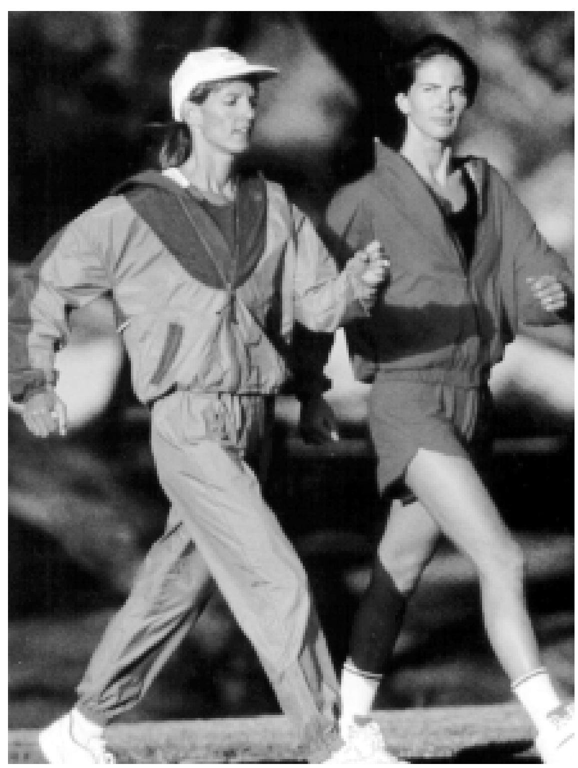
Product Properties and Applications Guide

DuPont Nylon

Nylon 66 Polymer

for Industrial, Textile, and Furnishing Applications



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Nylon—A DuPont Invention

DuPont researchers, led by Dr. Wallace Carothers, invented nylon 66 polymer in the 1930s. Nylon, the generic name for a group of synthetic fibers, was the first of the “miracle” yarns made entirely from chemical ingredients through the process of polymerization.

Nylon 66 polymer chip can be extruded through spinnerets into fiber filaments or molded and formed into a variety of finished engineered structures.

The Nylon Fiber Design Advantage

In 1939, the introduction of nylon into sheer stockings revolutionized the women’s hosiery market. Silk and cotton were quickly replaced by this more durable and easy-care product.

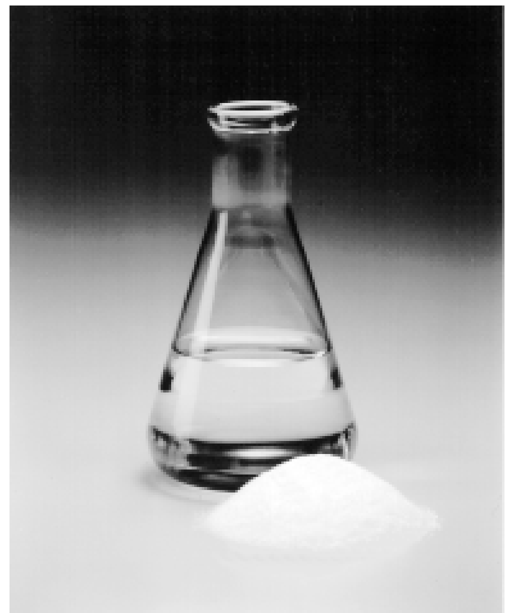
Nylon soon found its way into other end uses. In parachutes and fishing line, nylon provided a moisture- and mildew-resistant replacement for silk. In flak vests, nylon offered a strength and durability previously unattainable for protection against shell fragments. And, when used as aircraft tire reinforcement, nylon enabled heavy bombers to land safely on improvised airstrips.

Today, as the global leader in nylon polymer, DuPont offers a wide range of nylon 66 polymer types for use in industrial, textile, and furnishing/floor covering applications.

Nylon 66 Polymer Synthesis

Nylon 66 (polyhexamethylenediamine adipamide) is a polyamide made from adipic acid and hexamethylenediamine by polycondensation.

The resulting polymer is extruded into a wide range of fiber types. The fibers are drawn, or stretched, in a process that increases their length and reorients the material’s molecules parallel to one another to produce a strong, elastic filament. The thermoplasticity of nylon permits permanent crimping or texturing of the fibers and provides bulk and stretch properties.



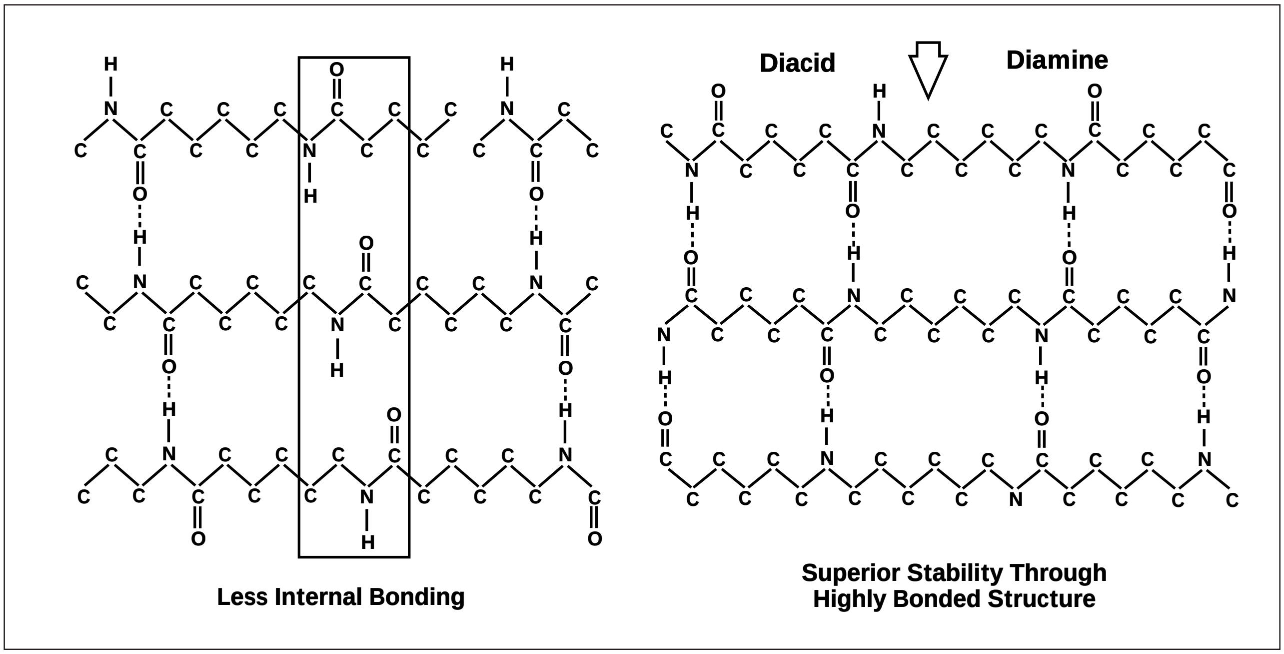
Advantages of Nylon 66

Nylon 66 is superior in many applications to nylon 6—the other large volume nylon—due to its outstanding dimensional stability, higher melting point, and more compact molecular structure (see **Figure 1**).

Nylon 66 exhibits only about half the shrinkage of nylon 6 in steam, for instance. And, with a less open structure, the 66 fiber has good dye wash fastness and UV light-fastness, and excellent performance in high-speed spinning processes. Typical advantages of nylon 66 over nylon 6 are its

- higher tensile strength in use,
- excellent abrasion resistance, and
- higher melting point.

Figure 1. The molecular structure of nylon 6 versus nylon 66 yields enhanced properties.



Nylon 66 provides *high tensile strength* for

- tough fibers at fine deniers,
- excellent performance for tire applications, and
- high-speed mill processing.

Excellent *abrasion resistance* makes nylon 66 polymer ideal for use in

- carpets,
- upholstery, and
- conveyor belts.

The rubber industry takes advantage of the higher melting point of nylon 66 in high-temperature tire curing. A *high melting point* also results in a fiber with

- high stretch and recovery in false-twist textured yarns (e.g., hosiery and socks) and
- thermal stability in high-temperature coating operations.

Also Known As . . .

Nylon 66 (pronounced "six-six") is known by many names. It is also called 6,6 (or 6/6) nylon, polyamide 66, N66, PA66, six-six polymer, and poly (hexamethylenediamine adipamide). All of these terms refer to the DuPont invention of over half a century ago.

Table 1
Advantages of DuPont Nylon 66 in Specific Fiber Applications

When processed into fiber form, DuPont nylon 66 polymer offers many advantages for customer applications.

Hosiery
- Excellent high-speed processing
- High stretch and recovery
- High durability and strength
- Good hand

Weaving and Warp Knitting
- High fiber modulus
  – minimizes yarn distortion possible during winding, warping, knitting, and weaving processes
  – minimizes barré and streaks during dyeing
- Wide operating window for heat setting, dyeing, and processing, which is especially important for fabric combinations with spandex
- Very good resistance to photodegradation
- Good dye light-fastness
- Good dye wet-fastness

Tires and Conveyor Belts
Heavy-duty tires and belts reinforced with nylon 66 polymer are capable of withstanding high temperatures and fast curing cycles. The superior performance is due to the high strength and modulus of nylon 66. Woven and modified nylon 66 tire cord provides aircraft and off-road vehicle tires with long life and high fatigue resistance.

DuPont nylon 66 has particular advantages in industrial products as a result of the polyamide's
- high melting point,
- superior dimensional stability, and
- reduced moisture sensitivity.

Coated Fabrics
Nylon 66 fabrics withstand coating temperatures with PU, PVC, and rubber up to 200°C (392°F) and display good dimensional stability for coating integrity.

Carpeting
During the late 1950s, two new developments opened up a new era for the carpet industry. First, equipment was developed to tuft carpet yarn into a backing material to produce pile carpeting. At the same time, DuPont invented a technique to impart bulk or "loft" to nylon by a fluid-texturing process called Bulk Continuous Filament (BCF). The combination of nylon 66 yarns, textured by the BCF process, yields carpets with
- high abrasion resistance,
- high resistance to pile crushing and matting,
- ease of level dyeing,
- high dye light-fastness, and
- high dye wet/wash-fastness.

Carpets of nylon now account for nearly 70% in a market that was once the exclusive domain of wool yarns.

The DuPont Product Offering

DuPont offers a wide range of nylon 66 polymer chip for use in industrial, textile, and furnishing/floor covering applications.

Industrial

For industrial uses, we offer polymers

- for direct use and post-polymerization,
- for light and heavy denier applications, and
- with thermal stabilizer packages.

Textile

DuPont provides the textile industry nylon with unsurpassed flexibility in design, including

- a complete line of lusters (from 0.0 to 1.8% TiO_2),
- types with antioxidant stabilizer packages,
- premium lines for improved spinnability, and
- products for all types of remelt processes.

Furnishings/Floor Coverings

DuPont offers the furnishings/floor coverings industry

- a complete line of lusters (from 0.0 to 1.0% TiO_2),
- products for direct use and post-polymerization feed,
- products intended for color addition during remelt, and
- a full line of dye variant polymers for yarn styling formulations.

Customer Needs Matched with Nylon 66 Polymer Types

DuPont currently produces about two dozen types of nylon 66 polymer for customer uses. We are pleased to match customer needs with an optimum nylon 66 product formulation. For more information, contact a DuPont Nylon inquiry/sales office listed on the back cover.

Engineering Polymers

DuPont also manufactures a wide grade range of nylon engineering polymers for injection molding and extrusion. These resins are used in automotive parts, electrical and electronic applications, machine parts, films, wire coatings, and monofilament. Engineering resins can also be glass reinforced, mineral filled, or otherwise modified to improve performance. For more information about the complete line of DuPont Zytel® nylon resins and Minlon® engineering thermoplastic resins, contact a DuPont Engineering Polymers inquiry/sales office listed on the back cover.

Use of Nylon 66 in Fiber Manufacturing

The processing of nylon usually begins by conditioning the received chip, with or without an increase in the as-received molecular weight. The chip is then melted, usually in a screw-type extruder, and spun into filament form. The filaments are then packaged in a process that may include drawing, bulking, or cutting into lengths of staple.

Preparing Nylon 66 Chip

Chip is normally conditioned in an inert atmosphere at temperatures in the 120–180°C (248–356°F) range. Processors may employ higher temperatures to increase molecular weight, especially for industrial uses. Both batch- and continuous-type conditioners may be used. It is important to avoid excessive exposure of the chip to oxygen, which may lead to degradation and yellowing of the product.

Remelting Nylon 66 Chip

Remelting is normally performed in a single or twin screw-type extruder, although the melting can be done in a heated grid-type melter. Single screws are preferred for smaller spinning plants because of their simplicity. Twin screws are preferred for larger installations or when more extensive mixing during remelt is required. Equipment must have the capability of heating the polymer to 280–290°C (536–554°F).

Handling of the Molten Polymer

Nylon 66 may produce undesirable cross-linked material (gel) if processing temperatures and holdup times are not properly maintained. Care must be taken to eliminate areas of stagnation in the screw and in the polymer piping. Good engineering practices require the application of optimum shear rates and frequent mixing of the melt.

Conversion—Molten Polymer to Final Product Form

Due to the wide variety of nylon 66 products that can be produced and the range of processing equipment available, it is beyond the scope of this bulletin to specify ideal processing conditions. In general, most modern filament-producing equipment will process nylon 66 polymer adequately. Please consult your DuPont professionals to determine the best nylon 66 polymer and processing conditions to meet your end-use needs.

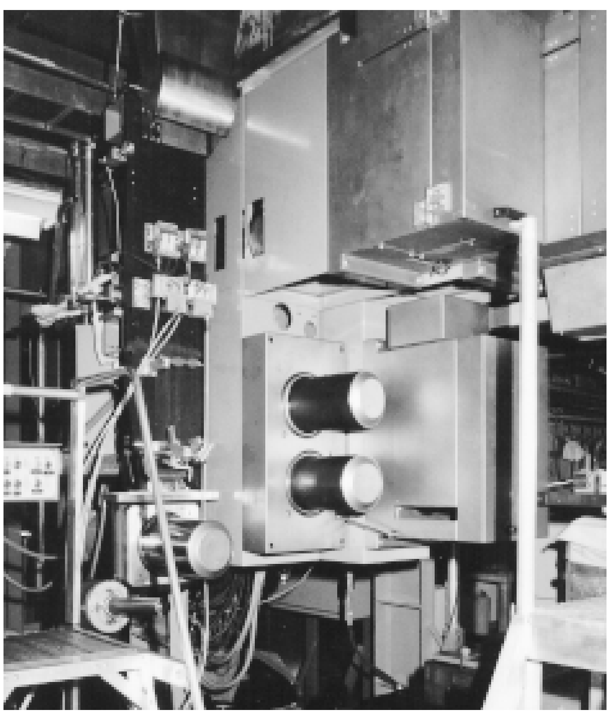
Due to their vast nylon 66 experience, DuPont engineers may be able to, on a case-by-case basis, provide specific advice that will result in higher productivity and lower waste processes.

DuPont Nylon Quality Commitment

The primary DuPont nylon 66 merchant sales plants (Camden, South Carolina, Chattanooga, Tennessee, Seaford, Delaware, USA; Wilton, UK; Rosenburg, The Netherlands; and Kingston, Ontario, Canada) are all registered to ISO 9002, the internationally recognized standard for quality assurance systems. Registration requires regular inspection of our quality systems by external auditors. All stages of the process are computer-controlled, which helps ensure reproducibility.

Product Quality

While “quality” is an all-embracing concept, the two specific areas that concern both DuPont and its customers are quality of service and quality of product. Quality of service at DuPont is unparalleled, from loading chip at the shipping dock to answering our customers’ calls. Quality of product is vitally important to our customers—and their customers—and is subject to a continuous process of improvement to ensure the highest standards all along the product chain.



Technical Service Support

Experienced technical specialists support production at our nylon plants. Laboratory personnel, located at strategic sites around the world, provide additional analytical assistance.

DuPont has committed the financial resources and the personnel to ensure that we meet customer needs. In the past several years, DuPont has invested over $60 million (U.S.) at our principal polymer sales sites to establish state-of-the-art process control and polymer handling facilities. We believe these facilities are unmatched in the world with regard to manufacturing nylon that meets the needs of our global customers.

Raw Materials

DuPont produces the key raw materials for production of nylon 66 polymer chip—adipic acid and hexamethylenediamine—on manufacturing units registered to ISO 9002 or British Standard 5750.

ISO 9002 Registration Data

Chattanooga: Certificate 11295
Issued February 12, 1990

Wilton: Certificate 1979
Issued February 16, 1990

Rosenburg: Certificate 10034
Issued May 1, 1990

Kingston: Certificate 000523
Issued November 1, 1991

Seaford: Certificate A1700
Issued November 4, 1993

Camden: Certificate A1937
Issued March 8, 1996

Typical Physical Characteristics

Table 2 shows the typical physical characteristics of DuPont nylon 66 polymer. This information should be regarded as a guide to the properties of DuPont nylon 66. Certain variable parameters of nylon 66 polymer are especially important in the specification of the product or in its quality maintenance. Technical information on these parameters (relative viscosity, amine end groups, and moisture content) is found on pages 11–13.

Safe Handling

DuPont nylon 66 polymer is considered an inert material. The primary hazard in its use is the high processing temperatures required to form the polymer into fibers, films, and molded structures. Following are the precautions that should be taken in the interests of health and safety when handling and processing nylons supplied as raw materials.

The discussion does not address the suitability of the materials for applications, nor any precautions that may be necessary during the use of any product made from the materials.

Potential Health Hazards

Inhalation

Nylon 66 polymer does not give off gases or odors at ambient temperatures. However, as with any polymeric material, proper ventilation must be provided around remelt processing areas.

Ingestion

Although polyamides are inert and can be regarded as harmless, certain compositions could contain additives that may be harmful. Therefore, ingestion should be avoided.

Table 2
Typical Physical Characteristics of Nylon 66

Property[a]	Unit	Value	Method/Standard[b]
Specific gravity		1.14	ASTM D792
Density	kg/m^3 (lb/ft^3)	1140 (71.17)	ISO R1183
Melt density	kg/m^3 (lb/ft^3)	965 (60.24)	
Bulk density	kg/m^3 (lb/ft^3)	ca. 670 (41.83)	
Water absorption (24 h)	% %	1.3 1.2	ISO 62 ASTM D570
Melting point	°C (°F)	260 (500)	ISO 1218 or ASTM D789
Glass transition temperature	°C (°F) °C (°F)	100 (212) 90 (194)	ISO 75 or ASTM D648
Self-ignition temperature	°C (°F)	>420 (788)	ASTM D1929
Flash ignition temperature	°C (°F)	>400 (752)	ASTM D1929
Specific heat	J/g·K (ft·lbf/lb·°F)	1.7 (3.16×10^{-4})	In-house method
Thermal conductivity	W/m·K (Btu/ft·h·°F)	0.3 (0.17)	Conco-Fisher apparatus
Flammability (UL)		V2	UL94 at 1.6 mm
Dielectric constant		3.9 at 50 Hz 3.7 at 1 kHz	IEC 250 or ASTM D150
Volume resistivity		10^{13} Ω	IEC 93 or ASTM D257

[a]Actual properties will depend on the type of polymer being used.
[b]Test methods and standards may vary depending on the manufacturing region in our worldwide supply network.

Skin Contact

Nylon 66 polymer is manufactured in a granular form, which does not normally lead to skin irritation. However, it is wise to take the usual precautionary measure of obtaining medical clearance for any employees who have a history of skin disease or allergy.

Potential Flammability Hazards

Typical thermal properties for the basic nylons are provided in **Table 2**. Nylon 66 polymers are flammable, although the materials do not present a severe fire hazard. When nylon 66 is heated, it will melt at about 260°C (500°F). Slow decomposition and discoloration occur in the melt and become significant at 330°C (626°F) and above. The gaseous products of this decomposition are irritating, noxious, and flammable. Significant quantities of flammable gases are produced above about 450°C (842°F). Once ignition occurs, sufficient heat is generated to sustain burning even after the removal of the original ignition source, providing oxygen is available. Burning is accompanied by the release of molten droplets of polymer, which could ignite adjacent flammable materials.

The limiting oxygen index for nylon that does not contain any flame retardant additive is about 25 (dry) or 28 (humidified), depending on type. Conventional fire extinguishers (foam or water) may be used on burning nylon. Sprays are preferable to solid jets of water to avoid spreading the flames, especially in the early stages of a fire.

Explosion

Nylon 66 polymer does not present a dust explosion hazard in the form in which it is supplied by DuPont. However, if it is ground to a fine powder, a dust cloud could ignite; therefore, standard dust precautions are advisable in such cases.

Storage

Store the polymer indoors in dry storage areas, away from heat sources, with natural ventilation and protection from extremes of temperature and humidity. Material spilled on floors should be cleared immediately because the granules may present a slipping hazard.

Packaging and Shipping

DuPont nylon 66 polymer can be supplied in bulk, flexible intermediate bulk containers (FIBCs), corrugated boxes, or sacks depending on such factors as volume and supplying facility.

The following information is representative of our standard arrangements, but packaging may vary by region. Special arrangements are possible to meet individual customer requirements.

Bulk Deliveries

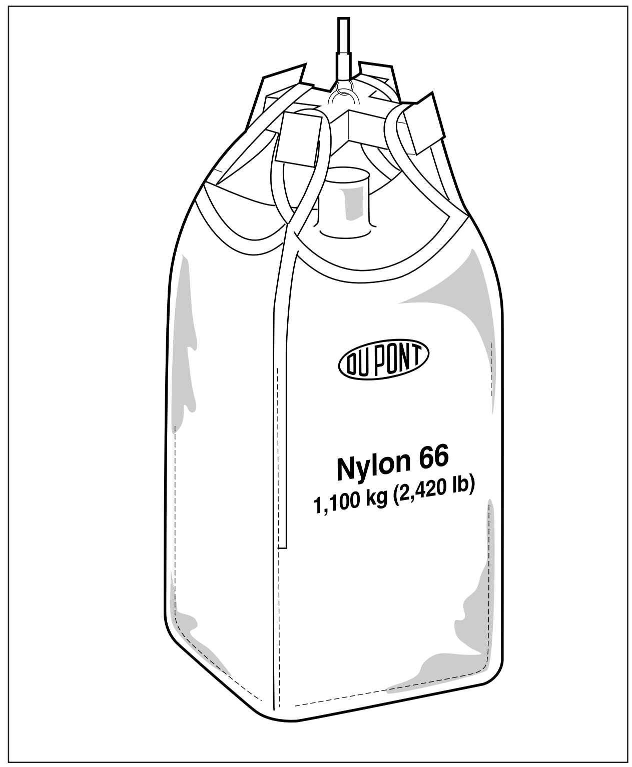
Deliveries may be made in 30-ft or 20-ft ISO containers (see **Figure 2**). Before filling, each ISO container is cleaned and lined with a new polyethylene liner. The liner is reinforced on the bottom and the front. A wooden bulkhead is also fitted at the rear of these containers. The maximum delivery size depends on the local road transportation regulations; a typical load might weigh as much as 19,200 kg (42,300 lb) for a 20-ft container or 23,000 kg (50,700 lb) for a 30-ft container.

Figure 2. 20-ft ISO Container Near a Loading Silo

Flexible Intermediate Bulk Containers (FIBCs)

DuPont 66 nylon is also supplied in polypropylene FIBCs that contain 750–1100 kg (1,650–2,420 lb) of polymer, typically on a 1.1 × 1.1 m pallet. The FIBC (see **Figure 3**) has an inner polyethylene liner to avoid contamination of the product and minimize absorption of moisture. FIBCs may be emptied through a discharge sock in the base or by suction from the top. If emptying from the top, the suction pipe must be placed centrally to keep the FIBC from tipping over during discharge. The typical delivery weighs 19,050 kg (42,000 lb), either on a 40-ft trailer or in a 40-ft ISO container.

Figure 3. Flexible Intermediate Bulk Container (FIBC)



Corrugated Boxes

Polyethylene liners in reusable corrugated containers (see **Figure 4**) help reduce moisture absorption for long-term storage and ocean shipments. Containers are supplied on pallets and each holds approximately 612 kg (1,350 lb). The pallet measures 1.0 × 1.1 m. Typically, a 40-ft container of these boxes will hold approximately 18,400 kg (40,500 lb) of polymer.

Figure 4. Corrugated Boxes (with Separate Tops)

Important Safety Factors When Emptying ISO Containers

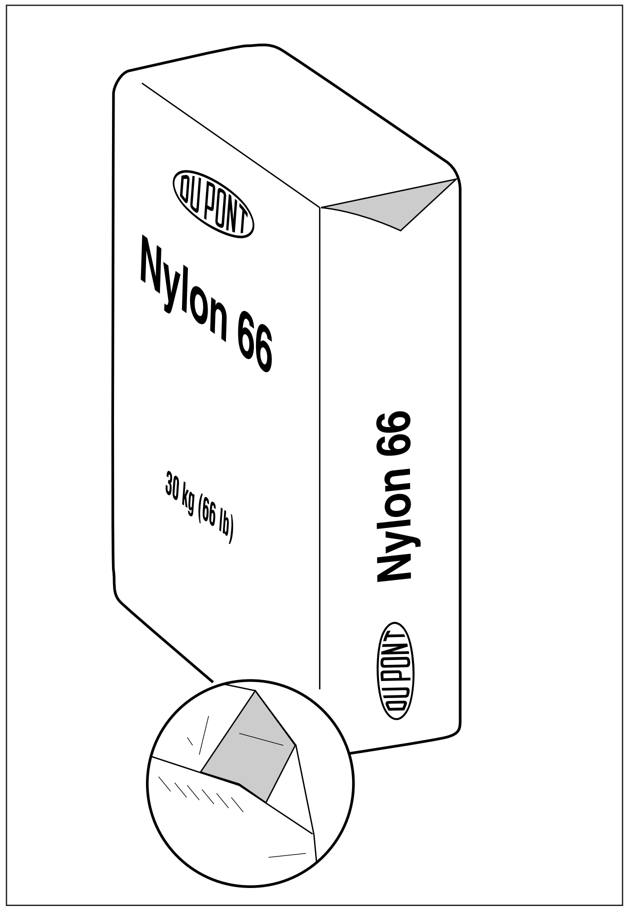
Containers are tipped to enable them to be discharged. It is important to ensure that:

- Headroom is at least equal to the length of the container to allow it to be fully tipped.
- The container is securely attached to the trailer.
- Great care is taken when containers are tipped in exposed situations or on windy days.
- All handling equipment is electrically grounded.

Sacks

DuPont nylon 66 may be supplied in 30-kg (66-lb) polyethylene sacks that are palletized and shrink- or stretch-wrapped (see **Figure 5**). The product is discharged by slitting the sack open above a receiving vessel. Operators should be trained in appropriate handling techniques to avoid injury when lifting 30-kg sacks. Deliveries of up to 23,000 kg (50,700 lb) can be made using a 40-ft trailer if roads permit. Alternatively, up to 15,500 kg (34,200 lb) can be packed into a 20-ft ISO container.

Figure 5. Nylon 66 Polymer in Sack



Product Specification Parameters

Relative Viscosity (RV)

The degree of polymerization of a polymer is directly proportional to molecular weight and is commonly measured by a solution viscosity technique.

Methods of Measurement

Common solvents used for viscosity measurements of nylon 66 include both formic and sulfuric acids. The details of these procedures are summarized in **Table 3**.

Table 3
Typical Details of Solvent Procedures Used to Measure Viscosity

	Formic Acid	Sulfuric Acid
Procedure reference	ASTM D789	DIN 16773
Acid strength, % ± 0.1	90.0	98.0
Polymer solution concentration, %	8.4	1.0
Measuring viscometer, BS/U type or Cannon Fenske, Size 350	E	D
Measurement temperature, °C ± 0.02 (°F)	25 (77)	25 (77)

RV is determined by comparing the time required for a specific volume of polymer solution to flow through a capillary tube with the corresponding flow time of the same volume of pure solvent. Results are corrected for moisture content of the sample; alternatively, the sample is dried to a low moisture level.

Values quoted in DuPont specifications are those measured in 90% formic acid.

Figure 6 shows the typical relationship between RV in 90% formic acid versus 98% sulfuric acid.

Amine End Groups (AEG)

A major nylon asset is its ability to accept a wide range of dyestuffs. These include both acid and premetallized dyestuffs that associate with the terminal amine groups of the polymer. The concentration of these end groups is an important factor in controlling dyeability (see **Figure 7**).

Figure 6. Correlation Between RV in 90% Formic Acid and 98% Sulfuric Acid

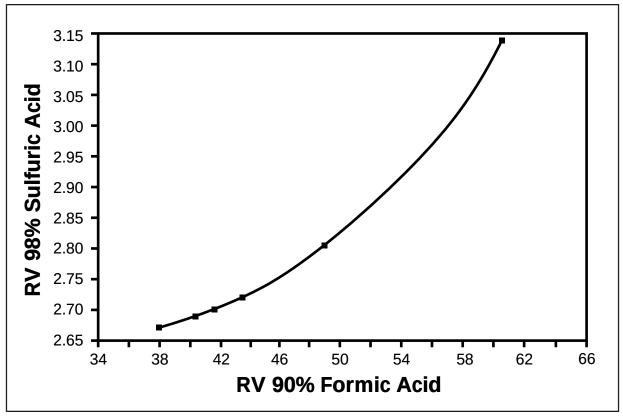
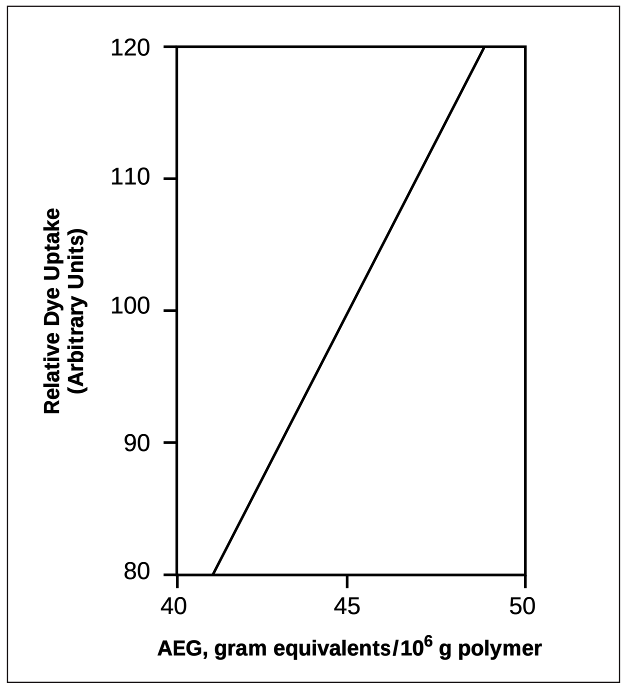


Figure 7. Relative Dye Uptake Versus Amine End Groups



Analysis Method

The technique commonly used for measuring AEG involves dissolution of polymer in 68/32 wt% phenol/methanol solvent and potentiometric titration with 0.05 m hydrochloric acid using commercially available equipment. Results are corrected for moisture and titanium dioxide content.

For typical textile grade products, amine end group concentration is usually within the range of 35–50 and is expressed as gram equivalents/10^6 g of polymer.

Moisture Content

Nylon is a relatively hygroscopic polymer. DuPont nylon 66 leaves our production plant with low moisture content (typically <0.3 wt%). However, the product can absorb more moisture (up to 8 wt%) depending on the relative humidity (see **Figure 8**) and length of exposure time (see **Figure 9**). Customers must take precautions to keep the product free of moisture.

Figure 8. Equilibrium Moisture Content Versus Relative Humidity

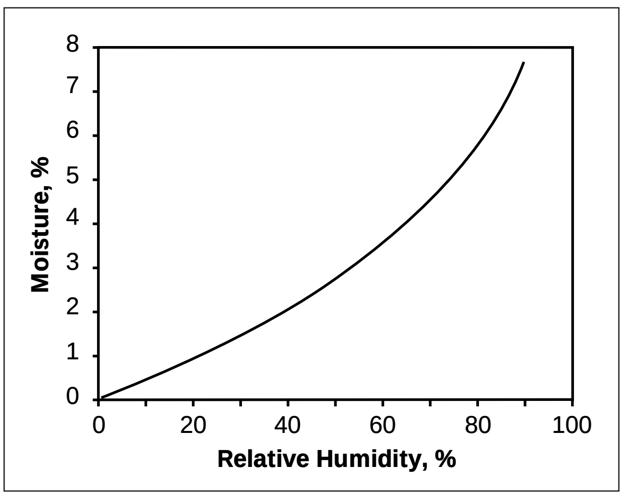
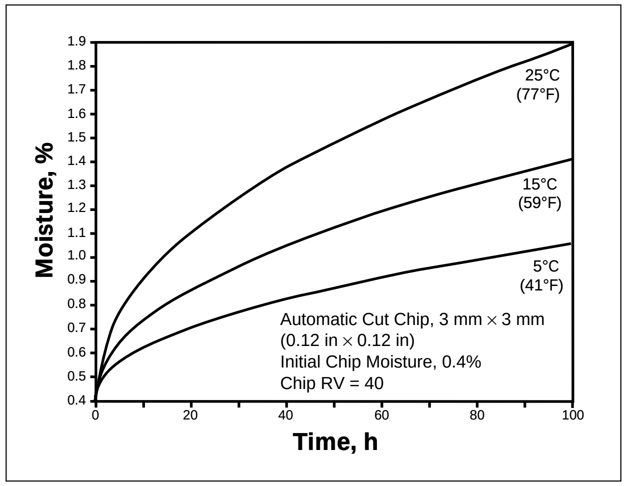


Figure 9. Rate of Chip Moisture Regain



Moisture Analysis Methods

Moisture plays a crucial role in the polyamidation reaction and in the melt because an equilibrium exists between free end groups, amide linkages, and water. Efficient use of the polymer usually requires a stable equilibrium between water and polymer in the processing equipment.

Different methods for moisture testing are common. If the temperature at which the measurement is made is relatively low, only the “free” moisture will be measured. At higher temperatures, this “free” moisture and moisture generated by polymerization will be measured. Methods typical of these two techniques are shown below. DuPont specifications are usually cited using an automated Karl Fischer method.

Mitsubishi Moisture Meter

A commonly used technique for measuring moisture involves use of the Mitsubishi Moisture Meter. This method uses the principle of heating polymer at 180°C (356°F) for 31 min under a stream of dry nitrogen and quantifying the evolved moisture by a direct Karl Fischer titration. It should be noted that moisture measured this way will originate from two sources:

- free moisture within the polymer or
- water of further polycondensation produced when polymer is held at 180°C (356°F) within the moisture meter.

Values quoted are total moisture expressed as either ppm or wt% based on polymer.

Loss Test

A "loss value" can be established using a technique that determines the % loss in weight of polymer when nylon 66 is heated to 255°C (491°F) under a vacuum of 25 mm Mercury for 30 min.

Moisture measured in this way will originate from three sources (in varying degrees):

- free moisture within the polymer,
- any water of polycondensation produced when polymer is heated at 255°C (491°F), and
- a contribution from the volatile material evolved during the heating process.

Measurements by the loss test are approximately 0.15% greater than those obtained using the Mitsubishi Moisture Meter (for example, a loss of 0.40% is equivalent to a moisture content of 0.25%).

For more information on nylon 66 polymer . . .

. . . For fiber and fiber spinning applications, contact:

DuPont Nylon • (800) 231-0998

or to place an order in the United States:

(800) 441-9766

For more information or to place an order outside the United States, contact the nearest DuPont representative or the Wilmington Sales Office listed below.

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DuPont Engineering Polymers (800) 441-0575

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