

Polymer Technology Dictionary

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times may be 90 s: the adiabatic exotherm temperature for a typical formulation without filler can be 40°C.

The maximum crystal growth rate for PA 6 is approximately 135°C so the reaction temperatures should be approximately 100 to 160°C: rapid crystallisation is essential for rapid solidification so that quick demoulding can be achieved. The cured RIM moulding releases easily from the mould - especially if one mould half is slightly (approximately 5°C) cooler than the other. Internal mould releases are not necessary. Reaction must be taken to approximately 96% conversion if monomer release is to be avoided.

Nylon 6 block copolymers are readily made by RIM as the reactants are readily mixed and are less sensitive to mix ratio than *polyurethane* RIM. However, higher temperatures are required and demoulding times are longer.

nylon 6T

Also known as **polyamide** 6T or as, polyhexamethyleneterephthalamide or as, polyhexamethylene terephthalamide. An abbreviation used for this type of material is PA 6T. A partially aromatic **polyamide** which is only soluble in strong acids. Prepared from hexamethylene diamine and terephthalic acid: a **polyamide** with a high melting point (T_m) of approximately 370°C. The mechanical properties are similar to those of *nylon 66* but the mechanical properties are retained to higher temperatures.

If trimethylhexamethylene diamine and terephthalic acid are reacted together then a transparent **polyamide** with a high melting point is obtained (Trogamid T). See *poly-trimethylhexamethyleneterephthalamide*.

nylon 7

Also known as nylon seven or as, **polyamide** 7 or as, polyenantholactam or as polyheptanoamide. An abbreviation used for this type of material is PA 7. Prepared from ω -aminoanthanic acid. The polymer has a melting point of approximately 225°C. Nylon 7 is similar to *nylon 6* and is used as a textile *fibre*.

nylon 8

Also known as nylon eight or as, polycaprylamide or as, polycapryllactam or as, polyoctanoamide. An abbreviation used for this type of material is PA 8. Not thought to be a commercial *nylon* because of the expensive monomers required (capryllactam or 8-aminocaproic acid) and because the properties are not sufficiently different from other, cheaper, nylon materials.

nylon 9

Also known as nylon nine or as, polypelargonamide. The monomer may be derived from whale oil: the polymer has been used as a textile material.

nylon 11

A high carbon nylon which is a linear, aliphatic nylon. Also known as nylon eleven, or as, **polyamide** 11 or as, poly(11-amino-undecanoic acid) or as, polyundecanoamide. An abbreviation used for this type of material is PA 11 or PA11.

PA 11 is a linear, semi-crystalline thermoplastics material which may be considered to be intermediate in properties between *nylon 6* (PA 6) and *polyethylene*. In general, nylon 11 and *nylon 12* have similar properties, price, and are processed similarly. PA 11 is made from aminoundecanoic acid, derived from castor oil, whereas PA 12 comes from dodecanelactam which is derived from butadiene.

Because of differences in crystal structure - caused through amide group (CONH) spacing - PA 12 has a slightly lower melting point and density than PA 11. PA 11 performs better at higher temperatures and in addition, has superior UV resistance. Both materials are reasonable electrical insulators whose electrical properties are not so sensitive to changes in humidity as other polyamides. At room temperature, the

mechanical properties, of PA 11 and PA 12, are similar but PA 11 has a higher heat distortion temperature and also a better low temperature impact resistance. Both have good resistance to shock and abrasion and are resistant to many chemicals. They may be extensively modified with plasticizers (for example, sulphonamides), reinforcements etc. PA 11 components may be used continuously at 65°C/149°F with some occasional use at 100 to 130 °C/212 to 266°F. When suitably stabilized (with *antioxidants*), the temperature of continuous use can be higher, especially if there is no strain on the component. These materials can be formulated to meet non-flammable specifications. Compared to PA 6, 66 and 610, these materials have a low melting point, density and by far, the lowest moisture regain (useful, for example, in gear wheels for water meters).

PA 12 is an easier flowing material - can be processed at slightly lower temperatures than PA 11, for example, 10°C lower. For both materials, the viscosity depends on temperature, water content and residence time: water content needs to be below 0.1 percent for *injection moulding*.

Shrinkage is comparatively low and is of the order of 0.005 to 0.02 mm/mm i.e. 0.5 to 2.0%. The actual value is dependent upon grade, component thickness and processing conditions. An increase in mould temperature gives an increase in *shrinkage*.

These materials are resistant to hydrocarbons (such as petrol), most organic solvents and medium strength alkalis (such as sodium hydroxide). Also to inorganic salts (such as, zinc chloride), organic salts, esters, ethers and alcohols (except benzyl alcohol). Low molecular weight alcohols will cause swelling to an equilibrium value (methanol worse than ethanol) which is still relatively low.

They are not resistant to extremes of pH (below 4 and above 12) to strong oxidizing acids (such as nitric and chromic acids), some halogenated compounds and phenols. Raising the temperature greatly alters the chemical resistance (as for most plastics).

PA 11 is slightly denser with a density of 1.04 gcm⁻³ (PA 12 is 1.02 gcm⁻³) and has a higher melting point of 185°C/365°F as compared to 175°C/347°F for PA 12. Both materials have similar hardnesses but the hardness depends on the grade selected. The natural colour of these materials ranges from slight milky translucent white for PA 12 and a beige-tinged, translucent white for PA 11. These materials can be separated from other types of **nylons** by melting point determinations or by dropping a piece into glacial acetic acid. PA 11 and PA 12 will float in glacial acetic acid while other **nylons** will sink.

As the natural colour of the materials is translucent white then a wide colour range is possible; this includes both translucent and opaque colours.

PA 11 and PA 12 are shear sensitive, so small gates on large components should not be used, during injection moulding, as shear-induced crystallinity may occur giving either highly stressed components or mouldings with excessive shrinkage values. Use as large a gate as possible, so as to allow the correct amount of cavity injection pressure (follow-up pressure) to be applied (so as to produce a component of the correct dimensions).

These materials are used as gear wheels (for water meters, gas meters and business machines) and as cable ties - two very important markets for these types of materials. Components maintain properties (e.g. flexibility and low coefficient of friction) over a wide range of temperatures. For these reasons PA 11 is used to make skirts for air-rifle bullets. Good chemical and shock resistance means the choice of this material as a battery casing for aircraft use. Cams, slides and bearings (for both filled and unfilled grades) are other widespread uses. In sports, used to make shuttlecocks and racket frames (carbon-fibre filled). As PA 11 has a richer drier feel than *nylon 6* or *66* it is preferred for some textile applications, for example, underwear.

nylon 12

A high carbon nylon which is a linear, aliphatic nylon. Also known as nylon twelve or as, **polyamide 12** or as, **polylauroamide** or as, **polylauryllactam** or as, **polydodecanamide**. An abbreviation used for this type of material is PA 12 or PA12. In general, PA 11 and 12 have similar properties, price, and are processed similarly. PA 11 is made from aminoundecanoic acid, derived from castor oil, whereas PA 12 comes from dodecanolactam which is derived from butadiene. PA 12 has a slightly lower density and, as is usual with even-numbered **nylons**, a lower melting point. Used in applications where the slightly lower moisture absorption is an advantage. See *nylon 11* for a comparison of nylon 11 and 12.

nylon 46

Also known as **polyamide 46** or, **polytetramethyleneadipamide** or, **polytetramethylene adipamide**. An abbreviation used for this type of material is PA 46 or PA 4-6. This polymer is used as an *injection moulding material* and has a melting point of approximately 295°C. The melting point is higher than that of *nylon 66* and so the mouldings have a higher *heat distortion temperature*.

nylon 66

Also known as nylon six-six or as, **polyamide 66** or as, PA 66 nylon or as 66 nylon or as, **poly(hexamethylene adipamide)** or as, **polyhexamethyleneadipamide** or as, **polyhexamethylene adipamide** or as, **poly-[imino-(1,6-dioxohexamethylene)-imino-hexamethylene]**. An abbreviation used for this type of material is PA 66 or PA 6-6.

The homopolymer, 66 nylon, is made from *nylon 66 salt*. By increasing the number of monomers, copolymers may also be prepared and any combination of copolymers and homopolymers may be blended, filled (for example, with *glass*) and plasticized so that a wide range of grades and of properties is possible from PA 66-type materials (see *nylon - grades of*). For example, the use of molybdenum disulphide and graphite, dispersed in the original moulding material, improves moulding wear. Polymers with 50% glass fibre loading have high strength, stiffness, abrasion resistance and good dimensional stability - ease of flow is, however, reduced and cylinder wear may be a problem. Glass beads give less warpage than glass fibres.

Like PA 6, this plastics material is a semi-crystalline, thermoplastics material which is often processed by *injection moulding*. PA 66 nylon has one of the highest melting points of commercial polyamides, very high strength and stiffness and very good retention of stiffness with increasing temperature. After moulding, it absorbs water (but not as much as PA 6) which causes swelling and an increase in toughness (the toughness may be doubled). When designing PA 66 mouldings, account must be taken of this moisture absorption as it affects dimensional tolerances and physical properties - for every 1% water absorbed, the size increases by approximately 0.003 mm/mm. The rate, and amount of water absorption, depends on wall thickness, relative humidity and compound composition. In the literature, many properties are shown as functions of moisture content. At 50% relative humidity (RH) and at 23°C/73°F the moisture content is 2.5 per cent.

Moulded components are tough even in thin sections. Because of the ease of flow of this material, such thin sections can be moulded relatively easily provided the mould can be filled before the hot material sets. PA 66 should cycle faster than PA 6. High weld strengths are also possible from this class of materials. The use of nucleated grades can result in significant reductions in cycle times (for example, of 10 to 15%) and in mould ejection forces - this in turn can mean less component distortion even though smaller ejection pins may be used. Both PA 6 and PA 66, have better abrasion resis-

tance and toughness than acetal. Super-tough PA 66 has good resistance to crack initiation and propagation and is therefore stress concentration resistant.

PA 66 is a low viscosity material which flows very easily. The viscosity is very dependent on shear rate and on temperature; the temperature, and the mould filling speed, must be controlled very precisely. For example, altering the melt temperature by 10°C can alter the viscosity by a factor of two. At 280°C/536°F the viscosity ranges from 40 to 400 Nsm⁻² (dependent on grade).

Shrinkage is of the order of 0.010 to 0.020 mm/mm i.e. 1 to 2%. The addition of glass fibre will reduce the shrinkage to 0.2 to 1%, but differences between the transverse and longitudinal directions (i.e. along and across the flow) can be as much as five: mineral filled grades give more isotropic mouldings while the use of a *nucleating agent* helps to reduce after-shrinkage (see *nylon - shrinkage*).

PA 66 is resistant to most solvents; insoluble in esters, ketones, aromatic hydrocarbons, chlorinated hydrocarbons, alkalis, dilute acid solutions and most organic acids. Some organic solvents, for instance chlorinated hydrocarbons, cause swelling. Excellent resistance to oils, fuels, greases and fats. PA 66 is not resistant to strong acids or to oxidizing agents. Formic acid and phenol are solvents. Outdoor exposure can cause colour fading and embrittlement unless the PA is stabilized. PA 66 is more resistant to chloroform, benzyl alcohol and trichloroethylene than PA 6. PA 6 will dissolve in 4N hydrochloric acid and boiling N,N-dimethylformamide (PA 66 will not). PA 66 is reversibly swollen by water which worsens the electrical properties.

The density is 1.15 gcm⁻³. As the natural colour of the material ranges from translucent white to translucent light brown, a wide colour range is possible; both transparent and opaque colours are available. As supplied the material is suitable for moulding however, if containers are left open, rapid water absorption will occur. Dry in a well ventilated, hot air oven for 4 to 5 hours at 85°C/185°F but be careful not to cause oxidation. When first ejected, injection mouldings are dry as they have not absorbed water: dry mouldings are more brittle than mouldings which have absorbed water and are therefore easier to reclaim.

PA 66 components may be solvent welded with aqueous phenol (12%) or a solution of PA 66 in ethanol and calcium chloride. If dimensions are very critical, then annealing, and/or moisture conditioning, may be necessary. Anneal by heating in a non-oxidizing oil for 20 minutes at 170°C/338°F. May be conditioned to equilibrium water content by immersion in water (maximum temperature 60°C/140°F): to get uniform water distribution wrap in polyethylene film after conditioning and store.

Like PA 6, this plastics material is often used in light engineering applications. Widely used in the automotive industry for fans, grilles, door handles, filters etc. Around the home, it is used in kitchen appliance housings, vacuum cleaner components and curtain fittings. Transport applications include conveyor belt components, castors, bearings and bicycle wheels. In such applications, the material is selected because of the low level of friction encountered without lubrication together with good oil and grease resistance. Often used where the components require impact resistance and impact strength. PA 6 and PA 66 are the most widely used of the so-called engineering plastics: they are also widely used as glass reinforced materials. Often used in the automotive industry, as fuel resistant, technical mouldings which must operate in the aggressive environment in, and around, the engine. That is, under the hood or bonnet. Alloys of PA are now being used for computer housings and for automotive panels: such panels may be required to withstand elevated paint shop temperatures and then, subsequent low temperatures in use.

nylon 66 salt

Also known as hexamethylene diammonium adipate. Used for the preparation of *nylon 66* as the use of the salt, produced by the reaction of hexamethylene diamine and adipic acid, gives high molecular weight polymers. This is because the use of the salt, gives the exact, equal ratios of the two monomers.

nylon 6/66

Also known as **polyamide** 6/66. An abbreviation used for this type of material is PA 6/66. A *nylon copolymer* which contains *nylon 6* and *nylon 66* repeat units. A softer material than the homopolymers and with a lower melt viscosity.

nylon 6/66/610

Also known as **polyamide** 6/66/610. An abbreviation used for this type of material is PA 6/66/610. A *nylon copolymer* which contains *nylon 6*, *nylon 66* and *nylon 610* repeat units. A softer material than the homopolymers and with a lower melt viscosity: softer than *nylon 6/66*.

nylon 610

Also known as nylon six-ten or as, **polyamide** 610 or as, polyhexamethylenesebacamide or as, polyhexamethylene sebacamide. An abbreviation used for this type of material is PA 610 or PA 6-10. A *polysebacamide*: a major *nylon copolymer* formed from *nylon 610 salt*. The polymer has a melting point of approximately 223°C and a relatively low water absorption: more dimensionally stable than *nylon 6* or *nylon 66* and more suited for electrical insulation applications. Widely used as a fibre material.

nylon 610 salt

Also known as hexamethylene diammonium sebacate. Used for the preparation of *nylon 610* as the use of the salt, produced by the reaction of hexamethylene diamine and sebacic acid, gives high molecular weight polymers. This is because the use of the salt, gives the exact, equal ratios of the two monomers.

nylon 612

Also known as nylon six-twelve or as, **polyamide** 612 or as, polyhexamethylenedodecanoamide or, polyhexamethylene dodecanoamide. An abbreviation used for this type of material is PA 612 or PA 6-12. The polymer has a melting point of approximately 218°C and a relatively low water absorption: even lower than *nylon 610* and is therefore even more dimensionally stable.

nylon 69

Also known as nylon six-nine or as, **polyamide** 69 or as, polyhexamethylenonamide or as, polyhexamethylene nonamide or, polyhexamethyleneazelamide. An abbreviation used for this type of material is PA 69 or PA 6-9. This material has a melting point of approximately 215°C and is similar to *nylon 610*.

nylon 77

Also known as nylon seven-seven or as, **polyamide** 77. An abbreviation used for this type of material is PA 77 or PA 7-7. A *nylon copolymer*.

nylon 91

Also known as nylon nine-one or as, **polyamide** 91 or as, polynonylamethyleneurea. An abbreviation used for this type of material is PA 91 or PA 9-1. A *nylon copolymer* whose properties are similar to *nylon 11*. The polymer has been used as a textile material.

nylon bandage

The fabric belt of a *steel-braced radial tyre*.

nylon belt

The fabric belt of a *steel-braced radial tyre*.

nylon copolymer

A **polyamide** which is based on two monomers: such a material is softer and tougher than a nylon homopolymer and of a lower melting point. See, for example, *nylon 610*.

nylon fibre

A manufactured, polymeric fibre in which less than 85% of the amide groups are attached directly to 2 aromatic rings.

nylon - grades of

A wide range of grades is available as, for example, *nylon 6* and *nylon 66* may be extensively modified with particulate or fibrous fillers, plasticizers, other plastics materials and elastomers. Glass, in one of its many forms, is a popular filler for PA as it is relatively cheap and its use can lead to significant improvements in some properties, for example, strength and stiffness. The impact resistance of PA 6 and 66 may be improved by the use of other plastics or, by the use of elastomers. For example, the impact resistance when dry, may be improved by the use of, approximately, 15% polyethylene (PE) - providing the two plastics materials are coupled together. High impact PA, results from the successful incorporation of an appropriate elastomer, for example, *ethylene-propylene (EPDM)* or *styrene-butadiene rubber (SBR)*. It is possible to get flame-retardant grades of PA, which are halogen and phosphorus free, and which are VO rated at 0.25 mm (0.010 in). A well dispersed silicone fluid, can result in a moulding material with low frictional losses. The use of a *nucleating agent*, can give fast cycling grades as such agents improve the rate of crystallization. Aluminum stearate, approximately 0.1%, eases ejection and also reduces ejection forces (for both the nucleated and the unnucleated grades) and so, minimizes ejection problems. The use of molybdenum disulphide and graphite, dispersed in the original moulding material, improves moulding wear.

nylon plastics

The collective name for the class of materials which contain the amide group used as a chain linkage. Another name for **polyamide** plastics. See *nylon 6*, *nylon 66* etc.

nylon salt

Also known as an AH salt. The reaction product of an aliphatic *diamine* and an aliphatic dicarboxylic acid: a 1:1 adduct. Used to produce **nylons** or polyamides as the use of the salt, produced for example, by the reaction of hexamethylene diamine and sebacic acid, gives high molecular weight polymers. This is because the use of the salt, gives the exact, equal ratios of the two monomers required.

nylon screw

Usually means that a screw, of an *extruder* or of an *injection moulding machine*, has been designed for *nylon* (for example, PA 6 or PA 66) that is, it is a *dedicated screw*. See *double parallel screw*.

nylon - shrinkage

Nylon 6 and nylon 66 are semi-crystalline, thermoplastics materials with relatively high *shrinkage*. The addition of *glass fibre* will reduce the shrinkage but differences between the transverse and longitudinal directions (i.e. along and across the flow) can be as much as five: mineral filled grades give more isotropic mouldings while nucleating agents help reduce after-shrinkage.

In general, thinner components exhibit less shrinkage than thick components. However, thin sections show more after-shrinkage than thick; also low mould temperatures can increase after-shrinkage. Shrinkage and after-shrinkage (*post-moulding shrinkage*) decrease component size but moisture absorption increases component size. So, after moulding, the component may increase in size due to water absorption and this, may negate the effect of shrinkage.