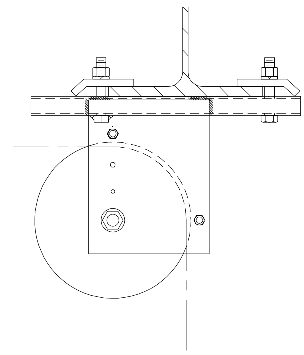
H&H Specialties Inc.
manufacturer of stage equipment

NYLATRON®



Tech Report

Plastics have, since the 1950's, shown the ability to out perform iron or steel in many applications. The crane industry, for example, has seen increased wire rope life and improved equipment operation since the introduction of nylon as a sheave material. Wire rope running over a nylon sheave can have its serviceable life extended as much as 450% through less crown and tangential breaks. Equipment operation is improved since nylon is lighter and has self-lubricating properties. These qualities allow for greater loads on booms and lower maintenance costs.

Nylon is one of a large family of thermoplastic polymers. Simply, nylon is made up of long chains of repeating chemical units arranged into crystal-like formations (crystallites). Crystallites are formed by these chemical units organizing themselves in closely ordered groups. These groups are surrounded by areas of disorder (amorphous regions). These crystal-like regions give the nylon its abrasion resistance. The amorphous regions give nylon its resiliency.[1]

Nylon, by nature, lends itself to bearing materials and other friction reducing applications. Nylon has a low coefficient of friction and resists abrasion. It provides a surface able to handle repeated abuse while retaining its original shape. Nylon will retain its inherent physical properties after continuous service at temperatures approaching 220°F.

In order to enhance the anti-friction qualities, nylon is often blended with either liquid or solid lubricants. The addition of lubricants does not significantly affect the physical properties of the nylon, while substantially adding to nylon's wear properties. One lubricant used is molybdenum disulfide (MoS_2). a natural lubricant. The Polymer Corporation of Reading, PA, has developed proprietary formulas of nylon and molybdenum disulfide called Nylatron® nylon.

Nylatron® nylon is available in a wide range of formulas in both nylon 6/6 and nylon 6 bases, each specially designed for specific needs. Nylatron® GS and GSM nylons have proven to be excellent all around choices for sheaves in the lifting industry. Nylatron® GS nylon is a resin that is cost effective for high speed injection molding. The manufacturing process of injection molding limits the maximum cross-section of a sheave, thus restricting it's load carrying capabilities. Nylatron® GSM nylon, however, is produced from a patented process of polymerizing material at atmospheric pressure. This process allows for large and complex sections to be produced free of voids. Nylatron® GSM nylon castings up to 48" in diameter and 700 pounds have been produced by The Polymer Corporation. In 1985, H & H Specialties Inc. introduced the Nylatron® GS nylon loft block sheave to the theatrical industry. Currently, loft block sheaves are manufactured using injection molded Nylatron® GS nylon and head blocks cast from Nylatron® GSM nylon.

Bearing Installation

Nylatron® nylon sheaves can easily accommodate many different styles of bearings. As a general rule, most bearings and bearing materials may be pressed directly into the sheave with satisfactory results. Consideration must be given to the thermal expansion coefficient of Nylatron® nylon which is several times that of cast gray iron. This expansion must be considered to insure that the bearings do not move within the bore of the sheave. To determine the correct bore, use the following equation:[2]

Bore = Bearing OD - Press Fit Allowance
Press Fit Allowance (d) = .009 / D
D = OD of bearing

Example: Find The correct bore for a precision bearing with an OD of 1-3/8”:

d=.009 / D

d = .009 / 1.375"

d = .009•1.173"

d = .011"

Bore = Bearing OD - Press Fit Allowance

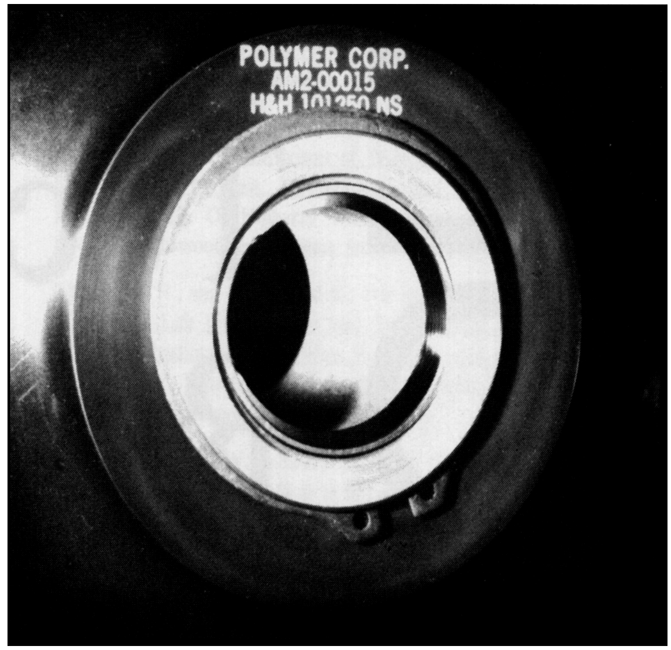
Bore = 1.375" - .011"

Bore = 1.364"

Experience with relatively thin cross-sectioned Nylatron® GS nylon loft block sheaves has shown that satisfactory results can be accomplished with pressing bearings directly into the sheave bore. The contact area between sheave material and bearing surface is adequate to retain the bearing in the bore. This procedure has proven acceptable at loads normally used in the theatrical industry. Additionally, the bearings are mechanically retained in the assembly by the sheave side plates.

Installation of bearings into sheaves with wide cross-sections or extreme loads requires positive retention of the bearings within the bore. Nylatron® GSM nylon is inherently resilient and flexible. Under high loads, this flexing may cause the bearings to move within a thick cross-section of material, resulting in bearing misalignment and poor performance. In the theatrical industry, head blocks are subjected to greater loads than loft blocks and the percentage of bearing contact surface is considerably less than a standard loft block assembly.

The most effective solution is to press a steel sleeve into the sheave material. This sleeve is mechanically retained in the bore with external snap rings, then bearings are pressed into the steel sleeve per manufacturer’s recommendations. This is the procedure normally followed on sheaves used in the crane industry.



An additional consideration is the pressure that the bearing will exert on the bore into which it is pressed. The maximum allowable bore pressure for normal operation of a Nylatron® GSM nylon sheave is 4000 psi. The following equation may be used to calculate the bore pressure.[3]

$P_b = 2(U/F_d)/D_b \bullet W_h$

P_b= Max. Bore Pressure (psi)

D_b = Bore Diameter (in.)

W_h = Width of Bearing in Contact with Bore (in.)

U = Breaking Strength of Wire Rope (lb.)

F_d = Design Factor for Wire Rope

Groove Pressure

As wire rope bends around a sheave, the individual wires contacting the groove surface exert pressure on the sheave material. This is known as groove pressure. Excessive groove pressure can result in premature wear and/or sheave failure. In sheave design, the type of material used and groove pressure are two important considerations. The theatrical industry has nominally used these allowable groove pressures for various materials: 480 psi for ASTM A48, Class 30-35 gray iron and 1000 psi for steel. Groove pressure can be calculated by using the following equation.[4]

P = 2T/Dd

P = Groove Pressure (psi)

T = Load on Rope (lbs.)

D = Tread Diameter (in.)

d = Rope Diameter (in.)

Example: Find the groove pressure for a sheave with a tread diameter of 8" and a load of 500 pounds on 1/4", 7 x 19 aircraft cable.

P = 2T/Dd
P = 2•500#/8"•.25"
P=1000#/2"
P = 500 psi

The Polymer Corporation publishes the following in their Nylatron® Nylon Sheave Design Manual, "If the groove pressure does not exceed 3500 psi, a Nylatron® (GSM nylon) sheave should perform satisfactorily under normal operating conditions."[5]

Wire Rope Life

The Polymer Corporation's tests have shown that the use of Nylatron® GSM nylon can extend wire rope life as much as 450%. One test involved running wire rope over both steel and Nylatron® GSM nylon sheaves with a load of 10% and 20% of the rope's breaking strength. During the test, the ropes were rigged in such a manner that one rope ran only over the steel sheave and one rope ran over only the Nylatron® GSM nylon sheave. The steel sheave was machined from cast steel with the groove flame hardened to Rockwell C32 per crane industry standards. The Nylatron® nylon sheave was machined from Nylatron® GSM nylon solid stock. Both sheaves were machined to the same set of dimensions. At set intervals, the test was stopped and the ropes were inspected. The criteria used for rope failure was ANSI Standard B30.5. This standard states that for running lines, "six randomly distributed broken wires in one lay or three broken wires in one strand in one lay" are reason for replacing the rope.[6]

The test apparatus was loaded to 10% of the wire rope breaking strength and run for approximately 136,000 cycles before the conclusion of the test. Wire rope on the steel sheave required replacement six times during the test, while the rope on the Nylatron® GSM nylon sheave was replaced once. Rope on the Nylatron® nylon side of the test apparatus lasted 4.5 times longer than the steel side. During the second part of the test the ropes were loaded to 20% of capacity and run for 68,000 cycles. During this test the steel side needed five wire rope replacements. The Nylatron® nylon side required two replacement ropes. During this phase, the Nylatron® nylon side showed an improvement of 220% over steel.

In both tests, crown breaks were cited as the leading cause of wife rope failure on the steel sheave side. Crown breaks occur when a cable contacts a material of similar or greater hardness than itself. During this contact, tremendous pressure is exerted on the individual wires; in time these wires will break. One solution is to provide a material which is softer than wire rope and able to handle the extreme pressures. Nylatron® GSM nylon with its inherent resiliency provides an excellent solution. As the rope bends around the sheave, the sheave material deforms slightly to provide increased contact area for the individual wires. This lowers the pressure on the wires and lessens the likelihood of crown breaks. The relationship between steel and the Nylatron® GSM nylon sheave material is expressed in the following Hertzian equation. This equation defines the maximum pressure at the center of the contact surface q_0 is a function of moduli E_1 and E_2 of the two contact materials.

$$q_0 = f\,[{}^3\!/_4(E_1 \bullet E_2/E_1 + E_2)^2]$$

Substituting E_1 = 30,000,000 psi for steel and E_2 = 400,000 for nylon or the ratio of 1 to 0.013, the numerical value in the brackets of the above equation will become .087. At the steel sheave side, $E_1 = E_2$, and the value in the brackets becomes 1. This indicates that the maximum contact pressure at the steel sheave side is 11.5 times of the contact pressure at the nylon sheave side.

This Hertzian equation shows that wire rope life can be greatly improved through the use of a material with a modulus of elasticity significantly different than steel.[7]

Endurance

In the past, many companies have considered replacement of steel sheaves with alternative materials. Two companies investigating the performance of Nylatron® GSM nylon sheaves were Clark Equipment Company and United States Steel Company.

Clark Equipment Company tested the ability of a Nylatron® GSM nylon sheave to handle various shock loads under different temperatures. Their test involved running a wire rope over a Nylatron® GSM nylon sheave with one end attached to a load cell. The other end of the wire rope was attached to a 5,000 pound weight which was dropped one foot. Additionally, the fleet angle was changed from 0° to 6° in various increments. Clark Corporate Laboratories stated:

"The shock load measured using a nylon sheave was 90-103% of the amount measured when using a metal sheave. No damage to either the nylon or metal sheave was observed." Clark Laboratories calculated the groove pressure peaked at 7,500 psi.[8]

United States Steel Corporation was interested in whether a Nylatron® GSM nylon sheave can support loads up to the breaking point of wire rope. A test was conducted by running a 1/2" IWRC wire rope over a Nylatron® GSM nylon sheave and securing both ends of the rope to the test bed. The sheave was attached to a load cell and a load was applied to the point of rupture. United States Steel Corporation reported:

"The total load on the platform at point of rupture of the wire rope was 54,900 pounds. There was no distortion of the sheave and only small superficial wire rope impressions were observed in the groove." The calculated groove pressure on the Nylatron® GSM nylon sheave at point of rupture of the wire rope was over 9,000 psi.[9]

Cold Flow

The phenomenon commonly called "cold flow" or creep, is a subject that has been studied in depth as it applies to engineered thermoplastics such as Nylatron® GSM nylon. Published data allows engineers to accurately predict the stresses which can cause creep, as well as defining the maximum deflection (or set) that a material will experience over an extended period of time at a given load (stress). Below a given minimum stress, creep is negligible and is not a design consideration. The Polymer Corporation's typical recommendation for minimum stress below which creep will not occur is approximately 2,000 psi for Nylatron® GSM nylon. Since the sheave groove pressures in the theatrical industry are typically 1,000 psi or less, any deflection will be "elastic", meaning it will be fully recoverable once the load is removed.[10]

The engineering principles are the same for Nylatron® GS nylon injection molding resin, however, cross-sectional area and design of the sheave will determine actual elasticity under load. A study performed at the facilities of H & H Specialties Inc. in 1985, indicated that under a static load test of approximately 1,400 pounds for over 90 days, the injection molded Nylatron® GS nylon sheave showed no abnormal deformation. The load imposed was almost twice that recommended by the manufacturer under normal operating conditions.

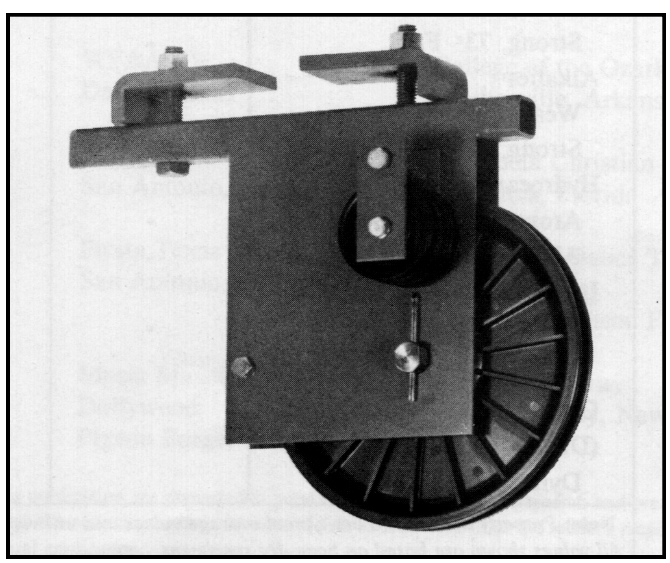
Theatrical Applications

In industries that have looked toward different ideas for improving their products, Nylatron® GS and GSM nylons have shown to be viable alternatives to cast iron, steel or other materials. The theatre and entertainment industry is no exception.

H & H Specialties Inc. has been the leader in the use of Nylatron® nylons in the theatre industry in North America. Since 1985, over 35,000 Nylatron® GS nylon loft block sheaves and over 1,600 Nylatron® GSM nylon head block sheaves have been installed in over 500 theatres all over North America. In every instance, the overall performance of the rigging system has been improved. The installation of the equipment is considerably easier since Nylatron® nylon is 1/7 the weight of cast iron. During a performance, personnel notice the differences in operational characteristics. Nylatron® nylon sheaves operate more quietly than cast iron or steel. Also, the reduced weight of the sheave along with the self-lubricating qualities of Nylatron® nylon and lower coefficient of friction, greatly reduces the amount of effort needed to operate even the heaviest counterweight set.

Nylatron® nylon is being used in other areas of the theatre. For years, arbors were guided with wood or pressed fiber products. These materials provided a hard wearing surface, but did little to reduce friction. H & H Specialties Inc. was the first to enhance the standard shoe guide arbor with the introduction of the first roller guided arbor in 1972. A roller guide utilizes a small ball bearing sheave that rolls along the guide rails. By rolling, rather than sliding, friction is reduced and operation is dramatically improved. Originally, these guides were equipped with standard nylon ball bearing sheaves. Today's design utilizes Nylatron® GS nylon ball bearing sheaves, providing a guide that not only rolls along the guide rail, but requires no outside lubrication.

Throughout history, manufacturers have sought to improve their products and consumers have demanded better performance and longevity. The crane and materials handling industries have seen that engineered plastics can provide better performing and more cost effective alternatives to iron or steel. The Nylatron® nylon family of products has shown superior durability and performance when used as a sheave material. H & H Specialties Inc. was the first to take this technology and introduce it to the theatre industry in 1985. Though skeptically received at first by some, the theatrical industry now accepts and embraces this material. From the largest rigging sheave to the smallest track component, from high schools to Broadway, Nylatron® GS and GSM nylons are providing exceptional performance economically.



Model# 832N25 with 3 Idlers

Typical Properties of Nylatron® GSM and GS Nylons

Property	Units	Test ASTM Method	Value GSM Nylon	Value GS Nylon
Mechanical/Physical Properties				
Tensile Ultimate Strength	PSI	D-638	11,000-14,000	13,500
Tensile Elongation at Break	%	D-638	10-60	15
Tensile Modulus	PSI	D-638	400,000	450,000-600,000
Compressive Strength	PSI	D-695	12,000	13,000
Shear Strength	PSI	D-732	10,500	10,500
Flexural Strength	PSI	D-790	16,000-17,500	16,500
Flexural Modulus	PSI	D-790	400,000	460,000
Tensile Impact	ft. lbs/in^2	D-1822	150	50-180
Hardness, Rockwell	R	D-785	120	119
Specific Gravity	-	D-792	1.16	1.16
Thermal Properties				
Melting Point	°F	D-789	430±10	482-500
Coefficient Linear				
Thermal Expansion	in/in/°F	D-696	$5.0x10^{-5}$	$3.5x10^{-5}$
Deformation Under Load				
(122° F, 2000 psi)	%	D-621	0.5-1.0	0.5-2.5
Deflection Temperature				
264 psi	°F	D-648	200	200
66 psi	°F	D-648	400-425	400-490
Continuous Service				
Temperature in Air (Max.)	°F	-	200	220
Flammability	-	D-635	Self-Extinguishing	Self-Extinguishing
Chemical Properties				
Water Absorption				
24 hours	%	D-570	0.6-1.2	0.5-1.4
Saturation	%	D-570	5.5-6.5	6.0-8.0
Acids				
Weak, 73° F	-	-	Acceptable	Acceptable
Strong, 73° F	-	-	Unacceptable	Unacceptable
Alkalies				
Weak 73° F	-	-	Acceptable	Acceptable
Strong, 73° F	-	-	Acceptable	Acceptable
Hydrocarbons				
Aromatic, 73° F	-	-	Acceptable	Acceptable
Aliphatic, 73° F	-	-	Acceptable	Acceptable
Inorganic Salt Solutions				
73° F	-	-	Acceptable	Acceptable
Bearing Properties				
Coefficient of Friction	-	-		
(Dry vs. Steel)				
Dynamic			.25-.28	.15-.35

Note: *Property data shown are typical average values and will vary on specific production lots and by size and configuration of product.*
All values shown are based on bone dry specimens.
Nylatron® is a registered trademark of the Polymer Corporation Division, DSM Engineering Plastic Products, Inc.

Footnotes

1. John H. Chen and Robert A. Alberts, *Engineering Plastics: Components in Construction Equipment* (Earthmoving Industry Conference, April 1982) p.2.

2. *Nylatron® Nylon Sheave Design Manual* (The Polymer Corporation, 1984) p.6.

3. Ibid.

4. *Wire Rope Users Manual* (Committee of Wire Rope Producers, American Iron and Steel Institute. 1981) p. 38

5. *Nylatron® Nylon Sheave Design Manual* (The Polymer Corporation, 1984) p.8.

6. John H. Chen and Paul E. Gage, The Polymer Corporation, *Improved Wire Rope Endurance Life with Nylon Sheaves.* (13th Annual OTC, May 1981, Offshore Technology Conference, 1981) p.444

7. John H. Chen and Paul E. Gage, The Polymer Corporation, *Comparison of Wire Rope Life Using Nylon and Steel Sheaves--Part 2: New Concept to Improved Predictability of Wire Rope Remaining Strength After Cycling* (Off-Highway Vehicle Meeting & Exposition, Sept. 1979, Society of Automotive Engineers, Inc., 1979.) p.2.

8. *Low Temperature Shock Load Testing of Nylatron® GSM Sheaves.* (Construction & Material Handling Industry Technical Bulletin. The Polymer Corporation, 1979).

9. *Static Load Testing of Nylatron® GSM Nylon Sheaves* (Construction & Material Handling Industry Technical Bulletin. The Polymer Corporation, 1980).

10. Unpublished letter from Thomas Connelly, Industry Manager, The Polymer Corporation to Reid Neslage, February 23, 1993.

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Connelly, Thomas W., Industry Manager for The Polymer Corporation, a letter to Reid Neslage, VP H & H Specialties Inc., dated February 23, 1993.

Low Temperature Shock Load Testing of Nylatron® GSM Sheaves. Construction & Material Handling Industry Technical Bulletin. The Polymer Corporation Reading PA, ST-1, 1979.

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Wire Rope Endurance Life Comparison for Nylatron® GSM vs. Steel Sheaves. Construction & Material Handling Industry Technical Bulletin. The Polymer Corporation, Reading, PA, WR-lr, 1981.

Wire Rope Users Manual, Second Edition. Committee of Wire Rope Producers, American Iron and Steel Institute, 1981.

Selected Project List

Issaquah High School
Issaquah, Washington

Fox Television
Los Angeles, California

El Camino College
Torrance, California

Ohlone College
Fremont, California

Moorpark College
Moorpark, California

MGM Grand Hotel
Hollywood Theatre
Las Vegas, Nevada

MGM Grand Hotel
Grand Theatre
Las Vegas, Nevada

New York-New York
Hotel & Casino
Las Vegas, Nevada

Fine Arts Complex
Arizona State University
Tempe, Arizona

Orpheum Theatre
Phoenix, Arizona

Eastern New Mexico
State University
Portales, New Mexico

Wortham Theatre Center
Houston, Texas

WFAA-TV
Dallas, Texas

Majestic Theatre
San Antonio, Texas

Six Flags Fiesta Texas
Theme Park
San Antonio, Texas

Music Mansion Theatre
Dollywood
Pigeon Forge, Tennessee

Mel Tillis Theatre
Branson, Missouri

Western Illinois University
Macomb, Illinois

Krannert Center
University of Illinois
Urbana, Illinois

Andrew Jackson Hall
Tennessee Performing
Arts Center
Nashville, Tennessee

James K. Polk Theatre
Tennessee Performing
Arts Center
Nashville, Tennessee

Florida Community College
at Jacksonville
Jacksonville, Florida

Pensacola Christian College
Pensacola, Florida

Mannequin Dance Theatre
Disneyworld
Lake Buena Vista, Florida

ABC Television
New York City, New York

Minskoff Theatre
New York City, New York

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