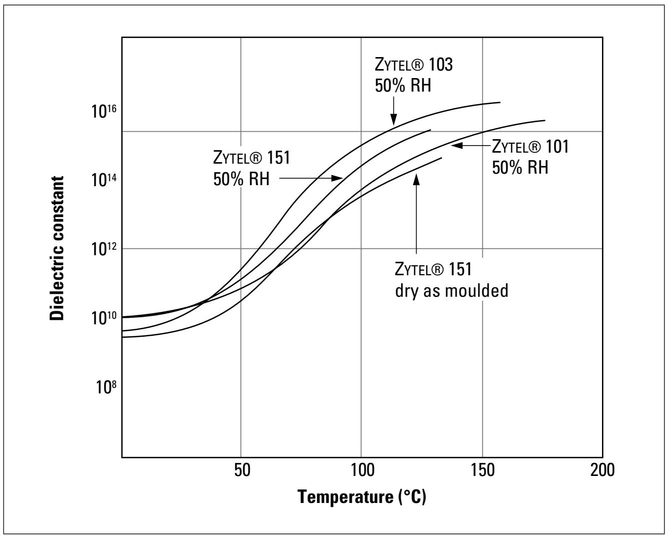


Figure 4.04 **Dielectric constant vs. temperature measured at 100 Hz. Samples conditioned as indicated. Typical values based on laboratory measurements**

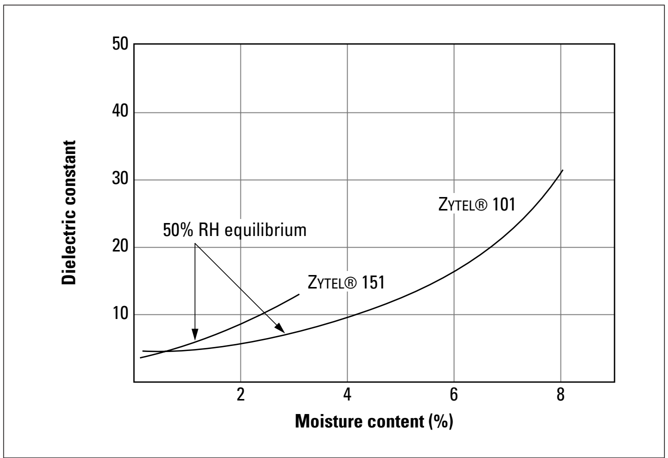


Figure 4.05 **Effect of moisture on dielectric constant measured at 100 Hz, using 3,3 mm thick plaques at 23°C.**
Typical values based on laboratory measurements

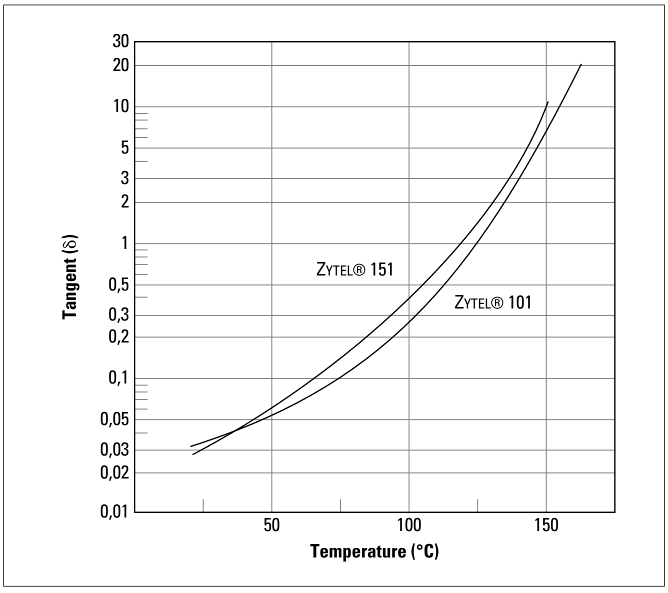


Figure 4.06 **Dissipation factor vs. temperature (100 Hz).**
Samples conditioned to 50% RH at 23°C.
Typical values based on laboratory measurements

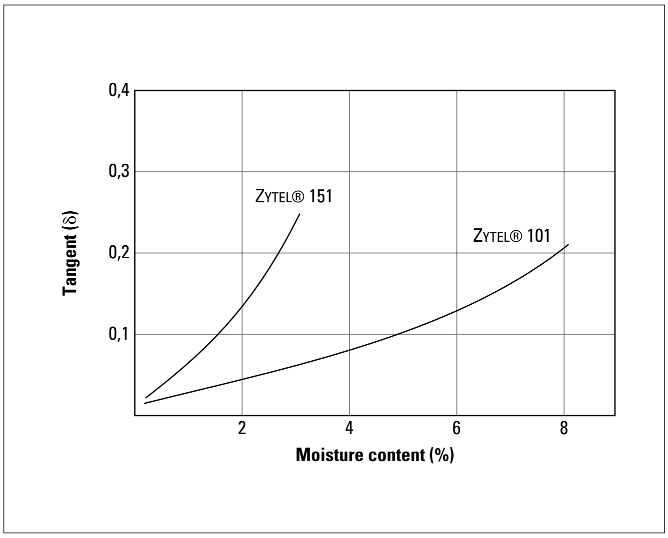


Figure 4.07 **Effect of moisture on dissipation factor measured at 100 Hz, samples at 23°C**

Flammability

General

Flammability and smoke-generating characteristics of plastics have come under scrutiny in recent years and a variety of laboratory-type tests have been developed to define these properties. Agencies within the Federal Government, as well as outside organizations such as the American Society for Testing Materials, the Underwriters' Laboratories, Inc. and many industrial corporations have contributed to new test development. Currently, a large number of procedures for defining many aspects of flammability are available for setting up safety and acceptability standards.

The individual tests are generally intended to predict the behaviour of the material during burning or during exposure to intense heat, as in a burning building or aircraft. Here, conditions are legion. Hence, a reason for many individual procedures is evident. There have been many attempts by the Plastics Industry to duplicate catastrophic fire in laboratory tests; however, the correlation of laboratory test data with actual conflagration remains controversial. The major contribution of the tests is to rank the various materials relative to each other and to the particular specifications.

The behaviour of ZYTEL® nylon resins when tested by these procedures is of importance to the designer, since it is necessary to know whether the material and proposed design will pass certain governmental or industrial codes. The following tests are among those referred to in many government and industrial specifications. Test data on some ZYTEL® nylon resins are shown in Tables 4.01 and 4.02. Table 4.02 shows also how ZYTEL® compares with other types of plastic materials in flammability and smoke generation.

Flame retardant compositions

The ZYTEL® product line includes a range of materials which have been modified to inhibit burning and thus give superior performance in many of the tests listed below. These flame retardant grades are designated ZYTEL® FR. Please consult your DuPont representative for full description of these modified materials.

Table 4.01 Flammability and smoke generation

Compositions	Oxygen index, % ASTM D2863		Underwriters' flammability		NB smoke generation		
	Dry	50% RH	Specimen thickness, mm	Rating	Energy source	D_m	D_s (a) 2 min.
ZYTEL® 101L	28	31	1,6	94 V2	R	13	0
			3,2	94 V2	RF	26	1
ZYTEL® 103HSL	28		1,6	94 V2			
ZYTEL® 151L	25	28	1,6	94 V2	R	37	0
			3,2	94 V2	RF	27	1
ZYTEL® 408	19	20	3,2	94 HB			
ZYTEL® ST801	18	19	0,8	94 HB			
ZYTEL® FR7200 V0F	30		0,5	94 V0			
Reinforced ZYTEL® resins							
ZYTEL® 70G30	–	–	1,6	94 HB	–	–	–
ZYTEL® FR70G25 V0	–	–	0,5	94 V0	–	–	–
ZYTEL® FR70G28 V1	–	–	1,6	94 V1	–	–	–
ZYTEL® FR70M30 V0	43	–	1,6	94 V0	–	–	–
MINLON® 10B140	–	25	1,6	94 HB	–	–	–
MINLON® 11C140	–	30	0,8	94 HB	–	–	–
MINLON® 23B1	–	28	–	94 HB	–	–	–

Note:
MINLON® 10B and 11C are listed on UL Yellow cards as UL 94 HB. MINLON® 23B1 has been tested at the DuPont Technical Services Laboratory using the ASTM D635 procedure and found to have burning rates similar to HB materials.
D_m = Specific optical density at maximum smoke accumulation.
D_s = Specific optical density.
R = Radiant source only (2,5 watts/sq. cm.)
RF = Radiant source plus flaming gas jets.

Table 4.02 Comparison of ZYTEL® 66* nylon with other materials. Oxygen index and NBS smoke generation

Material	Oxygen index, %	Material	Thickness, mm	Max. smoke density (D_m)**	
Polytetrafluoroethylene	95			RF**	R**
Polyvinyl chloride	45–49				
ZYTEL® 101 (66 nylon resins)	28–31	ZYTEL® 101 (66 nylon)	3,2	26	13
Polyphenylene oxide	28–29	Polycarbonate	3,2	174	12
Polycarbonate	26–28	Acrylic	5,6	107	156
Chlorinated polyethylene	21,1	ABS	1,2	660	71
Polystyrene	18,1	Polystyrene	6,4	660	372
Polypropylene	17,4	Polyvinyl chloride	6,4	535	470
Polyethylene	17,4–17,5	Polyethylene	6,4	150	470
Acrylic	17,3	Plywood, marine	6,4	62	285
Acetal homopolymer	15	Red oak	6,4	72	395
Acetal copolymer	14,8–14,9				
Paraffin, candle	16				

* Data from Flammability Handbook for Plastics, Carlos J.Hilado, Union Carbide Corp.; Technomic Publishing Company, Stamford, Conn., 06902.
** Note: See Table 4.01 for explanation of symbols.

Individual test descriptions

- Underwriters' Laboratories flammability ratings
  1. *Vertical flame test, subject 94 (V0, V1 and V2).* This test applies a flame to a vertically clamped test bar and is considered more severe than the ASTM D635 procedure.
  A material is rated as 94 V0 if it passes certain test requirements such as extinguishing within five seconds (average) after the flame application, and not dripping flaming particles. The 94 V1 is a lower (poorer) rating, and extends the flame extinguishing time. The 94 V2 rating permits flaming particles and ignition of the cotton. Also for this rating, the horizontal test is applicable. ZYTEL® 101 and other ZYTEL® 66 nylons are 94 V2 according to tests (see Table 4.01). Consult UL test description for details.
  2. *Horizontal flame test, subject 94.* In this test, similar to ASTM D635, the burning rate is determined on a horizontally clamped specimen. A material is 94 HB if its burning rate is 38 mm/min. or less for 3,2 mm thick specimens. ZYTEL® 408 and glass-reinforced ZYTEL® are rated 94 HB according to this test.
- *Oxygen index, ASTM D2863.* A plastic specimen in an atmosphere of oxygen and nitrogen is subjected to a candle-type flame test. The oxygen content is varied, and the minimum concentration needed to just support combustion is reported as the oxygen index. Materials that require high concentrations of oxygen to burn can be considered less flammable. These materials will have a high oxygen index. ZYTEL® 101 NC010 is resistant to burning as indicated by the relatively high oxygen index of 28, dry-as-moulded, and 31, when equilibrated to average humidity conditions (Table 4.02).

- *Smoke density, ASTM D2843.* A specimen is burned in a special chamber (XP-2) under continuous ignition. The generation of smoke causes a reduction in the intensity of a light beam. This is measured through the duration of the test and results are expressed in terms of maximum percent light absorption and a smoke density rating. The procedure is intended to provide a relative ranking of the smoke-producing characteristics of plastics under controlled standardized conditions. Under the conditions of this laboratory test, ZYTEL® 101 shows little smoke development (Table 4.01).
- *NBS smoke generation.* A procedure for measuring changes in optical density due to smoke generated by plastics exposed to a radiant and radiant plus flaming energy sources has been developed by the National Bureau of Standards. The equipment is currently commercially available, and the ASTM is reviewing the procedure. ZYTEL® nylons show up particularly well when compared with such materials as polyvinyl chloride or ABS polymers. Data for non-reinforced materials are shown in Table 4.01 and 4.02. Smoke generation of glass-reinforced ZYTEL® is slightly higher than for nonreinforced.
- *Flammability behaviour of ZYTEL® nylon resins.* ZYTEL® nylons readily pass the Federal Highway Administration Notice of Proposed Motor Vehicle Safety Standard No. 302, ‘‘Flammability of Interior Materials, Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses’’. They also easily pass the horizontal flame test section of the FAA Notice of Proposed Rule Making, ‘‘Transport Category Airplanes, Crashworthiness and Passenger Evacuation’’, Federal Air Regulation 25-15. Most ZYTEL® compositions pass the severe 60-second ignition vertical test section of the FAA tests.

Light transmission

Unpigmented and unreinforced ZYTEL® nylon is relatively translucent in thin sections <3,2 mm. Because of this, ZYTEL® has been used extensively in the automotive and aircraft industries for dome and courtesy lights.

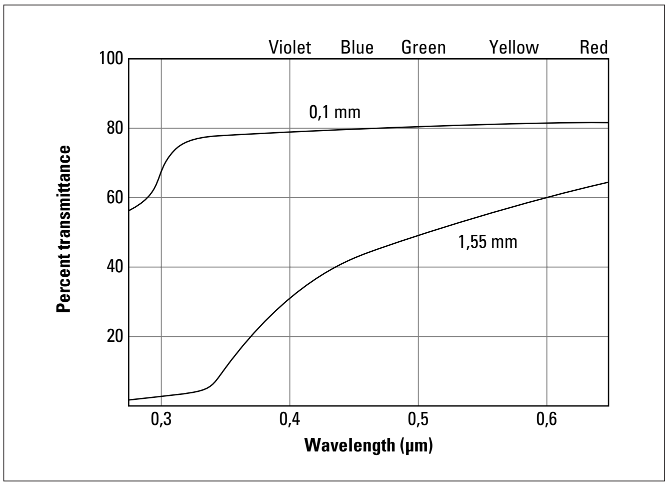


Figure 4.08 **Spectral transmittance curve of ZYTEL® 101 nylon resin. Ultraviolet and visible region 0,275–0,65 µm Cary Model 14 with integrating sphere. Sample thickness 0,1 and 1,55 mm. Transmittance vs. wavelength**

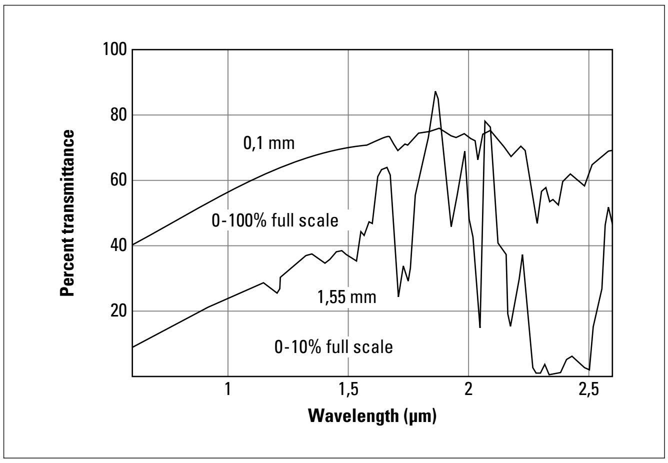


Figure 4.09 **Spectral transmittance curve of ZYTEL® 101 nylon resin. Near infrared region 0,6–2,6 µm Cary Model 14 without integrating sphere. Sample thickness 0,1 and 1,55 mm. Transmittance vs. wavelength**

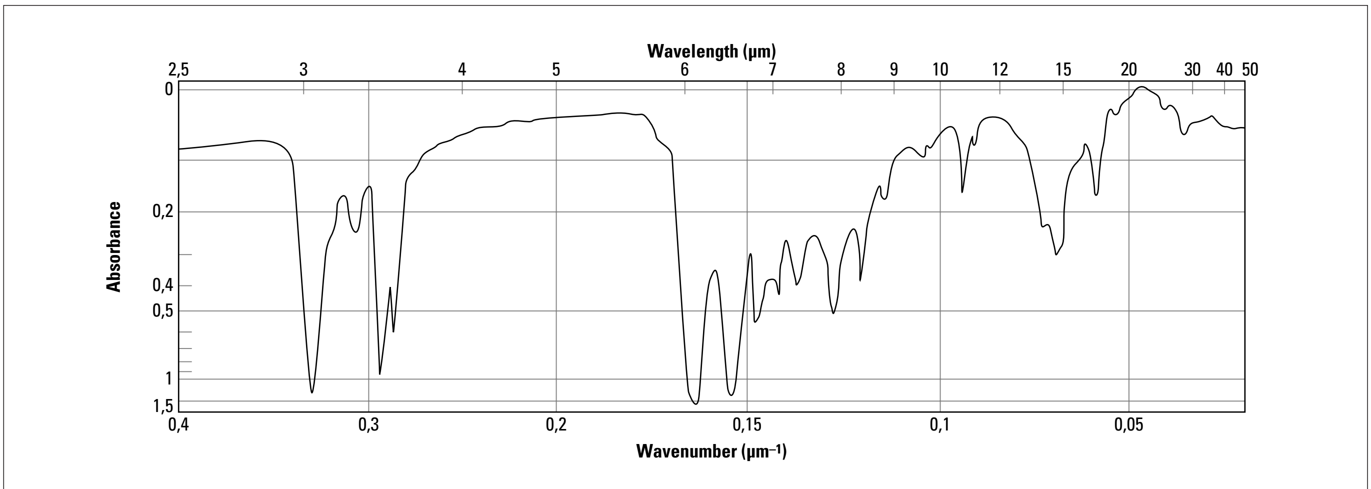


Figure 4.10 **Infrared absorbance curve of ZYTEL® 101 nylon resin. Film 13 µm thick with Perkin-Elmer model 621 spectrophotometer. Absorbance vs. wavelength**

ZYTEL® 151 is even more translucent than ZYTEL® 101. For sustained exposure to heat, ZYTEL® 103 is sometimes preferred although its colour is darker.

Spherulites are normally present in ZYTEL® and scatter light, thereby making the section translucent but not transparent. In fabricating thin sections by extrusion or moulding, however, sudden cooling may be utilized to form essentially amorphous sections of about 0,025 mm thickness. These are essentially transparent. Transmission characteristics in the ultraviolet and visible ranges and absorbance in the infrared ranges are given in Figures 4.08 to 4.10.

ZYTEL® 330 is a completely amorphous polyamide and is transparent to visible light. The property balance of this resin differs in some way, from semi-crystalline polyamides, and details of this material should be requested from your DuPont representative.

Thermal properties

Coefficients of thermal expansion for some unreinforced ZYTEL® grades, measured at different temperatures, are given in Table 4.03. Thermal expansion is an important factor in plastic design.

For reinforced nylons the expansion coefficient in flow direction generally is different from the one in transverse direction, resulting in different shrinkages in both directions, which can lead to warped parts after cooling down after moulding. Changed gate positions (flow directions) and optimal mould cooling can help to reduce the unwanted warpage to a minimum.

Values for specific heat and thermal conductivity are given in Tables 4.05 and 4.07. For viscosity values as a function of shear rate at different temperatures around the melt temperature of the materials listed in Table 4.07, see CAMPUS 2.4.

The heat deflection temperature, ISO 75-I-2, is the temperature at which a standard test bar deflects 0,25 mm under a stated stress level of either 0,45 or 1,82 N/mm2. Heat deflection temperatures reported in the literature may sometimes fail to agree because internal stress and absorbed moisture affect the experimentally obtained values. In Table 4.06, data are shown for dry-as-moulded specimens in which internal stress was relieved by annealing.

The heat deflection temperatures of ZYTEL® nylon resins do not relate to melting or upper-use-temperature.

Consider the case of a ZYTEL® nylon test bar under a given load at a variable temperature. Thermal plasticizing of the nylon as the temperature increases results in a modulus reduction and an increased deflection. Most of this deflection is accordingly recoverable when the load is removed. Amorphous plastics, on the contrary, do not show this recovery when the load is removed from the test bar.

Table 4.03 Coefficient of linear thermal expansion, mm/mm/°C

Temperature, °C	ZYTEL® 101	ZYTEL® 151	ZYTEL® 408
–40	63×10^{-6}	72×10^{-6}	61×10^{-6}
0	72×10^{-6}	81×10^{-6}	65×10^{-6}
23	81×10^{-6}	90×10^{-6}	72×10^{-6}
77	90×10^{-6}	108×10^{-6}	90×10^{-6}

Note: The values shown are based upon dry as moulded specimens. The coefficient of expansion is somewhat dependent on both temperature and moisture content. For example at 23°C dry, ZYTEL® 101 has a coefficient of $81 \times 10^{-6}/°C^{-1}$ but at saturation it has a coefficient of $117 \times 10^{-6}/°C^{-1}$.

Table 4.04 Coefficient of linear thermal expansion, mm/mm/°C

Material	C.L.T.E	Remarks
MINLON® 10B, MINLON® 11C, MINLON® 22C	36×10^{-6}	Dry
ZYTEL® 70G30HSL, ZYTEL® 77G33HSL	23×10^{-6}	In flow direction
ZYTEL® 70G43HSL, ZYTEL® 77G43HSL	23×10^{-6}	In flow direction

Table 4.05 Specific heat

Specific heat	ZYTEL® 1011 kJ/kg · °C	ZYTEL® 151 kJ/kg · °C
below 0°C	1,3	1,3
0–50°C	1,5	1,7
50–100°C	1,9	2,1
100–200°C	2,3	2,5

Table 4.06 Heat deflection temperature*

Material	0,43 MPa Temperature, °C	1,8 MPa Temperature, °C
ZYTEL® 101	235	80
ZYTEL® E42	235	80
ZYTEL® 408	230	69
ZYTEL® 151	180	90
ZYTEL® 158	180	90

*All materials annealed in oil at 50°C below melting point.

Table 4.07 Thermal properties of ZYTEL® and MINLON® resins, rheology data

Grade	Solid/liquid density kg/m³	Melt specific heat J/kg · °C	Latent heat J/kg	Conductivity J/m · s · °C
ZYTEL® 101F	1140/950	2604	54012	0,127
ZYTEL® 101L NC010	1140/950	2897	53594	0,135
ZYTEL® 103HSLC	1140/950	2897	53594	0,135
ZYTEL® 135F NC010	1140/1020	2504	43419	0,115
ZYTEL® 408 NC010	1090/950	2776	55185	0,140
ZYTEL® 450 NC010	1090/920	2734	47732	0,135
ZYTEL® 490 NC010	1090/920	2843	43964	0,120
ZYTEL® 42 NC010	1140/950	2705	52338	0,120
ZYTEL® ST801	1080/920	2835	37683	0,136
ZYTEL® 70G20HSL	1290/1120	2094	45220	0,160
ZYTEL® 70G30HSL	1350/1200	2290	32240	0,180
ZYTEL® 70G35HSL	1410/1270	2290	32659	0,186
ZYTEL® 70G43L	1510/1280	2290	33077	0,176
ZYTEL® 72G30HSL	1370/1210	2261	22819	0,186
ZYTEL® 73G30 NC010	1360/1200	2357	50000	0,203
ZYTEL® 73G45 NC010	1510/1345	2357	50245	0,205
ZYTEL® 73G50 BK264	1560/1360	2357	50245	0,205
ZYTEL® 79G13HSL	1210/1030	2186	33915	0,160
ZYTEL® 80G33 HSIL	1340/1140	2537	26378	0,189
MINLON® 10B140 NC010	1510/1280	2274	35171	0,201
MINLON® 11C140 NC010	1480/1270	2144	28053	0,241
MINLON® 13MM GY282	1240/1085	2600	41033	0,183
MINLON® 13T2	1370/1170	2345	30816	0,208
MINLON® 23B1	1460/1240	2236	33329	0,193
MINLON® EFE6052 NC010	1620/1440	2300	23029	0,201
MINLON® EFE6053 BK165	1470/1250	2554	23073	0,271

5 – Effects of environment on ZYTEL®

Resistance of ZYTEL® nylon resins to high temperatures

Introduction

Due to oxidation, plastic materials normally undergo property loss during exposure to high temperatures. The maximum temperature for successful service depends upon the material used as well as the environmental conditions. Because ZYTEL® nylon resins resist high temperatures and withstand oils, greases and gasolines, they have been used for years in automotive, electrical and appliance applications.

Heat-resistant ZYTEL® nylons

ZYTEL® 101, an unmodified moulding grade 66 nylon, has been used widely in applications requiring exposure to heat. However, compositions with increased heat resistance have been developed for more severe conditions, e.g. ZYTEL® 103HSL and ZYTEL® 70G30HSLR. Ask your DuPont representative for a description of these special grades.

Engineering data on the behaviour of ZYTEL® nylons exposed to high temperatures

Engineering data on the behaviour of ZYTEL® at elevated temperatures have been obtained by exposing test specimens to oven-aging conditions for various time periods and then measuring changes in key properties as a function of time. Information on property decay can be useful in comparing materials and estimating service life. However, service testing of parts under expected temperature conditions is recommended when feasible. This provides a more reliable basis for defining their suitability for an intended application.

Tensile strength and impact strength are primary criteria for most design considerations and are used to express load-bearing strength and ability to withstand sudden shock or impact. The ability of plastics to retain these properties without serious loss during prolonged exposure to service temperatures is important to many mechanical and electrical applications.

The decay of properties for ZYTEL® nylons has been plotted in Figures 5.01–5.07. Data show the effects of oven exposure at different temperatures on the decay of tensile strength as a function of time.

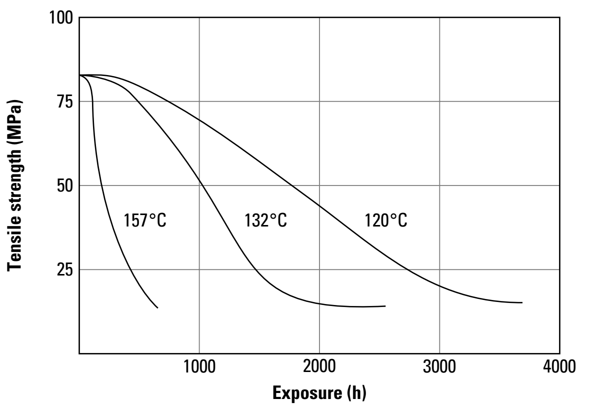


Figure 5.01 **Effect of air oven ageing of ZYTEL® 101 NC010 on tensile strength**

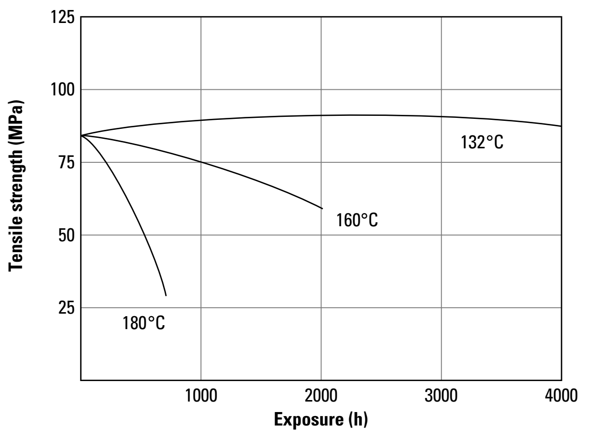


Figure 5.02 **Effect of air oven ageing of ZYTEL® 103HSL on tensile strength**

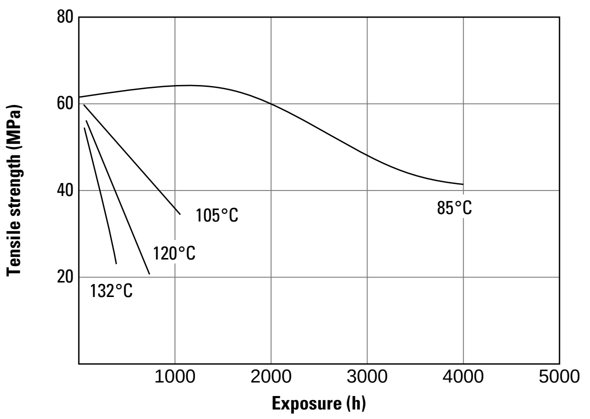


Figure 5.03 **Effect of air oven ageing of ZYTEL® 151 NC010 on tensile strength**

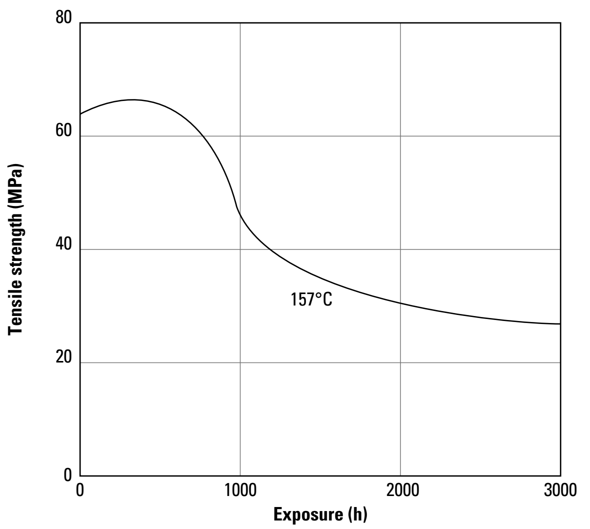


Figure 5.04 **Effect of air oven ageing on tensile strength of ZYTEL® 408HSL BK009**

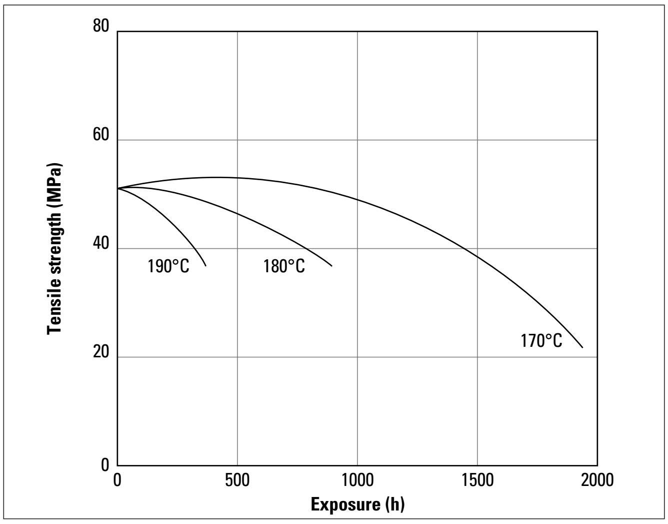


Figure 5.05 **Effect of air oven ageing on tensile strength of ZYTEL® ST801**

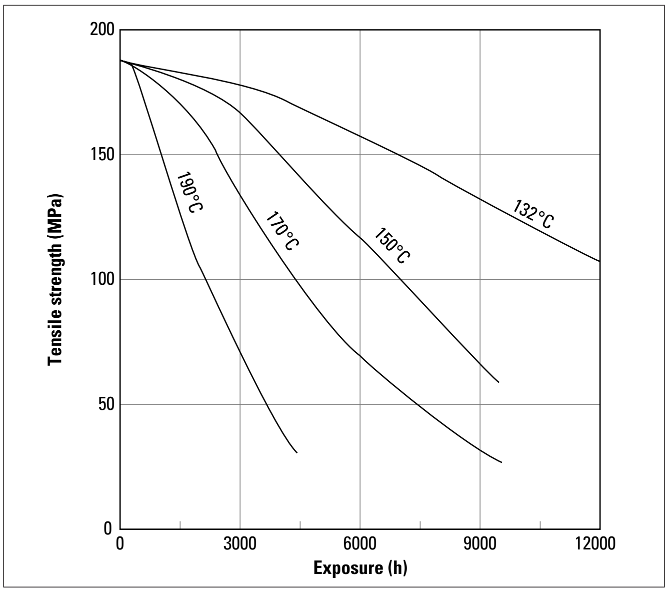


Figure 5.06 **Effect of air oven ageing on tensile strength of ZYTEL® 70G33L**

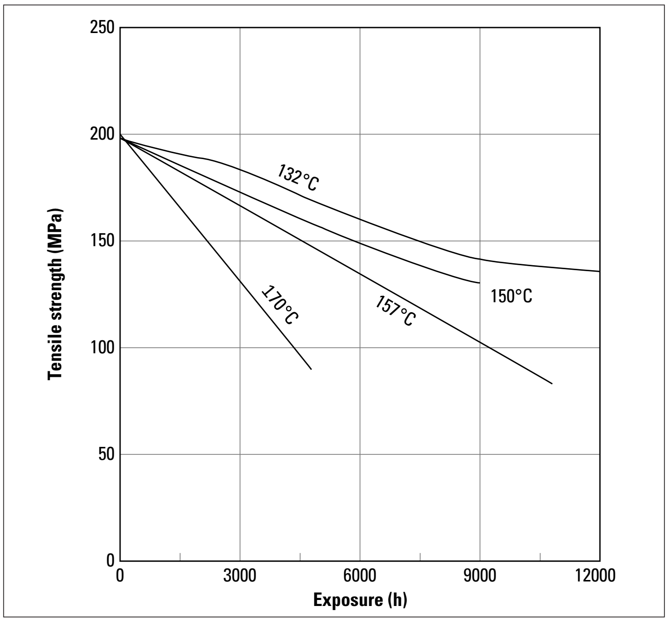


Figure 5.07 **Effect of air oven ageing of a heat stabilized ZYTEL® 70G33HSL on tensile strength**

Table 5.01 Heat ageing test results (ASTM D638) on ZYTEL® FN flexible nylon alloys.
(These results are typical for all grades)

	ZYTEL® FN	
	716	**726**
After 0 hours exposure		
Tensile strength at 23°C, MPa	30	33
Elongation at break at 23°C, %	260	270
After 1000 hours in 100°C air		
Tensile strength at 23°C, MPa	32	33
Elongation at break at 23°C, %	260	340
Elongation retained, %	100	120
After 1000 hours in 125°C air		
Tensile strength at 23°C, MPa	31	34
Elongation at break at 23°C, %	270	330
Elongation retained, %	100	120
After 1000 hours in 135°C air		
Tensile strength at 23°C, MPa	27	28
Elongation at break at 23°C, %	218	258
Elongation retained, %	83	95
After 2000 hours in 100°C air		
Tensile strength at 23°C, MPa	28	32
Elongation at break at 23°C, %	200	310
Elongation retained, %	77	110
After 2000 hours in 125°C air		
Tensile strength at 23°C, MPa	27	32
Elongation at break at 23°C, %	220	300
Elongation retained, %	83	110

Underwriters' Laboratories, Inc., ratings for ZYTEL® nylon resins

Many consumer devices – such as radios, TV sets, washing machines, business machines – are sold with an Underwriters' Laboratories, Inc. (UL) ''listing mark'' indicating compliance with UL standards. To obtain and retain this mark, the manufacturer must satisfy UL that the device will operate and/or fail in a safe manner over its expected life. UL assures compliance by periodic and unannounced visits to manufacturing locations in what is known as ''Re-examination and Follow-Up Service.''

In addition to ''listing'' devices, UL ''recognizes'' components such as thermostats, switches, etc. and basic plastic materials (ZYTEL® nylon for example) through a system of testing. This permits the manufacturer of an assembled device to use a number of ''recognized'' components with minimum further testing of these components by UL. Thus, considerable time and money is saved when the manufacturer seeks a ''listing'' for his device at UL.

The ''recognition'' of a basic plastic material involves the use of performance indexing tests on unaged moulded samples such as:

- Flammability classification*
- High amperage arcing ignition*
- Hot wire ignition*
- High voltage arc resistance*
- High voltage arc tracking rate*
- Volume resistivity
- Dielectric strength

* ZYTEL® nylon resins listed in the yellow cards showing the most up-to-date information on ZYTEL® nylons are available on request from local DuPont Sales Offices.

Heat deflection
Dimensional stability
Tensile strength
Impact strength

In addition, UL is interested in the long term behaviour of the following properties at temperatures above 50°C:
Electrical (dielectric strength)
Mechanical – without impact (tensile strength)
Mechanical – with impact (Izod or tensile impact)

This is done by a thermal aging procedure (UL Subject 746) utilizing moulded test bars and/or discs of specified thicknesses with results plotted on an Arrhenius plot. This predicts the temperature at which the specific property will decrease to one half of its original, unaged value at 60 000 hours of use.

Most of these tests have been completed on the many compositions of ZYTEL® nylon and are one file at UL under File No. E-41938.

Electrical properties

Decay rates for electrical properties also are important design information. Our general experience has been that electrical properties such as dielectric strength hold up usually better than mechanical properties. Spot checks on other electrical properties have confirmed field experience which has demonstrated satisfactory electrical property retention even after a considerable loss in mechanical properties has occurred.

Table 5.02 Examples of UL-rates ZYTEL® nylons

Nylon composition	UL rating on electrical properties, °C
ZYTEL® 101 and 101L (NC, WT, BK)	125
ZYTEL® 103HSL (NC, BK)	130
ZYTEL® 105 BK010A	125
ZYTEL® 42	125
ZYTEL® 151 and 158L	105

Resistance of ZYTEL® to hot water and steam

Introduction

ZYTEL® nylon resins are resistant to hot water and steam. Thus, ZYTEL® has found wide uses in such applications as hot water mixing valves, gears and baskets, equipment used for conveying in hot water and parts which must be subjected to steam, as in a sterilization cycle. This section discusses the resistance of ZYTEL® to numerous hydrolytic environments.

Factors important to performance in hot water and steam

- *Temperature.* Oxidative attack and embrittlement occur more severely at higher temperatures. A 15°C increase in temperature may reduce life by 40–50%. However, the effect of oxygen concentration in the water is sometimes more important than temperature.
- *Stagnant vs. fresh water.* ZYTEL® is less affected by stagnant boiling water than by boiling water aerated with air. As water is heated, the air flashes off to the atmosphere and at the boiling point, little oxygen remains. Water from a hot water heater is usually rich with air.
- *Chlorine.* The effect of municipal chlorinated water on the service life of parts of ZYTEL® is small and not easily defined quantitatively. Laboratory prepared chlorine contents of up to 8 ppm do have a small effect on ZYTEL® and may reduce service life 20–30%. Microcracking may occur.
- *Internal stress.* Moulded-in stress can be an important facet of expected life, particularly when potential stress cracking materials may be involved in service. Moulded parts should be nearly stress free.
- *Impact and fatigue.* In water-mixing valves and similar parts, impact and fatigue conditions (from water hammer) are elements of service. Experience has demonstrated the ability of ZYTEL® to withstand these conditions. However, for new applications involving impacts, service testing should be used.

Specific composition for maximum hydrolytic resistance

For severe conditions in steam or hot water, ZYTEL® 122 or 70G30HSLR should be used. Both are hydrolysis resistant 66 nylons.

Resistance of ZYTEL® to different types of water environment

The interplay of factors in a contemplated water or steam environment can make the prediction of service life difficult. Although nothing is as definitive as end-use testing, data obtained under several controlled conditions are useful in design considerations and in new applications. Accordingly, data on property retention were studied under the following environments: (1) stagnant water (without air), (2) fresh water (containing air) and (3) steam (containing air).

- *Resistance of ZYTEL® to stagnant boiling water.* In service conditions involving exposure to steam or hot water, oxygen is always present in some concentration. In this section, situations in which the oxygen concentration is low are considered and the hydrolytic environment is termed ‘‘stagnant’’.

  In these ‘‘stagnant’’ tests, test bars were placed in a vessel containing boiling water and the effect of exposure on tensile properties and impact strength were measured as a function of time. Every three days, the water from the container was replaced with fresh water which was heated immediately to boiling. The effect of temperature on estimated service life of ZYTEL® nylon in stagnant water is shown in Table 5.03. The life estimations for various temperatures are based on the assumption of low concentrations of oxygen.
- *Resistance of ZYTEL® to fresh water containing oxygen.* Water heated to 80°C in a home appliance and discharged directly into a water-mixing valve of a washing machine is supersaturated with respect to air (and oxygen). This water, rich in air, is more severe than stagnant water. Service life of ZYTEL® is shorter in oxygen-rich water. Tests on air-rich water were run at 80°C, a temperature common in home appliances. In the testing, 80°C water was continuously fed into a pressure cannister in which test bars were exposed to the combined effects of air and water. The test was designed to simulate a washing machine with fresh hot water filling the cannister every 30 seconds.

Test bars were removed periodically and tested for tensile properties in order to measure decay. As shown in Figure 5.08, ZYTEL® 122 stands up significantly better than ZYTEL® 101. It is also apparent that water at 80°C containing considerable air is more severe on ZYTEL® than is stagnant water.

- Resistance of ZYTEL® to steam. ZYTEL® 122 is used for prolonged exposure to steam; ZYTEL® 101 for less severe exposure. The behaviour of ZYTEL® 122 in a steam autoclave is shown in Table 5.04.

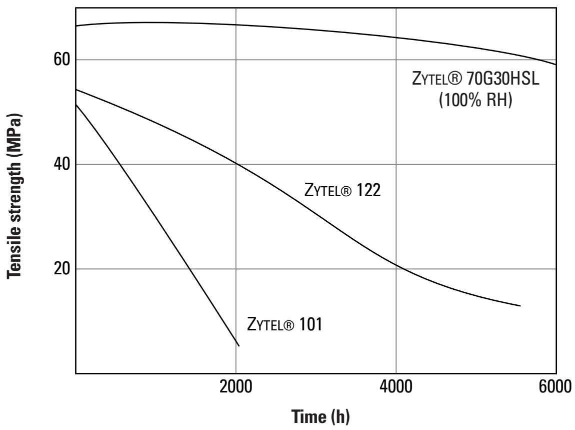


Figure 5.08 **Resistance of ZYTEL® 101, 122 and 70G30HSL to hot fresh water at 80°C**

Table 5.03 Estimated service life of ZYTEL® 101 and 122 in stagnant hot water

Water temperature	Exposure hours based on point where elongation and impact resistance decrease 25–50%	
°C	**Exposure hours ZYTEL® 101***	**Exposure hours ZYTEL® 122**
100	1500	5000
90	2000	6500
80	3000	10000
70	8000	25000

* These data can be used also for estimating the useful life of ZYTEL® 103HS and 105. For hot water rich in air, reduce exposure hours by 30–50%.

Table 5.04 Effect of 120°C steam on ZYTEL® 122

Property	Units	Control	200 hours	400 hours
Ternsile strength	MPa	73	74	70
Elongation	%	300	110	88

Weathering

General

Most plastic materials undergo some decay in properties and changes in appearance during prolonged exposure to outdoor weathering. Natural and pigmented ZYTEL® nylon resins have only moderate resistance to the effects of sunlight but special weather-resistant compositions retain their properties and appearance for years.

ZYTEL® 101 in natural and colours has been used successfully in outdoor applications. However, when exposure to ultraviolet light is severe and sustained and when maximum toughness must be retained over a period of years, weather-resistant compositions should be used.

Weather-resistant compositions

Weather-resistant compositions of ZYTEL® have been in service for more than 20 years. These materials contain a grade of carbon that has been uniformly dispersed to screen out attack by ultraviolet light.

Compositions used for maximum retention of physical properties are:

- ZYTEL® 105 BK010A. This is the preferred 66 nylon for outdoor use.
- ZYTEL® 101 WT007. White compositions are sometimes used for aesthetic reasons although weathering resistance is inferior to carbon-filled nylons. This 66 nylon maintains its appearance and properties in humid climates but is poor in arid areas.
- Reinforced composites have performed well in weathering tests. Ask your DuPont representative for a description of these special grades.

Properties observed in weathering studies

Moulded test parts exposed outdoors to ultraviolet radiation may ultimately fail for one of the following reasons: (1) loss of strength, (2) loss of toughness or (3) change in appearance.

Changes in tensile and yield strength over the time period studied were determined using ASTM D638. Toughness was measured using a mandrel bend test, in which test bars are bent rapidly 180° around a 3,2 mm diameter steel mandrel. A tough bar has the capability of being deformed in this manner without breaking.

The relative viscosity of nylon is related to its molecular weight. Exposure of nylon that is inadequately stabilized against ultraviolet light results in surface degradation with a corresponding drop in relative viscosity or molecular weight. The interest in relative viscosity accrues from the fact that serious loss in this property is related to a comparable loss in toughness.

Change in appearance has been measured by colour difference using Adams units which are similar to National Bureau of Standards (NBS) units.

Testing methods

The effects of weathering on the properties of ZYTEL® have been determined by exposing test specimens outdoors in various sections of the country and measuring property decay vs. time. Florida was selected as one location because of the high level of ultraviolet light radiation existing throughout the year. Arizona was also selected because of its unique combination of high ultraviolet radiation and arid conditions.

The exposure tests described in these localities represent more severe irradiation than would normally be expected in actual outdoor service. This is because all test samples are

Table 5.05 Florida weathering[c]

Composition	Property		Months 0	6	12	24	36	60	84	96	108	180
ZYTEL® 101 NC010	Yield stress	MPa	56	[a]	[a]	[a]	–	[a]	[a]	[a]	[a]	[a]
(66 nylon, not stabilized)	Tensile strength	MPa	73	37	31	31	–	23	16	19	24	24
	Elongation	%	300	10	6	6	–	5	5	5	–	–
ZYTEL® 105 BK010A	Yield stress	MPa	50	62	66	55	–	55	47	48	46	41
(66 nylon, light stabilized,	Tensile strength	MPa	63	62	66	55	–	55	47	48	46	41
black)	Elongation	%	160	60	41	32	–	55	41	51	50	32[b]
ZYTEL® 101 WT007	Yield stress	MPa	55	43	45	45	41	–	–	–	–	–
(66 nylon, with titanium	Tensile strength	MPa	72	61	46	45	41	–	–	–	–	–
dioxyde)	Elongation	%	205	290	230	65	30	–	–	–	–	–
MINLON® 10B140 NC010	Tensile strength	MPa	62	–	50	46						
	Elongation	%	7	–	6	6						
ZYTEL® 70G30HSL	Tensile strength	MPa	125	–	112	103	100	–	97			

a. Yield not distinguishable from tensile strength.
b. Material still tough at conclusion of test and can be bent 180° around a 3,2 mm (⅛ in.) steel mandrel.
c. Tensile bars tested as received; moisture contents ranged from 2–3% for ZYTEL® 101, 105 and 101 WT007.

Table 5.06 Arizona weathering exposure of ZYTEL® 101, 105 and 101 WT007*

Composition	Property		Months 0	6	12	18	24
ZYTEL® 101 NC010	Yield stress	MPa	78	–	–	–	
(66 nylon, not stabilized)	Tensile strength	MPa	78	31	25	45	
	Elongation	%	55	5	5	5	
ZYTEL® 101 WT007	Yield stress	MPa	81	–	–	–	
(66 nylon, with titanium dioxyde)	Tensile strength	MPa	81	42	26	43	
	Elongation	%	45	5	5	5	
ZYTEL® 105 BK010A	Yield stress	MPa	92	90	83	88	
(66 nylon, light stabilized, black)	Tensile strength	MPa	92	90	83	88	
	Elongation	%	25	20	25	25	

* All test bars exposed in dry-as-moulded condition.
After 12 months, ZYTEL® 101 and 101 WT007 show surface cracking and a broad range in tensile properties.

Table 5.07 Weathering exposure results on ZYTEL® 101 WT007* and 105 in moderate climate (Delaware, USA)

Composition	Property		Months 0	6	12	18	24
ZYTEL® 101 WT007	Yield stress	MPa	55	42	45	43	45
(66 nylon, with titanium dioxyde)	Tensile strength	MPa	71	48	45	43	45
	Elongation	%	295	250	95	70	65
ZYTEL® 105 BK010A	Yield stress	MPa	66	52	55	53	56
(66 nylon, light stabilized, black)	Tensile strength	MPa	66	52	55	53	56
	Elongation	%	215	200	70	45	45

* Bars contained 2,5% moisture at start of test.

Table 5.08 X-W Weather-Ometer exposure of ZYTEL® 101 NC010, 101 WT007 and 105 (wet-dry cycle), tensile bars 3,2 mm thick

Composition	Property		Hours 0	200	600	1000	2000	3000	6000
ZYTEL® 101 NC010*	Yield stress	MPa	54	58	**	**	**	**	**
(66 nylon, not stabilized)	Tensile strength	MPa	70	62	5	42	3	39	38
	Elongation	%	300	310	10	10	10	10	40
ZYTEL® 101 WT007*	Yield stress	MPa	55	58	58	55	60	61	65
(66 nylon, with titanium dioxyde)	Tensile strength	MPa	71	66	56	46	**	**	**
	Elongation	%	300	315	290	210	54	43	28
ZYTEL® 105 BK010A*	Yield stress	MPa	66	70	76	72	–	76	90
(66 nylon, light stabilized, black)	Tensile strength	MPa	51	51	53	50	64	**	**
	Elongation	%	210	105	60	46	10	14	18
ZYTEL® 408 BK010	Yield stress	MPa	53	–	64	–	66	–	–
	Tensile strength	MPa	59	–	64	–	66	–	–
	Elongation	%	39	–	45	–	25	–	–
ZYTEL® ST801 NC010	Yield stress	MPa	41	–	–	36	34	–	30
	Elongation	%	215	–	–	59	56	–	61
ZYTEL® ST801 BK010	Tensile strength	MPa	–	–	–	42	39	–	37
	Elongation	%	–	–	–	215	222	–	187

*Based on specimens conditioned to equilibrium at 50% RH.
**Yield not distinguishable from tensile strength.

on racks at an angle of 45° to the horizontal and facing the equator. (See ASTM D1435-65, Recommended Practice for Outdoor Weathering of Plastics).

Specialized equipment has been designed to produce ultraviolet radiation in higher concentrations than is found outdoors. The X-W Weather-Ometer, made by Atlas Electric Devices of Chicago, is an example of this type of equipment and has been used in DuPont accelerated weathering studies.

Weathering in various locations

- *Florida.* Florida weathering data are shown in Table 5.05 and may be summarized as follows:

  1. ZYTEL® 101 NC010 shows substantial loss of toughness at six months. The tensile strength, however, remains at 24 MPa after 180 months exposure.
  2. ZYTEL® 105 is still tough and strong at 180 months.
  3. ZYTEL® 101 WT007 is tough and strong at 36 months.

- *Arizona.* Experience with Arizona exposure tests has shown this climate to be more severe on ZYTEL® 101 WT007 and ZYTEL® 101 NC010 than on ZYTEL® 105 BK010A. For Arizona or similar climates, black stabilized compositions such as ZYTEL® 105 should be used. Arizona exposure data for ZYTEL® 101, 105 and 101 WT007 are shown in Table 5.06.

- *Delaware.* Wilmington ultraviolet light radiation is generally less severe than in Florida and exposed parts have generally been found to withstand Delaware better than Florida. Some data on weathering exposure results in Delaware on ZYTEL® 101, WT007, and ZYTEL® 105 are shown in Table 5.07.

X-W Weather-Ometer

An artificial weathering apparatus is sometimes used instead of direct exposure. In such an exposure, with a carbon arc as the source of radiation and periodic water spray to simulate rain, the test bars are subjected to accelerated weathering conditions. Although there is no precise relationship between outdoor weathering and the accelerated X-W Weather-Ometer tests, it is believed that 400–1000 hours produces a similar effect to a year in Florida. The effect of exposure in an X-W Weather-Ometer on the properties of ZYTEL® 101 NC010, 101 WT007, 105, 408 and ST801 are shown in Table 5.08. Weather-Ometer information about MINLON® 10B140 is shown in Tables 5.09

Table 5.09 Exposure of MINLON® 10B140 to Weather-Ometer (Xenon lamp)

		Wet-dry cycles, hours			
Properties		**0**	**1000**	**3000**	**5000**
Tensile strength	MPa	98	80	77	60
Elongation	%	3	3	3	4

Permeability and resistance to chemicals and reagent

Permeability

Permeability refers to the passage of a gas or liquid through a solid barrier. ZYTEL® nylon is an excellent barrier material but like all thermoplastics, some chemicals will diffuse through it at a measurable rate.

Tables 5.10 and 5.11 list permeation rates for common gases and liquids. This data can be used to compare the barrier characteristics of ZYTEL® as well as to calculate losses that can be expected through containers, film packages, conduits or other barrier parts.

Permeability is a property which is most difficult to measure accurately. It is dependent upon environmental pressure and temperature, test apparatus, as well as upon the materials involved. Consequently, although the data in Tables 5.10 and 5.11 are precise within the limits of the test procedure, they should be considered order-of-magnitude values. While most of the permeation rates have been measured on ZYTEL® 42 they can be used as good approximations for the permeability of other compositions of ZYTEL® nylon in the 66 family.

Table 5.10-A Permeation rates of various liquids from 2,5 mm thick bottles made from ZYTEL® 42

Liquid	Permeation rate at 0,1 MPa in $g/24\,h/m^2/mm$
Kerosene	0,08
Methyl salicylate	0,08
Motor oil (SAE 10)	0,08
Toluene	0,08
Fuel oil B (isooctane-toluene blend)	0,02
Water	1,2–2,4
Carbon tetrachloride	2,0
VMP naphtha	2,4

Chemical resistance – General

ZYTEL® nylon resins are outstanding in their resistance to a wide range of organic and inorganic substances. They are not affected by, nor do they affect, lubricating oils and greases, and aliphatic and aromatic hydrocarbons (including conventional fuels). Accordingly, they have found considerable use in automotive and aircraft applications. In many instances, the combined resistance of ZYTEL® to both heat and oils has permitted the use of high service temperatures, although tests on individual oils or greases are essential to ensure success.

ZYTEL® nylons are also resistant to a wide variety of proprietary items such as paints and lacquers, cosmetic preparations, detergents, aerosol preparations and food products including animal and vegetable fats. As a result, they are used for the packaging of many of these products.

ZYTEL® nylon resins are resistant to a wide variety of organic compounds, such as aldehydes, ketones, monohydroxyl alcohols, most esters, and most chlorinated aliphatic and aromatic materials. Some of these compounds will be absorbed by nylons in limited quantities with resultant dimensional changes. Physical properties in general are not impaired, although some materials, such as alcohols, will somewhat plasticize the nylon with a reduction in tensile strength, yield and modulus, and an increase in elongation and impact strength. Higher carbon-containing members of a homologous series are absorbed less. Partially halogenated hydrocarbons, such as methylene chloride, chloroform and ethylene dichloride, are absorbed in limited amounts and result in some plasticizing action resembling that of water.

Organic materials which do affect ZYTEL® generally do so through some degree of solvent action. Phenols and formic acid are powerful solvents and are used in certain bonding techniques. Trichloroacetic acid and some fluoroalcohols have similar action. Use in organic acids should be approached with caution. Acetic acid slowly attacks ZYTEL®; stronger acids have a more rapid effect. The higher fatty acids, such as stearic acid, present no problem.

ZYTEL® resists many inorganic reagents. Unlike most metals, it is not affected by electrolytic corrosion as found in and around salt water and in many industrial atmospheres. ZYTEL® resists even high concentrations of alkalies and is used in alkaline batteries. Some salts – either through acid reaction or by a specific solvent effect – will attack ZYTEL®.

Table 5.10-B Permeation rates of various gases and liquids from film made from ZYTEL® 42

Liquid	Units	RH %	Temperature °C	Permeation factor
Water vapour transmission	$g \cdot mm / m^2 \cdot d$	50	23	0,39
		100	32	7,9
Oxygene	$cm^3 \cdot mm / m^2 \cdot d \cdot N \cdot mm^{-2}$	50	23	7–15,6
Carbon dioxyne	$cm^3 \cdot mm / m^2 \cdot d \cdot N \cdot mm^{-2}$	50	23	35,0
Nitrogen	$cm^3 \cdot mm / m^2 \cdot d \cdot N \cdot mm^{-2}$	50	23	2,7
Helium	$cm^3 \cdot mm / m^2 \cdot d \cdot N \cdot mm^{-2}$	50	23	584
Motor oil	$g \cdot mm / m^2 \cdot d$	50	23	0,006
Petrol	$g \cdot mm / m^2 \cdot d$	50	23	0,04

Table 5.11 Air conditioning refrigerant permeation loss

	Loss*		
Material	CFC-12	HCF-134a	DuPont ternary blend**
Nitrile rubber	0,662	0,560	0,938
6/66 nylon copolymer	0,067	0,077	0,178
ZYTEL® FN 726	0,012	0,015	0,086

* Lb/ft × yr at 93°C for a 5/8" ID × 12" × 1 mm thick hose with refrigerant at saturated vapour pressure.
** HCFC-22 / HCFC-124 / HFC-152a.

Such salts as calcium thiocyanate, calcium bromide, calcium chloride, potassium thiocyanate and zinc chloride are known to have solvent action – particularly in high (50–80%) concentrations and at elevated temperatures.

Factors important to service life of a nylon in a chemical environment

The designer must define the specific conditions of the chemical environment before he can determine whether the probability for a successful application is good. Some of these conditions are:

- *Temperature.* Depending on the specific reagent, service life can be significantly reduced by an increase in temperature. Acids and oxidizing agents are particularly harmful to nylons at higher temperatures. It is difficult to generalize on the quantitative aspects of increased temperatures although a 15°C rise in temperature will frequently reduce service life by 25–50%.
- *Chemical concentration.* Chemical concentration has a bearing on service life of nylons. This is true for acids and will depend greatly upon the pH. The effect of concentration will vary from one material to another and generalizations are impossible to make.
- *Time.* This is important in defining the suitability of an application in a particular reagent. Does the application involve 60 days of intermittent exposure or two years of continuous exposure?
- *Part surface to weight ratio.* Here the ratio of surface area to weight is important. The greater this ratio, the more rapid the attack.
- *Stress level.* Although nylons are very resistant to attack from a wide variety of chemical agents, a few inorganic salts can cause severe breakdown of nylons under stress. Zinc chloride, for example, is especially harmful to 66 nylons such as ZYTEL® 101, but has a lesser effect on 612 nylons such as ZYTEL® 151. End-use tests should always be employed to determine the suitability of a nylon for a particular application.

Effect of specific types of chemicals

- *Solvent and reagents.* The data presented in Table 5.12 covers the effect of specific solvents and reagents on ZYTEL® nylon resins. ZYTEL® is resistant to a wide variety of chemical compounds and although some materials such as water, alcohols and partially chlorinated hydrocarbons are absorbed in limited quantities, physical properties are generally not impaired. Some plasticizing action often accompanies the absorption of solvents and the dimensions normally increase slightly. In Table 5.12, changes in weight and dimensions after exposure are expressed as a percentage of the initial weight and length measurements.
- *Automotive oils, greases, lubricants, hydraulic and transmission fluids ordinarily used at high temperature.* Tests have been run on a variety of brake fluids, chassis lubricants, power steering fluids and motor oils. These materials are complex formulations consisting of a hydrocarbon-oil base or other compound plus chemical additives such as antioxidants, thermal stabilizers, detergents, viscosity extenders or other agents. ZYTEL® nylons have generally good resistance to these proprietary automotive and aircraft materials and are widely used in unter-the-hood applications. At temperatures in excess of 65°C, however, certain specific lubricant additives may effect performance.

  Test data on the behaviour of ZYTEL® exposed to these automotive fluids at elevated temperatures is essential to the success of the intended use. This matter is discussed in detail in an SAE paper*.

  Another approach designed to measure the suitability of ZYTEL® in various environments involving exposure to automotive materials is discussed in a second portion of that same paper**. This describes how automotive parts were obtained and evaluated after extended in-use service.
- *Petrols.* ZYTEL® nylons are outstanding in their resistance to conventional automotive fuels. ZYTEL® shows an average weight increase of 0,6% and an average dimensional change of +0,01% after 270 days exposure at 23°C to a variety of petrols representing high and low test material from major suppliers.
- *Acids, bases and oxidizing agents.* ZYTEL® nylons are very resistant to alkalies even at high concentrations up to 40%. They are, however, rapidly attacked by strong mineral acids and / or oxidizing agents especially at high operating temperatures. Use in dilute solutions of acids or oxidizing agents under ambient conditions is often possible, but actual or simulated service tests should be conducted to ascertain the suitability of ZYTEL® for a particular application.
- *Soaps and detergents.* Tests conducted at 80°C shows that ZYTEL® nylons have excellent resistance to standard detergent formations such as ‘‘Tide’’, ‘‘Dreft’’, ‘‘Dash’’, ‘‘Oxydol’’, ‘‘Oakite’’, Calgon and Fels Naphtha soap.

Table of chemical resistance

Information on the resistance of unreinforced ZYTEL® to specific reagents is shown in Table 5.12. Ratings of excellent, satisfactory or unsatisfactory are based upon property retention for test bars exposed to the specified concentrations of the materials for the indicated time periods and temperature. Chemical resistance information in Table 5.12 is based on appearance and on retention of physical properties normally after drying to remove residual moisture and reagents.

Table 5.13 shows absorption data and axial transverse dimension changes for glass reinforced ZYTEL® nylon resin after immersion in chemicals.

The resistance of glass-fibre reinforced ZYTEL® to stress cracking when test bars are exposed to chemicals is illustrated in Table 5.14. None of a spectrum of chemical types caused stress cracking.

* ‘‘The Suitability of 66 Nylon Resins for Moulded Parts Insolving Long-Term Resistance to Heat, Gasoline and Salt’’, Society of Automotive Engineers, Mid-Year Meeting, Detroit, Michigan, May 18–22, 1970, Paper No. 700485.

** ‘‘Evaluating the Effect of Extended Service in Automobiles on Parts Made of 66 Nylon and Acetal Hompolymer’’, Society of Automotive Engineers, Mid-Year Meeting, Detroit, Michigan, May 18–22, 1970, Paper No. 700485.

MINLON® engineering thermoplastics exhibit low absorption of many chemicals as shown in Table 5.15. However, a number of compounds such as glycols, glycerin and polyhydric alcohols are absorbed by MINLON® engineering thermoplastics and have a plasticizing effect similar to that of water.

Certain organic liquids dissolve MINLON®. These include phenols, formic acid, trichloroacetic acid, and some fluoroalcohols.

Table 5.16 indicates the resistance of MINLON® engineering thermoplastics to blends of alcohol and petrol typically in use.

DuPont has also accumulated a large bank of information on chemical resistance of ZYTEL® to materials not shown in Tables 5.12–5.14 and for many conditions not listed. Consult your local DuPont Sales Offices if additional chemical resistance information is needed.

Table 5.12 Chemical resistance of unreinforced ZYTEL® nylon 66 resins

			Exposure conditions				Chemical resistance****			
Chemical	**Concentration, %**	**Type nylon resin****	**°C**	**Time (days)**	**Weight change*****	**% lenght change**	**Excellent (E)**	**Satisfactory (S)**	**Unsatisfactory (NS)**	**Comments on test results**
Acetaldehyde	90		52					×		
Acetic acid	5		23	30	H	+1,4		×		
	5		23	70	H	+1,7			×	
	5	ZYTEL® 158	23	90	M	+0,5		×		
Acetone	100		23	365	L	+0,0	×			
	100		50	365	M	+0,3	×			
	100	ZYTEL® 158	23	90	M	+0,2	×			
Alum. ammonium	10		24						×	
Aluminium salts of mineral acids	10		23					×		
	10		52						×	
Ammonia, liquid	100		–33	7			×			
	100		–33	14			×			
	100		24	200			×			
Ammonium carbonate	10		23					×		
Ammonium chloride	10		52						×	
Ammonium hydro¥ide	10		23	365	H	+1,7	×			
	10		70	365	H	+1,3			×	
n-Amyl acetate	100	ZYTEL® 151	98	45					×	
Antimony trichloride	10		24						×	
AROCLOR 1242	100		23	30	L		×			
Barium chloride	10		24						×	
Barium sulfate	10		24				×			
Barium sulfide	10		24					×		
Benzene	100		23				×			
	100	ZYTEL® 151	23	90			×			
Benzoic acid	10		24						×	
Boric acid	7		35	316					×	
Bromine	100		24						×	
Bromine water	25		23	30	H	+1,6	×			
Buffer solution pH 7	100		70	90	H	+1,5		×		
	100		70	365	H	+1,4			×	
	100		70	365	H	+1,3	×			
Buffer solution ph 10	100		70	90	H	+1,6		×		
	100		70	365	H	+1,5			×	
n-Butanol	100	ZYTEL® 151	50	45			×			
	100	ZYTEL® 158	23	90	M	+0,3		×		
Butyric acid	10		24						×	
Calcium chloride	5		60						×	Stress cracks at high temperature
Calcium hypochlorite	Satur.		35	77					×	
Calcium thiocyanate	50								×	Swells nylon
Carbon tetrachloride	100		50	365	L	+0,1	×			
	100	ZYTEL® 158	23	365	L	0,0	×			
Carbonic acid	10		24				×			
Cetane	100		23	365	H	+1,7	×			

Table 5.12 Chemical resistance of unreinforced ZYTEL® nylon 66 resins (continued)

Chemical	Concentration, %	Type nylon resin**	Exposure conditions °C	Exposure conditions Times (days)	Weight change***	% lenght	Chemical resistance**** Excellent (E)	Chemical resistance**** Satisfactory (S)	Chemical resistance**** Unsatisfactory (NS)	Comments on test results
Chlorine water	Dilute		23					×		
	conc.		23						×	
Chloroacetic acid	10		24						×	
Chloroform	100		23	56	H	+0,3	×			
	100	ZYTEL® 158	23	90	VH	+4,1		×		
Chlorosulfonic acid	10		24						×	
Chlorox	100		23	10			×			
Chromic acid	10		24						×	
Citric acid	10		35	77				×		
Copper chloride	10		24						×	
Copper sulfide	10		24						×	
m-Cresol	100	Any	24						×	Solvent for nylon
Diethylene glycol	90		24				×			
Ethanol	95		23	365	H	+2,4	×			
	95		50	365	H	+2,8	×			
	95	ZYTEL® 158	23	90	VH	+3,2	×			
Ethyl acetate	95		50	365	L	0,0	×			
Ethylene dibromide	100	ZYTEL® 151	50	45				×		
Ethylene dichloride	100		66	7	M	+0,3	×			
Ethylene glycol	100		23	56	M	0,0	×			
Formalin	38		23	14			×			
Formic acid	90		23						×	Solvent for many nylons including type 66
Glycolic acid	70			200					×	Stress cracking agent
Hexafluoroisopropanol	100		23						×	Solvent ZYTEL® 101
Hydrochloric acid	2,5		23	10			×			
	5		77	5					×	
	10		25	60					×	
Hydrogen peroxide	5		43	30					×	
Hydrogen sulfide (aq.)	Conc.		23						×	
HYLENE T	100		23	10			×			
Lactic acid	10		35	316			×			
Lanolin suspension	10		35	77			×			
Linseed oil (raw)	100	ZYTEL® 105	82	30			×			
Methanol	100		23	56	VH	+4,1	×			
Methyl chloroform	100		72	4			×			
Methyl isobutyl ketone	100	ZYTEL® 151	23	14			×			
Methylene chloride	100		23	28	VH	+4,1		×		
Naphtha (VMP)	100	ZYTEL® 151	98	45			×			
Nitric acid	10		23	60					×	
Nitromethane	100		23	30			×			
2-Nitropropane	100		72	30			×			
NUJOL	100		70	365	L		×			
Perchloric acid	10		24						×	
Phenol	90		23						×	Solvent for nylon
Phosphoric acid	5	ZYTEL® 151	98						×	
Potassium biearbonate	60		23				×			
Potassium carbonate	20	ZYTEL® 151	98	45			×			
Potassium chloride	90		23				×			
Potassium hydroxide	30		98	8				×		
Potassium permanganate	5		23	10					×	
Potassium thiocyanate	Conc.								×	Solvent for nylon
Sodium acetate	60		38				×			
Sodium bicarbonate	50		24				×			

Table 5.12 Chemical resistance of unreinforced ZYTEL® nylon 66 resins (continued)

			Exposure Conditions				Chemical resistance****			
Chemical	**Concentration, %**	**Type nylon resin****	**°C**	**Time (days)**	**Weight change*****	**% lenght change**	**Excellent (E)**	**Satisfactory (S)**	**Unsatisfactory (NS)**	**Comments on test results**
Sodium carbonate	2		35	77			×			
Sodium chloride	10		23	365	H	+1,0	×			
Sodium hydroxide	10		70	30	H	+1,2	×			
	10		70	365					×	
Sodium hypochlorite	5		23	10				×		
Sodium nitrate	5		24	10			×			
Sodium sulphate	90		24				×			
Sodium sulphide	90		24				×			
Stannic chloride	10		24						×	
Stannic sulfate	10		24						×	
Sulfur dioxide gas			38	100					×	Limited service satisfactory
Sulphuric acid	30		23	30					×	
Sulphurous acid	10		23						×	
2,2,3,3 Tetrafluoropropane	100								×	Solvent for nylon
Toluene	100		50	365	L	0,0	×			
Tricresyl phosphate	100		66	7	L	+0,2	×			
Xylene	100						×			
ZEREX antifreeze	40		104	92				×		Small cracks develop

* DuPont registered trademark for fluorocarbons.
** ZYTEL® 101 unless otherwise specified.
*** Low = <1 %, moderate = 1–4 %, high = 4–9 %, very high = >9 %.
**** Based on physical property measurements.

Table 5.13 ZYTEL® 70G30HSL NC010 – Effect of chemical immersion on glass reinforced ZYTEL® nylon resin

		% change from the dry condition after 1500 h immersion at 23°C		
			Dimension	
Chemical	**Concentration**	**Weight**	**Axial**	**Transverse**
Acetone	100%	+0,7	+0,1	+0,1
Ammonium Acetate	3M	+4,4	+0,2	+1,4
Ammonium Hydroxide	5M	+4,9	+0,3	+1,3
Benzene	100%	+1,0	+0,1	+0,2
Buffer Solution	pH7	+5,2	+0,3	+1,9
Butyraldehyde	100%	+2,2	+0,2	+0,3
Cyclohexane	100%	+0,8	+0,3	0
Ethyl Acetate	100%	+2,3	+0,4	0
Heptane	100%	+0,7	0	0
Lubricating Oil	100%	+0,5	+0,2	0
Methanol	100%	+6,8	+0,5	+3,0
Methyl Chloride	100%	+3,7	+0,4	+0,6
Petrol	100%	+0,8	+0,4	+0,6
Phenol	saturated acqueous solution		sample underwent serious attack	
Potassium Chloride	2M	+4,5	+0,1	+0,6
Pyridine	100%	+1,1	+0,1	+0,2
Sodium Hydroxide	5M	+4,7	+0,4	+1,5
Sulfuric Acid	concentrated		sample underwent serious attack	

Note: 1. Measurements made on the length and width of a 127 × 12,7 × 3,2 mm bar. The axial measurement given represents change in length. The transverse measurement given represents change in width.
2. Thickness changes were generally greater than those observed for width.
3. No measurement of physical properties has been made on immersed bars. Prototype testing is suggested.

Table 5.14 Stress-crack resistance of glass reinforced ZYTEL® nylon resins

Material: ZYTEL® 70G30HSL, Specimen 127 × 12,7 × 3,2 mm bar
Exposure stress 93 MPa. Exposure time 5 minutes. Exposure temperature 23°C

No stress cracking observed with 100% concentration of:

Acetone	Cyclohexane	Hexane	Methylene Chloride
Benzene	Ethyl Acetate	Lubricating Oil	Petrol
Butyraldehyde	Ethylene Glycol	Methanol	Pyridine

Table 5.15 Resistance of MINLON® to chemical

Composition: MINLON® 10B140		
Chemical	**Weight gain, %**	**Change in length, %**
Acétate d'éthyle	0,2	0,0
Acetone	0,2	0,0
Ammonium hydroxide (10% by wt.)	1,5	0,2
Automatic Transmission Fluid	0,1	0,0
Brake Fluid	0,0	0,0
Ethanol	0,4	0,0
Ethyl acetate	0,2	0,0
Ethylene Glycol (50/50 solution)	0,1	0,1
Petrol – Unleaded	0,3	0,0
Motor Oil 10W40	0,1	0,0
Methanol	2,3	0,2
Sodium chloride aq. (10% by wt.)	1,4	0,1
Toluene	0,1	0,0

Note: Above data based on 21days immersion at 23°C.

Table 5.16 Resistance of MINLON® to alcohol mixtures

Mixture	MINLON®	Length change, %
15% methanol	11C140	0,9
85% unleaded petrol	10B140	0,3
15% ethanol	11C140	0,03
85% unleaded petrol	10B140	0,03

Bacteria and fungi: Soil and underground conditions

ZYTEL® nylons have been found remarkably resistant to attack from bacteria, fungi and termites both in laboratory-type controlled tests and in burial tests.

Test specimens of ZYTEL® 42 were buried at Landenberg, Pennsylvania for 3 ½ years in termite-infested soil. Examination after burial showed no attack by termites nor any apparent deterioration from fungi, insects or other biological agencies. It was concluded that ZYTEL® was neither attractive to termites nor readily utilized by fungi. Control specimens of pine wood showed heavy infestation with termites.

ZYTEL® (ZYTEL® 101 NC010) has been tested microbiologically for its ability to support Salmonella typhosa growth, (food poisoning). The test proved that test samples would not support the growth of this bacteria. Moulded specimens of ZYTEL® 101 and 103HSL were tested for resistance to fungi representatives of the following groups: (1) chaetomium globosum, (2) rhizopus nigricans, (3) aspergilis flavus, (4) penicillium luteum, and (5) momononiells echinata.

The bars exposed for 28 days to active environments, with respect to fungi showed no visual evidence of attack after cleaning and no loss in physical properties. Also, no changes occurred in molecular weight.

Irradiation

Among plastic materials, ZYTEL® 101 is intermediate in its resistance to the heterogeneous radiation flux of an atomic pile*. Thus, ZYTEL® 101 is more resistant than such materials as cellulose acetate and methyl methacrylate polymer, but less resistant that polyvinyl chloride/acetate. During radiation, test bars of ZYTEL® 101 initially show increased tensile strength with some loss in toughness. With progressive radiation, brittleness develops.

Furthermore, ZYTEL® 101 is relatively resistant to the effects of gamma radiation**. Tests on nylon film (66 nylon) made after exposure to 6 megarads of gamma radiation indicate essentially no harm to the material. On the basis of the study, it was concluded that 66 nylon could be considered as packaging for food subject to preservation by high energy radiation.

* The United States Atomic Energy Commission ORNL-928, Sisman, O. and Bopp, C.D., June 29, 1951.

** Krasnansky, V.J., Ashhammer, B.G., and Parker, M.S., SPE Transactions, July 1961 – Effect of Gamma Radiation on Chemical Structure of Plastics.

Table 5.17 Chemical resistance of ZYTEL® FN flexible nylon alloys (measured on 3,2 mm thick plaques)

Fluid	Per cent swell FN 714	FN 716	FN 718	FN 726
ASTM #1 (3 days/100°C)	5	3	0	1
ASTM #3 (3 days/100°C)	23	15	4	18
Brake fluid (3 days/100°C)	8	7	4	8
DEXRON ATF (3 days/100°C)	15	10	1	6
Mineral oil (3 days/100°C)	8	6	1	3
10W-30 oil (7 days/100°C)	19	14	2	7
Fuel C (7 days/100°C)	–	12	2	–
50% ethylene glycol / 50% water (7 days/100°C)	3	4	5	5
10% ivory soap in water (3 days/70°C)	2	2	3	3
PRESTONE antifreeze (7 days/121°C)	8	10	12	12
Acetone (7 days/23°C)	2	2	1	1
Benzene (7 days/23°C)	37	13	4	–
Butanol (7 days/23°C)	–7	–8	–9	–3
Ethanol (7 days/23°C)	5	3	3	–
Ethyl acetate (7 days/23°C)	5	1	1	–
Deionized water (7 days/23°C)	1	1	2	–
85% fuel C / 15% methanol (7 days/23°C)	58	49	27	58
Hexane (7 days/23°C)	7	2	1	–
Methylene chloride (7 days/23°C)	53	43	34	–
50% methanol / 50% water (7 days/23°C)	2	2	3	3
Methyl ethyl ketone (7 days/23°C)	5	1	1	–
SKYDROL hydraulic oil (7 days/23°C)	1	1	1	0
20% sulfuric acid / 80% water (7 days/23°C)	21	18	6	Fail
Toluene (7 days/23°C)	33	12	4	–
Xylene (7 days/23°C)	29	20	4	15

6 – Dimensional stability

Introduction

ZYTEL® nylon resins find extensive use in industry for the fabrication of precision gears, bearings, housings and other mechanical devices where dimensional stability is critical. ZYTEL® retains its shape at high temperatures, has excellent fatigue resistance and is highly resistant to the effects of most chemicals. Although newly moulded parts of ZYTEL® pick up moisture from the moment they are removed from the mould, dimensional changes due to moisture absorption are generally quite small under service conditions.

Absorption of moisture

Freshly moulded objects normally contain less than 0,3% of water, since only dry moulding powder can be successfully moulded. Mouldings will then absorb moisture until an equilibrium condition based on relative humidity (RH) is reached and will vary according to the particular resin involved. Equilibrium moisture content as a function of RH for several ZYTEL® nylons in Figure 6.01. The lower moisture absorption of ZYTEL® 151 is a factor in its selection for use in humid environments.

The time required to reach equilibrium is dependent on the temperature, the thickness of the specimen, and the amount of moisture present in the surroundings. ZYTEL® 101F and other 66 nylons exposed in boiling water will reach the equilibrium level, 8,5%, much sooner than ZYTEL® in cold water. The relationship between water absorption and time in various environments for ZYTEL® 101 and 151 is given in Figures 6.02–6.05.

These figures also show the effect of thickness on rate. The equilibrium moisture contents are not affected significantly by temperature. Thus, final water content at equilibrium will be almost the same whether objects of ZYTEL® are exposed to water at room temperature or boiling temperature.

Desorption of water from ZYTEL® 101 and other 66 nylons is slower than absorption. As shown in Figure 6.04, approximately 50 days are required for 1,5 mm thick samples immersed in water to reach the 8,5% moisture level. Upon exposing these saturated samples to a dry atmosphere, more than double this amount of time is required to reach a dry-as-moulded condition (see Figure 6.06).

In an environment of constantly varying humidity, the most common exposure, no true equilibrium moisture content can be established. However, mouldings of ZYTEL® will gradually gain in moisture content until a balance is obtained with the mid-range humidities. A slow cycling of moisture content near this value will then occur.

In all but very thin moulding (1mm or less), the day-to-day or week-to-week variations in relative humidity will have little effect on total moisture content. The longer seasonal changes, such as between summer and winter, will have some effect depending on thickness and the relative humidity range. The highest average humidity for a month generally will not exceed 70%. In cold weather, heated air may average as low as 20% RH. Even at these extremes, the change in moisture content of ZYTEL® is small in most cases, because ZYTEL® has a very low rate of both absorption and desorption. Figure 6.07 shows the dimensional changes which can be expected due to cyclic variations in environmental humidity.

In contrast to most other polymer systems, ZYTEL® nylons undergo spontaneous relief of moulded-in stresses as the parts become equilibrated to ‘‘normal’’ atmospheric moisture conditions 23°C, 50% RH). During stress-relief, parts tend to shrink in the flow direction by an amount which is proportional to the stress level in the original moulding. Although it will vary depending on moulding conditions and part geometry, stress-relief shrinkage will often be about 0,5%.

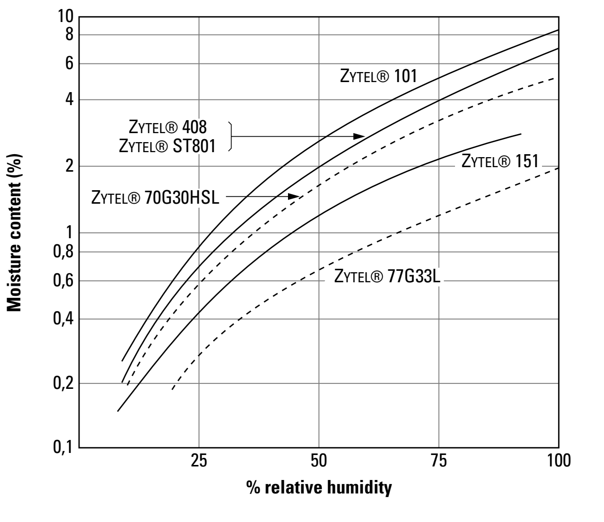


Figure 6.01 **Moisture content as a function of relative humidity**

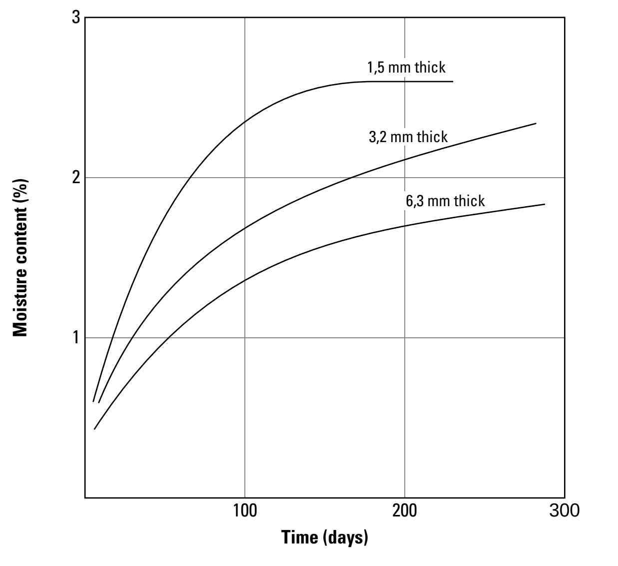


Figure 6.02 **Moisture content vs. time for ZYTEL® 101F exposed to 50% RH air at 23°C**

While shrinkage due to stress-relief is occurring, the polymer will increase slightly in size due to moisture absorption from the atmosphere or surroundings. In many cases, these two effects oppose one another resulting in a part whose dimensions are only slightly different from those in the dry-as-moulded condition. Figure 6.08 shows dimensional changes which can often be expected for unannealed samples after they have undergone stress-relief shrinkage and moisture absorption.

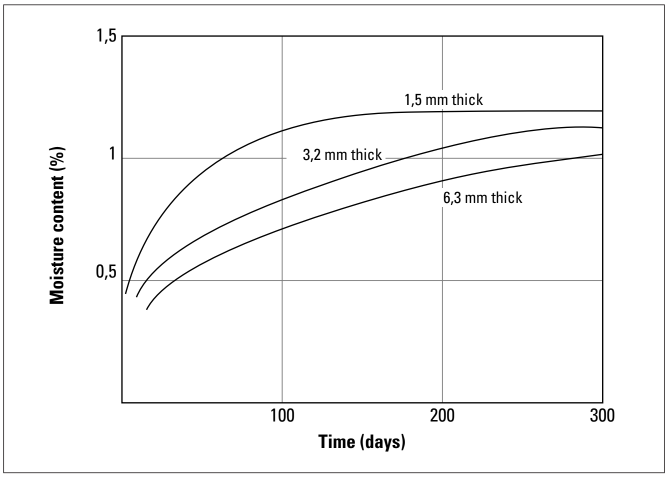


Figure 6.03 **Moisture content vs. time for ZYTEL® 151 exposed to 50% RH air at 23°C**

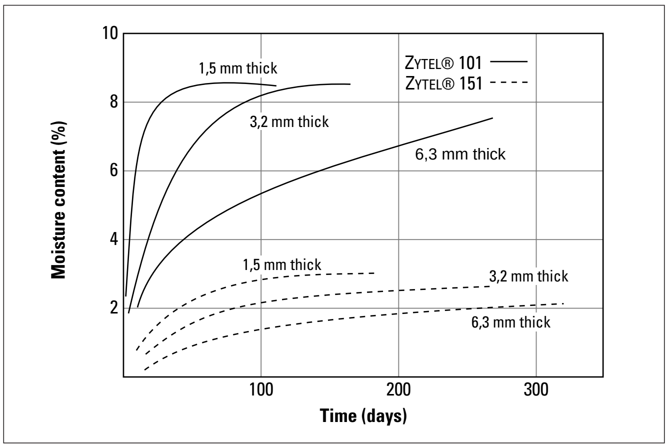


Figure 6.04 **Moisture content vs. time for ZYTEL® 101 and ZYTEL® 151 immersed in water at 23°C**

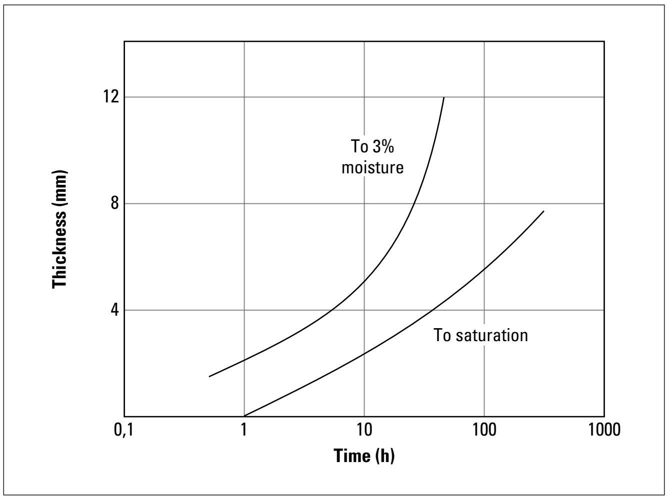


Figure 6.05 **Boiling times to condition ZYTEL® 101**

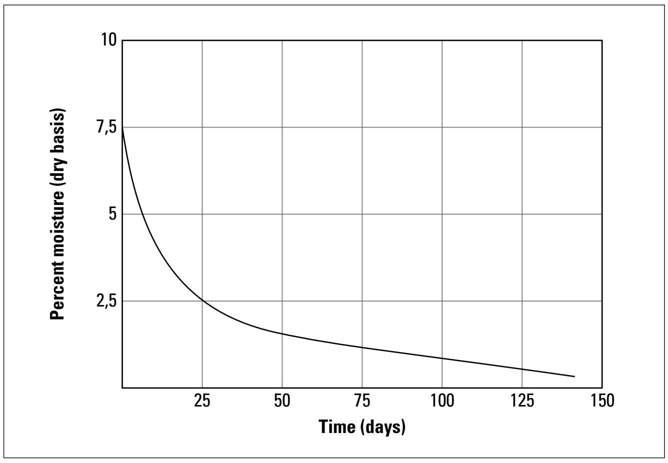


Figure 6.06 **Rate of moisture loss, ZYTEL® 101, 23°C, over "Drierite", 1,5 mm thick sample**

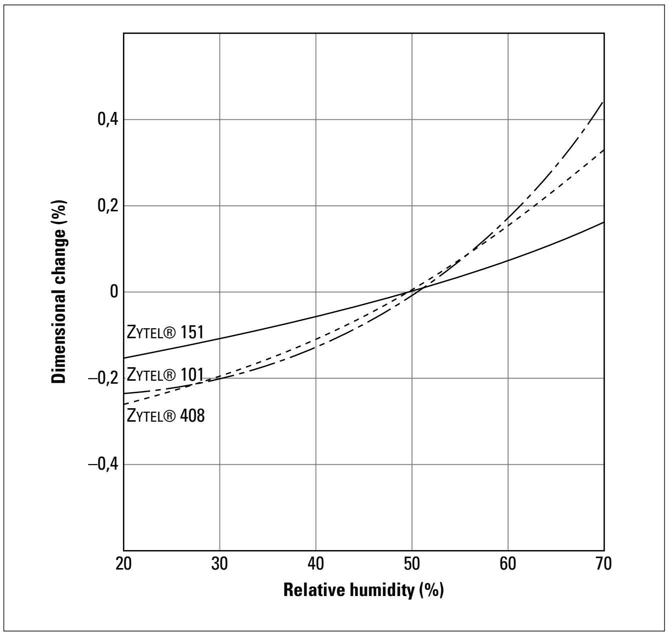


Figure 6.07 **Dimensional change as a function on cyclic variations in environmental relative humidity**

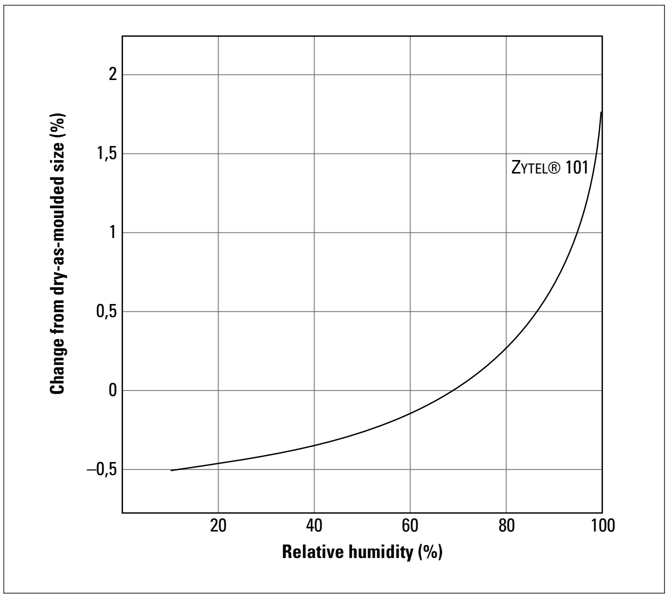


Figure 6.08 **Typical post-moulding changes due to stress-relief/moisture absorption, unannealed samples**

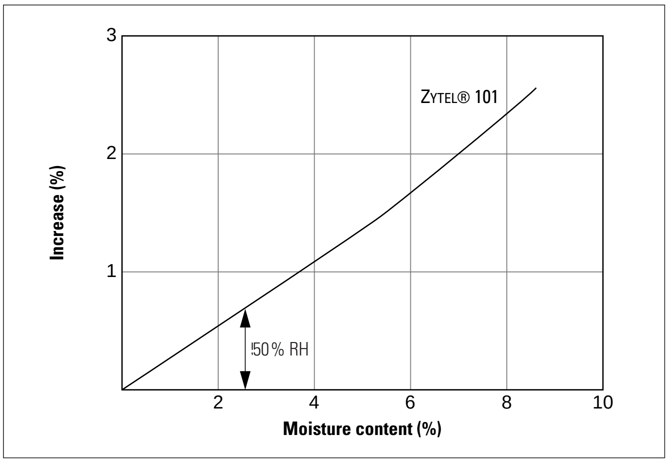


Figure 6.09 **Change in dimensions with moisture content for ZYTEL® 101 in the stress-free (annealed) condition**

Procedures for annealing ZYTEL® are discussed later in this Section. A hot water treatment (also described later) not only adds moisture but also is an effective annealing procedure. Unlike water conditioning, relief of moulded-in stresses is an irreversible change. Once stresses are relieved by annealing, there will be no further dimensional changes from this cause below the annealing temperature.

The above discussion explains the small dimensional change of some mouldings that stress-relieve themselves over a period of time while moisture is being absorbed.

If this part is exposed to higher temperatures before the gradual change is complete, stress-relief will occur more rapidly, resulting in some shrinkage of the long dimensions. This a time-temperature phenomenon. A few minutes at 150°C or several days at 70°C may produce the same effect. When stress-relief will occur in use and when dimensional change will affect the performance, parts should be designed to the correct size in the stress-free condition and annealed initially. If exposed to a normal air environment after annealing, the moulding will absorb moisture and behave as shown in Figure 6.09.

Note that the compensating effect on dimensional change discussed above will not always be the case, and that it will not prevent subsequent cycling of dimensions from variations in relative humidity. The dimensional increase due to moisture absorption is predictable, but a dimensional decrease due to stress-relief is heavily dependent on object shape and moulding conditions. Stress-relief may cause almost no dimensional change in some cases so that the effect of water absorption will predominate. In other cases, stress-relief may cause a shrinkage significantly greater than the increase due to moisture. This can only be established with certainty by trial.

Shrinkage and dimensional stability of unreinforced ZYTEL® resins

ZYTEL® nylons are crystalline plastics and generally shrink more from the molten to solid state than do amorphous plastics (e.g., acrylics, polystyrenes, etc.). This is a result of slight changes which occur in the structure as the polymer molecules orient themselves to achieve the most stable solid state configuration.

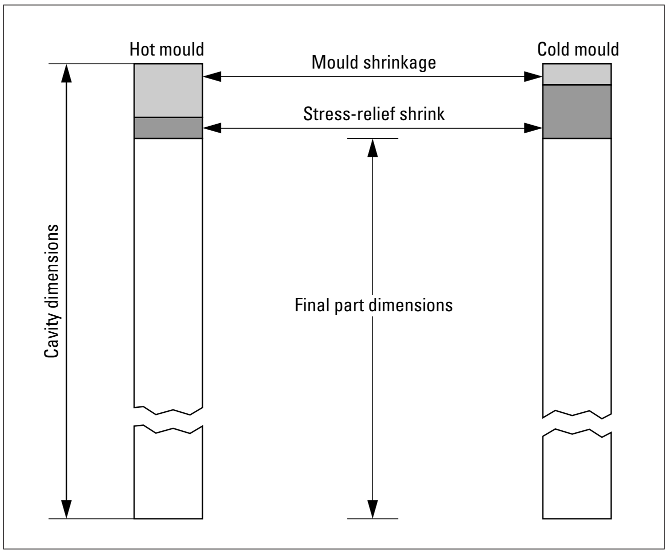


Figure 6.10 **Effect of mould temperature on shrinkage dimensions**

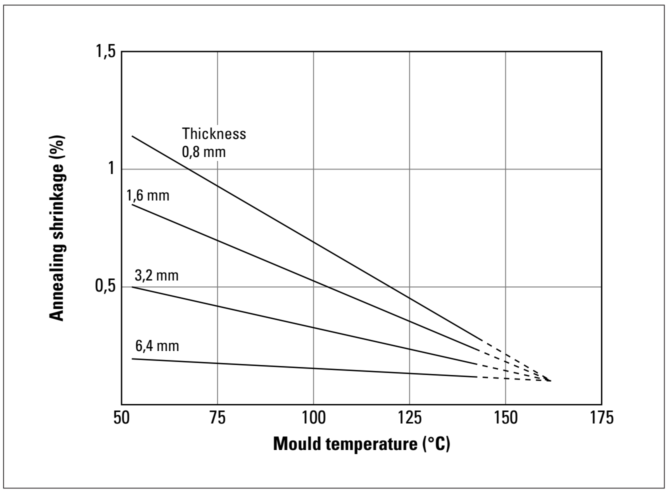


Figure 6.11 **Shrinkage during annealing vs. mould temperature for ZYTEL® 101 NC010**

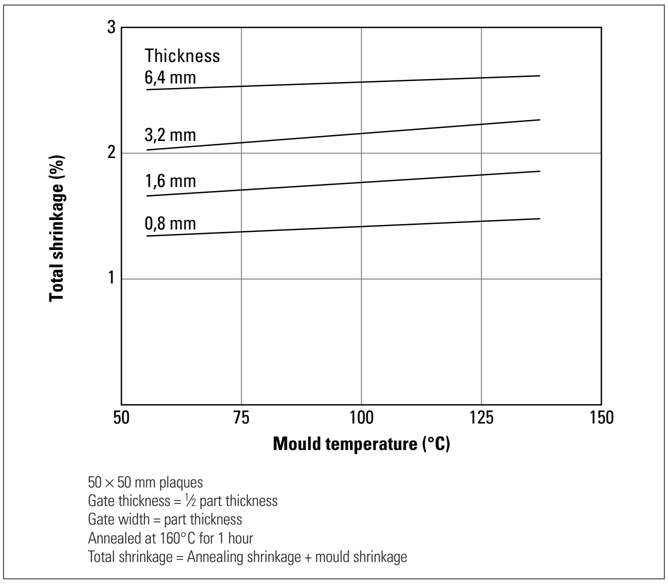


Figure 6.12 **Total shrinkage after annealing vs. mould temperature for ZYTEL® 101 NC010**

Owing to the rapid cooling of the polymer melt as it enters the mould cavity, this molecular reorientation is often arrested before complete stability can be achieved. As a result, small post-moulding changes often occur as these areas of moulded-in stress gradually become stabilized. The total dimensional change due to shrinkage is best expressed as the sum of mould shrinkage and stress-relief or annealing shrinkage. Each of these parameters is affected by mould temperature, but in opposite ways. High cavity temperatures tend to maximize mould shrinkage and minimize post moulding shrinkage.

Low mould temperatures have just the opposite effect as shown in Figure 6.10.

Data summarizing the effect of mould temperature and part thickness on shrinkage is illustrated in Figures 6.11 and 6.12 and shows that:

- As part thickness decreases at constant mould temperature, the annealing shrinkage increases.
- For any part thickness, the annealing shrinkage decreases with increasing mould temperature; e.g., the total dimensional change of the part is less.
- The combined effect of mould shrinkage and annealing shrinkage for any given part thickness is, for all practical purposes, independent of mould temperature.

Hence, it is easier to predict total shrinkage from initial mould cavity dimensions than it is to predict either mould shrinkage or annealing shrinkage alone. Each of these factors will vary depending on moulding conditions and part geometry. Total shrinkage, however, for any given part thickness is nearly constant.

Shrinkage and dimensional stability of reinforced ZYTEL® and MINLON® resins

The most common reinforcement of nylons are glass fibres. Glass has a lower coefficient of thermal expansion than nylon, so that fibre reinforced parts shrink less than unreinforced parts. However, due to the shear forces acting in the part during injection moulding, the fibres in the part will be oriented, causing different thermal expansions in flow direction and perpendicular.

The amount of fibres, which are oriented further depends on local thickness, location in the part with reference to the gate position and several process parameters. In moulded, fibre reinforced parts shrinkages have been measured between 0,2 – 0,4% in flow direction and 0,8 –1,2% in transverse direction. It is very difficult to give a global rule to calculate shrinkage for a given part. Experience with similar parts is the best reference so far, though computer analysis more and more can help in understanding the shrinkage and warpage behaviour of reinforced parts. To reduce warpage of reinforced plastic parts, (a part of) the fibres can be replaced by mineral fillers (MINLON® grades). These grades normally have a slightly higher shrinkage in flow direction and a somewhat lower shrinkage transverse. Due to the reduced differential shrinkages (anisotropy), warpage of these grades can be limited. Also here, experience with existing mouldings helps in getting the best results for new parts.

Combined dimensional effect of mould shrinkage, stress-relief and moisture absorption

As discussed above, it is easy to predict dimensional changes for ZYTEL® nylons if parts are subjected to separate annealing and moisture treatments. In practice, however, most parts are not annealed prior to use and, therefore, gradually undergo stress-relief over a period of time as moisture is absorbed from the environment. Since two changes are occurring simultaneously (shrinkage from stress-relief and increase due to moisture absorption), it is difficult to predict the exact size at any time prior to that when the part has achieved

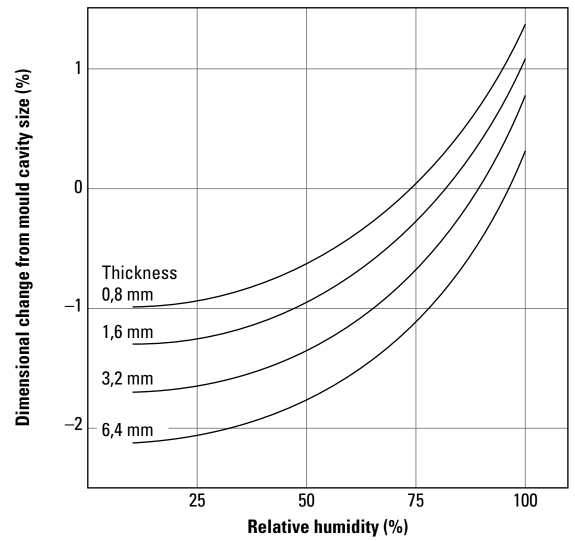


Figure 6.13 **Dimensional changes in parts of ZYTEL® 101**

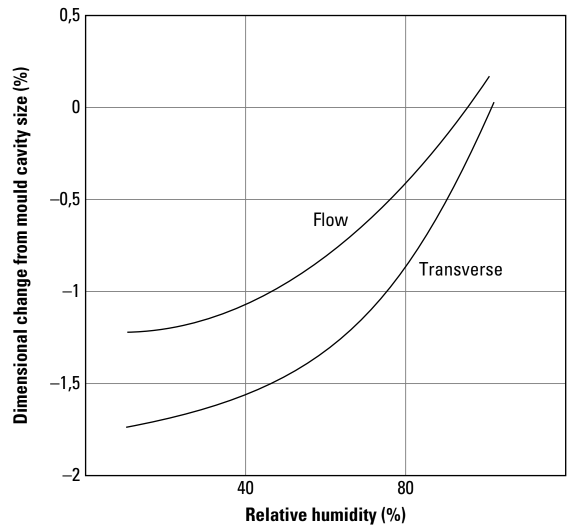
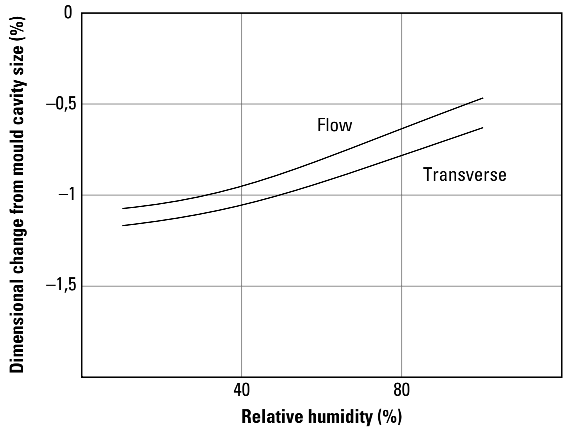


Figure 6.14 **Dimensional changes in parts of ZYTEL® 408**



76 × 127 × 1,6 mm plaques.
Mould temperature 66°C.
Injection pression 76 MPa.
Gate = ½ part thickness.
½ part width.

Figure 6.15 **Dimensional changes in parts of ZYTEL® 151**

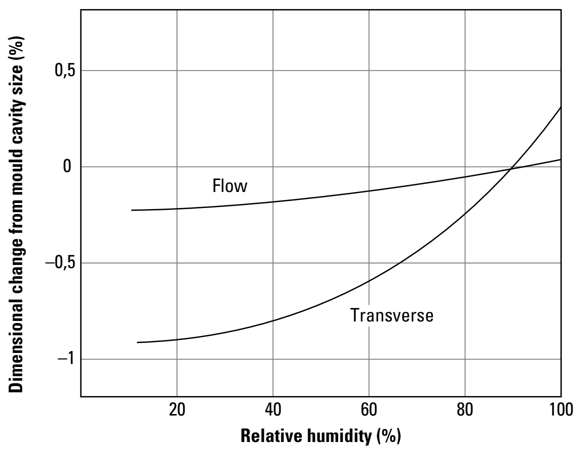


Figure 6.16 **Effect of humidity on dimensions ZYTEL® 70G30HSL (measured on 76 × 127 × 3 mm plaques)**

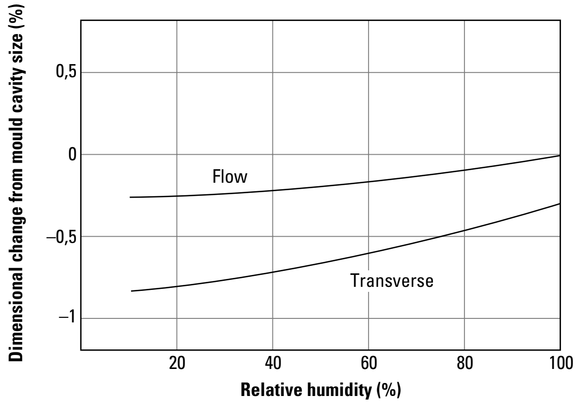


Figure 6.17 **Effect of humidity on dimensions ZYTEL® 77G33L (measured on 76 × 127 × 3 mm plaques)**

equilibrium with its environment. When environmental equilibrium has been achieved, part size can be accurately determined if it is expressed as a function of mould cavity size.

Figures 6.13, 6.14 and 6.15 show the part dimensions expressed as a function of mould cavity size which can be expected in use for three compositions, ZYTEL® 101, 408 and 151. For ZYTEL® 70G30HSL and ZYTEL® 77G33L this is illustrated in Figures 6.16 and 6.17.

ZYTEL® 73G30HSL BK behaves very similar to ZYTEL® 70G30HSL, as measured on 2 mm thick testplates, 64 days conditioned (50% RH and in water), according ISO 1110. The same test carried out on some other DuPont materials resulted in:

Material		Dimensional increase (%) Flow	Transverse
ZYTEL® 7300 NC	50% RH	0,22	0,40
	100% RH	1,20	2,00
MINLON® 11C140 NC	50% RH	0,45	0,35
	100% RH	1,85	1,30
MINLON® 73M40HSL	50% RH	0,55	0,35
	100% RH	2,00	1,30

Annealing the plates of the above test for 2 h at 120°C hardly changed the measured values.

These figures express the combined dimensional changes due to mould shrinkage, stress-relief or annealing shrinkage and moisture growth for a particular part thickness. Considering the mould cavity dimensions as a baseline, one can determine end-use dimensions of parts of ZYTEL® to a high degree of accuracy. It must be remembered that these values are accurate only for the specific conditions of mould temperature, melt temperature, injection pressure and environmental temperature outlined in the figures. Changes in any of these parameters can easily be compensated for, however, by using appropriate correction factors.

Moisture conditioning

Moisture conditioning is used occasionally to reduce the dimensional variations of ZYTEL® due to changes in moisture content. This is more common for mouldings to be used in water, where the original dimensional change is great, rather than in air. More frequently, moisture conditioning is used for two other purposes:

1. to produce parts for test to determine if the expected changes will have any effect on the performance of the part and;
2. to increase the impact resistance of newly moulded objects.

Two methods of moisture conditioning ZYTEL® are described below. In the first method, boiling in water, the amount of water absorbed is controlled by time and part thickness. Except at the completely saturated level, this method does not give a uniform distribution of water in the part as does exposure to a constant relative humidity for a long time. It simply begins the process of distributing water throughout the object and hastens the time of completion. Much of the increase in impact strength and dimensions will occur in this

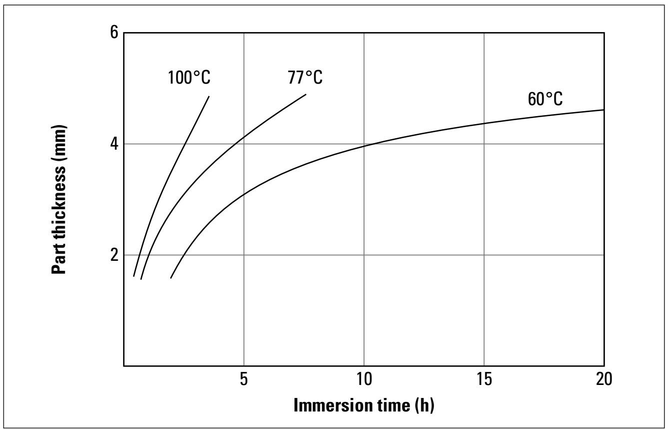


Figure 6.18 **Time to condition ZYTEL® 101 to 2,8% moisture**

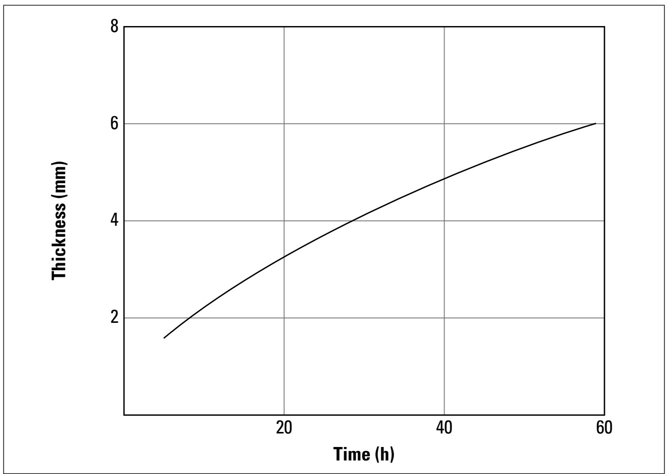


Figure 6.19 **Time to absorb 2,8% moisture for ZYTEL® 101 at 120°C in potassium acetate solution (125 g/100 ml water)**

procedure. Boiling in water is probably the only practical conditioning method for most of the applications that require conditioning. Parts can also be conditioned at temperatures less than boiling. See Figure 6.18 for conditioning time.

The second method, which calls for use of a potassium acetate solution, permits uniform distribution (equivalent to equilibrium with 50% RH) of water at less than the saturation level. This procedure is more complex, but it is useful for preparing test samples.

Both methods have a common disadvantage in that a long time is required to condition thick sections, even under the accelerated conditions. Thicknesses of 3,2 and 6,4 mm require about 3 and 18 hours respectively in boiling water or 20 and 65 hours in potassium acetate solution for conditioning. In greater thicknesses, incomplete conditioning may be adequate because of the extremely slow rate of further absorption in use conditions.

Moisture conditioning methods available for incorporating 2,8% of water in ZYTEL® 101 nylon and similar compositions include:

- *Boiling in water.* This method is the easiest to set up, but it cannot give a true equilibrium condition. The moisture is concentrated near the outer surface and can only redistribute itself with time. It is best to put in about 3% of moisture, since a small amount will tend to come back out and evaporate from the surface. The required time to absorb 3% by boiling is given in Figure 6.05. Test parts should always be measured or weighed before and after boiling to be sure the desired dimensional change or water absorption has occurred in the time selected.
- *Treatment with a solution of potassium acetate in water.* This method requires a heated vessel with a cover and a reflux condenser. By using the ratio of 125 parts by weight of potassium acetate to 100 parts by weight of water, a maximum of 2,8% of water (equivalent to 50% RH) is absorbed by ZYTEL® 101. Unlike the previous method, additional time beyond that required will not put in more moisture. Conditioning in potassium acetate solution is carried out at or near the boiling point of this solution 120°C for maximum acceleration of the process. The time required for any thickness may be read from Figure 6.19. The problems with this procedure are the cost of potassium acetata and the need to maintain the solution at the required concentration. This is an excellent method for preparing test samples, since a true equilibrium condition is established. It is not suitable where electrical or burning characteristics are to be studied because of absorption of small amounts of potassium acetate on the surface.

For service in water, moisture conditioning is carried out by the first method above, only the boiling time is lengthened to obtain completely saturated moldings (8% or more of water). The time for this process is also given in Figure 6.05. For sections greater than 6,4 mm (¼ in.), conditioning to saturation takes a very long time and is rarely necessary because of the extremely slow rate of absorption in use.

Annealing

When annealing of ZYTEL® is required, it should be done in the absence of air, preferably by immersion in a suitable liquid. The temperature of the heat-treating liquid should be at least 25°C above the temperature to which the article will be exposed in use – a temperature of 150°C is often used for general annealing. This will ensure against dimensional change caused by uncontrolled stress-relief occurring below this temperature. The annealing time required is normally 5 min. per millimetre thickness. Upon removal from the heat-treating bath, the part should be allowed to cool slowly in the absence of drafts; otherwise, surface stresses may be set up. Placing the heated article in a cardboard container is a simple way of ensuring slow, even cooling.

The choice of liquid to be used as the heat-transfer medium should be based on the following considerations:

- Its heat range and stability should be adequate.
- It should not attack ZYTEL®.
- It should not give off noxious fumes or vapours.
- It should not present a fire hazard.

High-boiling hydrocarbons, such as oils or waxes, may be used as a heat-transfer medium if the deposit left on the surface of the molded item is not objectionable, as in the case of parts which will be lubricated in use. In DuPont Laboratories, Primol 342 and Majoline 238-CRA from Esso as well as Ondina 33 from Shell, have been used for annealing. Experimental work has also shown the suitability of annealing in an oven using a nitrogen atmosphere, although this does require special equipment.

The heat-treating bath should be electrically heated and thermostatically controlled at the desired temperature. For best thermal control, heat should be supplied through the sidewalls as well as through the bottom of the vessel. A large number of small items is best handled by loading them into a wire basket equipped with a lid to prevent the parts from floating, and immersing the basket in the bath for the required period of time.

For applications where the maximum temperature will be 70°C or less, acceptable stress-relief can be obtained by immersion in boiling water. This method also has the advantage that some moisture is absorbed by the ZYTEL®, thus partially conditioning the piece. For stress-relief, 5 min. per mm of cross section is sufficient. Longer times will be required if the piece is to be moisture-conditioned to or near equilibrium.

7 – Quality of fabricated parts – writing of specifications

Introduction

An adequate system of quality control is basic to the successful fabrication or use of nylon parts. This involves, first, a verification of the identity of the nylon used. Then, those tests must be made which are necessary to ensure that the part was properly moulded or extruded from the resin specified.

It is important that the end-user defines the quality he needs. Excessive rejects and returns under warranty can be costly if inadequate standards are set. However, excessively high standards for any required characteristic will also raise costs unnecessarily. Exactly how the balance should be reached has to be worked out for each part.

A specification for moulded parts is frequently written up in three sections with the intention of: identifying the plastic, defining the quality of the plastic material and establishing part quality.

Identification of plastic

Ordinarily, a moulder need not be concerned about the identity of a moulding resin; he simply uses the correct ZYTEL® nylon composition. Of course, identification may be important if he is not careful about the labeling of regrind. The end-user, on the other hand, may quite correctly require verification of the type of nylon used in parts supplied to him.

The need for a way to identify the nylon may be met, in part, with melting point and specific gravity tests.

This particular combination of melting point and specific gravity identifies an unmodified 66 nylon. Some modifications are outside these ranges and, of course, these characteristics say nothing about stabilization, lubrication, etc.

Establishment of part quality

The part itself may be subject to appropriate quality requirements. For convenience, these may be grouped as follows:

- *Dimension and dimensional stability.* Limits on the essential dimensions are normally set for any moulding. In addition, limits may be set after annealing in an inert oil. This assures that moulded-in stresses are kept to a minimum. It may occasionally be necessary to include an annealing step in production to achieve the needed dimensional stability.

- *Part weight.* Monitoring part weight is an easy means of checking on the uniformity of a moulding operation. Variations may indicate changes in part dimensions or properties. Parts from different cavities in multicavity moulds may have slight inherent differences and it is essential that these are not allowed to cloud the quality picture.

- *End-use tests.* Practical tests on moulded or extruded parts are highly recommended. These are usually, but not necessarily, of the impact type. Energy-to-break testing provides a means of measuring the energy required to break a part when it is struck in a carefully defined way – most meaningful if it simulates critical conditions encountered in installation or service. Standard pendulum-type testers with special sample holders designed for the part in question are used. The distribution of energy to break required for a particular application should be at least approximately based on the requirements of the application, and production parts should be tested in accordance with accepted quality control procedures. Toughness at weld lines is often critical.

  Go, or no-go tests using a falling ball or dart are also useful although they are limited in that the energy to break is not itself measured. For example, a specification may require that no more than two specimens out of 25 selected randomly from a given lot shall fail when struck in a defined way.

  Adaptations of ASTM D746, ‘‘Brittleness Temperature of Plastics and Elastomers by Impact’’, have also been used. Where low temperature service is involved, it may be required that a certain percentage of parts must not be broken by a standard blow at some selected temperature.

  All tests of this type, of course, require careful control of moisture content and temperature as well as the more obvious mechanical elements.

  It should also be noted that these comments on end-use testing are intended only to make the reader aware of its possibilities. Details have to be worked out for each case with the help of appropriate texts on testing and quality control.

- *Relative viscosity (ASTM D789).* Relative viscosity, a solution viscosity related to molecular weight, is also a useful measure of the quality of a part. Toughness is a function of molecular weight. A substantial reduction of relative viscosity below that of the ZYTEL® composition used is indicative of poor processing and of reduced toughness. The problem is that of defining an allowable reduction. ZYTEL® 101 NC010 has a relative viscosity of about 50. We would generally hesitate to recommend a level of less than 40 for any part.

  The relative viscosity cannot be used as the sole criterion of toughness or quality because other factors may be the cause of poor toughness. A part with an obvious weld line may be brittle, but have a high viscosity.

- *Appearance.* Some of the factors affecting appearance are also related to toughness and other elements of quality. Ideally, a part should be without splay, burn marks, flash, sinks, voids, contamination, unmelted particles and visible weld lines. Some judgment is obviously required as these characteristics are difficult to express on a quantitative basis. The surface finish can be described and may be included.

  Use of standards with numerical ratings and showing acceptable and non-acceptable parts are useful in obtaining consistent evaluations. For example, mouldings showing the maximum allowable colour or splay may be retained as the basis for acceptance or rejection of production parts.

8 – Regulatory status

Regulatory compliance

For use in many applications, a material has either to be approved or must meet the requirements of various governmental or private agencies. This is mainly to protect the user, the general public or the environment.

Besides meeting such regulations, all products and / or their constituents have to be listed in the different chemical inventories. Specific regulations exist for certain application areas like electrical applications or applications in contact with food.

DuPont makes sure that all materials supplied to its customers in compliance with applicable regulations for the material itself.

As a subscriber to the RESPONSIBLE CARE initiative, DuPont also has accepted to share information and help the product users to handle, process, use, recycle and dispose of its materials safely and in an environmentally sound manner.

For selected specific application areas, DuPont has developed information which will enable the product user to obtain approvals from authorities or to certify compliance with regulations.

These areas are:

Material classifications by Underwriters' Laboratories, Inc.

For most of DuPont nylon resins UL 'yellow cards' are available showing flammability ratings and upper temperature limits for continuous use.

Compliance statements with European and non-European food contact regulations.

Europe:
The EU (European Union) Directive 90/128 and its subsequent amendments plus country specific regulations where applicable.

USA:
FDA 21 CFR 177.1500 (Food and Drug Administration of the United States Department of Health, Education and Welfare).

Canada:
HPB (Health Protection Branch of Health and Welfare).

Other countries:
Compliance statements can be established on request.

Compliance statements with European and non-European drinking water regulations.

Germany:
The KTW (Kunststoff-Trinkwasser-Empfehlungen) recommandation.

The Netherlands:
The KIWA (Keuringsinstituut voor Waterleidingartikelen)

USA:
The NSF (National Sanitary Foundation).

Support information for approval of applications for food processing equipment in the USA
by NSF (National Foundation) or USDA (United States Department of Agriculture).

Support information for approval of application under European and non-European pharmaceutical regulations.

Statements on the content of certain regulated chemicals
as required e.g. by the 'Deutsche Dioxinverbotsverordnung' or the 'Clean Air Act' in the USA.

Regulations are constantly adapted as new information becomes available, new test methods and also issues of concern developing within public opinion.

DuPont will adapt its products to the changing market needs or develop new products to satisfy new requirements. The same is true for information needed to support customers for regulatory compliance of their applications.

It is impossible in the frame of this bulletin to provide up-to-date information on all grades of DuPont nylons meeting the various specifications. The recommendation is therefore to consult with your DuPont representative on the best material selection for a given application in an early stage of a development.

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