Engineering Thermoplastic Sheaves & Sheave Design

"From sailboat halyards & boatlifts, aerial firetrucks, rock climbing equipment, stage equipment, construction cranes / utility equipment, through large amusement park and offshore LARS sheaves, we can provide them all!"

WS
HAMPSHIRE
CUSTOM COMPOSITE SOLUTIONS

Long known as North America's premier supplier of engineered thermoplastics, Timco was acquired by WS Hampshire in 2017. Today, WS Hampshire carries on Timco's excellent reputation for supplying thermoplastic sheaves and wear pads into construction equipment, and other material handling applications.

Cast Nylon Sheaves for Material Lifting Applications

Once made from cast iron or steel, Cast Nylon sheaves are the grooved wheel found in pulley systems that use rope or chain to change the direction of a pulling force. Sheaves made from cast nylon are commonly found on nearly every type of crane as well as aerial fire trucks, wire drawing and cable stranding machines, in elevators, on forklifts, telehandlers, manlifts and in many other mechanical systems. WS Hampshire is the premier North American supplier of machined non-metallic sheaves of all sizes and designs.

Cast Nylon fabricated sheaves have considerable advantages overcast iron or steel sheaves. The following pages will outline these advantages along with providing considerations on material selection and design guidelines to help improve the safety and efficiency of your equipment. Selecting sheaves requires a knowledge of product specifications: type of belt or rope to be used, bearing size and type, and dimensional restrictions. An experienced WS Hampshire application specialist can assist you in your designing your sheaves.

Benefits of Using WS Hampshire Engineering Thermoplastic Sheaves

1 Weight Reduction

- The specific gravity of most engineered thermoplastics is about 1/7 that of iron or steel, and about 1/3 that of aluminum.
- Reduced weight offers advantages in shipping cost, maintenance safety and increased lifting capacity.

2 Corrosion Resistance

- WSH engineered thermoplastic sheaves will not rust in wet environments.
    - This also prevents damage to sensitive components, such as telecommunications and electronic sensor lines.
- They will withstand all standard lubricants, though natural color materials may experience discoloration.

Benefits of Using WS Hampshire Engineering Thermoplastic Sheaves Continued...

3 Extended Wire Rope Life

- Wire rope usually fails from the inside out – with metal sheaves, the rope is flattened as it contacts the groove, causing internal wear.
- WSH engineered plastic sheaves provide surface deflection in the groove during contact, "cupping" the rope and greatly reducing internal rope wear.
  - The Hertzian contact stress on the wire rope can be reduced by a factor of 5 – 10 depending on load and groove design.
- The rope will imprint a pattern in the engineered plastic sheave groove, which is the rope "seating" itself for maximum cushioning and wear life.
  - This is not accelerated wear, and the grooves will not cut into the wire rope as would a metal sheave, requiring immediate replacement.
- Using WSH engineered thermoplastic sheaves can extend wire rope life by as much as 400%!!

Extended Sheave and System Life 4

- WSH engineered thermoplastic sheaves can extend component service life.
  - Wire rope sheaves last longer
    - Wire rope life is extended due to the increased contact area, and the rope groove imprint does not cut into the wires.
    - The sheave better withstands environment factors.
    - Engineered thermoplastic materials naturally resistant wear better than structural metals.
- Engineered thermoplastic materials are inherently sound and vibration dampening, which is beneficial to the wire rope, bearings, shaft, boom & housing structures.

Material Selection

Nylon

Nylon is by far the most widely used engineering thermoplastic material used for sheave applications because of the material's extraordinary combination of properties that is particularly well-suited to cable handling lift systems.

Can nylon sheaves handle loads like metal sheaves? **YES!!** As discussed above, the point contact pressure between a wire rope and a metal sheave will be much higher than between the same rope and nylon. Due to nylon's inherent resiliency, it deflects slightly under the rope load creating a much larger area to support the rope, then rebounds back when the load is cycled off that section.

There are two general types of nylon available for machining into sheaves. The properties are very similar, the choice is based on the size of the sheave.

1

- EXTRUDED NYLON 6/6 – Extrusion (resin is melted and pushed through a die) is the cost-effective way to produce small cross sections, typically ≤ 2" diameter.
- CAST TYPE 6 NYLON – This process is where the material components are poured into a mold where they polymerize into nylon. This process allows for very large and complex shapes to be economically produced, including "near net" shapes which minimizes waste and fabrication time.

Nylon Continued...

The cast nylon process also allows for material modification to heighten specific properties. For sheaves, the following versions are used in over 98% of the worldwide cast nylon sheave market:

2

- Natural cast nylon – This unfilled material was the first engineered thermoplastic used for sheaves in construction equipment and dominates the European market. Its advantages include consistency in properties, especially hardness, and they absorb less solar energy. The disadvantage is that the natural (off white) colored sheaves can become dirty in service very quickly, and over extended use can yellow from UV light.
- Black cast nylon – The exact same material as unfilled natural, with a small amount of black colorant added to make the parts look more "industrial", and to hide both in-service contaminants, (dirt, rope lube, etc.) and the UV color shift.
- Molybdenum Disulfide filled cast nylon – This version is still most popular in North America; when cast nylon sheaves were introduced here ~50 years ago. "MD" or "Moly filled" nylon is a grey-black, and the additive functions as a nucleating agent in the matrix (NOT as a lubricant), causing a tighter molecular structure that results in a harder and slightly more wear resistant material.

All these nylon versions are used across the globe with equal success!!!

The advantages listed are true for all types of engineered thermoplastic sheaves. The selection of the right material needs to consider several factors, such as service requirements (load / speed), environment of service (weather, chemical), size availability, and cost to manufacture. The most common material used is nylon, but there areother options:

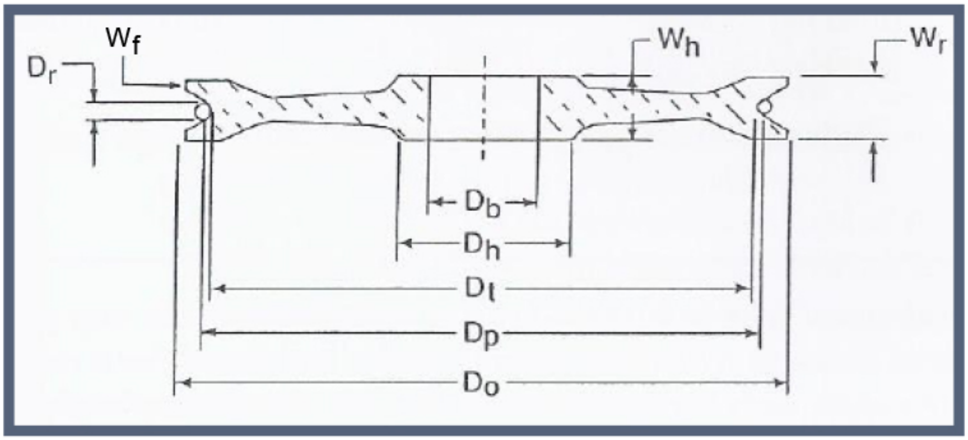
MATERIAL SELECTION CONTINUED...

3

- UHMW-PE – Ultra-high molecular weight polyethylene, this is the bearing & wear PE grade; it is very slick, the lightest weight material and is the lowest cost and lowest physical property sheave material; primarily uses are in very light duty applications such as marine / boat rigging pulleys, wire and cable accumulator sheaves and wire drawing guide rollers.
- ACETAL – Traditionally, this material is primarily chosen where relatively small diameter (2" and under), close tolerance, high production parts are required; its low moisture absorption makes this a good choice for wet applications like marine pulleys, and in small pulley assemblies for uses from flagpole hoists to back-country block and tackle systems. New production capabilities allow for much larger shapes in acetal, albeit at higher cost.
- SPECIALTY MATERIALS – There are several specialty materials offer unique properties, including:
  - Temperatures to 500F+, for systems in the primary metal, lumber kiln and other applications where strength at temperature is required or where metal may not appropriate due to heat transfer.
  - Glass filled materials that improve stiffness.
  - Static dissipative or electrically conductive applications where the electrical insulating properties of most plastics may be a disadvantage.

DESIGN CONSIDERATIONS

Many considerations are involved with effective nylon sheave design that balances the functional requirements against lowest cost / ease of manufacturing. The design information listed below applies to all nylon materials.



Terms

D_O = outside diameter

D_T = tread (groove) diameter

D_H = hub diameter

W_R = rim width

W_F = flange width @ edge

D_R = wire rope diameter

D_P = pitch diameter ($D_T + D_R$)

D_B = bore diameter

W_H = hub width

1

- **Sheave "Ratio"** – Most lifting applications use the Power Crane and Shovel Association (PCSA) design criteria, which is the ratio of the pitch diameter (DP) divided by the wire rope diameter (DR). This applies to groove pressure and is primarily focused on maintaining a safe bending radius of the wire rope. The minimum recommended ratio is 18:1, with 24:1 preferred. IN GENERAL, if the ratio is over 18:1, the groove pressure should be within limits; see the discussion below regarding single line pull safety factor assumptions.

Design Considerations Continued...

2

- Groove and Bore Pressure Calculations – These pressures are typically determined by the maximum safe lifting capacity (Rope Safety Factor) of the wire rope. It is generally determined by taking the ultimate breaking strength of the wire rope and dividing by 5.
    - For example, standard ¾" rope (6x19 EIPS IWRC) has a listed ultimate breaking strength of ~58,800 lbs, so a 5:1 safety factor means the maximum pull on that rope should be no more than 11,760 lbs. Some companies use a 3.5:1 safety factor, which in this example results in a single line pull maximum of 16,800 lbs.

NOTE: It is critical to know the maximum single line pull of the wire rope being used, especially as not every industry / company uses the same safety factors.

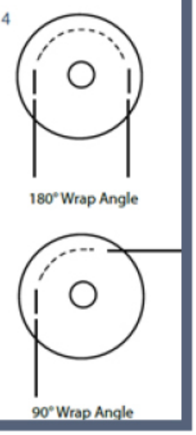
Once that is determined, the groove and bore pressures are determined by the formula:

Fig. 4

The GROOVE AND BORE PRESSURE can be calculated by:

For rope wrap angle of 180°	For rope wrap angle of 90°
$Pg = 2 \cdot T / r \cdot Dt$	$Pg = 1.414 \cdot T / r \cdot Dt$
$Pb = 2 \cdot T / B \cdot LTB$	$Pb = 1.414 \cdot T / B \cdot LTB$

Pg =	Groove Pressure (psi)	T =	Line Pull (lbs)
r =	rope diameter (in.)	Dt =	Tread Diameter (in.)
Pb =	Bore Pressure (psi)	B =	Bore Diameter
LTB =	Length through bore		



Safe design practice uses 3,000 psi in both the bore and groove as maximum pressure allowable. The groove pressure can withstand 4,000 psi for limited periods of time, but the bore pressure should remain limited at ≤ 3,000 psi.

NOTE: See "Bore – Design, Considerations, Bearings, Options" section below for further information regarding bearing types, installation, and service requirements

This assumes the rest of the sheave design and anticipated service are also within limits:

DESIGN CONSIDERATIONS CONTINUED...

3

- Groove Design

It is important to allow sufficient groove clearance specific to the wire rope size to be used so the rope properly seats itself in the groove. Again, there will be an initial wear pattern pressed into the groove – this is normal and is not indicative of accelerated wear:

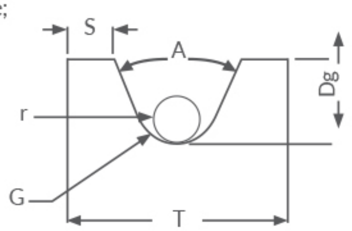
Groove Design

The groove depth should be at least 1.75 times the rope diameter.
The radius at the bottom of the groove should be slightly larger than the rope;

$G = 1.05 * r/2$

G = Groove radius   r = rope diameter

Typically, the groove angle is 30°. This provides for better rope support.
On occasion, a 45° angle is required for increased fleet angles (up to 4°).



Rim Dimensions

It is recommended to have a minimum shoulder width (distance between the outer edge of the rim and inside the groove) of 1/8". This allows for sufficient side loading support. With this, a calculation can be done to determine the width of the sheave at the rim.

Below is a table to dtermine the rim width based on the rope diameter, 30° groove angle, and 1/8" shoulder.

The minimum thickness of the sheave at the rim can be expressed as a function of the rope diameter (r).

T = ¼ + 2.99r

30°	35°	40°	45°
¼ + 3.00r	¼ + 3.20r	¼ + 3.40r	¼ + 3.60r

T = Thickness at the rim   r = rope diameter

Design Considerations Continued...

4

- Groove wear & sheave retirement criteria

As compared to steel sheaves, nylon sheaves can have some groove wear and still function satisfactorily without harming the wire rope. Two criteria are used to indicate sheave retirement via normal groove wear, *whichever occurs first:*

- The ratio falls below the 18:1 minimum ratio standard, or
- The groove diameter wears down the diameter of the wire rope used.
  - For instance, if the sheave has an initial tread diameter of 10" using a ½" diameter wire rope, when the tread diameter hits 9.5", the sheave should be replaced.

NOTE: the shoulder (inside rim) should also be checked for wear – Especially with rental fleets, users may exceed the fleet angle limits resulting in severe shoulder wear and potential rim failure.

5

- Web & Hub Design

To save machining time and cost, many sheave use a simple straight-side ("slab side") design, with no hub extensions – just an OD, tread diameter, thickness and bore, essentially a flat disc.

To reduce weight, or to simply make the nylon sheave look more like a typical metal sheave, a contoured web can be designed. If this type design is used:

1. The minimum web thickness at any point should be 1.25 times the wire rope diameter.
2. The minimum hub diameter (straight side area until the beginning of the contour) should be 1.67 times the bore diameter.
3. The minimum hub width through the bore should be at least the width of the rim, to provide proper support of the sheave body.
4. The transition between the hub and the web should be gradual (generous radius or slope) to prevent stress concentration.

Design Considerations Continued...

Bore - Design, Considerations, Bearings, Options

Typically, designers spend a lot of time on the "outer" design parameters – rim, groove, etc – but often it is the *bore* that dictates many design decisions.

The bore and groove load calculations are listed previously; you'll note that groove pressure often exceeds what the sheave can handle in the bore. This is because all forces are concentrated in the bore and results in the need for reinforcement.

1

- Nylon Sheaves Without Bearings

In some cases, a nylon sheave can function as its own bearing surface as nylon is an inherently good bearing material. In this case, loads and speed must be low, and minimization of any fleet angle from the groove center point is required.

- The bore will require design to include a normal nylon running clearance.
- The shaft material and finish must be considered.
- A lubrication method is recommended for all but the most lightly loaded applications.

Contact WS Hampshire to discuss the possibility of this approach with your application.

DESIGN CONSIDERATIONS CONTINUED…

2

- Bore Design - Bearing Press Fit

The formula below is the "standard" calculation for pressing in a bushing or bearing directly into the bore of a nylon sheave:

$$p = .009\sqrt{Db}$$

p = press fit Db = Diameter of the bearing or bushing

The value is subtracted from the nominal bearing OD to give you the bore dimension.

- For example, if you have a 4" OD bearing, the formula gives you a value of .018", so the nominal bore dimension would be 4.000" - .018" = 3.982"

This may seem to be an extremely high press fit – but remember that nylon has a compressive strength ~10% that of steel, so the press fit in a nylon sheave will be approximately 10X the press used for a metal sheave bore. This basic formula has been proven appropriate over the past 60 years of nylon sheave usage in a variety of applications. The nylon will not distort the bushings (or bearing race) in all but a very few specialized cases, noted below.

3

- Bearing Selection

Initially when introduced, and still common today, a given nylon sheave is replacing an existing metal sheave. The tendency is to use the same bushing / bearing as before to have standard availability for new production as well as aftermarket sales. In most cases, this will work, assuming the bore load is within compressive limits.

NOTE: Increasing the press fit typicallydoes **not** improve "grip" of the bushing or bearing; if increased compressive retention is needed, other options need to be considered – see below.

Design Considerations Continued...

4

- Bronze Bushings

As is well known in the thermoplastic bearing and wear application universe, the primary limitation of any given material is its ability to withstand heat, be it environmental, frictional, or both. Steel has a much higher tolerance to heat, plus a better ability to "bleed off" heat than does nylon. This is important when considering the use, continued or new, of bronze bushings in nylon sheaves. In high load and/or high speed (calculated as "PV", or pressure x velocity) applications, bronze bushings can generate heat which then is transferred to the nylon bore, causing expansion and surface softening, which can result in bushing movement within the bore. This can be offset somewhat by using oil-impregnated bronze, and even more so with adding external lubrication through a zerk either in the sheave body or at the end of the pin. This both reduces the frictional heat generated, and the lubrication will also help dissipate the heat that remains.

5

- Rolling Element Bearings

Today, most commonly, bearings (needle, ball, roller) are used to achieve reduced heat, increased load carry capability and reduced rolling resistance. The standard press fit for these is the same, and generally this provides a much more robust design at somewhat increased cost. These can be single, though-bore bearings, or dual bearings pressed from both sides against a nylon shoulder in the bore.

6

- ONE NOTABLE EXCEPTION

In some high load sheave applications, such as those used on oilfield workover or drilling rigs, it is common to use bearings that handle a load by generating a side thrust vector, such as two-row double-cup tapered roller bearings. **Nylon does not have sufficient compressive strength to retain these types of bearing systems!** See below for design options that can successfully utilize these bearings.

Design Considerations Continued...

7

- Composite Bushings

Some OEMs specify composite bushings, which usually have a relatively thin bearing surface on the ID, supported by a wound thermoset matrix body. Their primary advantages are less weight, reduced lubrication dependency and lower cost. These too can be pressed directly into a nylon sheave bore, but the press fit for these bushings may require a different calculation the application, these applications should be discussed with your WS Hampshire design assistant to make sure the service requirements of both the bushing and the nylon sheave are compatible.

Bore Design Options

There are applications where the pressure in the bore, bearings to be used or specific service requirements indicate the use of special bore design options.

1

- Two-Bearing Systems

With some designs, usually using ball bearings, it's necessary to press the bearings in from each side. Usually a center "shoulder", against which to press the bearings, is required and can be achieved by the following:

- Machining the bore to have a center shoulder (normal method), or
- Machining a snap ring groove into the bore into which a snap ring is inserted and used as the shoulder.

DESIGN CONSIDERATIONS CONTINUED...

2

- High Press-Fit Bearing Systems

With some applications or bearing systems, press fit strength beyond that of the nylon bore alone is needed, as mentioned above with the two-row double cup taper roller bearings. In those cases, a steel sleeve is inserted into the bore and the bearing is pressed into the sleeve to obtain the proper bearing press force. There are several ways to do this:

- The standard method is the sleeve can be retained by extending the sleeve beyond the bore width and retaining it with external snap rings.
- For applications where this extra width won't fit in the assembly, a center snap ring system can be designed, requiring centering grooves in both the sleeve and the sheave bore.

3

- High Pressure / Severe Rotation Applications

With some unusual applications, always with a friction bushing system (metal or composite), the forces are such that although the pressure in the bore is within limits, the rotational shear force is such that the steel sleeve and/or the bushing begin to rotate or "clock" (move a little, stop, move again, stop, etc.). Since all properly designed bearing systems require that the bearings stay in a fixed position, special design & processes are required. These may include:

- The use of a steel sleeve knurled on the OD, either inserted during the casting process or as a secondary operation.
- The use of special adhesives with a smooth sleeve, bushing OD, or both.

These are unique processes and require much engineering evaluation. Please contact your WS Hampshire design assistant to discuss how best to meet your specific application requirements.

Design Considerations Continued...

4

- Extreme Bore Width Applications

Some applications, such as winch alignment idler sheaves, have a standard sheave body design but have an unusually long length through the bore. With metal, usually a steel hub is welded onto a steel sheave body to achieve this bore length. Machining this configuration out of a thick cast nylon disc is usually cost prohibitive. However, a 3-piece assembly with a sheave body (usually the thickness of the rim width) and two nylon bore extensions mechanically fastened on either side of and through the sheave body can achieve the same cross section much more cost effectively. Contact your WS Hampshire design assistant to discuss such requirements.

About WS Hampshire

Originally formed in the 1890's as The Western Slate Company, WS Hampshire, Inc. occupies a 135,000 square foot facility in Hampshire, Illinois and is a custom fabricator of non-metallic materials with capabilities including CNC machining, punching, stamping, rotary die, vacuum forming, and assembly. We produce high quality, innovative, OEM quality fabricated components as well as small volume, make-to-order parts within a job shop environment, supported by customized supply chain programs. Our fabricated components are supplied to the Capital Equipment OEM, Electrical, Heavy Equipment/Vehicle, Primary Metals, Pulp & Paper, and MRO marketplaces.

Our recognizable brands of RYERTEX Composite Laminates and TIMCO Technical Plastics are the best in the industry, and when combined with our technical expertise and thorough application engineering, result in the right product the first time. Much of what we do is in replacing traditionally used materials with ones that are better suited for their environment, leading to reductions in downtime and operating expenses.

With the acquisitions of Hampshire Specialty Products (1998), Ryerson Plastics (2006), and Timco (2017) we have a global reach on raw materials and our capabilities mean there is no limit to the shapes, sizes, quantities, and materials that WS Hampshire can produce.

We strive to serve you, our customers and realize that we can be valued only as we make ourselves valuable.

Contact us today at
info@wshampshire.com
or 847.683.4400

WS HAMPSHIRE
CUSTOM COMPOSITE SOLUTIONS

WS Hampshire Inc.
365 Keyes Ave., Hampshire, IL 60140

Website: www.wshampshire.com
Email: info@wshampshire.com

Follow Us: