



WELLMAN

Engineering Resins

**DESIGN
GUIDE**

WELLMAN ENGINEERING RESINS DESIGN GUIDE

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INTRODUCTION

The purpose of this Design Guide is to provide basic recommendations to aid the product designer, engineer and process technicians in obtaining high quality, easily molded plastic parts when using Wellman Nylons.

Wellman encourages designers and engineers to include Wellman's technical support groups when forming a project team. Wellman can offer assistance with the selection and modification of materials, along with recommendations for tooling and part design.

Because of the fallibility of all the elements involved, we are strong proponents of prototype usage before committing to production design. All recommendations are based on good faith effort to assist in your application, they are, however, only recommendations. Therefore, the information in this document is provided "as is" without warranty of any kind, either expressed or implied, for fitness of use.

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SECTION 1

UNDERSTANDING THE MATERIAL

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WELLMAN PRODUCT DESCRIPTION

Wellamid Nylon 66, Engineering Resins

22O-N	General Purpose
22L-N	Lubricated, General Purpose
22LH-N	Lubricated & Heat Stabilized
21LN2-NNT	Lubricated & Nucleated

Typical Applications

Automotive components: gears:
switches: bearings: pulleys:
fasteners: electrical coil forms:
chain-saw hand guards: cable ties:
furniture hardware: small
appliance housings:
aerosol spray heads.

Wellamid Nylon 6, Engineering Resins

42O XE-N	General Purpose
42L XE-N	Lubricated, General Purpose
42LH XE-N	Lubricated & Heat Stabilized
42LHN2-N	Lubricated & Nucleated & HS

Automotive seat belt, buckle and
anchor components: convoluted
tubing for wire harnesses: furniture
hardware: curtain glides.

Wellamid Nylon 66 and 6 Impact Modified

22LH13 XE-N	Nylon 66, Improved Impact-1
22LH16 XE-N	Nylon 66, Improved Impact-2
22LH14 XE-N	Nylon 66, Improved Impact-3
22LH15 XE-N	Nylon 66, Improved Impact-4
42LH111 XE-N	Nylon 6, Improved Impact
XT1482	Nylon 66/6 Alloy, Superior Impact

Automotive fasteners: living hinge:
head lamp adjustment devices: Ink
pen components: wire separators:
hardware components: window
installation clips: safety equipment.
Sporting goods.

Wellamid Nylon 66 and 6 Glass Sphere Filled

GS25-66 22L-N	Nylon 66 with 25% glass spheres
GS40-66 22L-N	Nylon 66 with 40% glass spheres
GS40-60 42L-N	Nylon 6 with 40% glass spheres
GSF25/15-66 22L-N	Nylon 66 with 25% glass spheres and 15% short glass fibers

Potentiometer liners: electrical coil
forms: automotive window lift and
power door lock switch bodies:
gears: thick wall section moldings:
emission control valves.

Wellamid Nylon 66 and 6 Glass Fiber Reinforced

GF13-66 XE-N	Nylon 66 with 13% glass fiber
GF14-60 XE-N	Nylon 6 with 14% glass fibers
GF20-60 XE-N	Nylon 6 with 20% glass fiber
GF30-60 XE-N	Nylon 6 with 33% glass fiber
GF33-66 XE-N	Nylon 66 with 33% glass fiber
GF43-66 XE-N	Nylon 66 with 43% glass fiber

Radio and TV. components:
dishwasher roller carriages:
chain saw oil reservoirs: gears:
housings: door & window latches:
power hand tool housings:
high temperature devises:

For detailed product information, refer to technical data sheets. For special formulations, contact sales department

WELLMAN PRODUCT DESCRIPTION (cont.)

Wellamid Nylon 66/6 Alloy, Glass Fiber Reinforced

GF33-66/6 XE-N	Nylon 66/6 with 33% glass fiber
GF43-66/6 XE-N	Nylon 66/6 with 43% glass fiber
GF60-66/6 XE-N	Nylon 66/6 with 60% glass fiber
GFT13-66 XE-N	Nylon 66/6 Impact Modified & 13% GF
GFT15N050 N	Nylon 66/6 Impact Modified & 15% GF
GFT33N050 N	Nylon 66/6 Impact Modified & 33% GF

Typical Applications

Machinery gear trains and linkage:
conveyor belt links: fasteners:
auto under hood and door parts:
automotive door handles:
appliance parts: sporting goods:
lawn and garden equipment:

Wellamid Nylon 66 and 6 Mineral Reinforced

MR259 22LH-N	Nylon 66/6 lubricated, with 25% mineral
MR340 42H-N	Nylon 6 with 34% mineral
MR410 42H-N	Nylon 6 with 40% mineral
MR410 22H-N	Nylon 66 with 40% mineral
MR409 22H-N	Nylon 66 with 40% mineral
MRGF25/15 42H-N	Nylon 6 with 25% mineral & 15% GF
MRGF25/15 22H-N	Nylon 66 with 25% mineral & 15% GF
MRGF30/10 42H-N	Nylon 6 with 30% mineral & 10% GF
MRGF3822 BK	Nylon 66 with 28% mineral & 10% GF
MRT20 N	Nylon 66/6 toughened, with 20% mineral
MRT1304 N	Nylon 66/6 toughened, with 34% mineral

Lawn and garden equipment:
automotive trim: bezels: wheel
covers: window frames: gas tank
filler housings: brackets: metalized
lighting reflectors for automotive:
automotive cooling fans & shrouds:
automotive door handles: brackets:
automotive mirror shells: painted
parts: components for small gas
engines: sporting goods:
auto luggage rack components.

Wellamid Nylon 66, UL94V-O Flame Retardant

FR22F-N	Flame retardant Nylon 66
FRGF25-66-N	Flame retardant Nylon 66 with 25% GF
FRGS25-66-N	Flame retardant Nylon 66 with 25% GS

Electrical terminal blocks: electric
fan switch housings: coil forms:
multi-pin electrical connectors:
electric fan switch housings:
TV tuner components: automotive
switch housings.

Ecolon Post Consumer Recycled Nylon, Mineral and Glass Reinforced

Ecolon 2100-BK	Nylon 66 with 28% mineral / 10% GF
MRGF1616-BK	Nylon 6 with 25 % mineral / 15% GF
MR1660-BK	Nylon 66 with 40 % mineral
MRGF1619-BK3	Nylon 66 with 19 % min/glass
MRGF1926-BK1	Nylon 66 with 15 % min / 25% GF
MRGF1914-BK1	Nylon 66 with 25% min / 15% GF

Automotive cooling fans and shrouds
Knife handles, brackets, door handles
HVAC doors for automotive
Automotive air cleaner assemblies
Automotive cam covers.
Brackets, cam cover baffles, gaskets

For detailed product information, refer to technical data sheets. For special formulations, contact sales department

BASE RESINS OVERVIEW

Nylon is a member of the thermoplastic polyamide (PA) family, and is considered to be the first crystalline plastic. It was invented way back in the 1930's but introduced for injection molding around 1943.

Largest selling commercial types :

NYLON 66

Derived from hexamethylene diamine and adipic acid.

Melt point of 500 °F.

The generic formula is :

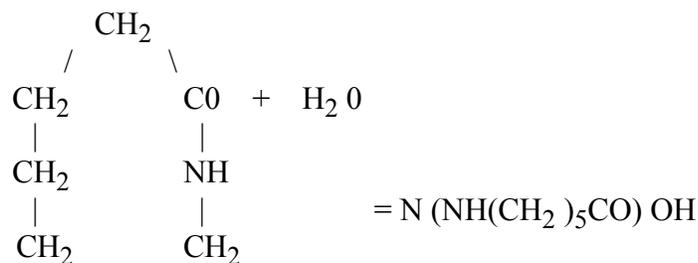


NYLON 6

Derived from caprolactam

Melt point of 420 °F

The generic formula is :



Nylons are among the toughest of all thermoplastics with excellent chemical, abrasion and creep resistance. This, together with high tensile strength, rigidity and heat distortion temperatures, makes nylon a very popular, cost effective, engineering resin.

All nylon compositions have certain molding advantages:

- Fast overall cycle times
- Good weld strength
- Good flow characteristics and toughness in thin sections.

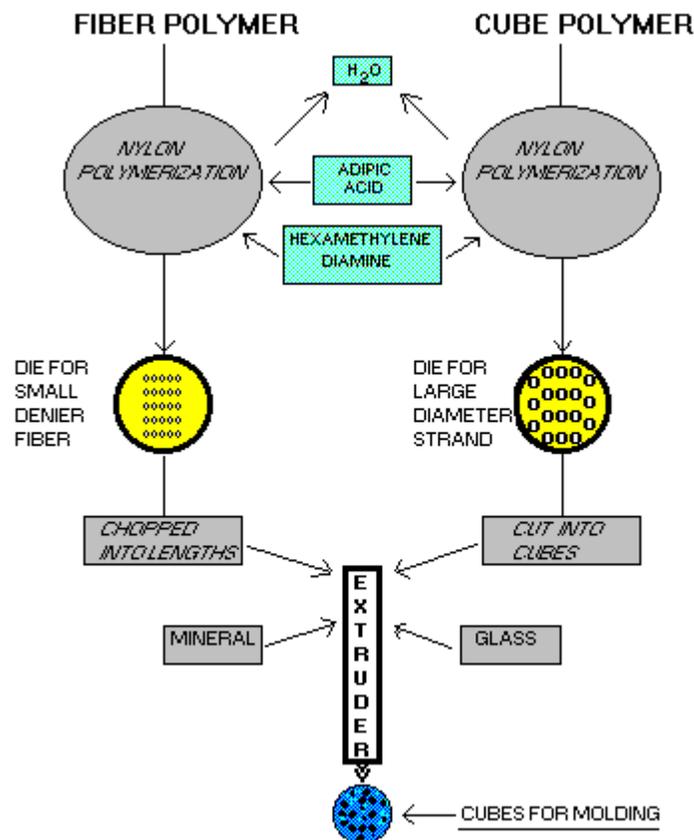
BASE RESINS OVERVIEW

VIRGIN POLYMER VS "FIBER" POLYMER

Wellman offers a full range of formulations which utilize both virgin polymer feedstock and fiber polymer feedstock. Our compounded fiber based products have the same heat history as virgin based. Very extensive testing of physical properties and performance show near identical results when comparing the two.

Figure 1.0 illustrates the general background of both virgin (cube) and fiber based polymers and how they flow through the manufacturing process.

Figure 1.0



BASE RESINS OVERVIEW

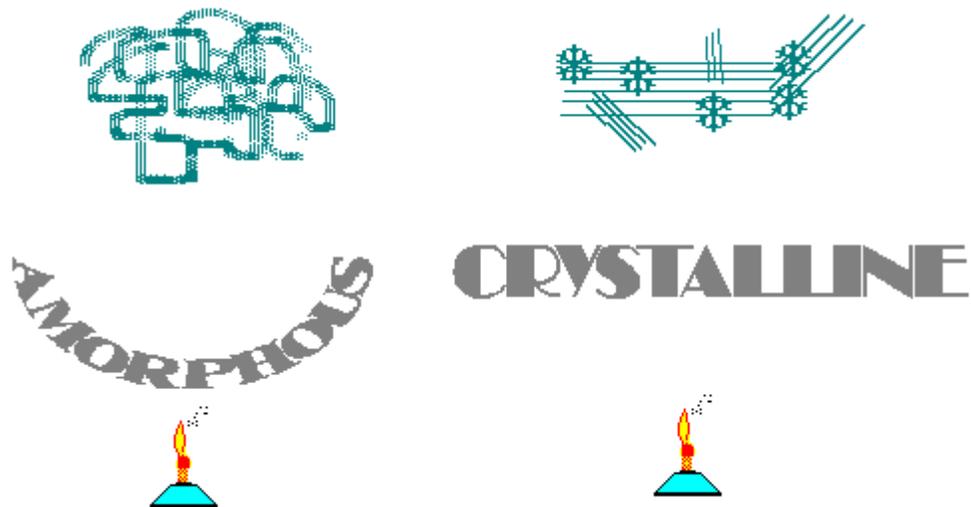
AMORPHOUS VS CRYSTALLINE

Most all of today's thermoplastics can be lumped into these two categories. There are, however, very distinct differences between the two as follows:

CRYSTALLINE polymers have a very dense "ordered" structure, in which the molecules in certain regions get tightly aligned. As heat is added, they remain solid until they reach their sharp melting point, then all crystalline structure is destroyed and they become a very easy flowing liquid like substance. Crystalline polymers include; Nylon, PBT, PET, Polypropylene and Polyethylene.

AMORPHOUS polymers don't really melt. Instead, they have a broad softening range. The molecular structure is more like random coils or "spaghetti like". Very stiff flowing at low temperatures, but as heat is increased, space is added between the molecules making it more easy flowing. Amorphous polymers include; ABS, Acrylics, Styrene and Polycarbonates.

Fig. 1.1



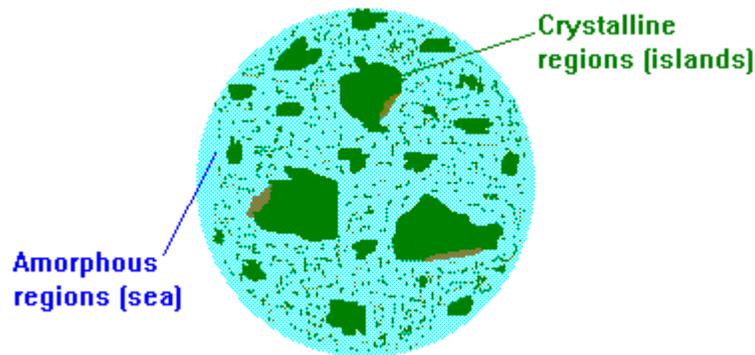
BASE RESINS OVERVIEW

CRYSTALLINITY

The morphological structure of both nylon 66 and nylon 6 is actually semicrystalline. If you were to observe both through a microscope, two separate and distinct phases would be revealed : an ordered crystalline phase and a random amorphous phase. This could appear like crystalline islands surrounded by an amorphous sea. (Figure 1.2)

Processing can greatly effect the level of crystallinity in molded parts because the more slowly a melt of crystalline nylon is allowed to cool, the greater the degree of "as-molded" crystallinity.

Fig. 1.2 Crystallinity



Slower cooling promotes crystal formation.

Increased crystallinity means:

- **Greater initial shrinkage**
- **Less chance for additional shrinkage**
- **Increased dimensional stability**
- **Better chemical resistance**
- **Increased heat deflection temperature (HDT)**

FILLERS, REINFORCEMENTS AND ADDITIVES

Nylons processing and property characteristics can be altered greatly by incorporating different types of fillers, reinforcements and additives.

FILLERS: Nonmetallic minerals, metallic powders, glass spheres and organic material are added at fairly high percentages to nylons. They usually act as "extenders" to reduce the resin cost, but may also reinforce the resin to some extent or provide thermal property improvements.

REINFORCEMENTS: Usually fibrous in nature. The principal ones in use today are glass, carbon and aramid fibers. Less common are ceramic, alumina and boron fibers.

ADDITIVES: Flame retardants, pigments, plasticizers, lubricants, heat and UV stabilizers and impact modifiers are typical examples of other additives that are commonly used with nylon.

Table 1.3 describes some of the most common types of fillers, reinforcements and other additives, and their effects on physical properties.

FILLERS, REINFORCEMENTS AND ADDITIVES

Table 1.3



FILLER OR ADDITIVE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
GLASS FIBER	1/8" short strand 10 - 60 % loadings are common.	Increases: strength, stiffness, HDT and dimensional stability. Reduces shrinkage and cycle time.	Decreases true toughness and flexibility. Increases density and can cause warpage.
GLASS BEADS	40 - 50 micron solid spheres. Usually at 25 or 40 % loadings.	Increases compressive strength, stiffness and dimensional stability. Reduces shrink, cycle time and warpage.	Decreases flexibility and toughness. Increases notch sensitivity and brittleness.
CALCINED KAOLIN	Mineral (clay), very small particle size (2-3 microns) 25-40 % loadings are typical.	Increases stiffness and HDT. Reduces cost , sink marks and warpage. Improves paintability.	Increase notch sensitivity, decreases flexibility and toughness. Mineral splay is typical.
WOLLASTONITE	Mineral. " needle like " particles of various size with an aspect ratio larger than clay. 25-40 % loadings are typical.	Increases stiffness and HDT when compared to clay, while decreasing shrinkage and mineral splay. Improved flow.	Slightly rougher surface finish when compared to clay. Decreases toughness and can increase warpage.
TALC	Mineral in the form of small "plates". More common with nylon 6.	Increases stiffness, decreases tool wear when compared to other minerals. Reduces cost.	Decreases flexibility and toughness. Increases notch sensitivity.
GLASS FIBER AND MINERAL	Various minerals used together with short strand glass fibers.	Has similar stiffness to a GF product with less warpage, lower cost, and improved surface finish.	Slightly lower strength and impact resistance, and increased notch sensitivity when compared to a GF product.

FILLERS, REINFORCEMENTS AND ADDITIVES

Table 1.3 (cont.)



FILLER OR ADDITIVE	DESCRIPTION	ADVANTAGES	DISADVANTAGES
METALLICS	Stainless steel, copper, bronze and aluminum etc. in various fibers, flakes or powders.	Improves thermal and electrical conductivity. can improve static dissipation.	Reduces toughness, increases density and cost.
FLAME RETARDANTS	Various halogenated compounds.	Can improve fire retardancy to a UL94 V0 rating.	Decreases flexibility. High heat sensitivity can make processing more difficult.
IMPACT MODIFIERS	Various Thermoplastic elastomers used in various loadings	Improves impact resistance, flexibility and toughness.	Decreases stiffness and tensile strength. Increases melt viscosity.
HEAT STABILIZERS	Various copper salts, iodides and bromides used at low percentages.	Reduces degradation from oxidation in high heat applications.	Can discolor natural materials and make color matching more difficult.
LUBRICANTS	Aluminum, sodium, zinc, magnesium and various other metallic stearates.	Can improve mold release and machine feed characteristics.	Can reduce paint adhesion and increase mold deposit.
PIGMENTS	Carbon black, Titanium dioxide etc.	Carbon black improves UV resistance and weathurability. TiO ₂ can improve appearance and cycle time.	Decreases physical properties slightly.

PHYSICAL PROPERTIES

In this section we will discuss some of the physical properties most often reported on Material Data Sheets. It is important to realize that property data can be influenced by varying test speeds, specimen preparation, specimen thickness, etc. Therefore, the importance of end-use testing must be kept in mind.

TENSILE STRENGTH

Standard test: ASTM D638 / ISO 527

Tensile strength is a measure of a materials ability to resist being pulled apart. Testing is carried out on a universal testing machine using dry as molded test bars or " dogbones ". The dogbone is gripped between a fixed and moveable crosshead. The moveable crosshead is made to travel at a constant rate until breakage occurs. The testing machine is equipped with sensors to measure the stress being exerted on the specimen.

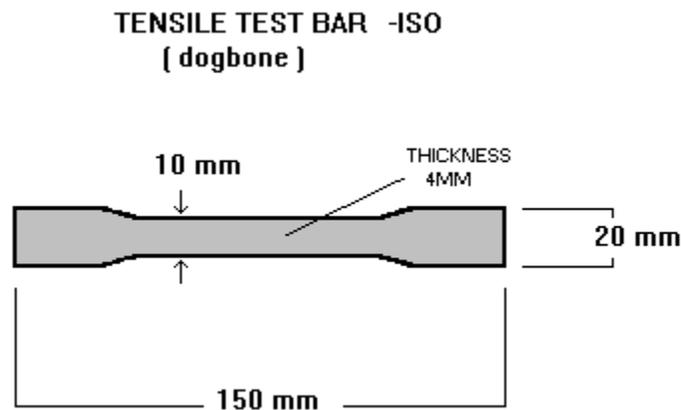
With nylons, tensile strengths can range dramatically depending on the specific grade being tested. With the more flexible nylons (impact modified) results can be as low as 7,000 Psi. (48 Mpa). Where higher strength formulations such as glass filled, can well exceed 30,000 Psi. (207 Mpa).

ELONGATION AT BREAK

Standard test: ASTM D638 / ISO 527

Elongation is the total amount of stretching that occurs during the tensile test until the final breakage point is reached. An extensometer (strain gauge) is attached to the dogbone to record the amount of elongation or strain.

The more flexible nylons will typically register greater then 50% elongation, where the higher strength formulations, on the other hand, may break with less then 5% elongation.



PHYSICAL PROPERTIES

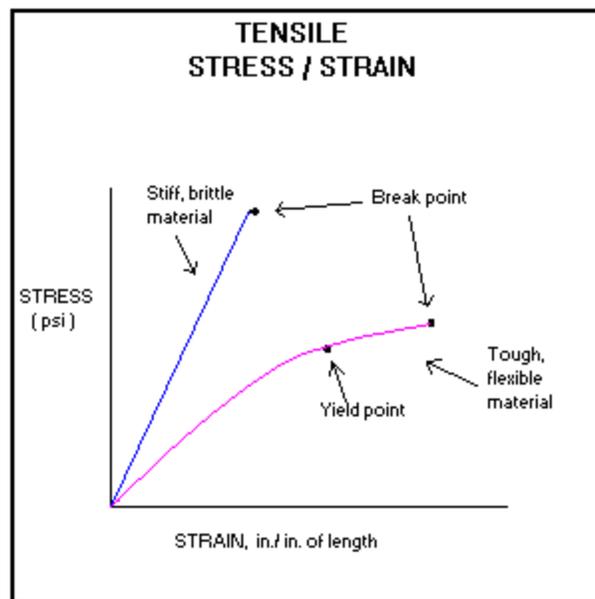
TENSILE MODULUS

Standard test: ASTM D638 / ISO 527

During tensile testing the amount of stress exerted on the dogbone, and the amount of strain as measured by the extensometer, is captured on a computer and a graph of the stress / strain curve can then be obtained.

Tensile Modulus is the ratio of the tensile stress to the corresponding strain before the plastic begins to deform.

Fig. 1.4



For actual stress / strain data for a specific material, contact technical department

PHYSICAL PROPERTIES

FLEXURAL STRENGTH

Standard test: ASTM D790 / ISO 178

Flexural strength is an indication of "stiffness", and is a measure of how well a material resists bending.

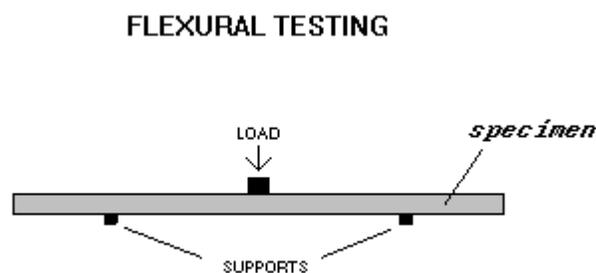
During this test, a dry as molded test specimen (80 mm long x 10 mm wide x 4 mm thick) is supported at each end, and a load is applied to the middle. The load is forced downward at a constant rate until a break occurs on the outer surface. The maximum stress applied is recorded as the Flexural Strength, and is expressed in megapascals.

FLEXURAL MODULUS

Standard test: ASTM D790 / ISO 178

Flexural modulus is an approximation of "Young's Modulus of Elasticity" and is expressed as the ratio of stress to corresponding strain below the materials yield point.

Fig. 1.5



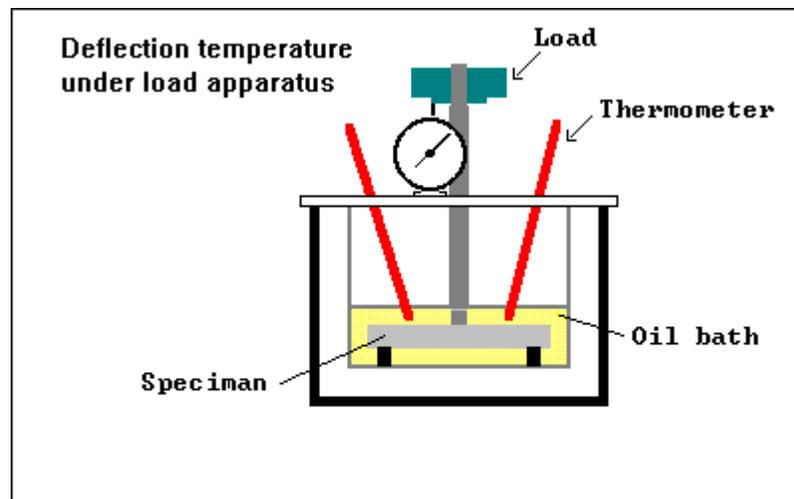
PHYSICAL PROPERTIES

DEFLECTION TEMPERATURE UNDER LOAD Standard test: ASTM 648 / ISO 75

DTUL, sometimes referred to as Heat Deflection Temperature (HDT), is used as an indication of high temperature performance, by measuring how elevated temperatures effect stiffness.

This test is very similar to the flexural strength test, except the applied load is held constant at the required force (in newtons). The test specimen is held on edge and is placed in an oil bath. The temperature of the oil is then increased by 120 K/h., until a bar deflection of 0.32 mm is detected (based on a test speciman height of 10 mm). The temperature (° C) is then recorded as DTUL.

Fig. 1.6



PHYSICAL PROPERTIES

IMPACT STRENGTH

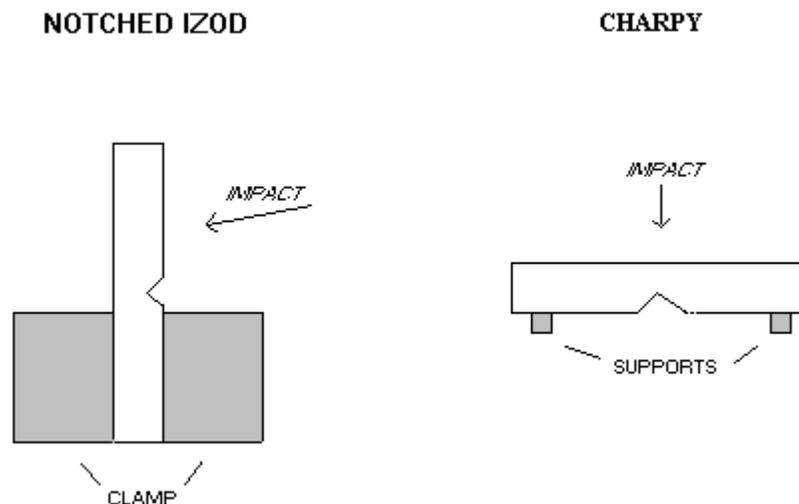
Standard test: ASTM D256 / ISO 180

Impact strength is an indication of material "toughness". Impact data can be obtained by a number of different testing methods, but the most common tests used in the U.S. are the IZOD IMPACT and CHARPY IMPACT.

For measuring IZOD IMPACT (ISO 1A method) a dry as molded test specimen measuring 80 X 10 X 4 (mm) is used. This bar can be tested un-notched or notched with a 8 mm, "V" cut into the bar with a 0.25 mm radius at the base of the groove. Both tests utilize a swinging pendulum type machine which delivers an impact on the notched (or un-notched) specimen. The machine records the loss of energy, and results are reported in kilojoules per square meter (kJ / m²) of specimen width.

Toughened nylons can exceed 80 kJ/m², where the more notch sensitive formulations, such as mineral filled, can break at less then 3 kJ/m².

Fig. 1.7



PHYSICAL PROPERTIES

COEFFICIENT OF LINEAR THERMAL EXPANSION

Standard test: ASTM D696

Like all other materials, including metal, plastics will contract when cooled and expand when heated. The CLTE is the ratio of the change in dimension from the original dimension, per degree change of temperature. Results are expressed in, in./in./ ° F X 10⁻⁵ (or cm/cm/ ° C x 10⁻⁵).

The test specimen utilized can vary in dimensions, but the one typically used is a flex bar that has been cut down to 3" in length. The bar is conditioned to 50% relative humidity and 23 °C.

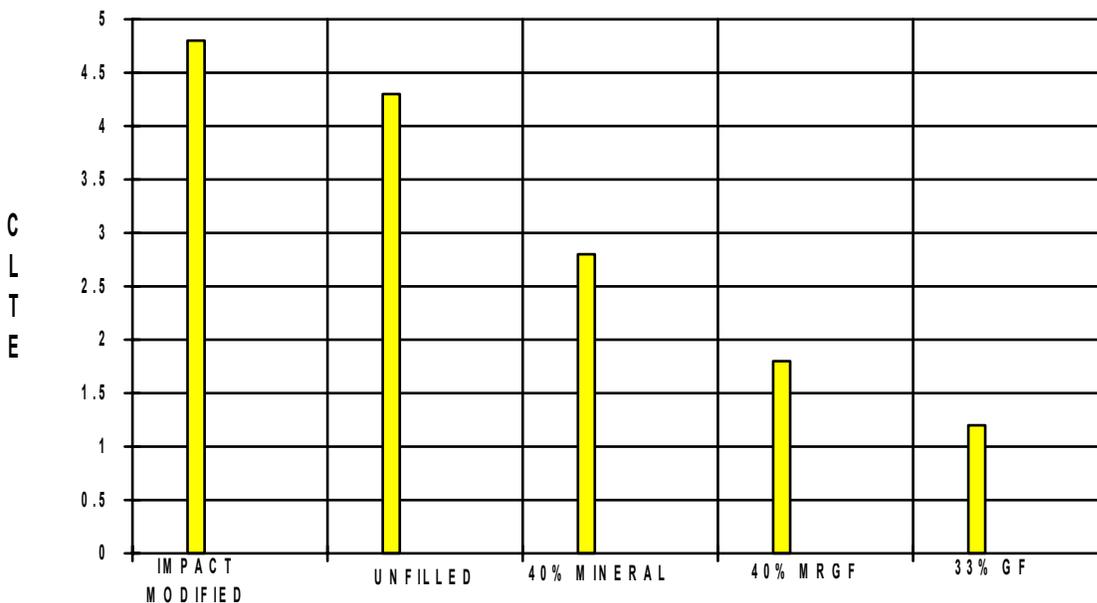
The test is carried out by first measuring the conditioned specimen to the nearest 0.001", then mounting the bar into a FUSED-QUARTZ-TUBE DILATOMETER, which goes into a bath cooled to -30° C (-22° F). The measurements and actual temperature is recorded. The Dilatometer is then placed into a +30° C (86° F) bath and the measurements and actual temperature is recorded. The CLTE over the temperature range is then calculated as follows;

CLTE = change in length / original length X change in temperature.

For a given material, thermal expansion and contraction can be greatly reduced by incorporating various fillers and, or, reinforcements, such as glass fiber or mineral.

Table 1.8

EFFECTS OF ADDITIVES ON CLTE (PA 66)



PHYSICAL PROPERTIES

SPECIFIC GRAVITY

Standard test: ASTM D792 / ISO 1183

Specific Gravity and Density are often times used interchangeably, there is, however, a difference between the two.

Density is the measure of mass per unit volume, and is typically expressed as; grams / cm³, or kg/m³ (per ISO 1183).

Specific gravity is a dimensionless quantity, and is defined as the ratio of the density of a given material, to the density of water.

$$\text{Specific gravity} = \frac{\text{Density of the material}}{\text{Density of water}}$$

$$\text{Density (g / cm}^3\text{)} = \text{Specific gravity (23}^\circ\text{C)} \times 0.998$$

Wellman performs the test by weighing a small piece cut from a dry as molded tensile bar, and then submerging the same piece in 23 ° C water, and then re-weighing while it is submerged. The Density is calculated from the weight difference.

Material suppliers determine Specific Gravity for quality assurance reasons, but is also used for determining part weight and cost. For example, if you would like to convert material costs (\$), to cost in cents / in.³, you could use the following equation;

$$\text{cost in cents / in.}^3 = \$ / \text{lb.} \times \text{S.G.} \times 3.61$$

Wellman Impact Modified grades have a specific gravity in the 1.04 - 1.12 range, where the more highly filled formulations can exceed 1.50.

PHYSICAL PROPERTIES

WATER ABSORPTION 24 Hr.

Standard test: ASTM D570

Water absorption (24 hr.) is the % increase in weight of a material due to absorption of H₂O. The test specimen used is a 2" x 1/8" thick disc. The test is carried out by first weighing the disc dry as molded, and then submerging into 73 ° F. water for 24 hours, then re-weighing and calculating the weight increase.

Although this can be an indication of dimensional stability, it can also be misleading because in applications the actual rate of moisture absorption is dependent upon part geometry and the environmental factors of relative humidity, temperature and time.

Typical water absorption values (24 hr.) for various Wellman nylons are shown in table 1.9.

Table 1.9

	PA 66	PA 6
Unfilled	1.40	1.60
Impact modified	1.20	1.20
40% mineral	0.70	1.00
40% MRGF	0.60	0.80
33% GF	1.25	1.25

PHYSICAL PROPERTIES

MELT FLOW RATE

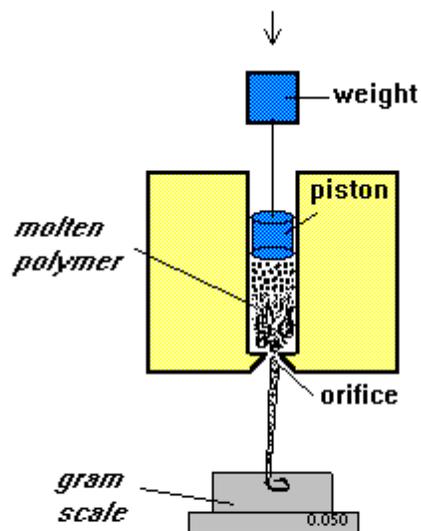
Standard test: ASTM D1238 / ISO 1133

The melt flow rate test, also referred to as the melt index test, measures the amount of polymer flow through an extrusion plastometer.

The test is carried out by feeding the material into a cylinder where it is heated to a specific temperature and then forced down by a weighted piston through a small orifice, where it is weighed. The results are then calculated to reflect what amount (measured in grams) would have been extruded in 10 minutes time.

This test is best suited for quality assurance reasons, such as checking lot consistency, rather than for comparing different materials flow or processing characteristics.

Fig. 1.10



EXTRUSION PLASTOMETER

PHYSICAL PROPERTIES

FLAMMABILITY

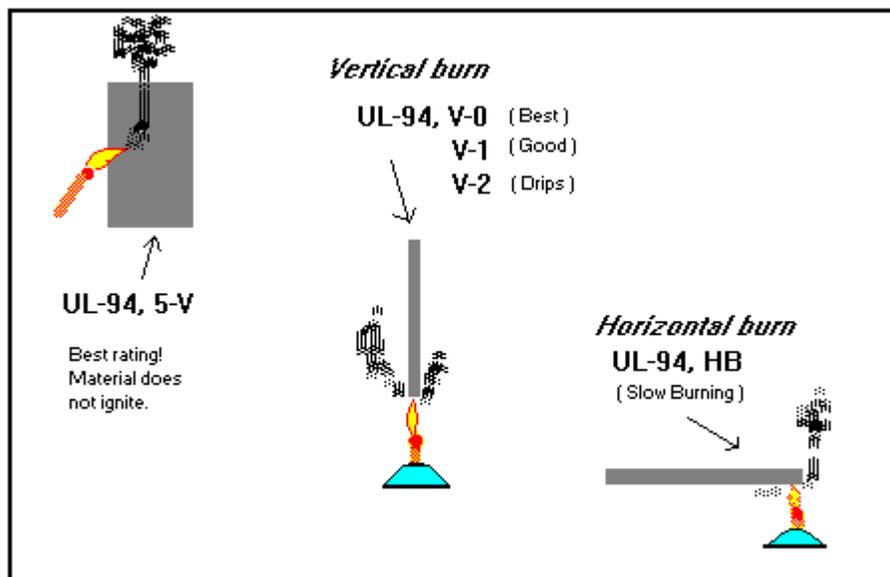
Standard test : U. L. 94

Flammability testing attempts to measure how a material reacts upon exposure to an actual flame.

UL-94 Flammability class (V-O, V-1, V-2, 5V, HB) tests are carried out using separate specimens per class. In each test a specimen is subjected to a specified flame exposure. Whether or not burning continues after the flame is removed is the basis for classification.

The series of tests are performed by first exposing a material to a very hot flame. If it does not ignite or drip it is given a **94-5V** rating. Which is the best rating. If the material ignites, it must then undergo the VERTICAL BURN test, where it is given a **94-VO** rating if it extinguishes itself in a short amount of time. A **94-V1** rating can be given if it takes longer to self extinguish. If the material drips and takes longer to extinguish itself it can be given a **94-V2** rating. If the material does not extinguish itself, it must then undergo the HORIZONTAL BURN test, where the burning rate is measured and calculated in inches per minute. If the material burns slowly and does not exceed 1.5" per minute for specimens having a thickness of 0.120" to 0.500", or exceeds 3" per minute for thinner specimens of less then 0.120", a **UL-94 HB** rating can be given.

Fig. 1.11



SECTION 2

PART DESIGN CONSIDERATIONS

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PART DESIGN CONSIDERATIONS

This section is intended to present some basic guidelines that experience has shown to be useful in optimizing the design of plastic parts molded from Wellman Engineering Resins.

WALL THICKNESS

Wall thickness is probably the largest factor in determining part strength, stiffness, polymer flow, mold shrinkage, overall cycle time and cost. Typical working ranges for nylons are between 0.030 in. and 0.150 in. That does not mean parts cannot be molded thicker or thinner.

STRENGTH AND STIFFNESS:

Increasing wall thickness generally improves part strength, stiffness and impact resistance. However, overly thick walls can cause high internal stress and therefore reduce part strength. Impact resistance can suffer if the part is too stiff and unable to deflect and distribute the applied force.

Measuring stiffness

Stiffness = (Modulus of the material) X (Geometry or shape)

Stiffness = (Young's Modulus) X (Moment of Inertia)

Stiffness = (E) X (I)

For an element B of a wall that is t thick :

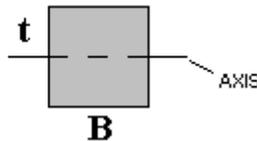
E = flex modulus (psi)

I = moment of inertia (in.)⁴

B = element width (in.)

t = thickness (in.)

$$I = \frac{Bt^3}{12}$$



Moment of Inertia of a body with respect to an axis is the sum of the products obtained by multiplying the area of each element times the square of it's distance from the axis. The moment of inertia of a body is the minimum when the axis goes through the center of gravity.

WALL THICKNESS

DESIGNING FOR EQUAL STIFFNESS

To get the same stiffness in plastic as in metal:

$$(E_{\text{plastic}}) (I_{\text{plastic}}) = (E_{\text{metal}}) (I_{\text{metal}})$$

$$(E_p) (B t_p^3 / 12) = (E_m) (B t_m^3 / 12)$$

$$(E_p) (t_p^3) = (E_m) (t_m^3)$$

$$t_p^3 = (E_m / E_p) (t_m^3)$$

Where :

- E_p = flex modulus of plastic (psi)
- E_m = flex modulus of metal (psi)
- I_m = moment of inertia, metal (in.)⁴
- I_p = moment of inertia, plastic (in.)⁴
- B = element width
- t_p = wall thickness, plastic (in.)
- t_m = wall thickness, metal (in.)

For example, to replace a 0.060" thick aluminum wall in a die casting, with a glass reinforced nylon and maintain equal stiffness:

$$E_{\text{aluminum}} = 10^7 \text{ psi} \quad E_{\text{plastic (GF nylon)}} = 10^6 \text{ psi}$$

$$t_p^3 = (E_m / E_p) t_m^3 = (10^7 / 10^6) (0.060)^3 = .00216$$

$$t_p = \sqrt[3]{.00216} = 0.129''$$

The GF nylon wall thickness would have to be 0.129" to be equal in stiffness to an aluminum wall of 0.060"

WALL THICKNESS

DESIGNING FOR EQUAL STRENGTH

To get the same strength in plastic as in metal:

$$(T_p)(CSA_p) = (T_m)(CSA_m)$$

$$CSA_p = (T_m / T_p)(CSA_m)$$

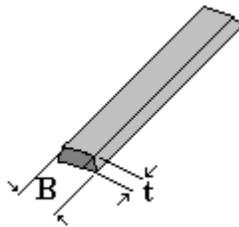
$$CSA = Bt$$

$$CSA_p = Bt_p = (T_m / T_p)(Bt_m)$$

$$t_p = (T_m / T_p)(t_m)$$

Where :

- T_p = tensile strength of plastic (psi)
- T_m = tensile strength of metal (psi)
- CSA_p = cross sectional area, plastic (in.)²
- CSA_m = cross sectional area, metal (in.)²
- B = width of an element (in.)
- t = wall thickness (in.)



For example, to replace a 0.060 in. thick aluminum wall in a die casting, with a mineral reinforced nylon :

$$T_m = 19,000 \text{ psi} \qquad T_p = 9,000 \text{ psi (at 50\% RH)}$$

$$t_p = (19,000 \text{ psi} / 9,000 \text{ psi}) (0.060 \text{ in.}) = 0.127''$$

The wall thickness of the mineral reinforced nylon would have to be 0.127 " thick, to be equal in strength to the 0.060 " thick aluminum die casting.

WALL THICKNESS

POLYMER FLOW:

The approximate maximum flow length to thickness ratio for unfilled nylon is **250:1**. This will decrease as you add fillers and or reinforcements. Flow length is also greatly influenced by injection pressure, cavity fill rate, gate size, melt and mold temperature.

MOLD SHRINKAGE:

Thicker parts cool slower, which result in increased "as-molded" crystallinity, and thus greater shrinkage. Typical shrink values for an unfilled nylon, obtained with various wall thicknesses, are shown in table 2.0.

Table 2.0

Wall thickness, in.	Mold Shrinkage, in / in.
0.060	0.008 - 0.015
0.125	0.010 - 0.020
0.250	0.017 - 0.025

CYCLE TIME:

The thickest wall section of the part is the dominant factor in determining overall cycle time. A rough guide to estimate total cycle time for unfilled nylon (22L-N) is 30 seconds per 1/8 inch thickness. Nucleated or filled resins can often be molded on much shorter cycle times. Table 2.1 shows estimated cycle times based on part thickness, using a melt temperature of 550° F and a mold temperature of 200° F.

Table 2.1

Part Thickness (Inches)	Overall Cycle (Seconds)	
	Wellamid GF33-43	Wellamid GF13-66
1/32	7 – 9	9 - 11
1/16	11 – 13	13 - 15
1/8	15 – 20	20 - 25
1/4	30 – 40	35 - 45
1/2	60 – 75	75 - 90

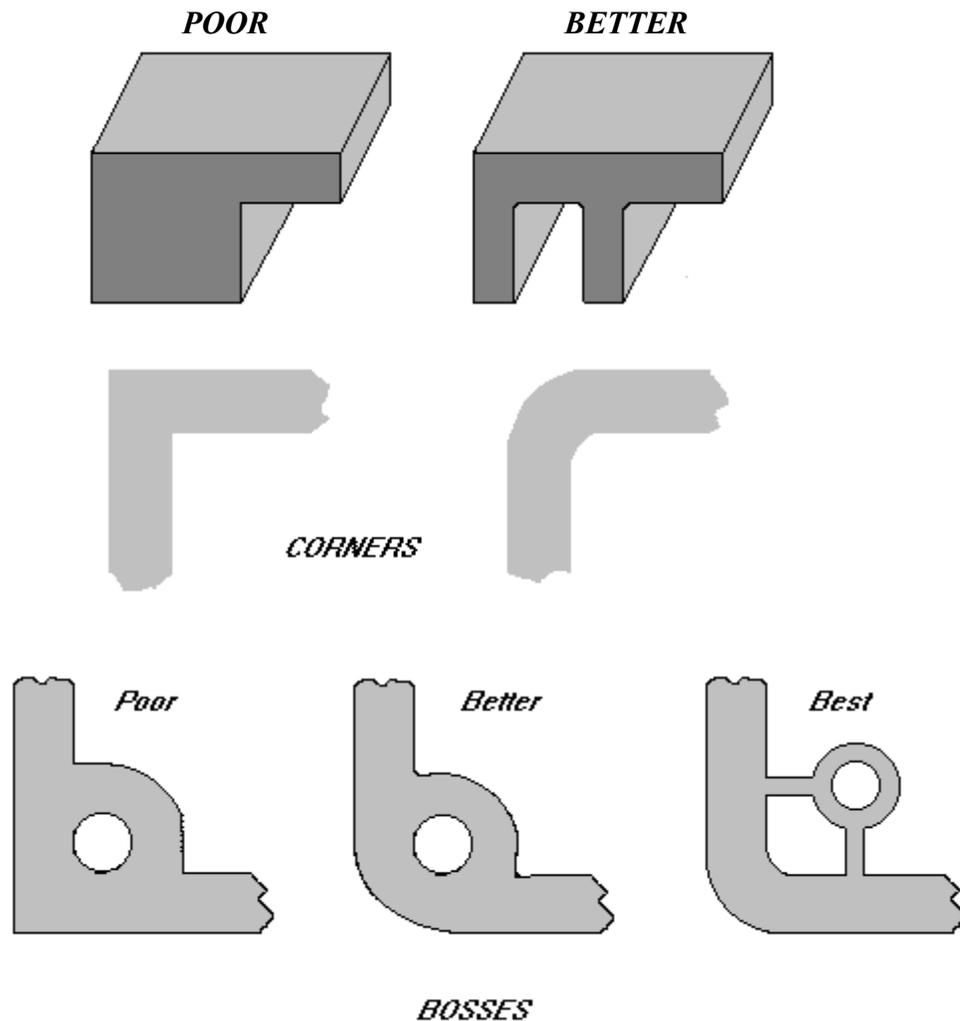
DESIGNING FOR UNIFORM WALLS

The wall thickness should be kept as uniform as possible throughout the plastic part to minimize warpage, internal stress and cracking. If the wall thickness must change, the change should not exceed 15% of the nominal wall and should be gradually blended in.

Plastic is frequently used as a replacement for metal die cast parts. Non-uniform walls are common in metal design, so usually the product design will require modifications before a suitable plastic part is to be obtained.

Figure 2.2 illustrates some examples for designing uniform walls:

Fig. 2.2



GATING

Gates are designed to act as flow monitors and as flow switches. The dimensions of the gate control how much polymer flows through and controls how long the gate stays open by freezing off when flow stops.

Gates are of many designs. The rectangular gate is commonly used because by changing the thickness it is possible to change gate freeze time. Conversely changing the width of the gate will control the amount of polymer that will flow for a given amount of time. Round gates are also very popular but lose the independent control on freeze off and flow rate. A change in dimension in a round gate will change both freeze and flow rates.

Listed below in table 2.3 are some popular gate types other than round and rectangular gates:

Table 2.3

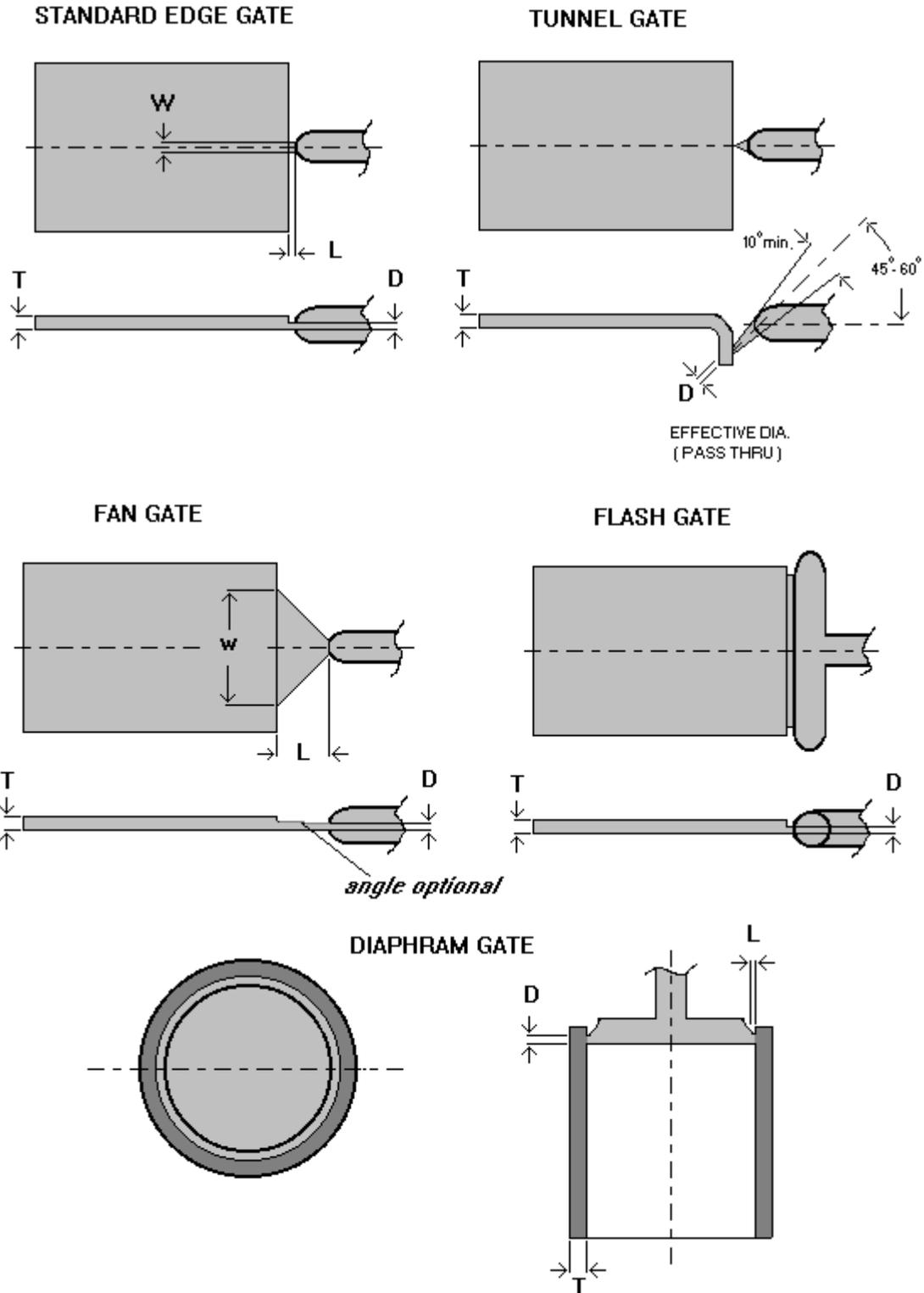
<u>GATE TYPE</u>	<u>APPLICATION</u>
Fan gate	Uniform filling of thin parts
Flash gate	Rapid fill and freeze times
Pin Point gate	Direct gating with 3-plate molds
Tunnel gate (sub-gate)	Automatic degating

Gates should be located in areas which will allow for uniform filling of the cavity. If possible, gate at the thickest section of the part. Try not to gate at a junction of a thick and thin section.

To minimize jetting or splay marks, gates that impinge flow against a wall have proven to be successful. Circular parts that require assured roundness may require gating to take place at the center of the part.

GATING

TYPES OF GATES



GATE SIZING

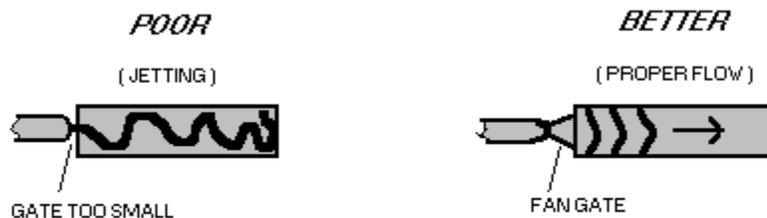
Gate sizing is a balance of part design, mold design, polymer flow characteristics and aesthetics. Material suppliers usually prefer larger gates to assure a minimum amount of shear heat at the gate end, and to maximize part packing. Part producers usually prefer smaller gates for quick cycle times and pleasing appearance. Often, the proper gate size is a compromise of the two.

Gates that are too small can cause excessive shearing and material degradation, excessive mold shrinkage, voids, jetting, sink marks and warpage. Gates that are too large can prolong the cycle time and the excessive gate vestige can be visually unpleasant.

Wellman recommends these general guidelines for minimum gate dimensions.

Rectangular	Gate thickness = 60% of part wall thickness Gate width = 1 to 2 times gate thickness.
Round	Gate diameter = 50% of the wall thickness.

Fig. 2.4

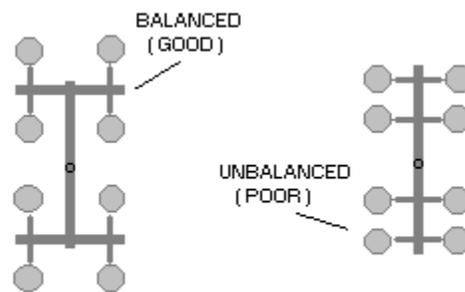


RUNNER DESIGN

Following, are some " Rules of Thumb " for proper runner design:

- 1) In multi-cavity molds the runner should be balanced in that each cavity has the same distance of runner feeding it. To maintain part to part consistency all cavities should fill at the same time and at the same rate. See Fig. 2.5.

Fig. 2.5

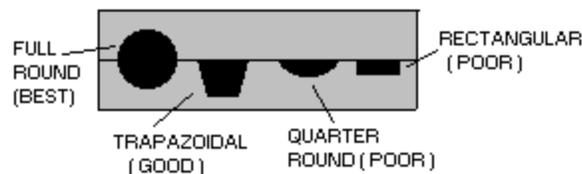


- 2) Runner size is important in that they should be as small as possible to keep rework to a minimum and provide a maximum number of parts per pound

processed, yet large enough to provide adequate cavity pressure with minimal heat and pressure losses. Ideally, the anticipated pressure drop should be calculated and used to size the runner.

- 3) Full round runners are the preferred shape in that they provide a minimum of surface area which gives the lowest heat and pressure losses. Trapezoidal runners also work well and are popular because they only have to be machined into one half of the mold. (Figure 2.6).

Fig. 2.6



VENTING

Vents are small channels cut into the parting line, which should be large enough to allow air and gases to escape during fill, yet small enough to not allow the plastic to escape (or flash).

In general, venting locations are a function of part and mold design. Most molds will require that venting take place at the weld lines, and or, at the end of fill. Round parts that are center gated should have enough vents spaced around the cavity to account for a minimum of 20 % of the total part perimeter.

Wellman nylons are semi-crystalline polymers that turn from a liquid molten state to a solid state in a short period of time. To successfully fill a cavity, fast fill times need to be used. If adequate venting is not available, the resulting entrapment of air may manifest to these problem conditions :

- Weak weld lines.
- Burning of the nylon.
- Cavity corrosion, charring or pitting.
- Shot size variations.

Vents for cavities and runners are recessed areas usually 0.100" to 0.250" wide and 0.0005" to 0.002" deep. The actual depth is determined by the type of material being used. (See table 2.6A) These vents should have short land lengths of 0.030" to 0.060", and then should be gradually deepened to around 0.040" deep and flow out to the exterior of the mold.

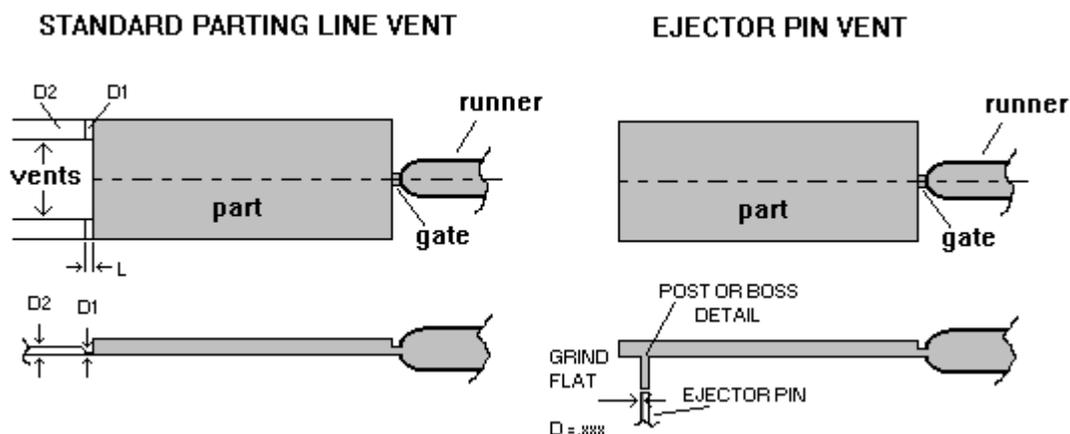


Table 2.6A VENT DIMENSIONS (IN.)

	<u>Depth (D1)</u>	<u>Land (L)</u>
Wellman Unfilled nylon	0.0005" - 0.001"	0.030" - 0.060"
Mineral / Glass Reinforced	0.001" - 0.002"	0.030"

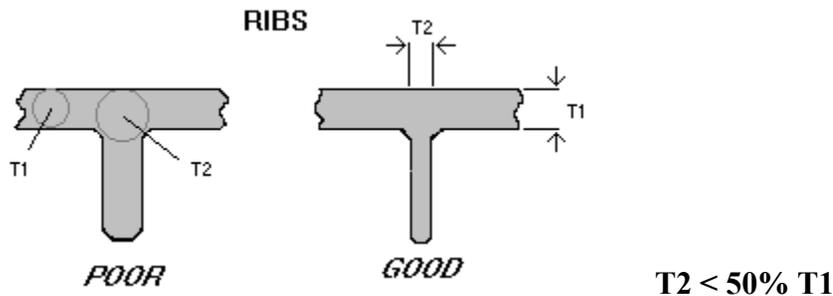
RIBS, BOSSES AND HOLES

RIBS

Ribs are used to add strength and stiffness to molded parts without increasing section thickness. Ribs should be no thicker than 50% of the adjacent wall in order to minimize sink (depression) marks. Try to avoid placing ribs behind "class A" surfaces requiring high gloss finishes because even the thinnest of ribs can sometimes produce a sink. Textured surfaces can hide these depressions.

The overall height of the rib should be no more than 5 times the thickness of the adjacent wall. All ribs should have a minimum of 1/2 degree draft per side and 0.010" - 0.040" radius at the base. The larger the radius the better, however, this will enlarge the effective rib thickness at the base and possibly increase potential for sink marks. (See Figure 2.7).

Fig. 2.7



BOSSES

Bosses are projections from the nominal wall which serve as reinforcement around holes for mounting purposes. The same design principles you would use for ribs apply for bosses as well. (See Figure 2.8). If the boss is designed for use with self tapping screws, one should use the following design procedures:

Boss hole dimension

For maximum stripping force use a hole diameter that is equal to and not smaller than the core diameter of the screw. (Core diameter is equal to screw diameter with the threads removed).

Boss outside diameter

Make the outside boss diameter 2.0 times the boss hole diameter. Thinner bosses may be prone to crack. Thicker bosses add very little in additional strength.

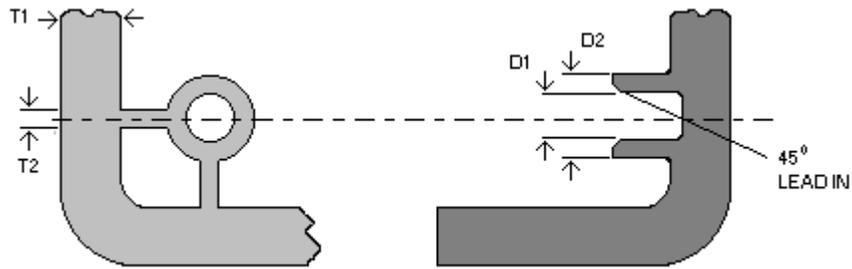
Screw engagement length

Stripping torque rises rapidly as engagement length increases. It levels off at around 2.5 times pitch diameter of screw.

RIBS, BOSSES AND HOLES

BOSSES

Fig. 2.8



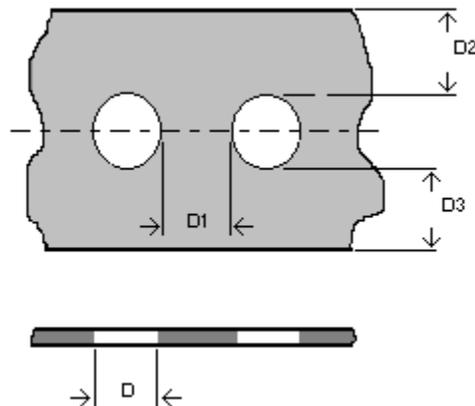
D1 = 80 % of screw O.D.

D2 = 2.5 x D1

HOLES

Through holes are easily produced by core pins that are supported at both ends and preferred to blind holes which are produced by core pins supported at only one end. The blind hole depth is more limited and usually held to twice the diameter of the core pin. If greater depth is required a stepped core pin and or stepped hole should be used. Holes should be located no closer than one diameter away from the edge of the part or adjacent wall. (See figure 2.9)

Fig. 2.9



D1 = or > D

D2 = or > D

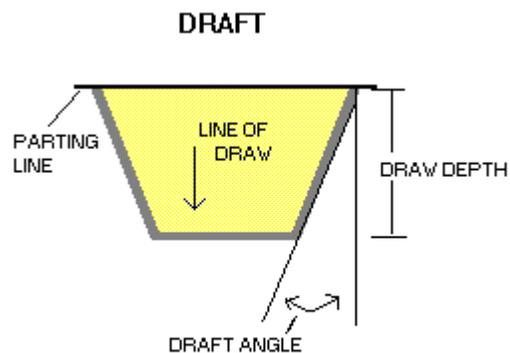
D3 = or > D

DRAFT AND UNDERCUTS

DRAFT

Draft is taper in the line of draw. Ribs, bosses and side walls should have a minimum draft of $1/2^\circ$ per side and be draw polished to minimize drag resistance during part ejection. Deep draw parts may require $1-2^\circ$ draft per side. Textured surfaces will require 1° draft per 0.001" grain depth. See figure 2.10.

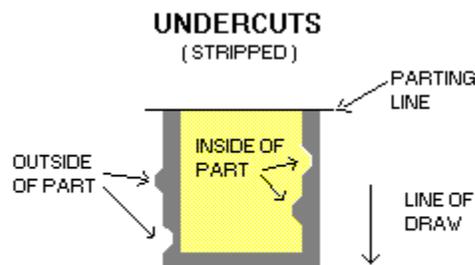
Fig. 2.10



UNDERCUTS

Undercuts are formed by either collapsible cores, split cavities or stripping the part from the core. The amount of undercut allowable for stripping depends upon tool design, material type and mold temperature. With unfilled nylons undercuts up to 10% have been stripped successfully. Reinforced nylons should be limited to under 2%. Hot molds around 200°F and well rounded corners will ease part removal.

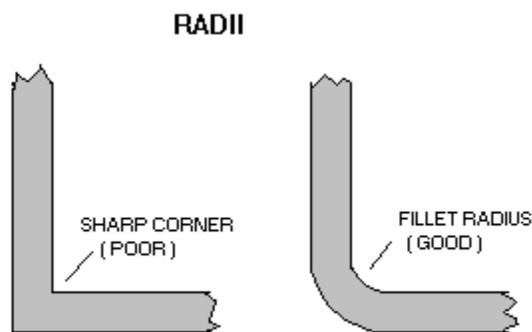
Fig. 2.11



RADII

All corners should have a minimum of 0.020" radii. Generally, the greater the amount of radii the stronger the corner. Sharp corners are stress concentrators and can cause poor flow patterns and reduce mechanical properties. Generous radii will promote easier flow and part ejection, reduce stress and improve part strength. (Figure 2.12)

Fig. 2.12

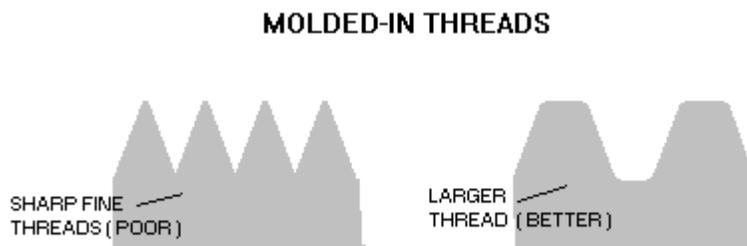


THREADS

Internal molded-in threads usually require an unscrewing mechanism, which can make tooling complicated and costly. External molded-in threads can be molded in split cavities, but will have a parting line across the thread. With nylon, both internal and external threads are commonly used with success.

Pipe threads, sharp V type or very fine threads should be avoided when designing with plastic. Plastic threads should have well rounded roots and crests. (Figure 2.13)

Fig. 2.13



MOLD SHRINKAGE

Mold shrinkage is the expected difference in dimensions between cavity steel and fully cooled parts. All plastic experience volume reduction as they cool. Crystallization causes additional volume reduction which means more shrinkage.

Mold shrinkage is usually expressed as in. / in., but can sometimes be expressed as a percentage or in mils / in. In other words:

0.005" in. / in. shrinkage = 0.5% shrinkage = 5 mils / in. shrinkage

The shrinkage of parts molded from Wellamid resins is characteristic of each grade and dependent on the thickness and geometry of the molded part, molding conditions, and post molding conditions such as annealing and moisture conditioning.

Part thickness is one of the most significant factors affecting mold shrinkage. Thinner parts shrink less, and thicker parts more. Typical shrinkage values obtained with various wall thicknesses for an unfilled nylon are shown in table 2.14.

Table 2.14

Wall Thickness, in.	Mold Shrinkage, in. / in.
0.060	0.008 - 0.015
0.125	0.010 - 0.020
0.250	0.015 - 0.025
0.500	0.025 - 0.040

Processing conditions can have a significant effect on mold shrinkage. The following adjustments decrease mold shrinkage, making the molded part larger:

- 1. Reduce wall thickness**
- 2. Increase injection pressure**
- 3. Increase injection forward time**
- 4. Increase gate size**
- 5. Lower mold temperature**
- 6. Lower material temperature**
- 7. Increase injection speed**
- 8. Increase cycle time.**

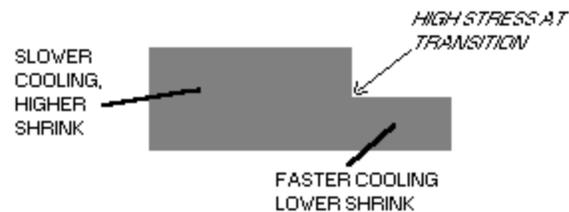
WARPAGE

Warpage is the result of non-uniform shrinkage. Non-uniform shrinkage can be caused by:

WALL THICKNESS VARIATIONS

Thicker sections will cool slower than thin sections, resulting in a higher crystalline content and higher shrinkage. (Figure 2.15)

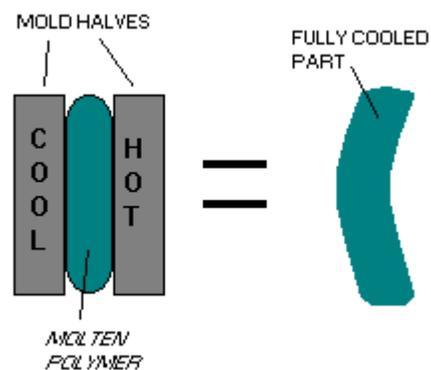
Fig. 2.15



TEMPERATURE DIFFERENTIALS

Warping can occur if the mold surfaces are at different temperatures, or if one area of the part cools at a different rate. (Figure 2.16)

Fig. 2.16

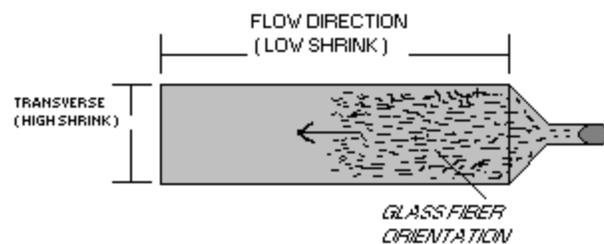


WARPAGE

ORIENTATION

With glass fiber reinforced materials, the fibers will orientate in the direction of flow (like logs in a river) creating less shrinkage in the flow direction. (Figure 2.17)

Fig. 2.17



PRESSURE DISTRIBUTION

An even pressure distribution is required for a balanced packing of the part. Variations in pressure can result in un-even shrinkage causing warp. Gate size, gate location, processing and part geometry determine how evenly the pressure is distributed. (Figure 2.18)

Fig. 2.18



End gating long thin parts minimizes warpage by providing a gradual pressure drop across the cavity.

SECTION 3

ASSEMBLY TECHNIQUES

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- Welding	44
- Adhesive bonding	46
- Snap fit	47

SELF TAPPING SCREWS

Mechanical assembly using self-tapping screws can provide an economical fastening technique. Because of the differences in nylon compositions and the many screw designs, there are no universal guidelines that can predict with absolute certainty their interaction. The vast number of materials, screw designs, sizes and configurations preclude a detailed study that would provide precise and specific data on every combination. There are however, some general guidelines that will provide adequate design procedures.

SCREW TYPES

There are two major types of self-tapping screws : thread forming and thread cutting. As their names imply, thread cutting screws cut and remove plastic from the thread area as the screw is inserted. Thread forming screws deform the material as it is inserted, forming threads along the way.

Which type of screw to use is best determined by the flexural modulus of the materials into which the screw will be inserted. Basically, flexible and malleable materials with a flexural modulus below 250,000 psi are best suited for thread forming screws, while thread cutting screws are used in stiff and inelastic materials with a modulus above 450,000 psi.

Unfilled and unreinforced nylons with flexural modulus of 250,000 to 450,000 psi are in the range that the type of screw used is indeterminate. Both have been used with success. The use of thread forming screws will require greater care in design but if repeated assembly and disassembly are required, it is the preferred screw type. To reduce the high hoop stress that these screws produce a number of screw designs that use sharper threads have shown promise. Screws employing triangular shape and using dual height threads are variations on that theme.

One thing to remember when using self-tapping screws is that for a high strip to torque ratio (which is good), all parts should be free of oil or other lubricants. Also, holding power can be increased if at joining time either the plastic or the screws are heated to around 200 ° F. This will provide thermoforming action to some degree and will keep the stress level down.

For additional guidance, screw fastener manufactures should be consulted. They provide a primary and important source of design procedures and recommended screw designs.

THREADED INSERTS

If a part is expected to be disassembled and re-assembled repeatedly, the use of threaded inserts is recommended. Threaded inserts come in a wide variety of sizes and types and can be "molded-in" or inserted into a boss or through hole later by ultrasonic or mechanical means.

MOLDED-IN inserts may require pre-heating up to 200 ° F in order to reduce stress around the insert and improve weld line strength. Hand loaded inserts usually result in slower cycle times and can become dislocated, causing damage to the mold.

MECHANICAL push-in type insertion can be relatively inexpensive but will induce high levels of stress and only fair holding power.

ULTRASONIC insertion is preferred to mechanical insertion because the plastic is melted around the insert creating a very strong bond with very little induced stress. Ultrasonic machinery can be expensive and involves a secondary operation.

WELDING

Joining two of the same or similar plastic types by thermal welding is a very common method of assembly, and can be accomplished by various means as follows:

ULTRASONIC WELDING is very popular with the smaller parts. The equipment and power required can be costly and uneconomical for the larger parts. The process involves the use of very high frequency (20 - 40 kHz) vibrational energy directed to a joint in the interface area, which causes the plastic at the joint to melt. Follow-up pressure as the melt cools causes rapid solidification creating a very strong bond in a very short time. For optimum weld strength, nylon parts should be dry as molded.

VIBRATIONAL WELDING relies on frictional heat to melt the plastic. The two parts are more or less "rubbed" together through a lower frequency vibration (120 - 240 Hz) until the interface is molten. Bonding occurs as the melt cools. Vibration welding is popular with the larger parts.

WELDING

SPIN WELDING is designed for circular surfaces and much like vibration welding relies on frictional heat. This process involves the "spinning" of one part which is pressed to a fixed part creating the frictional heat necessary for melting to occur in the joint area. Once melted, the rotation stops. Pressure is maintained as the melt cools creating a bond. The equipment required for spin welding can be rather simple and relatively inexpensive.

HOT PLATE WELDING is a form of thermal welding. Melting at the joint interface is the result of direct application of the plastic's surface to hot platens. This process is not recommend for use with nylon. Nylon's crystalline nature can cause the molten weld line area to partially solidify before the parts are fully joined, creating a weak weld.

ELECTROMAGNETIC WELDING uses inductive energy and requires the use of an additional part, or preform, made from a special magnetically active material which is placed in the joint interface area. The preform will melt when activated by a radio frequency magnetic field and will fuse to the mating parts causing polymer to polymer linkage. Electromagnetic welding has many advantages, such as: large partcapability, the process can be fully automated, joints can be welded in more than one plane, and potential exists to "unweld" the part by reactivating the bond line. Disadvantages are that it can be costly, and the part needs to remain free of metal in the weld line area so as not to be subjected to the radio frequency field.

With any of the aforementioned welding techniques a proper joint design is essential to the ultimate success of the weld. For additional guidance welding equipment manufacturers should be consulted. They can provide more detailed information regarding joint design procedures and welding equipment. Manufactures of welding equipment include:

BRANSON SONIC POWER CO.
Eagle road, Danbury CT 06810

DUKANE CORP.
St. Charles, Ill. 60174

EMABOND INC.
Norwood N.J.

**FORWARD TECHNOLOGY
INDUSTRIES INC.**
Minneapolis, MN 55441

ADHESIVE BONDING

Adhesive bonding can be used to join nylon parts or to join nylon to dissimilar materials. The process is best suited for low volume or prototyping operations that assemble large or complicated shapes.

Recent regulations set forth by EPA and OSHA altered the use of many adhesive technologies. Hence, no particular grade of adhesive can be universally recommended. Adhesive suppliers offer the best source of information on the techniques and type of adhesive used. A partial listing of the many suppliers are listed below.

Regardless of the adhesive used, the following information applies to assembling with adhesive bonding:

- Lap joints or tongue and groove joints will provide a much stronger bond than butt joints. The larger the joint surface area the better.
- A fixture is desirable to prevent movement of pieces during cementing and curing.

ADHESIVES SUPPLIERS

National Starch & Chemicals

10 FINDERNE AVENUE
BRIDGWATER, NJ 08807
(201) 685-5418

Ciba-Geigy

4917 DAWN AVENUE
E. LANSING, MI 48823
(517) 351-5900

Loctite Corp.

705 NORTH MOUNTAIN ROAD
NEWINGTON, CT 06111
1-800-323-5106

Reichold Chemicals

525 N. BROADWAY
WHITE PLAINS, NY 10603
(914) 682-5700

ITW Adhesive Systems

30 ENDICOTT STREET
DANVERS, MA 01923
(617) 777-1100

Lord Corp. (Tyrite Tradename)

2010 W. GRANDVIEW BLVD>
ERIE, PA 16514
(814) 868-3611

SNAP FIT

In all molded-in snap fit designs, a section in the joint area must be able to flex during assembly and then return again or "snap back" to its original position, locking the two mating halves together. The applied bending stress which occurs during deflection must not exceed the allowable strain limit of the material. (Figure 3.0)

Bending stress can be reduced by moisture conditioning "dry as molded" parts prior to assembly, or by making the locking tabs longer and or thinner.

Fig. 3.0 FLEXING FINGER DESIGN

$$Y = FL^3 / 3EI$$

$$S = FLC / I$$

Combining:

$$3YEI / L^3 = F = SI / LC$$

$$3YE / L^2 = S / C$$

$$S = 3YEC / L^2$$

F = force (lbs.)

E = flex modulus (psi)

I = moment of inertia (in.)⁴

L = length (in.)

T = beam thickness (in.)

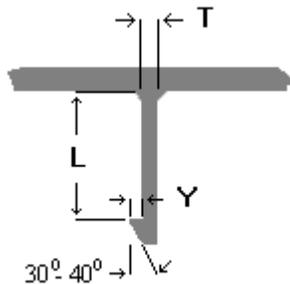
Y = deflection (in.)

S = stress (psi)

C = distance to neutral axis (in.) or T / 2

The snap fit flexing finger, or cantilever lug, is a very popular assembly method. The undercut is usually formed by a core projecting through the part in line of draw, or by a moving side core. Tapering the lug will promote a more uniform stress distribution. All sharp corners should be eliminated, especially at the lug or tab. (Figure 3.1)

Fig. 3.1



SECTION 4

ENVIRONMENTAL EFFECTS

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- Friction.....55

ENVIRONMENTAL EFFECTS**DIMENSIONAL STABILITY**

Wellman Nylons are used with success in many applications where dimensional stability is critical. All successes are the result of careful prototype environmental testing and cannot be forecast by simple calculations. Nylons do absorb moisture and they do change in dimensions, but the dimensional change is often small and it is predictable. Therefore the key to understanding dimensional stability is to understand the variables that will affect dimensions.

Two forces act upon nylons after molding. The first is the absorption of moisture which will cause the volume of the nylon to grow and the second is stress relief, the relaxation of the nylon at a molecular level, which will cause the resin to shrink. The two forces act in opposite directions and tend to cancel each other out resulting in part dimensions that are very close to "dry as molded" dimensions. In controlled environments, the two forces are quite apparent. Freshly molded samples shrink during stress relief, then when exposed to an ambient environment grow with the absorption of moisture.

ABSORPTION OF MOISTURE

The amount of moisture absorption is dependent upon the environment that the part will be exposed to. Constantly varying humidity levels that are experienced in most environments produce no true equilibrium moisture level. However, this does not present a dimensional problem in that conditioned nylons absorb and give up moisture very slowly. For all practical purposes, unless the part is in an extreme environment (water submersion or heated oven, etc.), typical humidity levels fall between 50 to 70% and produce moisture levels of 2.5 to 3.0%. Figure 4.0 is an illustration of the amount of moisture content achieved under constant humidity environments. The dimensional change in nylon as a function of moisture content is illustrated in figure 4.1.

Examining the dimensional change of unfilled 66 nylon from the dry as molded condition to total saturation, (8.5% water by weight), nearly 80% of the entire dimensional change occurs between 70% RH (4.3% water) and 100% RH (8.5% water). 50% RH produces 11% of the total change, and 60% RH produces 13%, only very high humidity levels produce significant nylon growth.

DIMENSIONAL STABILITY

Fig. 4.0

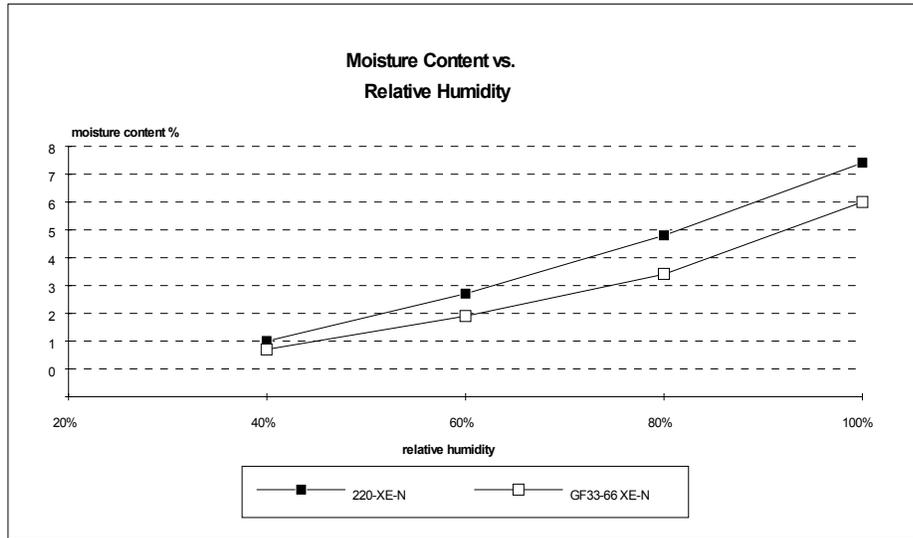
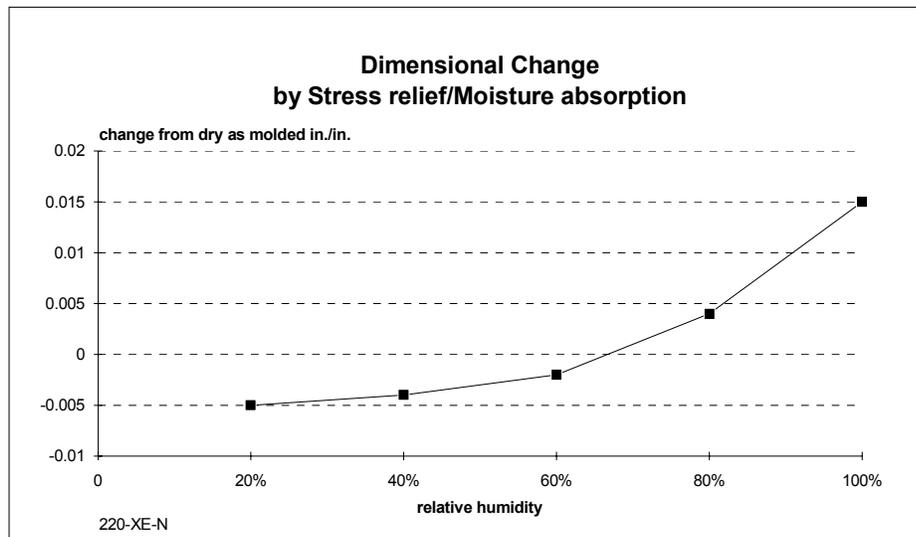


Fig. 4.1



DIMENSIONAL STABILITY

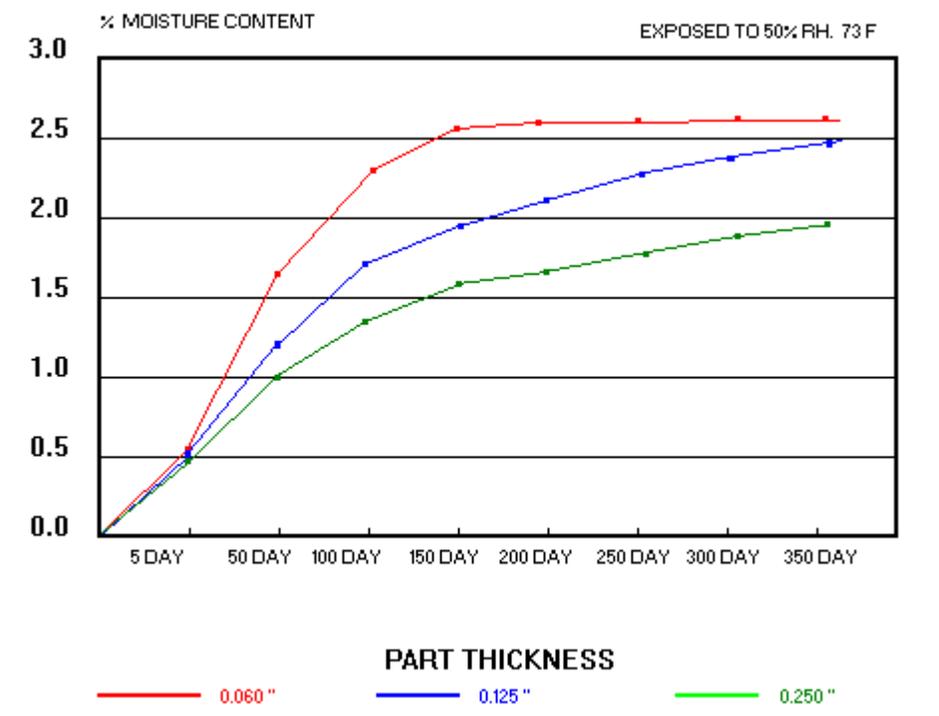
STRESS RELIEF

The second variable in dimensional stability is stress relief and relaxation of the nylon, the final orientation of the nylon at a molecular level. All injection molded plastic parts have some degree of molded-in stress, this variable is the most difficult to predict and is part specific. An equation of stress relief derived from one part will not accurately predict stress relief of another part design. In today's more sophisticated moldings, large dimensional changes may occur in a most critical dimension or may produce no change in the dimensionally critical area while all movement is taking place elsewhere in the part. This phenomenon may stem from gate location, molding parameters, flow patterns and varying wall thickness or part handling after molding.

TIME

The time in which nylon becomes fully equilibrated to its working environment (stress relief completed and moisture absorbed) is dependent upon part thickness and part design. Equilibration of thin moldings will produce dimensionally stable parts in a day or two while thicker moldings will take many days. Regardless of the amount of total change, the change will continue to specific point then stop. The amount of stress relief is fixed and the change due to a specific moisture level is fixed. Figure 4.2 will provide general guidelines for the time involved for moisture absorption.

Fig. 4.2 MOISTURE CONTENT VS. TIME
Wellamid (22L-N)

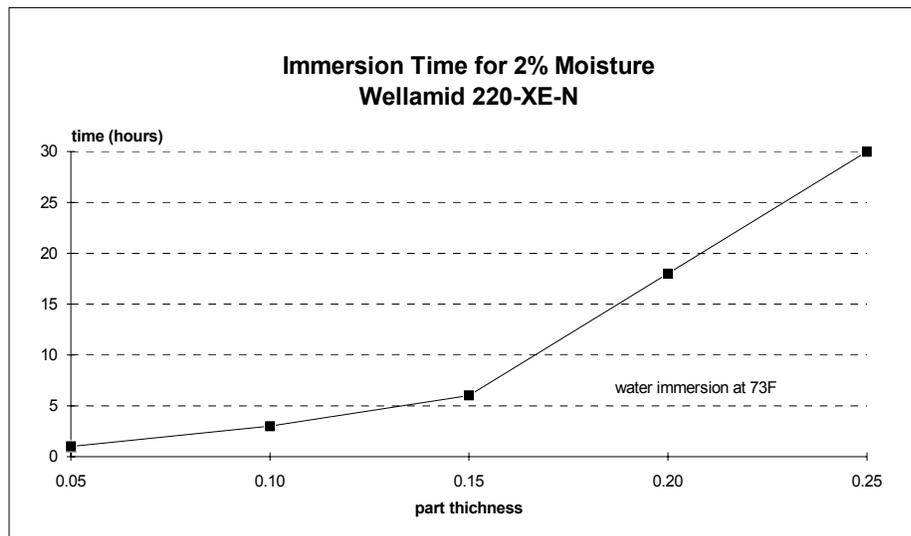


EFFECTS OF MOISTURE ON TOUGHNESS

Part toughness is influenced by the moisture level of the nylon. Wellman nylons, like many other engineering polymers are hygroscopic. Hygroscopic polymers absorb moisture from the air. To successfully mold Wellman nylon, the nylon must be dried to low moisture levels (.25% or below). Once molded the nylon will slowly pick up moisture from the air, usually 2.5% moisture. Parts of low moisture levels will exhibit poorer toughness characteristics. Conversely, parts that have had a chance to absorb moisture from the air will exhibit better toughness characteristics.

The time involved for moisture absorption and better toughness characteristics to result is dependent upon the relative humidity and temperature of the environment, and the thickness of the part. Thin moldings can show improved toughness in a day or two while thicker moldings will take longer. If the time for moisture absorption is not available, providing the nylon an easier access to moisture (part immersion) will shorten the time required for moisture absorption.
(Figure 4.3)

Fig. 4.3



THERMAL EXPANSION AND CONTRACTION

A table listing different coefficient of linear thermal expansions (CLTE) for various Wellman nylons is presented on page 19.

If a nylon part is to be attached to a dissimilar material, and the differences in CLTE are severe, and then exposed to elevated temperatures (such as a paint oven), the differential expansion and contraction must be compensated for or part buckling or bowing can occur.

Severe expansion difference due to thermal effects, are often compensated for by utilizing "slotted" holes (figure 4.4) and only finger tightening the fasteners prior to high heat exposure. Later, after the assembly has fully cooled to room temperature, the fasteners can be fully tightened. This technique is especially common when long, thin plastic parts are attached to steel.

Fig. 4.4

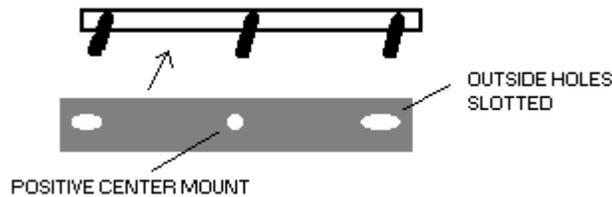


Table 4.5 lists some typical values for CLTE for other common materials.

Table 4.5

MATERIAL	CLTE in./in.^o F 10⁻⁵
Polyethylene	7.1
Polypropylene	4.9
Acetal	4.7
Nylon	4.5
ABS	4.1
Polycarbonate	3.5
Nylon GF	1.3
Alluminum alloys	1.2
Copper alloys	1.0
Concrete	0.7
Iron and Steel	0.6
Glass	0.5

CREEP AND FATIGUE

CREEP

Creep, or cold flow, is defined as increasing strain over time when subjected to a constant stress. In other words, when a plastic part is put under load there is a given amount of initial deformation (strain) that is a direct result of the modulus of the material. Creep is the following additional part deformation, or dimensional change, that can continue to increase even though the load has not increased and is held constant.

The amount and rate of creep depends on the type of material, applied loads, temperature, time and moisture content.

Crystalline resins typically have lower creep rates than amorphous resins. The addition of glass fibers or mineral as reinforcements improve creep resistance in all Wellman nylons.

FATIGUE

Fatigue testing attempts to measure how well a material can withstand repeated loadings.

When a plastic part fails due to repeated or cyclic impacts, tension and or compressive stresses, vibration, or any combination thereof, the failure is deemed a fatigue failure.

Examples of applications where fatigue could come into play are: flexing fingers for snap fit assembly, latches, springs, gear teeth and bearings.

Wellman nylons generally provide excellent resistance to fatigue failures, due to their outstanding chemical resistance and high temperature properties.

FRICITION

The wear and frictional characteristics of Wellman nylons are excellent. Nylons in general have very good lubricity and tend to have a low coefficient of friction with themselves or other materials, and can often be used in applications without any lubricants. However, Wellman can supply special formulations containing extra lubricants, which can improve the frictional properties further still. (See table 4.6)

The excellent wear resistance and natural lubricity inherent of unfilled nylon is often retained with the addition of mineral and glass fiber reinforcements.

Because of the many different variables that can be involved in actual applications placed in high frictional environments, the importance of end use testing cannot be overlooked.

Table 4.6

	<u>COEFFICIENT OF FRICTION</u>			
MATERIAL	STATIC VS ITSELF	KINETIC VS ITSELF	STATIC VS STEEL	KINETIC VS STEEL
22LH-NBK1	.18	.18	.17	.17
22LH-NBK1 (+ 3% Silicone)	.17	.17	.22	.22
GS40-66	.21	.21	.21	.21
GS40-66 (+ 3% Silicone)	.19	.17	.19	.19
WE1315 BK	.29	.29	.28	.28
WE1315 BK (+ 3% Silicone)	.23	.23	.23	.23
GF20-60 XE-NBK1	.21	.21	.22	.22
GFX 1356 BK01	.17	.17	.23	.23