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Konecranes Nuclear Equipment & Services
5300 S. Emmer Drive, New Berlin, WI 53151
P 262.364.5700 **F** 262.364.5701

99901451

Date: 2/14/18

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Cc: Chief, Quality Assurance Vendor Inspection Branch-2, Division of Construction Inspection and Operational Programs, Office of New Reactors.

Ref.: NRC letter dated December 6, 2017 to Konecranes Nuclear Equipment & Services, LLC.

This letter serves as the Konecranes Nuclear Equipment & Services, LLC (KNES) official response to NRC letter dated December 6, 2017 which addressed areas of concern by the NRC staff.

KNES believes the areas of concern have been addressed in this official final response.

Enclosures include an affidavit for your consideration with a detailed listing of "proprietary documents" as deemed applicable by KNES. These include an attachment and revised calculations.

Excerpts from December 6, 2017 NRC letter to KNES referencing concerns a, b, and c followed by KNES official responses:

1. Your response to NON 99901451/2017-201-01 failed to address several areas of concern to the NRC staff. Clarify your response as follows:

a. The response states, in part, that Konecranes Nuclear Equipment and Services (KNES) has updated proprietary calculations to clearly show that the stresses within the bottom block sheaves are within the allowable limits set by the original equipment manufacturer. Section 10.0, "Quality Assurance," of NUREG-0554, "Single-Failure-Proof Cranes for Nuclear Power Plants," states, in part, that a quality assurance program should be established to the extent necessary to include the recommendations of this report for the design, fabrication, installation, testing, and operation of crane handling systems for safe handling of critical loads. In addition, Section 5150 and Table 7200-1 in NOG-1-2004, identify the sheaves as critical items subject to special considerations for material, design, control of manufacturing processes, and examination of final product. Describe the quality measures that have been employed to ensure the allowable limits are applicable to the polymer sheaves as fabricated and appropriate for the design, given the difference in material properties between polymers and steel.

IE09
NRO

KONECRANES RESPONSE TO ITEM A

Table 7200-1 in NOG-1-2004 requires the sheaves be supplied with a "Certificate of Conformance from the Item Manufacturer." A Certificate of Conformance for the sheaves was supplied by the manufacturer and is shown in Attachment A. Coupled with this defined deliverable, special considerations were made for material, design, control of manufacturing processes and examination of final product as shown below.

Material & Design – A detailed design study was performed by Konecranes to determine a lighter product that would handle the nuclear power plant environmental conditions and would also enhance wire rope life. The protection of the wire rope is paramount as clearly illustrated in multiple NRC documents that have identified rope failures. NUREG-1774 (Reference 2) states: "*Among events occurring during the period 1968 through 2002 involving cranes suitable for an upgrade to a single-failure-proof design, most load drop events have been the result of poor program implementation or human performance errors that led to hoist wire rope or below-the-hook failures.*"

Although there are multiple types of plastics available, Nylatron GSM is the most commonly used grade for sheaves due to its impact resistance and enhanced load bearing capabilities. Nylatron sheaves have been used by manufacturers including P&H (Konecranes) in cranes for decades for multiple reasons (Attachment B). In addition to the significant weight savings, one of the important benefits of the Nylatron is longer wire rope life since the Nylatron sheaves impose less pressure on the wire rope as documented in Attachment C. As shown in these papers, at loads equal to 10% and 20% of the ultimate strength of the wire rope, the rope on the Nylatron-type sheave endured 4.5 and 2.2 times as many cycles as compared to the wire rope on the steel sheaves; note the Konecranes safety factor is 10:1 for the wire rope per NOG-1 or 10% of the ultimate strength.

The mechanical design of the sheave is also a vital part of the "health" of the wire rope. The Konecranes' sheaves were designed to satisfy the requirements of NOG-1-2004, Sections 5427 & 5426 plus all other mechanical requirements applicable to sheaves in the Standard. Konecranes then further verified the sheaves met the technical requirements of Quadrant (Original Equipment Manufacturer of the Nylatron) by documenting the pressure and dimensions in our reeving calculations (References 3 and 4), which has been previously submitted to the NRC.

Control of the Manufacturing Process – Manufacturing was performed by an ISO 9001-2000 certified company. They have an extensive testing process internally to ensure their product continues to meet requirements including proprietary methods for Nitrogen purging when casting the Nylatron to ensure a uniform material with no voids or layers in the plates. The vendor also ensured they met the design requirements with a detailed dimensional inspection prior to shipping to Konecranes (Attachment B.)

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As an additional safe guard / defense-in-depth check to ensure the material we received from the vendor meets the needs of the design, Konecranes is going to perform material testing on one of the sheaves from the lot of material that was received. We are going to randomly select an Auxiliary sheave to sample. The relevant mechanical characteristics in the sheave calculations will be compared to the actual test results to ensure they are enveloped. Once a test coupon has been taken from this one Auxiliary sheave, we will perform a 125% rated load test of the sheave to ensure the structural integrity of the sheave has not been adversely affected. Note that on any future sheaves that are made, Konecranes will also take a sample from the lot to ensure the material meets the minimum requirements of our design.

Examination of Final Product – Once received by Konecranes, a detailed dimensional check is performed by our QA department to verify the product designed by Konecranes Engineering has been received. After the Konecranes Quality Department has released the sheaves to Manufacturing, a 125% load test of the crane (and thus the Nylatron sheaves) has been performed per NOG-1-2004, Section 7000. A final detailed inspection of the sheave grooves was performed after the load test to document the sheave conditions. The 125% load test and the post inspection were all performed satisfactorily with no adverse indications observed.

b. Section 5.35 of both the APS Main Hoist Reeving Calculation #36676-01, Revision 7, and APS Aux Hoist Reeving Calculation #36676-26, Revision 5, include the following statement: Although NOG-1-2004....

However, Section 4.3 of NUREG-0554 states that the individual component parts of the [dual] vertical hoisting system should each be designed to support a static load of 200 percent of the maximum critical load. Also, as stated previously, NOG-1-2004, Sections 5150 and Table 7200-1, identify the reeving system sheaves as critical items on a Type I crane that are subject to special considerations for material, design, control of manufacturing processes, and examination of final product. Reconcile the statement drawn from Section 5.35 of the reeving system calculations with the requirements specified in the purchase order with respect to conformance with NUREG-0554 and ASME NOG-1-2004.

KONECRANE RESPONSE TO ITEM B

Section 5.3.5 of both the APS Main Hoist Reeving Calculation #36676-01, Revision 7 (Reference 4), and APS Aux Hoist Reeving Calculation #36676-26, Revision 5 (Reference 4) will be revised to include the following statement to be consistent with NUREG 0554

- *Sheaves are designed per Section 4.3 of NUREG-0554, which states that the individual component parts of the [dual] vertical hoisting system should each be designed to support a static load of 200 percent of the maximum critical load.*

In addition, the statement preceding the calculations in the same section will be revised to state the following,

- *The following section of this calculation provides justification that the sheaves meet the design intent of NUREG 0554 and the design requirements provided by the original equipment manufacturer of Nylatron and that the material is being properly used.*

c. Noting that the use of sheave materials other than steel was not considered in NUREG-0554, the use of steel sheaves is required for Type I cranes by Section 5427.1 of ASME NOG-1-2004, and Section 5150 of ASME NOG-1-2004 states that sheaves are subject to special considerations in the selection of materials, provide justification that the polymer material is not subject to failure modes different from steel. At a minimum, address the potential for polymer creep over time and the potential for sudden, catastrophic failure under high load compared with the energy dissipating yielding of steel sheaves.

KONECRANE RESPONSE TO ITEM C

The manufacturer of Nylatron did consider other failure modes for their product and a discussion paper on their analysis is in Attachment D with material specific data. Specific failure modes that are applicable to the APS application are:

Overload of Material – Konecranes performed calculations to show the pressures on the Nylatron sheaves are well below the allowables for the material (References 3 and 4.) In addition, since these sheaves are part of a Single Failure Proof NOG-1-2004 crane, there are numerous independent and redundant system to prevent overload including a load weighing system and an energy absorbing hydraulic system.

Catastrophic Failure Under High Load – Per NOG-1-2004, Section 5210, elongation of mechanical components shall be $\geq$15%. Nylatron's elongation is listed as 30% (Attachment D, data in red box), which is twice as conservative as the requirement of NOG-1. When compared to steel such as A36 or A572 which has an elongation of approximately 20%, the Nylatron sheaves are approximately 50% more ductile than a steel sheave. Thus, during

shock loads, the Nylatron would be more forgiving and better able to handle the loading than a less ductile steel sheave.

Temperature – Material properties for the Nylatron vary when temperatures are below -25°C (-13°F) or above 93.3°C (200°F); the properties are relatively stable when inside that band. Since the operation of these sheaves will never occur outside this band, this failure mechanics is not applicable.

Creep – When a force is applied to a perfectly elastic material, it stretches a set amount until the force is removed. The material then returns to its original condition. No material is perfectly elastic, and thermoplastics such as Nylatron are actually viscoelastic. A viscoelastic material will have a higher modulus (stiffness) when a load is applied for a short period than when it is applied over a long duration; hence the stiffness of the Nylatron will depend on the how long the material is under load. This loss of stiffness under load over time is known as creep. A material specific graph for creep for different temperatures of Nylatron is in Attachment D (last page.) This linear-log graph clearly shows that creep is not an issue for the sheaves based on the duration the crane will be holding a load (normally hours). Even if a load is stuck on the hook for 4 days (≈100 hours), the change in the dynamic modulus is only about 12% and would have no effect on the load holding capabilities of the crane.

Attachments:

A – C of C from Cope and Quadrant & related design criteria (considered as proprietary by KNES)
B – Product Data sheets from Quadrant
C – Papers verifying wire rope improvement with nylon sheaves
D – Failure Modes and specific material data for Nylatron

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Excerpt from December 6, 2017 NRC letter to KNES referencing concerns detailed in letter section 2.a followed by KNES official responses:

2. Your response to NON 99901451/2017-201-02 failed to address several areas of concern to the NRC staff. The response states, in part, that "Based on the reason for the nonconformance, as the action to prevent recurrence we are now implementing a process change going forward with a plan to test weld filler metal that will be used on safety related components. Testing will be done [to] verify the critical characteristics established by KNES engineering and quality to meet design requirements based on the applicable sections of AWS code by a KNES 3rd party lab accredited to ISO/IEC 17025 and/or 10CFR50 App. B KNES audited laboratory." Clarify your response as follows:

a. Confirm whether Konecranes plans on buying the weld filler metal as safety-related or as commercial grade and then perform commercial-grade dedication of the weld filler metal for its use on safety-related components.

KONECRANE RESPONSE TO ITEM 2.a

Currently, the heat lot controlled weld filler metal is being purchased commercial grade by our approved fabrication supplier and then dedicated in accordance with AWS A5.20. A heat lot controlled weld filler metal test coupon is prepared for the test in accordance with the AWS test specification by our Konecranes approved fabrication supplier.

The dedication testing of the heat lot controlled weld filler metal sample coupon is done only by an approved KNES audited 10CFR50 Appendix B supplier: Currently, using Anderson Laboratories (audit was reviewed during the recent NRC inspection at Konecranes).

If at some time in the future, KNES decides to do a 10CFR50 Appendix B audit of the weld filler metal supplier, we would take appropriate credit for same at that time.

Attachments: E

Konecranes Nuclear Equipment & services, LLC

Tom McCann
Global Director of Nuclear Quality

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AFFIDAVIT PURSUANT TO 10CFR 2.390

Konecranes Nuclear Equipment and Services, LLC.
State of Wisconsin
County of Waukesha

I, Jay Douglas Edmundson, depose and say that I am a Vice President of Konecranes Nuclear Equipment and Services, LLC., duly authorized to execute this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conformance with the provisions of 10 CFR 2.390 of the Commission's regulations for withholding this information.

The information for which proprietary treatment is sought is listed below:

- Calculation #36676-01 – Main Hoist Reeving Calculation, Rev. 08
- Calculation #36676-26 – Auxiliary Hoist Reeving Calculation, Rev. 06
- Attachment A – Certificate of Conformance from Vendor

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Konecranes Nuclear Equipment and Services, LLC in designating information as a trade secret, privileged, or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.390 of the Commission ' s regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

I) The information sought to be withheld from public disclosure involves specific design details which are owned and have been held in confidence by Konecranes Nuclear Equipment and Services, LLC. including but not limited to:

- All information on how we use the Nylatron® sheaves and the research/calculations we have developed to show they are acceptable.
- The hydraulic upper block that is used for our energy absorption system to prevent two-blocking events. This patented assembly is very unique in the industry and separates us from our competitors. This unique system is being considered for the new era of cranes in Europe and is very valuable to us.
- Design of the drum and other trolley components to reduce weight and maximize the strength of the material to distributing our loadings without creating high stress areas.

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- Use of the Magnatorque® for emergency lowering and providing additional breaking in the drive train.
- The specialty Python® wire rope we use and the subsequent calculations which provides us a weight and reduction in drum/sheave size advantage to our competitors.
- Where we source our hooks and the subsequent calculations which provides us a weight and price advantage to our competitors.

2) The information is of a type customarily held in confidence by Konecranes Nuclear Equipment and Services, LLC. and not customarily disclosed to the public. Konecranes Nuclear Equipment and Services, LLC. has a rational basis for determining the types of information customarily held in confidence by our corporation.

3) Public disclosure of the information is likely to cause substantial harm to the competitive position of Konecranes Nuclear Equipment and Services, LLC. because the information consists of descriptions of the design and analysis of a Single Failure Proof crane with special weight considerations, the application of which provide a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Konecranes Nuclear Equipment and Services, LLC., take marketing or other actions to improve their product's position or impair the position of Konecranes Nuclear Equipment and Services, LLC.'s product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

Further the deponent sayeth not.

LAURIE A. THALACKER
NOTARY PUBLIC
STATE OF WISCONSIN

[signature]

Jay D. Edmundson, P.E.
Vice President of Engineering

Subscribed and sworn before me this 16th day of February, 2018

Laurie A. Thalacker

Notary Public
My Commission Expires: 8/21/2021

COPY

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 6, 2017

Mr. Thomas P. McCann, Quality Manager
Konecranes Nuclear Equipment
& Services LLC
5300 S. Emmer Dr.
New Berlin, WI 53151

SUBJECT: KONECRANES NUCLEAR EQUIPMENT & SERVICES LLC'S RESPONSE TO THE U.S. NUCLEAR REGULATORY COMMISSION INSPECTION REPORT NO. 99901451/2017-201, AND NOTICE OF NONCONFORMANCE

Dear Mr. McCann:

Thank you for your October 9, 2017, and October 18, 2017, letters in response to the Notice of Nonconformance (NONs) that was discussed in the subject U.S. Nuclear Regulatory Commission (NRC) inspection report (IR).

We have reviewed your letters and the associated attachments and found that they are not fully responsive to NONs 99901451/2017-201-01 and 99901451/2017-201-02. Specifically:

1. Your response to NON 99901451/2017-201-01 failed to address several areas of concern to the NRC staff. Clarify your response as follows:

   a. The response states, in part, that Konecranes Nuclear Equipment and Services (KNES) has updated proprietary calculations to clearly show that the stresses within the bottom block sheaves are within the allowable limits set by the original equipment manufacturer. Section 10.0, "Quality Assurance," of NUREG-0554, "Single-Failure-Proof Cranes for Nuclear Power Plants," states, in part, that a quality assurance program should be established to the extent necessary to include the recommendations of this report for the design, fabrication, installation, testing, and operation of crane handling systems for safe handling of critical loads. In addition, Section 5150 and Table 7200-1 in NOG-1-2004, identify the sheaves as critical items subject to special considerations for material, design, control of manufacturing processes, and examination of final product. Describe the quality measures that have been employed to ensure the allowable limits are applicable to the polymer sheaves as fabricated and appropriate for the design, given the difference in material properties between polymers and steel.

   b. Section 5.35 of both the APS Main Hoist Reeving Calculation #36676-01, Revision 7, and APS Aux Hoist Reeving Calculation #36676-26, Revision 5, include the following statement:

      > Although NOG-1-2004, Section 5427.1 states that a sheave shall be steel, it goes on to only require sizing based on the wire rope plus discussion on lubrication of the center bearing. No structural

requirements are required of the sheave and Section 7000 has no requirements for a sheave other than certificate of Conformance from the manufacturer.

However, Section 4.3 of NUREG-0554 states that the individual component parts of the [dual] vertical hoisting system should each be designed to support a static load of 200 percent of the maximum critical load. Also, as stated previously, NOG-1-2004, Sections 5150 and Table 7200-1, identify the reeving system sheaves as critical items on a Type I crane that are subject to special considerations for material, design, control of manufacturing processes, and examination of final product. Reconcile the statement drawn from Section 5.35 of the reeving system calculations with the requirements specified in the purchase order with respect to conformance with NUREG-0554 and ASME NOG-1-2004.

c. Noting that the use of sheave materials other than steel was not considered in NUREG-0554, the use of steel sheaves is required for Type I cranes by Section 5427.1 of ASME NOG-1-2004, and Section 5150 of ASME NOG-1-2004 states that sheaves are subject to special considerations in the selection of materials, provide justification that the polymer material is not subject to failure modes different from steel. At a minimum, address the potential for polymer creep over time and the potential for sudden, catastrophic failure under high load compared with the energy dissipating yielding of steel sheaves.

2. Your response to NON 99901451/2017-201-02 failed to address several areas of concern to the NRC staff. The response states, in part, that "Based on the reason for the nonconformance, as the action to prevent recurrence we are now implementing a process change going forward with a plan to test weld filler metal that will be used on safety related components. Testing will be done [to] verify the critical characteristics established by KNES engineering and quality to meet design requirements based on the applicable sections of AWS code by a KNES 3rd party lab accredited to ISO/IEC 17025 and/or 10CFR50 App. B KNES audited laboratory." Clarify your response as follows:

   a. Confirm whether Konecranes plans on buying the weld filler metal as safety-related or as commercial grade and then perform commercial-grade dedication of the weld filler metal for its use on safety-related components.

In accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 2.390 "Public Inspections, Exemptions, Requests for Withholding," of the NRC's "Rules of Practice, "a copy of this letter, its enclosure(s), and your response will be made available electronically for public inspection in the NRC Public Document Room or from the NRC's Agencywide Documents Access and Management System, accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html. To the extent possible, your response should not include any personal privacy, proprietary, or safeguards information so that it can be made available to the Public without redaction. If personal privacy or proprietary information is necessary to provide an acceptable response, then please provide a bracketed copy of your response that identifies the information that should be protected and a redacted copy of your response that deletes such information. If you request that such material is withheld from public disclosure, you must specifically identify the portions of your response that you seek to have withheld and provide in detail the bases for your claim (e.g., explain why the disclosure of information will create an unwarranted invasion of personal privacy or provide the information required by 10 CFR 2.390(b) to support a request for withholding confidential commercial or

financial information). If safeguards information is necessary to provide an acceptable response, please provide the level of protection described in 10 CFR 73.21 "Protection of Safeguards Information: Performance Requirements."

Please contact Mr. Yamir Diaz-Castillo at 301-415-2228, or via electronic mail at Yamir.Diaz-Castillo@nrc.gov, if you have any questions or need assistance regarding this matter.

Sincerely,

/RA/

John P. Burke, Chief
Quality Assurance Vendor Inspection Branch-2
Division of Construction Inspection
and Operational Programs
Office of New Reactors

Docket No.: 99901451

SUBJECT: KONECRANES NUCLEAR EQUIPMENT & SERVICES LLC'S RESPONSE TO THE U.S. NUCLEAR REGULATORY COMMISSION INSPECTION REPORT NO. 99901451/2017-201, AND NOTICE OF NONCONFORMANCE

Dated: December 6, 2017

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NAME	YDiaz-Castillo	JBurke
DATE	12/05/17	12/06/17

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Palo Verde Nuclear Generating Station - APS Main Hoist Reeving Calculations

Morris Material Handling
Calculation # 36676-01
Customer PO # 500556483

Revision # 08

Author: ______________________ Date: February 15, 2018
Dan Ford, P.E.

Checker: ______________________ Date: February 15, 2018
Pugazhendhi Kanakasabai, Ph.D.

Approver: ______________________ Date: February 15, 2018
Jay Edmundson, P.E.

REVISION PAGE

Revision	Description of Revision	Date of Revision
0	Initial Release	February 8, 2012
1	Adjusted References section Adjusted Methodology section Changed Calc Title Added calc # and revision to all pages	May 4, 2012
2	Added Section 6: Broken Rope Calculations Adjusted References section Updated calculations to reflect design changes Added Attachment 3	January 25, 2013
3	Updated References section Updated calculations to reflect design changes and comments	January 17, 2017
4	Updated References section Updated calculations to reflect design changes and comments	July 28, 2017
5	Updated trunnion pin calculation methodology and material name (5.4) Changed crosshead yield strength and calculation methodology (5.4)	August 25, 2017
6	Added Section 5.3.5	September 1, 2017
7	Added Section 5.3.4.4	September 28, 2017
8	Updated Section 5.3.5 to address comment 1b of NRC Inspection Report # 99901451/2017-201	February 15, 2018

TABLE OF CONTENTS

1. PURPOSE

Evaluate the main hoist reeving system for the 225 ton Single Failure Proof containment building polar crane and verify that it meets the requirements of the specification as given in Ref. 9.

THE REMAINING SECTIONS OF THE (107 PGS) ARE CONSIDERED PROPRIETARY

Palo Verde Nuclear Generating Station - APS Aux Hoist Reeving Calculations

Morris Material Handling
Calculation # 36676-26
Customer PO # 500556483

Revision # 06

Author: ______________________ Date: February 15, 2018
Dan Ford, P.E.

Checker: ______________________ Date: February 15, 2018
Pugazhendhi Kanakasabai, Ph.D.

Approver: ______________________ Date: February 15, 2018
Jay Edmundson, P.E.

REVISION PAGE

Revision	Description of Revision	Date of Revision
0	Initial Release	February 8, 2012
1	Adjusted References section Adjusted Methodology section Changed Calc Title Added calc # and revision to all pages	May 4, 2012
2	Adjusted seismic factor Changed rope specs to reflect design changes Updated drum analysis to reflect design changes	January 31, 2013
3	Updated References section Updated drum analysis to reflect design changes Updated calculation to address comments	February 3, 2017
4	Added Section 5.3.5 Added note to Section 5.1 to reflect comments Updated References section	September 1, 2017
5	Added Section 5.3.4.4	September 28, 2017
6	Updated Section 5.3.5 to address comment 1b of NRC Inspection Report # 99901451/2017-201	February 15, 2018

TABLE OF CONTENTS

1. PURPOSE

Evaluate the aux hoist reeving system for the 35 ton Single Failure Proof containment building polar crane and verify that it meets the requirements of the specification as given in Ref. 9.

THE REMAINING SECTIONS OF THE (107 PGS.) ARE CONSIDERED PROPRIETARY.

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Attachment A
Cope and Quadrant Certificate of Conformance

[

PAGES 2 THRU 5 OF ATTACHMENT A ARE CONSIDERED PROPRIETARY.

]

Attachment B
Product Data Sheets from Quadrant

Quadrant Engineering Plastic Products

global leader in engineering plastics for machining

Monocast Cable Sheaves

QUADRANT
ENGINEERING PLASTIC PRODUCTS

A New Name built on Talent and Innovation

QUADRANT
ENGINEERING PLASTIC PRODUCTS

ERTA® INDUSTRY'S PARTNER FOR PLASTICS ENGINEERING

POLYPENCO

POLYMER CORPORATION ENGINEERING PLASTIC PRODUCTS

cestidur

DSM Engineering Plastic Products

SYMALIT

www.quadrantplastics.com

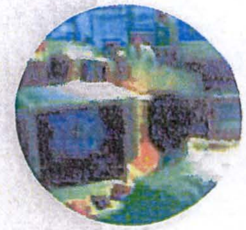
Monocast® Cable Sheaves have great advantages over metal

WEAR OF METAL SHEAVES AND WIRE ROPE

For many years' manufacturers of heavy duty lifting equipment have sought ways to increase wire rope endurance life and decrease wear on metal sheaves. Early attempts included lining the grooves of metal sheaves with resilient materials and mounting rims made of these materials on metal hubs.

WEIGHT AND CORROSIVE PROPERTIES OF METAL

The growth of mobile lifting equipment added a new design requirement as the dead weight of metal sheaves on a boom or mast must be reduced for improved lifting and over-the-road performance. The expansion in offshore exploration has generated a need for lifting equipment with corrosion resistant parts.



MONOCAST® CABLE SHEAVES - 4 SOLUTIONS IN ONE

With the development of MONOCAST® Cable Sheaves, we have achieved greatly improved wire rope life, improved lifting and transport with reduced weight, non-corrosive benefits for land or sea use and easier handling.

AID TO ENGINEERING EVALUATION AND DESIGN

This leaflet is intended to help engineers evaluate and design MONOCAST® cable sheaves for their particular type of equipment. However one should always consider load capacity for specific operating conditions under which the equipment will be used.

ABOUT MONOCAST® GSM

MONOCAST® GSM is a high strength cast nylon containing finely divided particles of molybdenum disulphide (MoS_2) solid lubricant for increased lubricity. Its superior strength enables to support bearing loads greater than other thermoplastics. Because of its inherent resilience, non-uniform or rapidly applied working stresses cause no permanent deformation. Wear resistant MONOCAST® is capable of reducing overall equipment weight while protecting mating metal surfaces.

TEMPERATURE FLUCTUATIONS

Typical room temperature mechanical properties for MONOCAST® nylon are shown on page 11. At lower temperatures, ultimate strength and modulus increase, while impact strength and elongation decrease.

UNIQUE MONOMER CASTING PROCESS

MONOCAST® nylon is made by a unique monomer casting process in which liquid monomer is directly polymerised into nylon in metal moulds. Parts of virtually unlimited size and thickness can be produced while retaining internal soundness.

PROPERTIES AND CAPABILITIES

The properties and production capabilities offered by MONOCAST® provide particular advantages for sheaves when compared to metal. MONOCAST® sheaves extend wire rope life, reduce weight, are corrosion resistant and improve service life.

WITH MANY APPLICATIONS GLOBALLY

MONOCAST® cable sheaves are widely used in mobile and offshore lifting equipment, offshore & shipping, automotive, military, chemical & petrochemicals, building & construction, railways & transport and agriculture.

Advantages of MONOCAST ® Cable Sheaves

Extended wire rope life

Quadrant Engineering Plastic Products in conjunction with an internationally recognised independent research institute, has been conducting wire rope endurance tests to obtain a comparison of the fatigue life of wire rope used with MONOCAST® sheaves and hardened steel sheaves under the same conditions.

Test results at stress levels of 10%, 20% and 28,6% of ultimate wire rope strength indicate dramatic improvements in the endurance life of wire rope when used with MONOCAST® sheaves. *Table 1* summarises results of the wire rope life testing. The tests prove MONOCAST® sheaves substantially increase rope cycle life; especially at higher sheave ratio's.

The retirement criteria used for the wire rope are covered by Dutch spec. NEN 3233. The failure criteria for test purposes were taken to be visible strand and/or core separation. However, conventional rope retirement criteria based only upon visible wire breaks may prove inadequate in predicting rope failure. The user of MONOCAST® sheaves is, therefore, cautioned that retirement criteria should be established based on the user's experience and the demands of his application.

More information regarding retirement criteria is mentioned in report number 89.3.TL2559 of dr.ir.L Wiek of the Technical University of Delft. A detailed description of the test procedures used can be found in Polymer Technical Bulletin WR-2 'Comparison of Wire Rope Fatigue Life and Margin Cycles When Using Nylatron® (MONOCAST®) and Steel Sheaves.

Reduced weight

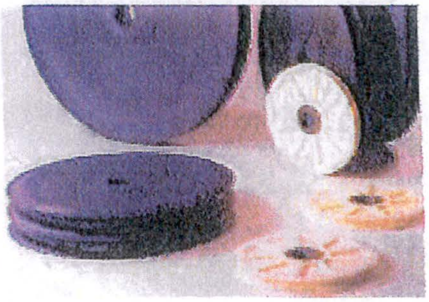
MONOCAST® nylon is approximately one seventh (1/7) the weight of conventionally used cast steel. Although the design has to be changed when converting steel into plastic, weight usually drops to 40 – 60% of the steel sheave weight; thus MONOCAST® nylon sheaves reduce dead weight at the end of a boom. This provides mobile cranes with greater stability and lifting capacity.

MONOCAST® sheaves also reduce weight over the axles on mobile cranes making it easier to comply with highway weight regulations. Large cranes equipped with cast MONOCAST® sheaves can be moved between job sites with less chance of damage to axles and tyres.

The reduced weight of MONOCAST® sheaves makes handling, installation and replacement significantly easier than with comparable metal sheaves.

Table 1 - **Wire rope lift testing results**

Sheave ratio	Rope tension for test	Design factor	Approximate duration of test	Increase in rope life attained with MONOCAST® GSM sheaves compared to hardened steel sheaves
24/1	10.0% of breaking strength	10.0	136,000 cycles	4.50 times
24/1	20.0% of breaking strength	5.0	68,000 cycles	2.20 times
24/1	28.6% of breaking strength	3.5	70,000 cycles	1.92 times
18/1	28.6% of breaking strength	3.5	39,000 cycles	1.33 times



Improved service life

Virtually unaffected by the corrosive elements found in marine environments, MONOCAST® sheaves eliminate the rust and corrosion that occurs with steel and cast iron. In addition, MONOCAST® sheaves provide wear life comparable to unhardened steel and cast iron sheaves under normal operating conditions. Initial lubrication in the rope groove is recommended for optimum results.

Competitive price

MONOCAST® nylon sheaves can be economically cast-to-configuration in a wide range of sizes with a minimum of machining required.

This economical production permits MONOCAST® sheaves to be priced competitively with cast and forged steel sheaves.

Custom sheaves

MONOCAST® sheaves can also be custom made to meet specific size requirements.

It is only necessary to provide a drawing of the sheave or key dimensions including rope diameter, outside diameter, groove diameter, hub width and rim width. The required type of bearing must also be supplied to determine the proper press fit dimension for the bore and validate maximum loading.

To obtain optimum serviceability from either custom or standard sheaves, certain considerations should be observed by equipment engineers when designing sheaves for a particular application. Of special importance are groove configuration, bore configuration, rib configuration, bearing retention and lead capacity.

Standard sheaves

MONOCAST® nylon standard sheaves are available in a range of 250 up to 1260 mm outside diameter.
They are cast as semi-finished blanks and can be machined to specific customer dimensions as ordered.

This dimension flexibility, along with reduced price and delivery for small quantities, is aimed at servicing OEM needs for initial prototype and production runs.

Small series with an outside diameter greater than 1260 mm can be obtained by machining solid cast discs.

Quality guaranteed

Whatever product we produce, quality is always number one. Our people are trained and educated to test and inspect the product during production. QC people inspect the production processes on a regular basis and take care of the final inspection before shipping the goods to our customers.

Our production facility is ISO 9001-2000 certified.
Specific products can be supplied under type approvals from Lloyd's, DNV, American Bureau of Shipping, RINA, German Lloyd's and others.

Design of MONOCAST ® Cable Sheaves

When designing with custom or standard sheaves, certain considerations should be observed by equipment engineers. Of special importance are groove configuration, bore configuration, bearing retention and load capacity. *Figure 1* should help to clarify important parameters. The basic design of any sheave should conform with the appropriate minimum (D7 / Dr (=rope diameter)), which is referred to as sheave ratio. For increasing rope life time, this ratio should be minimum 18, but most European rope manufacturers prefer a ratio of 24.

Rim configuration

The rim width (W1), outside (D1) and groove (D2) diameter are typically fixed design dimensions. The rim flat (T2) between the groove wall and rim edge should, according to DIN 15061, be minimum 3 mm to provide adequate side load stability. For the same reason, the rim edge thickness (T1) should be minimum 70% of the cable diameter.

Groove configuration

The groove radius for a MONOCAST® sheave should be approximately 5% greater than the nominal rope diameter to accommodate rope tolerances while giving adequate rope support.

Experience indicates that a groove angle of 45° will generally provide optimum rope support for crane sheaves. Unless otherwise specified, MONOCAST® sheaves are supplied with a 45° groove angle.

Sizes and tolerances of the groove are covered by DIN 15061-2.

Typical American and European practice requires that the depth of the rope groove for mobile crane sheaves be made a minimum of 1,75 times the rope diameter. MONOCAST® sheaves are supplied with a corresponding groove depth unless otherwise specified.

Web configuration

Practical experience with crane sheaves has shown that the required design strength can be maintained with a minimum web width that is 20% greater than the rope diameter. The benefit of reducing the web width is weight savings. Additional strength can be obtained by adding ribs to the design.

Rib configuration

All MONOCAST® cast sheaves are designed as standard with ribs, depending on the outside diameter, in order to withstand the sidewards deflection of the sheaves as the result of side forces encountered during operation.

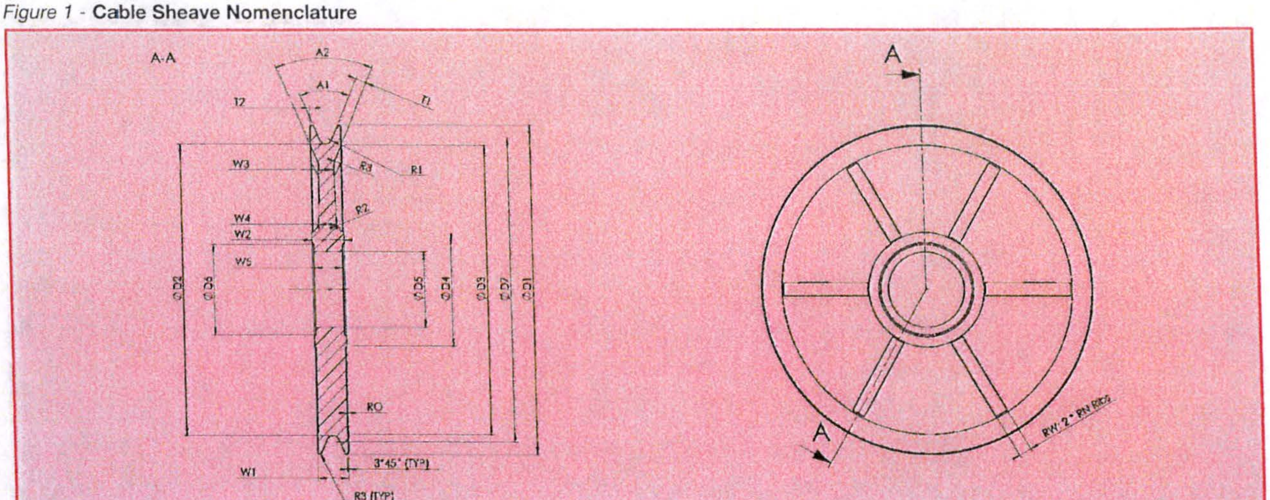
Validating of the total design can be done with assistance of a unique computer program. Displacements and stresses can be visualised; this analysis shows how the ribs assist in absorbing the stresses.

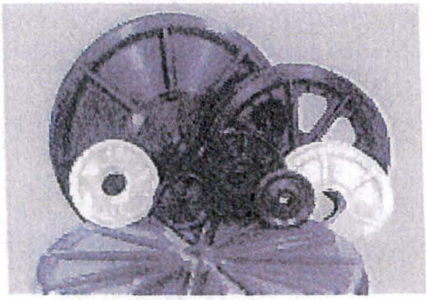
Hub configuration

The hub width (W2) is generally a design requirement specified by the end user. In most cases it should be equal to or greater than the rim for stability of the sheave in use. The minimum hub diameter (D4) is 1,5 times the bearing outside diameter (D5) for adequate wall support of the bearing. The wall thickness between the bearing and hub diameter should be always greater than 25 mm.

The transitions from the hub diameter to the web and the web diameter to the rim must be tapered and radiused as appropriate based upon the design thickness and diameter.

Figure 1 - **Cable Sheave Nomenclature**





Bore configuration

MONOCAST® sheaves for heavy-duty applications should be installed with anti-friction bearings. Cylindrical or needle roller bearing are generally recommended as they provide a continuous contact area across the width of the bore.

As the coefficient of thermal expansion of MONOCAST® nylon is several times that of metal, the press fit allowance must be large enough for the bearing to maintain contact with the bore at temperatures up to 50°C. A satisfactory press fit allowance for heavy-duty anti-friction bearings can be obtained from *Table 2* or by using equation 1:

$$A = 0,04\sqrt{D5} \quad (1)$$

Where A = Press fit allowance (mm)
D5 = Bearing outside diameter (mm)

The press fit allowance should be reduced somewhat for light duty thin walled bearings and by use at extreme low temperatures to prevent possible close in of the bearings on the shaft.
Bronze bearings are not recommended for main load applications. Their use should be limited to moderate unit loads to avoid excessive frictional heat build up and possible movement of the bearing in the bore.

For lightly loaded applications where pressure-velocity (PV) values are not excessive, it may be possible to plain bore MONOCAST® sheaves for running directly on the shaft. Detailed description of calculating PV-values can be found in the 'Quadrant Engineering Plastic Products' design & fabrication reference guide.

Recommended shaft running clearance can be obtained from *Table 3*.

Table 2

Press Fit Allowance A vs Bearing OD	
OD mm	**A* mm**
50	0.28
75	0.35
100	0.40
125	0.45
150	0.49
175	0.53
200	0.57
225	0.60
250	0.63
275	0.66
300	0.70

Table 3

Shaft Running Clearance C vs Shaft Diameter D	
D mm	**C** mm**
25	0.23
50	0.33
75	0.41
100	0.46
125	0.51
150	0.56

* *The diameter of the sheave bore will be the OD of the bearing minus the press fit allowance*
** *The diameter of the sheave bore will be the diameter of the shaft plus the shaft running clearance.*
The recommended shaft finish should be comparable to that of commercially hardened and ground shafting.

Design of MONOCAST ® Cable Sheaves

Bearing retention

Circumferential bearing retention can be achieved using the press fit allowances recommended in *Table 2* and pressing directly into the bore of the MONOCAST® sheave. A hydraulic press can be used or the sheave can be heated up to 85-95°C and the bearing dropped into the expanding bore.

Thrust washers, thrust plates or snap rings should be placed on either side of the sheave hub to maintain sideways bearing retention. This is necessary to restrict bearing movement which may occur as the result of side forces encountered during operation. See *Figure 2.*

There are two exceptions to bearing retention using the above procedure:

- The use of bronze bearings in idler sheaves where the sheave is free to move from side-to-side on a shaft. In this case, positive retention can be accomplished by extending the length of the bearing beyond the hub and placing external retaining rings on the bearing on each side of the hub.
- Under conditions where the use of steel inserts are recommended due to heavy loading. A positive retention method is to place a steel sleeve insert in the bore of the MONOCAST® sheaves into which the bearing is pressed. The insert is held in the bore by external retaining rings of the WRE-type on each side of the hub.

If thrust washers or thrust plates cannot be used, other means of retention must be found to restrict sideways movement of the bearing. Metal plates bolted to the hub and overlapping the ends of the bearing can be used for this purpose. See *Figure 3.*
Quadrant's technical engineers can assist you in designing and assembling the bearing construction.

Load capability of MONOCAST® sheaves (with bearings)

Industry standards for cranes specify sheave ratio D7/Dr and design factor Fd as two variables that affect crane design and sheave application.

When MONOCAST® sheaves are used in heavy-duty service, the user should first determine the sheave ratio and design factor which are appropriate for the application. Using specific values for the variables, nominal static pressures can be calculated for evaluation of sheave load carrying capacity. The maximum groove pressure of the rope for any sheave can be calculated from equation 2.

$$Pg = \frac{2\left(\frac{F_{rope,ult}}{Fd}\right)}{Dr \cdot D2} \qquad (2)$$

Where		
	Pg =	Max. groove pressure (N/mm^2)
	$F_{rope,\,ult}$ =	Breaking strength of wire rope (N)
	Fd =	Safety factor for wire rope
	$F_{rope,\,ult}/Fd$ =	Max. nominal single line pull (N)
	Dr =	Rope diameter (mm)
	$D2$ =	Groove base diameter (mm)

The formula above does not include wrap angle ω (see *Figure 4*) and so groove pressure is independent of this value. Calculation of individual thread pressure is not necessary if sheave ratio is 18:1 or larger.

Figure 2 - **Bearing retention**

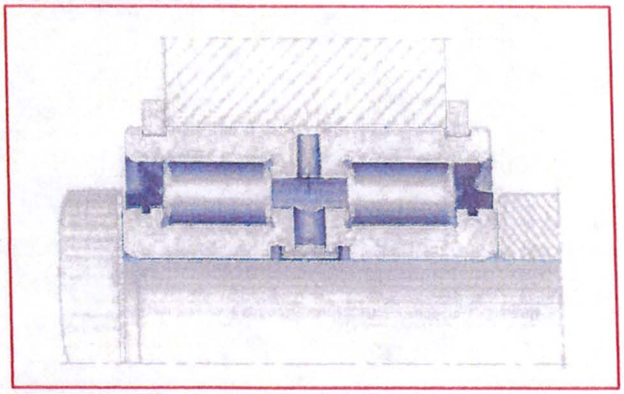
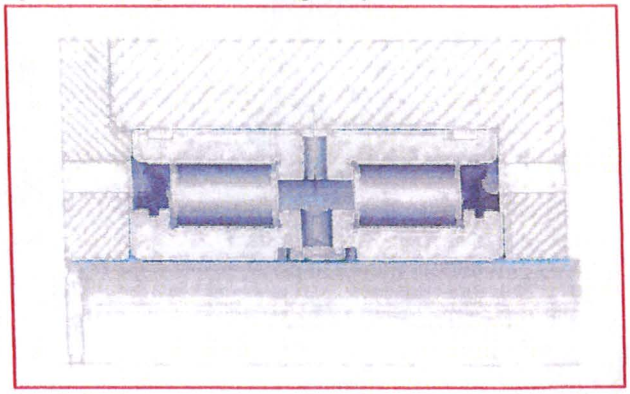


Figure 3 - **Bearing retention using side plates**



The bore pressure consists of two factors: the first caused by radial component of the loading, the second by the axial component (sidewards pull due to fleet angle).

$$Pb,total,\max = Pb,radial + Pb,axial,\max \qquad (3)$$

The radial component can be calculated using equation 4:

$$Pb,radial = \frac{2 \cdot \sin\left(\frac{\omega}{2}\right) \cdot \left(\frac{F_{rope,ult}}{F_d}\right) \cdot \cos(\delta)}{D5 \cdot W5} \qquad (4)$$

Where
- D5 = bore diameter (mm)
- W5 = Total sum of individual bearing width (mm)
- ω = wrap angle (see *Figure 4*)

The radial component has a constant value over the bearing width, The axial component has a maximum at the outer width of the bearing, and can be calculated with equation 5:

$$Pb,axial,\max = \frac{4 \cdot \sin(\delta) \cdot \left(\frac{F_{rope,ult}}{F_d}\right) \cdot \left(\frac{D2}{2}\right) \cdot \cos\left(\frac{\omega}{2}\right)}{D5 \cdot Wbearing,\max^2} \qquad (5)$$

Where
- Wbearing, max = Maximum outer distance between outside of (both) bearing(s) (mm)
- δ = fleet angle (see *Figure 5*)
- ω = wrap angle (see *Figure 4*)

Figure 4 - **Wrap angle ω**

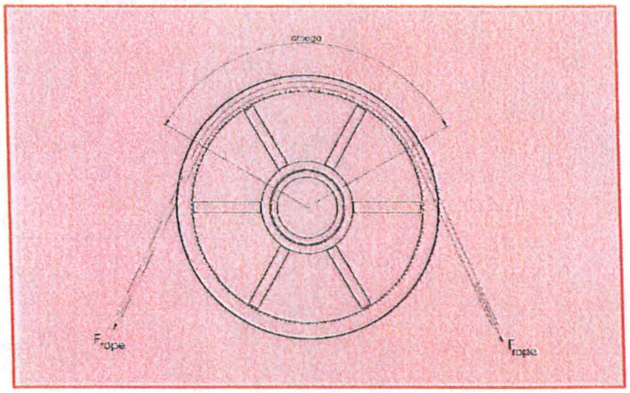
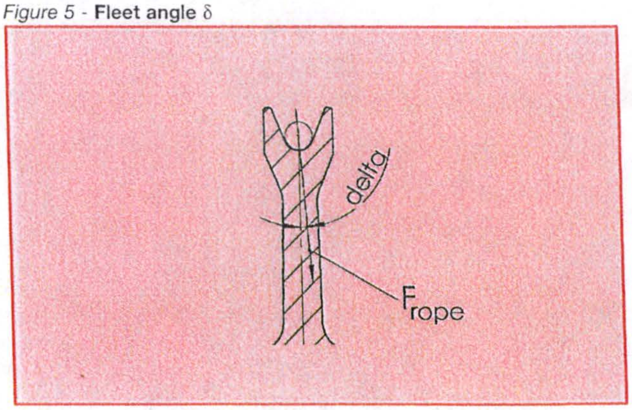


Figure 5 - **Fleet angle δ**



Under normal operation conditions, at room temperature and normal humidity, MONOCAST® sheaves equipped with anti-friction bearings should perform satisfactorily when both groove and surface are kept below the values given below.

The pressure and load capacity limits recommended above are based on intermittent cyclical loading as in typical mobile hydraulic crane operation. If operation involves continuous cycling or loading, high speeds and acceleration, or heavy impact forces, the limits should be reduced and the applications thoroughly evaluated.
Excessive loads and/or speeds may cause distortion of the bore and loss of press fit with the bearing. Accelerated groove wear may also result.

Table 4

Operating condition	Remark	Maximum surface pressure
Static	More than one week	< 10 N/mm²
Static/Dynamic	Up to one week	< 25 N/mm²
Dynamic	Short term use: a few minutes	< 60 N/mm²

MONOCAST ® Technical data

Load capacity plain bored sheaves

The load capacity for a plain bored MONOCAST® sheave is based on the ability of the bore to act as a bearing. To determine the recommended load capacity, refer to 'Quadrant Engineering Plastic Products' design & fabrication reference guide, and make calculations as follows assuming that the bore of the sheave is a MONOCAST® bearing.
First, obtain the recommended pressure velocity value PVa for the given operating conditions from the manual. Then calculate the maximum bore pressure using equation 6.

$$Pb = \frac{PVa}{V} \quad (6)$$

Where	Pb =	Max. bore pressure N/mm2
	PVa =	Pressure velocity value from manual (N/mm2 x mm/sec)
	V =	Shaft surface speed (mm/sec)
	=	π x (shaft rpm/60) x Ds (mm/sec)
	Ds =	Shaft diameter (mm)

Bore pressure Pb should not exceed 7 N/mm2. Take the calculated value for Pb or 7 N/mm2, whichever is less, and substitute in the following equation to obtain the maximum load capacity for the conditions specified:

$$LC = Pb \cdot Ds \cdot Wh \quad (7)$$

Where	LC =	Max. load capacity (N)
	Wh =	Width of hub in contact with shaft (mm)

The pressure and load capacity limits recommended above are based on practical experience with bearings and sheaves. If operation is higher than recommended limits, thorough service evaluation should be made, taking into account the special characteristics of the application. Excessive loads and/or speeds may cause accelerated wear and increased clearance in the bore.

Equipment operation

MONOCAST® sheaves provide definite advantages for cranes and similar equipment when designed for use within the parameters outlined.
To obtain optimum results, equipment should also be operated using accepted industry practices. Situations to be avoided include:
(1) two-blocking hook block and sheaves against boom point sheaves
(2) pulling hook and ball with exposed rope end into sheaves, and
(3) excessive fleet angle or side angle pull. Anti two blocking sheave guards are recommended for both multiple and single reefing systems.
Use original OEM-specified type of cable.

Hertzian pressure

The nominal values calculated for groove pressure are based on the assumption that the area of contact is the projected area of the rope groove and that the wire rope makes intimate contact with the groove. Actual contact values for surface pressure will be higher than nominal, however, as the individual strands make point contact with the groove. As shown below, the point contact pressure for a steel sheave will be much higher that for a MONOCAST® sheave. The resilience of the MONOCAST® nylon results in a larger contact area and greater support for the wire rope.

The maximum contact pressure q_0 that can occur at the centre of the contact surface is a function of the modulii E1 and E2 of the two contacting materials as shown by the Hertzian equation:

$$q_0 = f\left(\sqrt[3]{4\left(\frac{E1 \cdot E2}{E1 + E2}\right)^2}\right) \quad (8)$$

Where	q_0 =	Maximum contact pressure (N/mm2)
	f =	Geometrical and force factor; a constant in this case
	E1 =	Modulus of elasticity for rope (N/mm2)
	E2 =	Modulus of elasticity for sheave (N/mm2)

Substituting E1 and E2 = 220,000 N/mm2 as unity for a wire rope and steel sheave, the value in the brackets becomes 1.
Substituting E1 = 220,000 N/mm2 for a wire rope and E2 = 2,850 N/mm2 for a MONOCAST® sheave, as the ratio of 1 to 0.013, the numerical value in the brackets of the equation becomes 0.087. This means that the maximum contact pressure with a steel sheave is 11.5 times the contact pressure with a MONOCAST® sheave.

Above certain stress levels, plastic deformation and cold working of the MONOCAST® groove surface will take place. The resulting wire rope imprint, however, does not cause abrasion of the wire rope as would be the case with a steel sheave. In effect, it increases the groove surface area supporting the wire rope. This demonstrates the capabilities inherent in the resilience and strength of MONOCAST® cast nylon, lightweight MONOCAST® sheaves can support cyclical loads while providing extended wire rope endurance life.

Publications

A special loose lead manual containing detailed test data, case histories, technical articles and other material pertinent to MONOCAST® nylon sheaves is available upon request.

MONOCAST ® Physical properties

(indicative values►)

PROPERTIES		Test methods ISO / (IEC)	ASTM	Units	MONOCAST 6 PLA	MONOCAST GSM
Colour		–		–	natural (ivory) black	grey-black
Density		1183	D 792	g/cm³	1.15	1.16
Water absorption:						
- after 24h / 96h immersion in water of 23°C (1)		62		mg	44 / 83	52 / 98
		62		%	0.65 / 1.22	0.76 / 1.43
- at saturation in air of 23°C / 50% RH		–		%	2.2	2.4
- at saturation in water of 23°C		–		%	6.5	6.7
Thermal Properties (2)		–				
Melting temperature		–		°C	220	220
Thermal conductivity at 23°C		–		W/(K · m)	0.29	0.30
Coefficient of linear thermal expansion:						
- average value between 23 and 60°C		–		m/(m · K)	80 x 10⁻⁶	80 x 10⁻⁶
- average value between 23 and 100°C		–		m/(m · K)	90 x 10⁻⁶	90 x 10⁻⁶
Temperature of deflection under load:						
- method A: 1.8 MPa	+	75	D 648	°C	80	80
Max. allowable service temperature in air:						
- for short periods (3)		–		°C	170	170
- continuously: for 5,000h / 20,000h (4)		–		°C	105 / 90	105 / 90
Min. service temperature (5):		–		°C	-30	-30
Flammability (6):						
- "Oxygen index"		4589	D 2863	%	25	25
- according to UL 94 (3 / 6 mm thickness)		–	-94	–	HB / HB	HB / HB
Mechanical Properties at 23°C (7)						
Tension test (8):						
- tensile stress at yield / tensile stress at break (9)	+	527	D 638M	MPa	85 / –	78 / –
	++	527	D 638M	MPa	55 / –	50 / –
- tensile strain at break (9)	+	527	D 638M	%	25	25
	++	527	D 638M	%	> 50	> 50
- tensile modulus of elasticity (10)	+	527	D 638M	MPa	3 500	3 300
	++	527	D 638M	MPa	1 700	1 600
Compression test (11):						
- compressive stress at 1 / 2 / 5% nominal strain (10)	+	604	D 695	MPa	26 / 51 / 92	25 / 49 / 88
Creep test in tension (8):						
- stress to produce 1% strain in 1,000h ($\sigma_{1/1,000}$)	+	899	D 2990	MPa	22	21
	++	899	D 2990	MPa	10	9
Charpy impact strength - Unnotched (12)	+	179/1eU		kJ/m²	no break	no break
Charpy impact strength - Notched	+	179/1eA		kJ/m²	3.5	3.5
	++	179/1eA		kJ/m²		
Izod impact strenght - Notched	+	180/2A	D 256	kJ/m²	3.5	3.5
	++	180/2A	D 256	kJ/m²	7	7
Ball indentation hardness (13)	+	2039-1		N/mm²	165	160
Rockwell hardness (13)	+	2039-1	D 785	–	M 88	M 84
Chemical Resistance at 23°C						
Acids - weak		–	–	–	B	B
Acids - strong		–	–	–	C	C
Alkalies - weak		–	–	–	A	A
Alkalies - strong		–	–	–	B-C	B-C
Aromatic hydrocarbons		–	–	–	A	A
Aliphatic hydrocarbons		–	–	–	A	A
Ketones, esters		–	–	–	A	A
Ethers		–	–	–	A	A
Chlorinated solvents		–	–	–	B	B
Alcohols		–	–	–	A	A
Inorganic salt solutions		–	–	–	A	A
Hot water		–	–	–	B	B
UV Resistance						
Outside applications		–	–	–	B / Black: A	A

Note: 1 g/cm³ = 1,000 kg/m³; 1 MPa = 1 N/mm²

Legend

+ : values referring to dry material
++ : values referring to material in equilibrium with the standard atmosphere 23°C / 50 % RH (mostly derived from literature)

(1) According to method 1 of ISO 62 and done on discs ø 50 x 3mm.
(2) The figures given for these properties are for the most part derived from raw material supplier data and other publications.
(3) Only for short time exposure (a few hours) in applications where no or only a very low load is applied to the material.
(4) Temperature resistance over a period of 5,000 / 20,000 hours. After these periods of time, there is a decrease in tensile strength of about 50% as compared with the original value. The temperature values given here are thus based on the thermal-oxidative degradation which takes place and causes a reduction in properties. Note, however, that, as for all thermoplastics, the maximum allowable service temperature depends in many cases essentially on the duration and the magnitude of the mechanical stresses to which the material is subjected.
(5) Impact strength decreasing with decreasing temperature, the minimum allowable service temperature is practically mainly determined by the extent to which the material is subjected to impact. The values given here are based on unfavourable impact conditions and may consequently not be considered as being the absolute practical limits.
(6) These estimated ratings, derived from raw material supplier data, are not intended to reflect hazards presented by the materials under actual fire conditions. There are no UL-yellow cards available for these stock shapes.
(7) The figures given for the properties of dry material (+) are for the most part average values of tests run on test specimens machined out of rods ø 40 - 60 mm.
(8) Test specimens: Type 1 B
(9) Test speed: 20 mm/min (5 mm/min for ERTALON 66-GF30, ERTACETAL H-TF and ERTALYTE TX).
(10) Test speed: 1 mm/min.
(11) Test specimens: cylinders ø 12 x 30 mm.
(12) Pendulum used: 15 J.
(13) 10 mm thick test specimens.

Chemical resistance
A: acceptable service
B: limited service
C: unacceptable service

► This table is a valuable help in the choice of a material. The data listed here fall within the normal range of product properties. **However, they are not guaranteed and they should not be used to establish material specification limits nor used alone as the basis of design.**

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Comparison of Wire Rope Life Using Nylon and Steel Sheaves— Part 1: Test Methodology and Comparison of Wire Rope Endurance Life

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ABSTRACT

A méthodology was developed to test wire rope endurance characteristics to ANSI B30.5 removal criteria. Under field simulated loads, wire rope was cycled so that each rope section had 180° contact with one nylon sheave and one steel sheave until the rope replacement criteria designated by wire breaks was attained.

At a load equal to 10% and 20% of the ultimate strength of the wire rope, the rope at the nylon sheave side endured 4.5 and 2.2 times as many cycles as compared to the wire rope on the steel sheave side.

THE OBJECTIVES of this test project are to:

1. Compare the cyclic fatigue life to removal criteria of wire rope specimens operating under the very same loading conditions and cycled over nylon and steel sheaves having identical dimensions.

2. Compare the condition of the nylon and steel sheaves resulting from identical loading and cycling.

HISTORICAL BACKGROUND

Manufacturers, owners, and operators of lifting devices have historically searched for means of increasing wire rope life by lining rope grooves on sheaves with protective materials, such as wood, leather, rubber, plastic, and hemp. Such linings have not received wide acceptance, since they do not have sufficient durability.

Development of plastic-lined sheaves started as early as 1954 in Europe. (1) Different types of nylon and high density polyethylene were tried as machined linings on wire rope sheaves in the field. The trials illustrated that linings made from block polymerized nylon were particularly wear resistant. (2)

The availability and flexibility of the new nylon monomer casting process led to the use of all nylon sheaves in the late sixties. Alicke reported favorable results with the use of cast nylon sheaves in bucket, crane, and elevator applications. (3)

The growing use of mobile hydraulic cranes in the early 1970's provided additional impetus for nylon sheaves with the need for reduced boom weight as well as increased wire rope life. Nylon sheaves are now widely used by crane manufacturers in both England and Germany. (4) They have gained acceptance in the United States

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for use on cranes ranging in size from 15 to 100 ton capacity. They are also being evaluated for a variety of other lifting devices including mobile lattice boom cranes, locomotive cranes, oil well drill and service rigs, dock and offshore cranes, and overhead traveling cranes.

A research program was initiated by the Wire Rope Technical Board and the Wire Rope Producers Committee of the American Iron and Steel Institute to investigate performance and replacement criteria of wire rope when used with steel sheaves. (5)

The test equipment built for the WRTB tests was offered to investigate the performance and replacement criteria of wire rope when used with both steel and nylon sheaves. This comparative test, which is still continuing, is the basis for this report.

TEST MATERIALS

Early experience gained in Europe illustrates that monomer cast type 6 nylon is the most suitable material for reducing wire rope stress while providing sheave life comparable to cast steel sheaves. This high strength thermoplastic has been processed for molecular weight and crystallinity to provide the best combination of properties for sheave applications. It has been carefully tailored by additives such as molybdenum disulphide for improved lubricity and wear resistance. Typical properties for nylon sheaves used in this test project are listed in (Table 1). The traditional cast steel sheaves used on lifting cranes are generally cast oversize in the rope groove and machined to a smooth surface. The steel sheaves used for this test project were machined from 1040 steel and then hardened to Rockwell C32 to conform to typical industry usage. The groove on the nylon and steel sheaves were identical.

The solid nylon and steel sheaves were both machined to 20" (508 mm) outside diameter and 17-3/8" (441 mm) tread diameter for use with 3/4" (19 mm) diameter wire rope. (Figure 1) The sheave ratio (pitch diameter to rope diameter) was 24 to 1 with the rope groove providing a 140° contact angle. The design of the test sheaves corresponds to the design of nylon main load sheaves now used in production on a 60 ton mobile boom crane.*

The wire rope specimens were taken from a single 1,000 ft. (305 m) spool of U.S. Steel 6 x 25 IWRC (independent wire rope core) wire rope. Ultimate tensile strength of the new 3/4" wire rope from three specimens averaged 65,147 lbs. or 290,000 N. The IWRC wire rope represents a basic construction used for load hoisting applications.

Table 1 - Properties of cast nylon sheaves

Property	Units	ASTM No.	Value
Specific Gravity	—	D-792	1.15-1.17
Tensile Strength	psi	D-638	11,000-14,000
Elongation	%	D-638	10-60
Modulus of Elasticity	psi	D-638	350,000-450,000
Compressive Strength	psi	D-695	
@ 0.1% Offset			9,000
@ 1.0% Offset			12,000
Shear Strength	psi	D-732	10,500-11,500
Hardness (Rockwell)	—	D-785	112-120
Tensile Impact	ft.lb./in.^{2}	—	80-130
Deformation Under Load 122°F, 2000 psi	%	D-621	0.5-1.0
Stiffness	psi	D-747	200,000-400,000
Heat Distortion Temp.			
66 psi	°F	D-648	400-425
264 psi	°F	D-648	200-425
Melting Point	°F	D-789	430±10
Flammability	—	D-635	Self-extinguishing
Coefficient of Linear Thermal Expansion	in./in. °F	D-696	5.0 x 10-5
Water Absorption—24 hours	%	D-570	.6-1.2
Water Absorption—Saturation	%	D-570	5.5-6.5

Resistant to:
Common solvents, hydrocarbons, esters, ketones, alkalis, dilute acids.
Not Resistant to:
Phenol, formic acid, concentrated mineral acids.

TEST EQUIPMENT AND METHODOLOGY

The test equipment consists of a horizontally mounted machine equipped with two in-line testing sheaves, one nylon and one steel, at opposite ends. A wire rope loop made of two ten-foot sections passes over the sheaves.

Fixed end links were used to connect two rope sections to prevent rope rotation. Loading was introduced by a hydraulic servo load

*The Polymer Corporation has applied for patents on the design of their Nylatron® nylon sheaves.

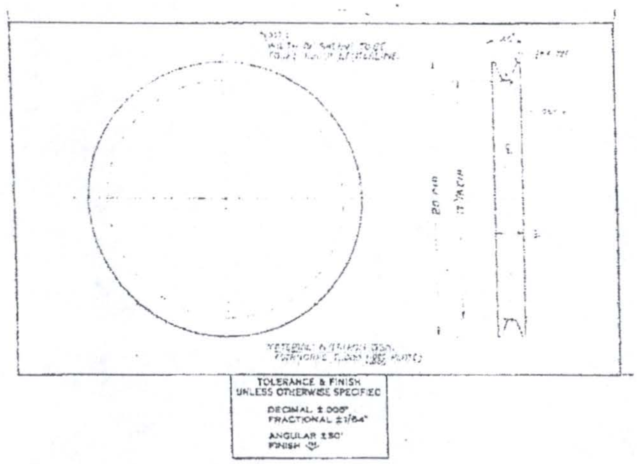


Fig. 1 - Configuration of nylon and steel sheaves

control system on the sheave at one end while the sheave at the other end was anchored. Cycling of the wire rope was accomplished by an oscillating ram, which was linked to an eccentric rotating arm. As in the application of hoisting equipment, the rope is driven and not the sheave. A schematic of the test set-up is illustrated in (Figure 2).

During cycling of the machine, one section : ..ie rope passes over the Nylatron sheave and ..ne other section over the steel sheave. As the crank arm of 28" (17-3/4" x $\pi/2$) rotates 360 degrees, the wire rope moves in one direction 56" and reverses to the opposite direction the same distance and stops at the starting point in approximately 1.2 seconds. The time varies with load.

The loading was conducted using wire rope strength factors of 10 and 5, i.e., 10% and 20% of ultimate tensile strength of the rope. Since two rope cross-sections bear the load, the pull on the servo load controller is twice that of the wire rope tension. The machine is programmed for loading, halting, wire rope reversals, halting and unloading. This loading cycle was repeated every six seconds. (Fig. 3) This methodology simulates the actual application of loads and cycles used on lifting cranes.

The machine is automated to periodically stop for inspection of both wire ropes and sheaves until the removal criteria is attained. The removal criteria for wire rope cyclic fatigue is the same as that used for WRTB tests. This is covered by American National Standard Institute (ANSI) B30.5 which states that in running ropes, six randomly distributed broken w s in one lay or three broken wires in one ..and in one lay are reason for replacement.

Each level of loading for each test phase was considered complete when a combined total of seven (7) rope sections were replaced from two sides.

Inspection frequency was set for 2,500, 1,000, and thereafter 500 cycle intervals. If a broken wire was found, the next inspection intervals were reduced to 200 cycles until the replacement criteria of the wire rope was reached. Using a magnifying glass and high-intensity light, wear, deformation, crown breaks (due to contact between rope and sheave surfaces), and tangential breaks (caused by strand-to-strand friction) can be detected during routine inspections. Conditions of sheave grooves and temperature of the sheaves were examined at each inspection interval.

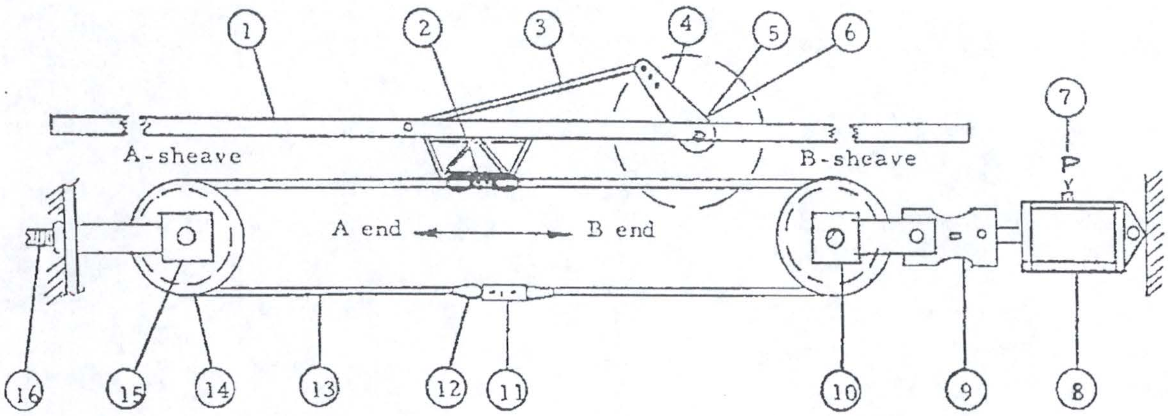
The retired wire rope sections were tensile tested to failure and the percent of remaining strength determined.

The experimental part of this paper was conducted at Southwest Research Institute. (Ref. 6)

TEST RESULTS

1. WIRE ROPE ENDURANCE LIFE - The first phase of the test, conducted at a stress level of 10% of the ultimate strength of the wire rope (strength factor of 10), ran for approximately 136,000 cycles. (Figure 4) Six wire ropes were retired from the steel sheave side and only one from the Nylatron sheave side. The wire rope endurance life on the Nylatron sheave side was 4.5 times that on the steel sheave side. The second phase of the test, conducted at a stress level of 20% of the ultimate strength of the wire rope (strength factor of 5), ran for approximately 68,000 cycles. (Figure 5) Five wire ropes were retired from the steel sheave side and two from the Nylatron sheave side. The wire rope endurance life on the nylon sheave side was 2.2 times that on the steel side.

2. CONDITION OF WIRE ROPE - Inspection of the wire rope during the test revealed that after several thousand test cycles, a slight



No.	Description
1	Oscillating ram-inertial
2	Ram clamp to wire rope specimen at bridge (rope attached to drive mechanism)
3	Connecting link-eccentric drive arm to ram
4	Eccentric drive arm-output from 60:1 gearbox
5	Electric clutch
6	10 hp. electric motor
7	30 hp hydraulic electric pump - 3000 psi
8	Automatic load controlled servo system using load cell output
9	Strain gaged load cell
10	Load input bridle
11	Connecting link or swivel
12	Zinc poured sockets
13	Wire Rope test samples two 10 ft specimens
14	Special test sheaves: Polymer sheave on fixed end, steel sheave on loading end
15	Anchor end or stationary bridle
16	Adjustable end on stationary bridle for variations in lengths and connecting links.

Fig. 2 - Schematic of test set-up

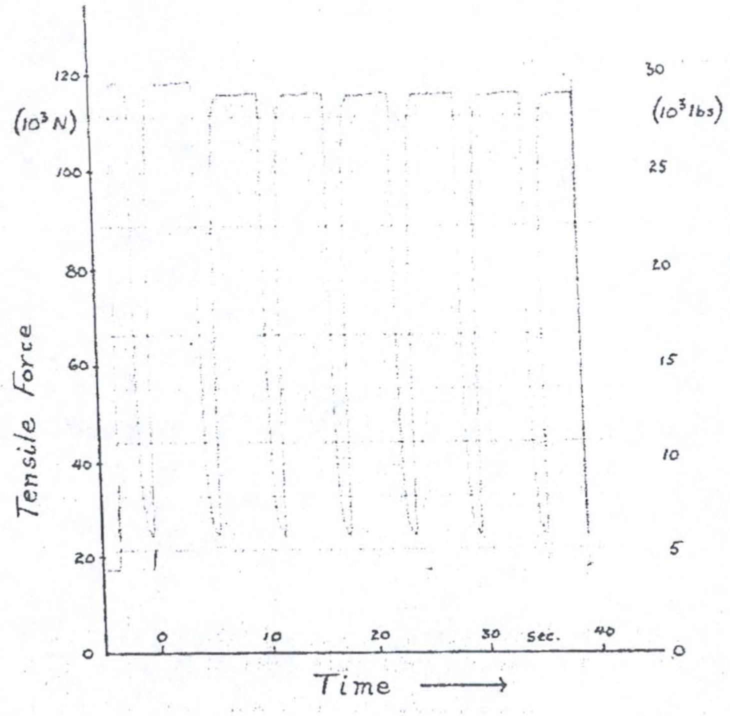


Fig. 3 - Recording of cyclic loading on dual test specimens

wearing of each wire rope occurred on the steel sheave side compared to a polishing of each rope on the nylon sheave side. The frictional wear on the steel sheave side progressed with additional cycles until wire breaks occurred. The polishing on the nylon sheave side progressed much more slowly leading to eventual wire breaks.

At a load level of 10%, all wire failures on the steel sheave side were crown breaks due to crown wear while both crown breaks and tangential breaks occurred on the nylon sheave side. At a load level of 20%, the incidence of crown breaks remained predominant on the steel sheave side. The incidence of tangential breaks became predominant on the nylon sheave side.

3. CONDITIONS OF SHEAVES - Inspection of the nylon sheaves after the first 1,000 cycles of t, at both load levels, revealed an im-...ion of the wire rope in the bottom contour the sheave groove. Little change was observed thereafter. Inspection of the steel sheaves after the first 2,000 to 3,000 cycles of test at the same stress levels revealed that some ridges were found along with observable wear and debris. Formation of the ridges and abrading away of the ridges are repeated on the steel sheave side. Both the nylon and steel sheaves were still in serviceable condition after completion of the cyclic load tests. (Figures 6 and 7) show condition of the rope grooves of the nylon and steel sheaves at completion of the test conducted at 20% of rope breaking strength.

SUMMARY

A wire rope endurance test machine was constructed and a test methodology was developed. The test methodology simulates the actual application of loads and cycles used in lifting cranes. Nylon and steel sheaves were installed for this comparative testing.

Nylon sheaves imparted as much as 220% and 450% longer endurance life to wire rope compared with steel sheaves at rope strength factors of 5 and 10, respectively.

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IMPROVED WIRE ROPE ENDURANCE LIFE WITH NYLON SHEAVES

by John H. Chen and Paul E. Gage,
The Polymer Corporation

ABSTRACT

The endurance life of a 3/4" diameter wire rope was tested using nylon and steel sheaves on a simulated lifting device at design factors of 3.5, 5 and 10 employing sheave ratios of 18/1 and 24/1.

The nylon sheaves imparted a distinctively longer endurance life of 1.33 to 4.5 times to the wire rope compared with steel sheaves depending on load level and sheave ratio employed. The performance of wire pe on nylon sheaves was consistent with only a small viation of data. After retiring a total of seven (7) ropes from both the nylon and steel sides, the nylon and steel sheaves were still in operational condition.

The substantially longer endurance life of wire rope against nylon sheaves, as compared to steel sheaves, can be attributed to the unique properties of nylon including resiliency and elasticity. It was demonstrated that drastically reduced contact pressure and better rope support with nylon sheaves resulted in delay of initiation of crown breaks as well as tangential breaks.

A linear relationship of remaining strength vs. an introduced fatigue factor was found. This linear relationship can be utilized to evaluate the reliability of wire rope/sheave systems. If the test results from a wire rope/sheave system yield small deviations from the linear relation, it is feasible to predict the remaining strength of cycled ropes for optimal retirement. Test results indicate that a minimum sheave ratio of 24/1 is an important criterion for rope endurance life.

INTRODUCTION

Historically, manufacturers and operators of wire rope/sheave devices have looked for means of increasing rope life by inserting protective materials in rope grooves. In the early 1950's, attempts were made to use wear resistant plastics by strip lining metal ooves and by mounting grooved rings on metal hubs. ylon was found to be particularly effective. Nylon grooved rings were used on cableways to reduce noise as well as cable wear.[1,2]

The availability of the nylon monomer casting process in the 1960's led to the development of cast-to-size nylon sheaves. With this process, the roller bearing is pressed directly into the nylon bore. Early installations on lifting equipment included clam shell buckets, bridge cranes, and tower cranes.[3,4]

The growing use of mobile lifting equipment has provided an additional need for cast nylon sheaves to reduce dead weight at the end of the boom and over the axles. The expanded use of offshore lifting equipment has also highlighted the advantages of nylon sheaves for corrosion resistance.

Cast nylon boom point sheaves are now offered by a growing number of equipment manufacturers in both Europe and the U.S.A. They are widely used to improve wire rope life, reduce weight, and eliminate corrosion in a variety of applications including mobile construction cranes, mobile oil-field rigs, and offshore pedestal cranes.

Service experience with mobile lifting equipment has shown that wire rope life is definitely improved with nylon sheaves. To qualify the degree of improvement, a series of comparative wire rope endurance life tests have been conducted with nylon and steel sheaves in a simulated lifting device. Partial test results and initial findings were reported previously.[5,6,7] Complete test results have been summarized and analyzed for the first time in this paper.

WIRE ROPE ENDURANCE TEST

The wire rope specimens were taken from a single 1,000 ft. (305m) spool of 3/4" 6 x 25 FW PRF RRL EIPS IWRC wire rope. Ultimate tensile strength of the new wire rope from three specimens averaged 65,100 lbs. or 290,000 N. The IWRC wire rope represents a basic construction used for load hoisting applications.

References and illustrations at end of paper

The nylon sheaves used for test were monomer cast by anionic polymerization of caprolactam in the presence of a catalyst and initiator. Typical properties for this type 6 cast nylon, containing molybdenum disulphide solid lubricant, are listed in Table 1. The steel sheaves used were machined from 1040 steel and hardened to Rockwell C32 to conform to typical industry usage for surface hardened cast steel sheaves.

The solid nylon and steel sheaves were both machined to desired dimensions, so that the sheave ratios (pitch diameter to rope diameter) were 18/1 or 24/1 with the rope groove providing a 140° contact angle. The design of the test sheaves corresponds to the design of nylon main load sheaves now used in production on a 60 ton mobile hydraulic crane.*

A cast nylon and a steel sheave were installed at each end of the test machine for comparative testing (Fig. 1). The machine was programmed for loading, halting, wire rope reversal, halting and unlaoding. During cycling of the machine, one section of the rope passed only over the nylon sheave and the other section over the steel sheave. The two rope sections were connected by fixed end links to prevent rope rotation. The loading was applied using design factors of 10, 5 and 3.5, for the 24/1 sheave ratio sheaves and a design factor of 3.5 for the 18/1 sheave ratio sheaves. A minimum design factor of 3.5 is specified for running ropes in American National Standard Institute (ANSI) B30.5.

The machine was stopped periodically for inspection of wear, deformation, and wire breaks until the replacement criteria for the wire rope was attained. The replacement criteria used is covered by ANSI B30.5 which states that in running ropes, "six randomly distributed broken wires in one lay or three broken wires in one strand in one lay" are reason for replacement. Tests at each load level were considered complete when a combined total of seven ropes were removed from both sides. The retired wire rope sections were tensile tested to failure and the percent of remaining strength determined.

The experimental part of this paper was conducted at Southwest Research Institute.[8]

TEST RESULTS

Results of the wire rope endurance tests, including number of ropes retired, low, average and high values of wire rope life cycles, and relative wire rope life at the two sheave sides for four (4) test phases, are summarized in Table 2. Six wire ropes were retired from the steel sheave side and only one from the nylon sheave side at a stress level of 10% of the rope breaking strength. At 20% of the breaking strength, 5 ropes were retired from the steel sheave side and 2 from the nylon sheave side. At 28.6% of the breaking strength, more ropes were retired from the steel sheave side at both sheave ratios tested. At 10%, 20% and 28.6% (D/d = 24 and 18) of the rope breaking strength, the wire rope endurance life on the nylon sheave side was 4.5, 2.2, 1.9 and 1.3 times that on the steel sheave side respectively. It was noted that rope life cycle data was quite scattered at the steel sheave side, while consistent results were obtained at the nylon sheave side.

Inspection of the wire rope during the tests revealed that, on the steel sheave side, wear on each wire rope occurred after a few thousand test cycles. The abrasive wear between wire rope and steel sheave then progressed with additional cycles until wire breaks occurred. On the nylon sheave side, a slight polishing of the wire rope was initially observed. The polishing progressed slowly until an eventual wire break occurred.

Inspection of the nylon sheaves after the first 1000 cycles at all load levels revealed an impression of the wire rope in the bottom of the sheave groove. Little change was observed thereafter. Inspection of the steel sheaves after the first 2,000 to 3,000 cycles of test, revealed that some ridges were formed along with observable wear and debris. Formation of the ridges and abrading away of the ridges were repeated on the steel sheave side. Both the nylon and steel sheaves were still in serviceable condition after a total of 7 ropes were retired at each load level of the cyclic test. Figure 2 (a) and (b) show the condition of the rope grooves of the nylon and steel sheaves at completion of the test conducted at 20% of the rope breaking strength. It should be noted that the wire rope impression on a nylon sheave will have little effect on the performance of the sheave or the wire rope.

MODES OF WIRE BREAKS

Under cyclic loading and unloading over a sheave, rope wires are subject to tensile, torsional, and bending forces as well as abrasion and contact pressure. Wear areas on 61 retired hoist and drag ropes from various surface coal mines were examined by Beeman[9]. By dismantling the ropes into individual wires, it was found that most wear occurred at contact regions of rope/sheave, strand/IWRC and strand/strand at averages of 15.3%, 8.9% and 3.5%, respectively. The outer wear due to rope/sheave contact was by far the most severe.

Visible breaks can be classified as crown breaks and tangential breaks due to contact of rope/sheave and strand/strand respectively. Examples of crown breaks are shown in Figures 3 and 4 and examples of tangential breaks are illustrated in Figure 5 from present test work. The type and average number of wire breaks at rope replacement are summarized in Table 3.

On the steel sheave side at a sheave ratio of 24/1 and a design factor of 10, the wire breaks were exclusively crown breaks. At design factors of 5 and 3.5, the wire breaks remained predominately crown breaks. On the nylon sheave side, the incidence of crown breaks was drastically reduced at all load levels. At design factors of 5 and 3.5, tangential breaks were the main reason for retirement.

On the steel sheave side at a sheave ratio of 18/1 and a design factor of 3.5, the average numbers of crown and tangential breaks are approximately equal. On the nylon sheave side, tangential breaks remain the main reason for rope retirement.

* The Polymer Corporation has applied for patents on the design of nylon sheaves.

The types of first wire breaks found during testing are depicted in Figure 6 where a stress factor (to be described later) is plotted against the number of load cycles on a semi-logarithmic scale. The stress factor incorporates the effects of both load level and sheave ratio. The data illustrates that nylon sheaves retard the initiation of both crown breaks and tangential breaks at all conditions tested. It is also shown that the tendency towards crown breaks decreases with increasing sheave ratio and design factor.

CONTACT PRESSURE

The test data demonstrates that cyclic stressing associated with highly concentrated contact pressure resulting in wear, deformation, and crack formation is the major factor causing wire breaks. The wire breaks shorten the useful life of a wire rope.

Contact pressure between two elastic solids can be evaluated by employing Hertzian equations.[10] The maximum pressure at the center of the contact surface q_o is a function of moduli E_1 and E_2 of the two contacting materials, i.e.

$$q_o = f\left[\sqrt[3]{4\left(\frac{E_1 \cdot E_2}{E_1 + E_2}\right)^2}\right] \quad \ldots\ldots\ldots\ldots [1]$$

At the steel sheave side, substituting $E_1 = E_2$ as unity, the value in the brackets becomes 1. Substituting $E_1 = 30{,}000{,}000$ psi for the wire rope and E_2 400,000 psi for nylon, as the ratio is 1 to 0.013, the numerical value in the brackets of the equation becomes .087. This means that the maximum contact pressure at the steel sheave side is 11.5 times the contact pressure at the nylon sheave side.

On the steel sheave under pressure, rope wires will make diamond-shaped contact. Because of localized pressure concentration on the steel groove, there is a repetitive process of fine ridge formation and ridge abrasion that takes place as observed during these tests. The debris adds to abrasion at the contact surfaces. Under the high contact pressure with addition of flexing, the wire rope tends to wear, deform and crack with resulting crown breaks.

Because of the resiliency and elasticity of a nylon sheave, a larger surface area of the wire rope makes contact with the groove and the magnitude of the unit contact pressure is significantly reduced. Above certain stress and endurance levels, the nylon will permit plastic deformation and cold working of the groove surface. The resulting imprint, however, does not cause abrasion and cracking of the wire rope as would be the case with an imprint in a steel sheave. The lack of abrasion and improved rope support reduces the incidence of crown breaks and tangential breaks.

STRESS FACTOR AND FATIGUE FACTOR

"Endurance life cycle" for a wire rope is a subjective term as a variety of replacement criteria are used by different organization and individuals. Remaining strength, however, should be one of the most useful criteria for judging serviceability.

The reduction in strength of a wire rope in service is caused by tensile, bending, torsion, and localized compressive stresses. The remaining strength in such a rope can be described in terms of stress factor and fatigue factor.

The degree of stress in a wire rope loaded over a sheave can be expressed by a stress factor F_s as follows:

$$F_s = f\,(P,\ D/d, \theta) \quad \ldots\ldots\ldots [2]$$

where F_s = Stress factor

P = Line pull at operation

D/d = Sheave ratio where D is sheave pitch diameter and d is rope diameter

θ = Arc of contact of wire rope over sheave

As the angle θ is kept constant in this investigation, the stress factor can be expressed as:

$$F_s = aP\,(24\ d/D)^p \quad \ldots\ldots\ldots [3]$$

where a and p are constants

The identity 24 d/D is unity for a sheave ratio of 24/1 and decreases with increasing sheave ratio. The line pull P can be expressed as:

$$P = P_b/F_d \quad \ldots\ldots\ldots\ldots [4]$$

where P_b = Breaking strength of new uncycled rope

F_d = Design factor

As the breaking strength of a new rope P_b can be considered a constant in a wire rope lifting system, the stress factor F_s can be expressed as:

$$F_s = \frac{b\,(24\ d/D)^p}{F_d} \quad \ldots\ldots\ldots [5]$$

where b is a constant

This expression shows that the degree of stress in a wire rope decreases as the sheave ratio and design factor increases.

The degree of fatigue in a wire rope cyclically loaded over a sheave can be expressed by a fatigue factor F_f as follows:

$$F_f = f\,(P,\ D/d,\ \theta,\ n,\ S) \quad \ldots\ldots [6]$$

where F_f = Fatigue factor

n = Number of cycles over sheave to replacement

S = Stroke amplitude

The fatigue factor F_f can be written in terms of stress factor F_s and number of cycles n as follows, if S is kept constant:

$$F_f = \frac{c\ (24\ d/D)^p\ (n)^q}{F_d}\ . . . . [7]$$

where c and q are constants

Evaluation of the test data shows that the constants have values of c = 1, p = 1.51 and q = 1/2. The fatigue factor F_f, of a rope undergoing various load cycles can then be expressed as:

$$F_f = (24\ d/D)^{1.51} \cdot \Sigma\ (\sqrt{n}/F_d) . . . . [8]$$

To equate fatigue factor with remaining strength, values for F_f have been calculated and plotted against % remaining strength in Figure 7 for each rope tested. This data shows that a linear relationship exists between fatigue factor and remaining strength. Linear regression analysis of all 28 tests points indicates that there is a certainity of linearity of better than 99.0%. The test points for nylon sheaves are very close to the linear relationship while the test points for steel sheaves are scattered. One point each at a design factor of 10 and 5 is unusually low and three points at a design factor of 3.5 are high as shown by arrows. It was observed, that the former two points were due to irregular friction and abrasion processes between ropes and steel sheaves, while the latter were caused by large amounts of grease exuding from the wire rope during the test.

If the above points are substituted by points representing remaining strength at F_f = 0, the certainty of linear relationship will become very close to 100%. The linear relationship can then be expressed as:

$$y = 99.6 - 0.619\ F_f\ . . . . [9]$$

where y = % remaining strength

lower limits of 99% confidence

$\sigma t = 2.114 \times 2.508 = 5.30\%$

σ = Standard deviation about the regression line

t = Student t

The linear relationship in Figure 7 demonstrates that it is feasible to predict with reasonable confidence the remaining strength of a wire rope which has been subjected to a number of single bends over a sheave under known loading provided a sufficient number of data points have been obtained. It also indicates that the degree of scattering obtained can be used to evaluate the reliability of the system. It further suggest that nylon sheaves can provide a greater degree of reliability for any wire rope/sheave system.

The data in Figure 7 was replotted in Figure 8 using sheave ratio D/d as a separate parameter. It can be readily seen that rapid deterioration in remaining wire rope strength takes place when using smaller sheaves. The reduction in rope strength using sheave ratios of 18/1, and 15/1 is 154% and 203% respectively as compared to a sheave ratio of 24/1. This suggests that a minimum sheave ratio of 24/1 is an important design criterion for endurance life of wire ropes.

NOMENCLATURE

Crown Breaks -	Outer wire breaks caused by contact of wire rope crown and sheave groove surface often accompanied by abraided press marks.
Design Factor, F_d -	The ratio of new rope breaking strength to design operating load. It is expressed also as Strength Factor or Safety Factor.
Fatigue Factor, F_f -	The term introduced to express reduction in rope strength due to bend-over-sheave fatigue. It can be expressed as a function of design factor, sheave ratio, and number of cycles to retirement.
Remaining Strength -	The ultimate tensile strength of a retired wire rope, which has been cyclicly loaded. It is conveniently expressed as percentage of new rope tensile strength.
Sheave Ratio, (D/d)-	The ratio of sheave pitch diameter to wire rope nominal diameter.
Stress Factor, F_s -	A factor of wire rope stresses induced by bend-over-sheave. It can be expressed as a function of design factor and sheave ratio.
Tangential Breaks -	Wire breaks caused by contact between neighboring strands typified by indented or abraided press marks.
3/4" 6 x 25 FW PRF - RRL EIPS IWRC	3/4" nominal diameter wire rope, 6 strands of 25 wires each with filler wires, preformed, right regular lay, extra improved plow steel grade, using independent wire rope core.

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REFERENCES

1. Renfordt, H., "Erhörte Seilsicherheit durch kunststoffegefütterte Seilscheiben", DEMAG Nachrichten, H. 139 (da. 1955), p.21-24.
2. Strickle, E. and Tietz, J., "Erfahrungen mit Seilrollenfutter aus Polyamiden", Part 1 and 2, dhf, February and March 1971.
3. Alicke, G., "Erfahrungen mit Seilrollen aus Polyamide", Fördern und Heben, No. 8, June 1974.
4. Polypenco Ltd., Welwyn Garden City, Herts., England, Private Correspondence.

5. Chen, J. H. and Ursell, C. R., "Comparison of Wire Rope Life Using Nylon and Steel Sheaves, Part I, Test Methodology and Comparison of Wire Rope Endurance Life", SAE Technical Paper 790904.

6. Chen, J. H., and Gage, P. E., "Comparison of Wire Rope Life Using Nylon and Steel Sheaves, Part II, New Concept to Improve Predictability of Wire Rope Remaining Strength After Cycling", SAE Technical Paper 790905.

7. Chen, J. H. and Gage, P. E., "Improved Reliability and Fatigue Life of Wire Ropes With Nylon Sheaves", in ASME Reliability, Stress Analysis and Failure Prevention Methods in Mechanical Design, p.275/83, edited by W. D. Milestone, 1980.

8. Ursell, C. R. and Kerr, D. J., "Comparative Cyclic Fatigue Evaluation of Cast Nylon Sheaves Versus Steel Sheaves", SWRI Report No's. 03-5239-001 to -003 for The Polymer Corporation, January and July, 1979 and August 1980.

9. Beeman, G. H., "Factors Affecting The Service Life of Large-Diameter Wire Rope", Battelle Northwest Laboratory for U. S. Dept. of Energy under Contract EY=76-C-06-1830, March 1978.

10. Timoshenko, S., "Strength of Materials, Par II - Advanced Theory and Problems", Van Nostrand, Priceton, Third Edition 1956.

TABLE 1

Typical Properties of Cast Nylon Sheaves

Property	Units	ASTM No.	Value
Specific Gravity	—	D-792	1.15-1.17
Tensile Strength	psi	D-638	11,000-14,000
Elongation	%	D-638	10-60
Modulus of Elasticity	psi	D-638	350,000-450,000
Compressive Strength	psi	D-695	
@ 0.1% Offset			9,000
@ 1.0% Offset			12,000
Shear Strength	psi	D-732	10,500-11,500
Hardness (Rockwell)	—	D-785	112-120
Tensile Impact	ft.lb./in.²	—	80-130
Deformation Under Load 122°F, 2000 psi	%	D-621	0.5-1.0
Stiffness	psi	D-747	200,000-400,000
Heat Distortion Temp.			
66 psi	°F	D-648	400-425
264 psi	°F	D-648	200-425
Melting Point	°F	D-789	430±10
Flammability	—	D-635	Self-extinguishing
Coefficient of Linear Thermal Expansion	in./in. °F	D-696	5.0 x 10-5
Water Absorption—24 hours	%	D-570	.6-1.2
Water Absorption—Saturation	%	D-570	5.5-6.5

Resistant to:
Common solvents, hydrocarbons, esters, ketones, alkalis, dilute acids.

Not Resistant to:
Phenol, formic acid, concentrated mineral acids.

TABLE 2

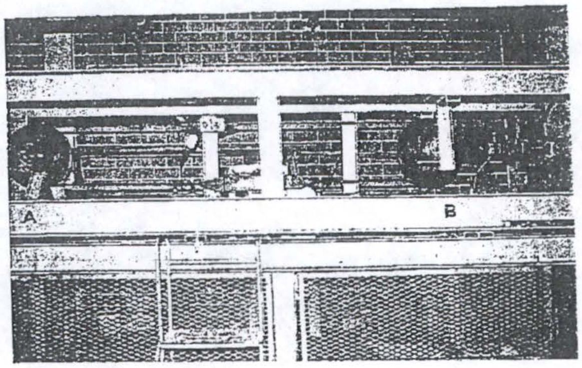
Wire Rope Life Using Nylon or Steel Sheaves

SHEAVE ROPE DIA. RATIO	LOAD, % ROPE BREAKING STRENGTH (DESIGN FACTOR)			STEEL SHEAVE SIDE	NYLON SHEAVE SIDE
24:1	10% (10)	No. of Ropes Retired		6	1
		Wire Rope Life Cycles	Low	18,947	103,106
			Average	22,694	
			High	28,983	
		Relative Wire Rope Life		1.0	4.54
24:1	20% (5)	No. of Ropes Retired		5	2
		Wire Rope Life Cycles	Low	12,784	28,676
			Average	13,539	29,208
			High	15,347	29,739
		Relative Wire Rope Life		1.0	2.16
24:1	28.6% (3.5)	No. of Ropes Retired		5	2
		Wire Rope Life Cycles	Low	11,748	27,070
			Average	14,137	27,193
			High	18,957	27,316
		Relative Wire Rope Life		1.0	1.92
18:1	28.6% (3.5)	No. of Ropes Retired		4	3
		Wire Rope Life Cycles	Low	8,376	12,120
			Average	9,626	12,834
			High	10,075	13,763
		Relative Wire Rope Life		1.0	1.33

TABLE 3

Type and Average Number of Wire Breaks at Rope Replacements

SHEAVE RATIO	DESIGN FACTOR	AVERAGE NUMBER OF	WIRE ROPES ON STEEL SHEAVES	WIRE ROPES ON NYLON SHEAVES
24/1	10	Life Cycles	22,700	103,100
		Crown Breaks	17.5	7.0
		Tangential breaks	0	2.0
24/1	5	Life Cycles	13,500	29,200
		Crown Breaks	10.4	1.0
		Tangential breaks	0.4	6.0
24/1	3.5	Life Cycles	14,100	27,200
		Crown Breaks	12.0	1.0
		Tangential breaks	1.0	9.0
18/1	3.5	Life Cycles	9,600	12,800
		Crown Breaks	8.5	1.0
		Tangential breaks	8.7	21.0



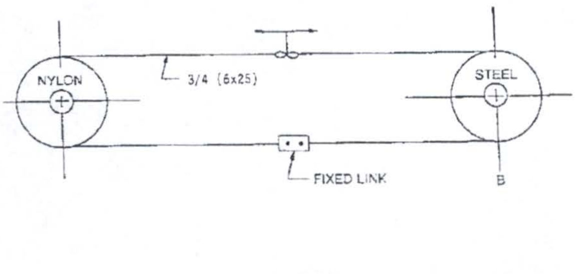
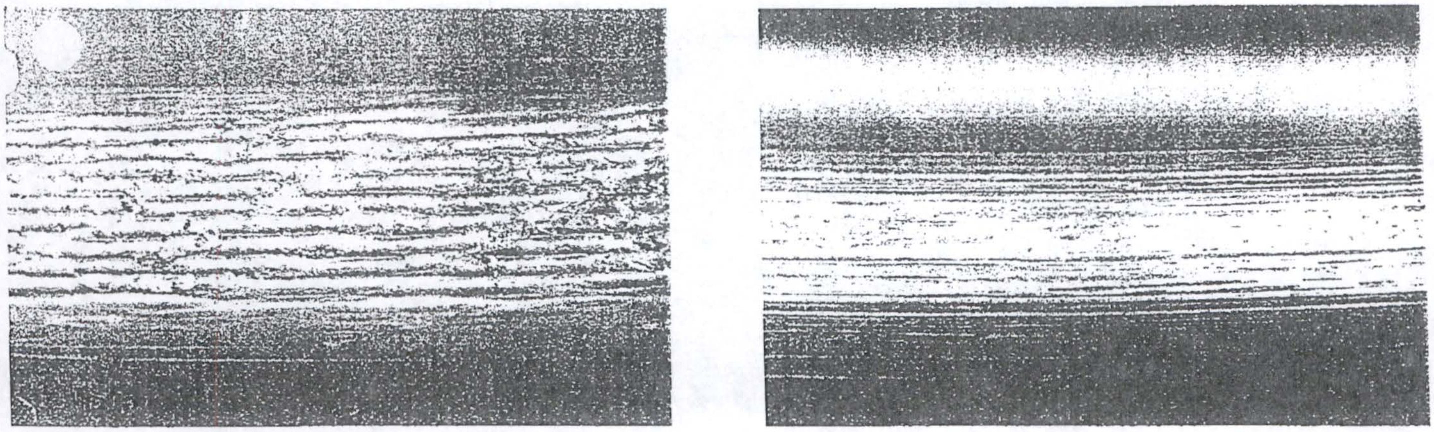


Fig. 1 - Set-up for fatigue life testing of wire ropes with nylon and steel sheaves.



(a) Nylon groove (b) Steel groove

Fig. 2 - Condition of nylon and steel sheave grooves after 67,700 cycles at a load of 20% of rope breaking strength.

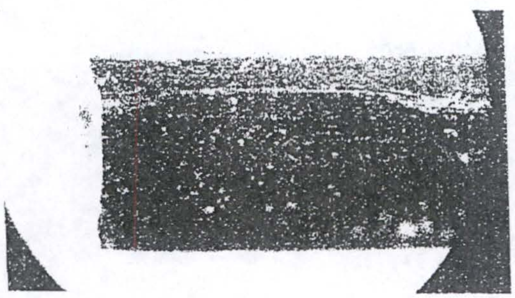


Fig. 3 - A crown break showing heavily worn and deformed area on steel sheave side. D/d = 18. Wire diameter = .050" (1.27 mm).

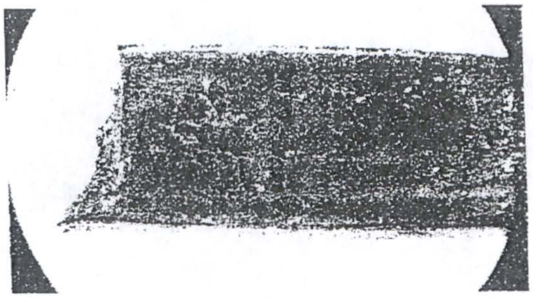
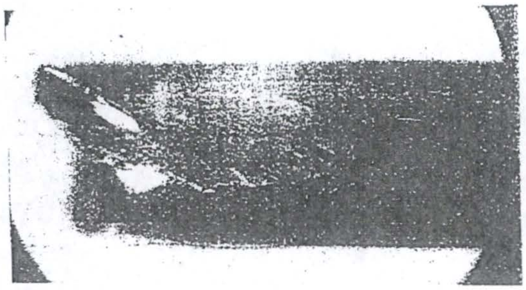
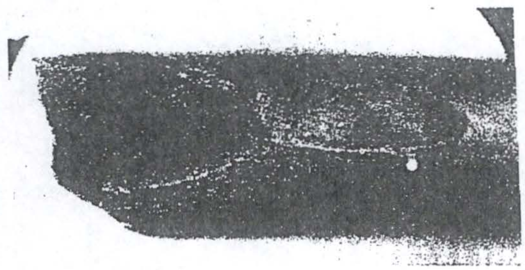


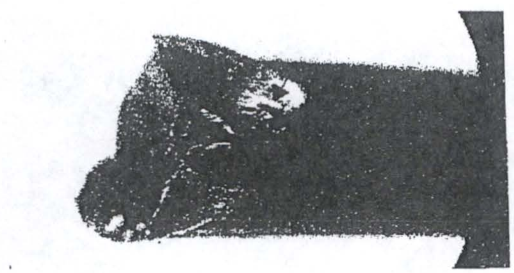
Fig. 4 - Concentration of Contact Pressure initiated this crown break on steel sheave side. D/d = 18. Wire diameter = .050" (1.27 mm).



(a) on nylon sheave side.



(b) on steel sheave side.



(c) on steel sheave side.

Fig. 5 - (a)-(c) - Indentation marks of strand/strand contact are shown close to tangential wire breaks. Sheave ratio = 18/1. Design factor = 3.5. Wire diameter .050" (1.27 mm).

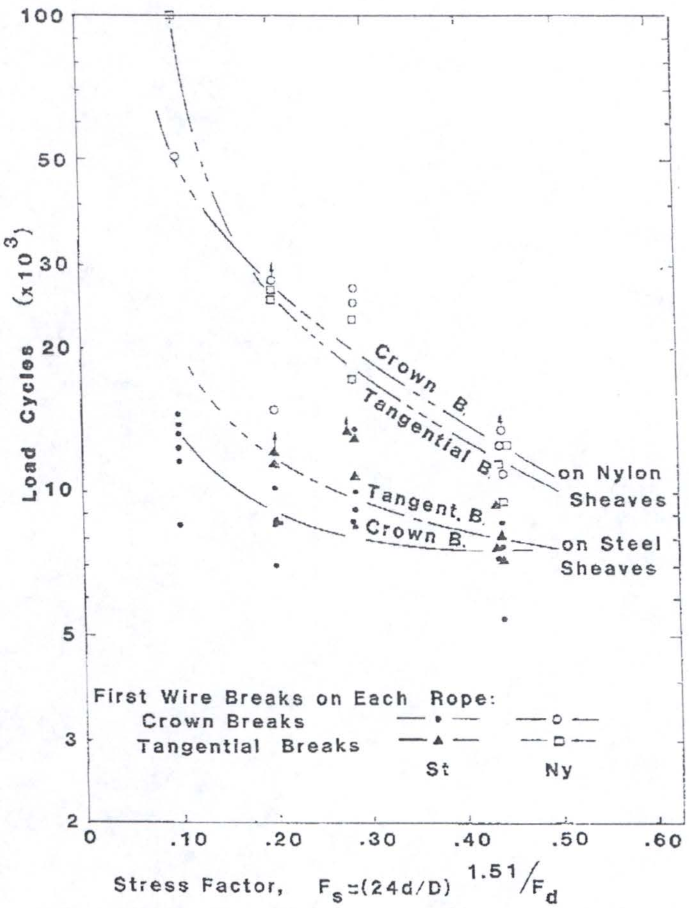


Fig. 6 - Nylon sheaves retard the initiation of crown and tangential breaks.

KONECRANES®
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Attachment D
Failure Modes and Specific Material Data for Nylatron

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Operating instructions for Monocast cable sheaves

If nominal load capacity of any type of crane allows it, Monocast polyamide cable sheaves can mainly be used to increase rope lifetime and reduce weight. Although originally designed for mobile cranes, Monocast sheaves are currently used for all kind of lifting devices like harbour cranes, drilling rigs, elevators etc.
Due to the difference in operating frequency between mobile and other cranes, and since operating frequency has increased over the last years, a review on safety and lifetime is needed.

Known failure modes of nylon sheaves are:
- Overload causing deformation of the groove
- Overload causing deformation of the bore

For safety reasons, it is strongly suggested to have the shaft fixed on both sides of the sheave. When a sheave failure occurs, the rope will be supported by the shaft.

1 Sheave lifetime

When Monocast cable sheaves are used, they will have to be replaced due to change of geometry effects (wear and deformation) and material effects (material degradation). The combination of these effects will determine the lifetime.
Sheaves should be inspected at least every 6 months regarding damage, cracks, wear and deformation.

Sheave lifetime can be negatively influenced by:
- Wrong bearing. Quadrant advices clearance class minimum C3
- Wrong cable. Quadrant advices to use rotation-resistant ropes.
- Fleet angle too big, causing the sheave to deflect or break outer flange. For a groove angle of 45°, maximum fleet angle is 3°. Larger fleet angles require design changes.

2 Wear and deformation

Monocast cable sheaves are designed as idle pulleys. However due to friction in the bearings and acceleration of the cable, the initial cable speed may differ from the sheave speed. This will cause a sliding effect and could cause higher wear.
Groove depth is easy to measure but will not indicate wear in axial direction of the groove. Therefore Quadrant recommends to use T1, which is the minimum wall thickness of the flange. Sheaves are produced T1 between 80% and 100% of the nominal cable diameter, and should be replaced when it has been reduced to 60% of the nominal cable diameter.
When a cable sheave is overloaded due to one of the failure modes mentioned above, elasticity limit is exceeded and plastic deformation will occur. Sheave will show signs of buckling or a deformed bore surface. In that case, a sheave must be replaced immediately.

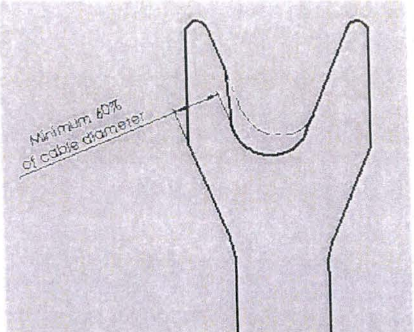

Figure 1: Thickness T1 in worn sheave

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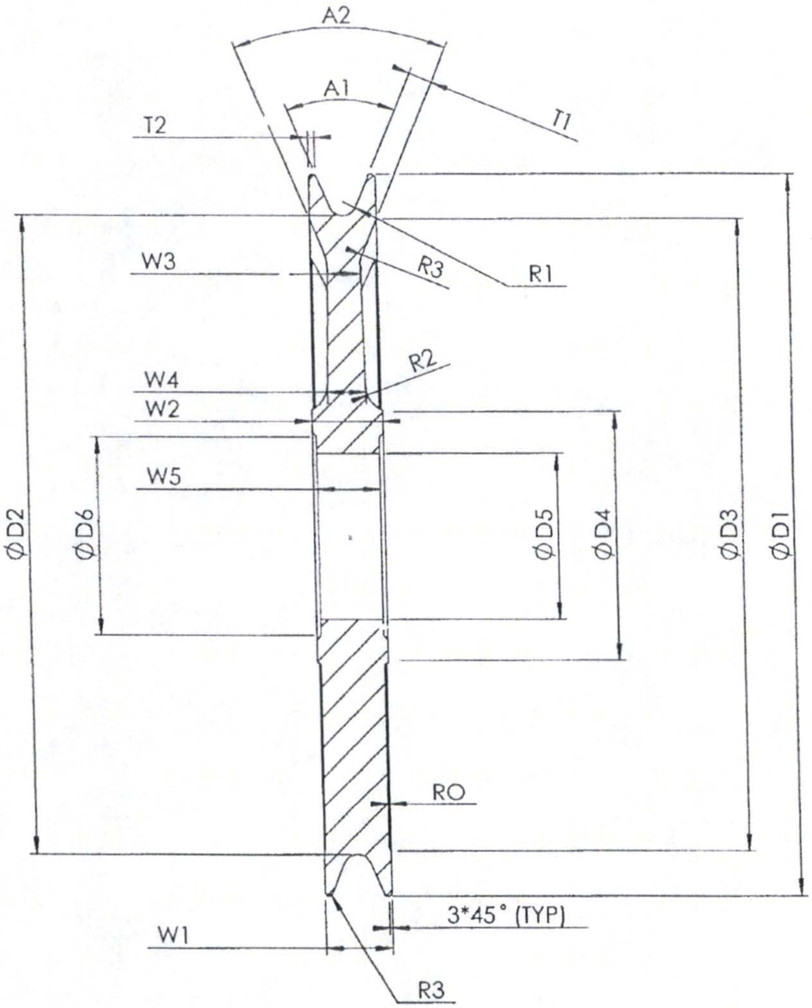

Figure 2 – cable sheave nomenclature

3 Material degradation

Polyamide is a strong engineering plastic, but mechanical properties deteriorate due to environmental effects, time under load, UV degradation, temperature and/or moisture.

- Due to the risk of creep, caused by long term static loads, loading time and conditions should be known at time of designing a sheave. Generally sheaves are calculated for use in dynamic conditions, meaning that the sheave will keep rotating and only stop shortly when subjected to high loads.
- Mechanical properties will vary with temperature: below –25°C the material is very stiff and brittle, above +40°C the material becomes too flexible and buckling may occur.
- Absorption of moisture out of surrounding air is a very slow process. Since this penetration starts at the outside surface, it will (dependant on the cross section) take more than 10 years before the core is saturated. Sheave stiffness will reduce, but

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toughness will increase due to the absorbed water.
- UV radiation will stop at the outside surface of the material and can not penetrate deep into the material.
- Sheaves are designed according to the circumstances mentioned above. Changing circumstances need to be verified or communicated to Quadrant.

4 Cleaning and chemical resistance

Sheaves can be cleaned, but one should be careful with chemicals. Also cleaning with hot water could result in accelerated moisture absorption. A summary of chemical resistance (at 23°) is given below. A separate brochure with an extended list is available upon request.

Resistant:
- Both aromatic and aliphatic hydrocarbons (petroleum, petrol, kerosene, diesel fuels)
- Weak alkali's
- Ketones, esters and Ethers
- Inorganic salt solutions
- Mineral oils and greases

Partially resistant:
- Weak acids
- Chlorinated solvents

Non resistant:
- Strong mineral and organic acids
- Strong alkali's

5 Maintenance

Initially, bearings are mounted using a press fit allowance and for cylindrical roller bearings a snap ring in addition. Since arising forces of this press fit are below the limit of creep, the dimensions of the bore will return to their original values after removing the bearing. Therefore the bore should not be re-machined when replacing bearings.
During the disassembly and later assembly of a new bearing, perfect alignment and supporting of the sheave hub must be assured to prevent permanent deflection/deformation of the sheaves or the bore.

6 Conclusion:

- Standard Monocast cable sheaves can be used in temperature range of –25°C up to +40°C. Material for other temperature ranges is available upon request.
- Monocast cable sheaves can standard be used in relative humidity of 30% - 70%.
- In normal use, the lifetime of Monocast cable sheaves is minimum 10 years.
- Monocast cable sheaves are designed for dynamic loading; long term static loading should be avoided.

SHAPE DATA

	#	PRODUCT DESCRIPTION	UNIT	TEST METHOD	Quadrant® Nylon 101	Nylatron® GS	Nylatron® GF30	Nylatron® MC907	Nylatron® MC901	Nylatron GSM
					Unfilled PA66	MoS_2 Filled PA66	30% Glass Filled PA66	Unfilled PA6	Blue, Heat Stabilized PA6	MoS_2 Filled PA6
					Extruded	Extruded	Extruded	Cast	Cast	Cast
MECHANICAL	1	Specific Gravity, 73°F.	-	ASTM D792	1.15	1.16	1.29	1.15	1.15	1.16
	2	Tensile Strength, 73°F.	psi	ASTM D638	12,000	12,500	13,500	12,000	12,000	11,000
	3	Tensile Modulus of Elasticity, 73°F.	psi	ASTM D638	425,000	480,000	675,000	400,000	400,000	400,000
	4	Tensile Elongation (at break), 73°F.	%	ASTM D638	50	25	5	20	20	30
	5	Flexural Strength, 73°F.	psi	ASTM D790	15,000	17,000	21,000	16,000	16,000	16,000
	6	Flexural Modulus of Elasticity, 73°F.	psi	ASTM D970	450,000	460,000	650,000	500,000	500,000	500,000
	7	Shear Strength, 73°F.	psi	ASTM D732	10,000	10,500	10,000	11,000	11,000	10,500
	8	Compressive Strength, 10% Deformation, 73°F.	psi	ASTM D695	12,500	16,000	18,000	15,000	15,000	14,000
	9	Compressive Modulus of Elasticity, 73°F.	psi	ASTM D695	420,000	420,000	600,000	400,000	400,000	400,000
	10	Hardness, Rockwell, Scale as noted, 73°F.	-	ASTM D785	M85 (R115)	M85 (R115)	M75	M85 (R115)	M85 (R115)	M80 (R11
	11	Hardness, Durometer, Shore "D" Scale, 73°F.	-	ASTM D2240	D80	D85	-	D85	D85	D85
	12	Izod Impact (notched), 73°F.	ft. lb./in. of notch	ASTM D256 Type "A"	0.6	0.5	-	0.4	0.4	0.5
	13	Coefficient of Friction (Dry vs. Steel) Dynamic	-	QTM 55007	0.25	0.2	-	0.2	0.2	0.2
	14	Limiting PV (with 4:1 safety factor applied)	ft. lbs./in.^{2} min	QTM 55007	2,700	3,000	-	3,000	3,000	3,000
	15	Wear Factor "k" x 10^{-10}	in.^{3}-min/ft. lbs. hr.	QTM 55010	80	90	-	100	100	90
THERMAL	16	Coefficient of Linear Thermal Expansion (-40°F to 300°F)	in./in./°F	ASTM E-831 (TMA)	5.5 x 10[illegible]	4 x 10[illegible]	2.0 x 10[illegible]	5.0 x 10[illegible]	5.0 x 10[illegible]	5.0 x 10
	17	Heat Deflection Temperature 264 psi	°F	ASTM D648	200	200	400	200	200	200
	18	Tg-Glass transition (amorphous)	°F	ASTM D3418	N/A	N/A	N/A	N/A	N/A	N/A
	19	Melting Point (crystalline) peak	°F	ASTM D3418	500	500	500	420	420	420
	20	Continuous Service Temperature in Air (Max.) (1)	°F	-	210	220	220	200	260	200
	21	Thermal Conductivity	BTU in./hr. ft.^{2} °F	E 1530-11	1.7	1.7	1.7	-	2.37	-
ELECTRICAL	22	Dielectric Strength, Short Term	Volts/mil	ASTM D149	400	350	350	500	500	400
	23	Surface Resistivity	ohm/square	EOS/ESD S11.11	$>10^{12}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$
	24	Dielectric Constant, 10^6 Hz	-	D150	3.6	-	-	3.7	3.7	3.7
	25	Dissipation Factor, 10^6 Hz	-	D150	0.02	-	-	-	-	-
	26	Flammability @ 3.1 mm (1/8 in.) (5)		UL 94	V-2	V-2	V-2	HB	HB	HB
CHEMICAL (3)	27	Water Absorption Immersion, 24 Hours	% by wt.	ASTM D570 (2)	0.3	0.3	0.3	0.6	0.6	0.6
	28	Water Absorption Immersion, Saturation	% by wt.	ASTM D570 (2)	7	7	5.5	7	7	7
	29	Acids, Weak, acetic, dilute hydrochloric or sulfuric acid	@73 °F		L	L	L	L	L	L
	30	Acids, Strong, conc. hydrochloric or sulfuric acid	@73 °F		U	U	U	U	U	U
	31	Alkalies, Weak, dilute ammonia or sodium hydroxide	@73 °F		L	L	L	L	L	L
	32	Alkalies, Strong, strong ammonia or sodium hydroxide	@73 °F		U	U	U	U	U	U
	33	Hydrocarbons-Aromatic, benzene, toluene	@73 °F		A	A	A	A	A	A
	34	Hydrocarbons-Aliphatic, gasoline, hexane, grease	@73 °F		A	A	A	A	A	A
	35	Ketones, Esters, acetone, methyl ethyl ketone	@73 °F		A	A	A	A	A	A
	36	Ethers, diethyl ether, tetrahydrofuran	@73 °F		A	A	A	A	A	A
	37	Chlorinated Solvents, methylene chloride, chloroform	@73 °F		L	L	L	L	L	L
	38	Alcohols, methanol, ethanol, anti-freeze	@73 °F		L	L	L	L	L	L
	39	Continuous Sunlight	@73 °F		L	L	L	L	L	L
OTHER	40	FDA Compliance			Y	N	N	Y	N	N
	41	Relative Cost (4)			$$	$$	$$	$$	$$	$$
	42	Relative Machinability (1-10, 1=Easier to Machine)			1	1	4	1	1	1

KEY: A = Acceptable Service L = Limited Service U = Unacceptable QTM = Quadrant Test Method

NOTE: Property data shown are typical average values. A dash (-) indicates insufficient data available for publishing.

(1) Data represents Quadrant's estimated maximum long term service temperature based on practical field experience.

(2) Specimens 1/8" thick x 2" diameter or square.

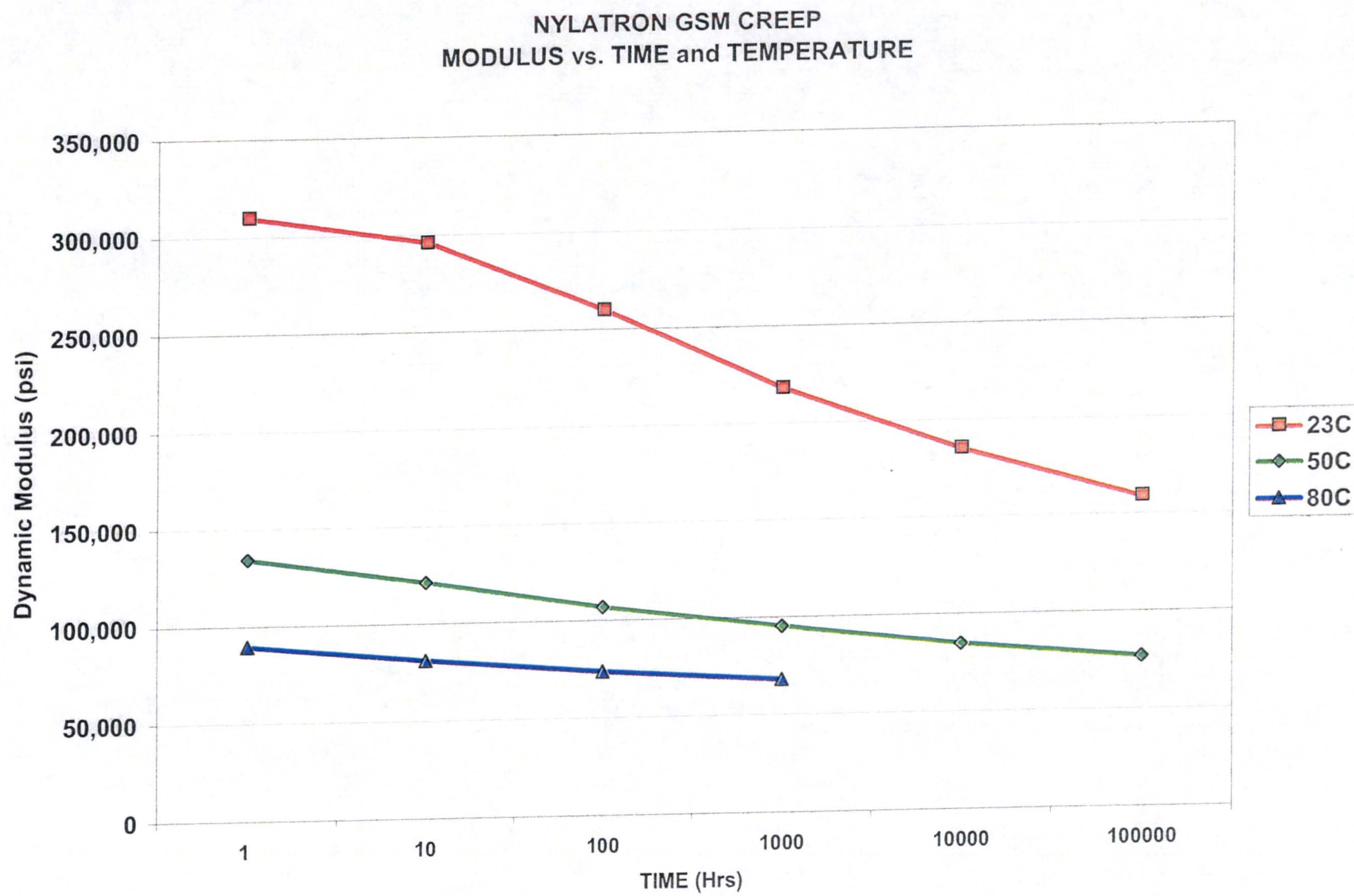
(3) Chemical resistance data are for little or no applied stress. Increased stress, especially localized, may result in more severe attack. Examples of common chemicals also included.

(4) Relative cost of material profiled in this brochure ($ = Least Expensive and $$$$$$ = Most Expensive).

(5) Estimated rating based on available data. The UL 94 Test is a laboratory test and does not relate to actual fire hazard.

Contact Quadrant at TechServices@qplas.com for specific UL "Yellow Card" recognition number.

	Nylatron® LIG / LFG	Nylatron® GSM Blue	Nylatron® NSM	Nylatron® 703XL	Nylatron® 4.6	Acetron® GP POM-C	Acetron® POM-H	Acetron® AF POM-H	Quadrant® PC 1000	Semitron® ESd 225	Ertalyte® PET-P	Ertalyte® TX
	Oil Filled PA6 LFG is FDA Compliant	MoS_2 and Oil Filled PA6	Premium, Solid Lubricant Filled PA6	Premium, Solid Lubricant Filled PA6	Heat Resistant PA46	Premium Porosity-free POM-C	Unfilled POM-H	PTFE Filled POM-H	Unfilled PC	Static Dissipative POM	Semi-crystalline PET	Premium, Solid Lubricant Filled PET
	Cast	Cast	Cast	Cast	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded	Extruded
1	1.14	1.15	1.15	1.11	1.19	1.41	1.41	1.5	1.2	1.33	1.41	1.44
2	9,900	10,000	11,000	9,000	15,000	9,500	11,000	8,000	10,500	5,400	12,400	10,500
3	465,000	500,000	410,000	400,000	470,000	400,000	450,000	435,000	320,000	200,000	460,000	500,000
4	50	30	20	15	25	30	30	15	100	15	20	5
5	15,000	15,000	16,000	13,000	17,000	12,000	13,000	12,000	13,000	7,300	18,000	14,000
6	525,000	500,000	475,000	360,000	450,000	400,000	450,000	445,000	350,000	220,000	490,000	360,000
7	9,300	-	10,000	-	-	8,000	9,000	7,600	9,200	6,000	8,000	8,500
8	13,500	13,000	14,000	10,000	16,000	15,000	16,000	16,000	11,500	8,000	15,000	15,250
9	330,000	425,000	400,000	360,000	325,000	400,000	450,000	350,000	300,000	175,000	420,000	400,000
10	M85 (R120)	M80 (R117)	M80 (R110)	M65	M97	M88 (R120)	M89 (R122)	M85 (R115)	M75 (R126)	M50 (R108)	M93 (R125)	M94
11	-	-	D85	-	-	D85	D86	D83	D80	D76	D87	D80
12	1.0	0.9	0.5	0.7	0.6	1	1	0.7	1.5	1.5	0.5	0.4
13	0.14	0.18	0.18	0.14	-	0.25	0.25	0.19	-	0.29	0.2	0.19
14	6,000	5,500	15,000	17,000	2,700	2,700	2,700	8,300	-	2,000	2,800	6,000
15	72	65	12	26	100	200	200	60	-	30	60	35
16	5.6×10^{-5}	5.5×10^{-5}	5.5×10^{-5}	4.9×10^{-5}	5.0×10^{-5}	5.4×10^{-5}	4.7×10^{-5}	5×10^{-5}	3.9×10^{-5}	9.3×10^{-5}	3.3×10^{-5}	4.5×10^{-5}
17	200	200	200	200	320	220	250	244	290	225	240	180
18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	293	N/A	N/A	N/A
19	420	420	420	420	554	335	347	347	N/A	320	491	491
20	220	200	200	200	300	180	180	180	250	180	210	210
21	-	-	-	-	2.1	1.6	2.5	-	1.29	-	2	1.9
22	-	-	400	-	-	420	450	400	400	-	385	533
23	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{12}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$>10^{13}$	$10^{9} - 10^{10}$	$>10^{13}$	$>10^{13}$
24	-	-	-	-	-	3.8	3.7	3.1	3.17	4.31	3.4	3.6
25	-	-	-	-	-	0.005	0.005	0.01	0.0009	0.036	0.02	0.02
26	HB	HB	HB	HB	-	HB	HB	HB	HB	HB	HB	HB
27	0.3	0.3	0.3	0.47	0.6	0.2	0.2	0.2	0.2	2	0.07	0.06
28	6	6	7	7	7	0.9	0.9	1	0.4	8	0.9	0.47
29	L	L	L	L	L	L	L	L	A	L	A	A
30	U	U	U	U	U	U	U	U	U	U	L	L
31	L	L	L	L	L	A	A	A	A	A	A	A
32	U	U	U	U	U	U	U	U	U	U	U	U
33	A	A	A	A	A	A	A	A	U	A	A	A
34	A	A	A	A	A	A	A	A	L	A	A	A
35	A	A	A	A	A	A	A	A	U	A	A	A
36	A	A	A	A	A	A	A	A	U	A	A	A
37	L	L	L	L	L	L	L	L	U	L	U	U
38	L	L	L	L	L	A	A	A	A	A	A	A
39	L	L	L	L	L	L	L	L	L	L	L	L
40	N / Y	N	N	N	N	Y	Y	N	N	N	Y	Y
41	$$	$$	$$ +	$$ +	$$	$$	$$	$$$	$$ +	$$ +	$$ +	$$ +
42	1	1	1	1	1	1	1	1	3	1	2	2


NYLATRON GSM CREEP
MODULUS vs. TIME and TEMPERATURE
Dynamic Modulus (psi)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1
10
100
1000
10000
100000
TIME (Hrs)
23C
50C
80C

7

KONECRANES®
Lifting Businesses™

Attachment E

SRI Filler Metal Testing and Inspection Data

13 PGS.

KONECRANES®
Lifting Businesses™

Quality Documentation

SRI – Filler metal

Lincoln Electric Lot#: 15288198

Vendor: Weld All Manufacturing

KNES Order Number: US52-00222

KNES Master Copy

ANDERSON LABORATORIES, INC.

Specialists in Materials Evaluation

KNES
JL
10/09/2017
QUALITY

Original October 2, 2017
Revised October 3, 2017
Revised October 6, 2017

Mr. Jeff Mueller
Weldall Manufacturing, Inc. W019
2001 South Prairie Avenue
Waukesha, WI 53189

Dear Mr. Mueller:

Project Number: P17-1418B
Supplement to Project Number P17-1418 & P17-1418A

We have completed the evaluation of the weld plate submitted to us recently. This work was done according to your Purchase Order dated September 18, 2017. This work will be invoiced against your purchase order number 57018-00.

Objective

We were requested to provide an electrode qualification of the submitted weld plate. The testing was performed according to the American Society for Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section II, Part C, AWS A-5.20. One (1) plate was submitted and identified as *UltraCore 712A80-H Plus, SFA-5.20, E71T-12M-JH4, lot number 15288198.*

Procedures and Data

Prior to testing the plate was radiographed and the plate met the requirements of the specification. The NDT reader's report appears in the Appendix of this report.

The chemical composition was performed according to AWS A-5.20, Clause 10. The results, expressed in weight percent, are as follows:

File Number Sample	17-42114 Weld Pad	AWS A-5.20 E7XT-1X
Silicon	0.42	0.90 max.
Sulfur	0.006	0.03 max
Phosphorus	0.012	0.03 max
Manganese	1.45	1.75 max
Carbon	0.05	0.12 max
Chromium	0.04	0.20 max
Nickel	<0.01	0.50 max
Molybdenum	<0.01	0.30 max
Copper	0.02	0.35 max
Iron	Base	Base
Vanadium	<0.005	0.08 max

The material met the chemical requirements of the specification.

Established 1939
6330 Industrial Loop, Greendale, WI 53129-2434
(414) 421-7600 (800) 950-6330 FAX (414) 421-6540
www.andersonlabs.com

KNES QUALITY

Tensile testing was performed according to AWS A-5.20, Clause 12. The test specimen conformed to the requirements of AWS B4.0:2016, Figure 4.1. The results of this test were as follows:

Sample Laboratory File Number	Weld Metal I7-42102	E7XT-1X AWS A-5.20
Sample Dimensions (inches)	0.504	N/A
Cross Sectional Area (square inches)	0.19950	N/A
Tensile Strength (psi)	86,800	70,000 min.
Tensile Load (lbs)	17,311	N/A
Yield Stress (psi)	75,600	58,000 min.
Yield Load (lbs)	15,087	N/A
Elongation in 2" (%)	24.5	22 min.
Reduction of Area (%)	67.4	N/A

The mechanical properties met the requirements of the specification.

Charpy V-notch testing was performed according to AWS A-5.20, Clause 14. The test specimens were machined and tested according to AWS B4.0:2016, Clause 7 and ASTM A370. The results of this test are as follows:

Specimen Location: **Weld Metal** Laboratory ID: I7-42106

Specimen Size (mm)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10
Impact Energy (ft-lbs)	117	110	98	105	110
Impact Energy (J)	159	149	133	142	149
Test Temperature	-40 ºF	-40 ºF	-40 ºF	-40 ºF	-40 ºF

The impact values met the requirements of the specification. The test specimens are being returned under a separate cover.

The material was tested under Quality Procedure Manual Rev. N dated 01/30/17. 10CFR21 and 10CFR50 Appendix B applies.

Anderson Laboratories, Inc.

Rick Pearson
Mechanical Testing Group Leader
AWS Certified SCWI 10080028

Lori Felber
Quality Assurance Manager

The above tests were performed using one or more of the following specifications: ASTM A48, A247, A262, A370, B117, B328, B368, B748, E2 (SM 11-22), E3, E8, E9, E10, E18, E21, E23, E34, E45, E92, E112, E212, E290, E340, E350, E352, E353, E381, E384, E404, E407, E415, E562, E663, E766, E883, E986, E1019, E1024, E1077, E1086, E1251, E1508, G053, G154, ASME IX, AWS D1.1, MIL-S-867A, NAVSEA S9074-AQ-GIB-010/248, SAE J81, EN 10002 Part 1, EN 10045 Parts 1 & 2, EN 10204 Section 3.1.C and Anderson Laboratories Quality Manual Revision N dated 1/30/17.

APPENDIX

NDT Reader's Report

NDT Specialists, Inc.

7365 S. Howell Ave., Oak Creek, WI 53154

Phone 414-483-9700 www.ndtspecialists.com Fax 414-762-5447

Customer Anderson Laboratories	*Location* Greendale, WI		*Part Number or Description* Weld Qualification Plate		*Purchase Order No.* 17-0299
Source/Kv 310 Kv	*Focal Spot* .222"	*Wall Thickness* 1.0"	*Front Screens* .001"	*Procedure Number* NDT-S-RT1	*Revision* 1401
Curies/Ma 10 mA	*SFD/FFD* 43"	*Block Thickness* NA	*Back Screens* .001"	*Acceptance Criteria* AWS A5.20	*Revision* Current
Time :28 Seconds	*Film Type* D4 RediPak	*Shim Thickness* NA	*Development Time* Auto 12 Minute	*Film Size* 4.5 x 17"	*Number of Film* 1 SL
Technique Type SWE/SWV	*Unsharpness Factor* <.020"	*Penetrameter Type* ASTM E1025	*Penetrameter Size* #20 (2)	*Material Specification* A36	*Job Number* 1709262

Film Identification	Conforming	Non Conforming	Cracks	Porosity	Inclusions	Inc. Penetration	Inc. Fusion	Burn Thru	Concavity	Surface	Film Artifact	Processing Marks	Penetrameters	Density	Remarks
P17-1418															712A80-H Plus
0-1	/												/	2.9-3.2	

[illegible]

Stephanie Schmitt — Signature of Technician

Stephanie Schmitt — *Printed Name of Technician*

II — *Level*

9.22.2017 — *Date*

NDTS-1 Rev.02-2012

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

KNES
10/09/2017
QUALITY

CERTIFICATE OF CONFORMANCE
&
CERTIFIED MATERIAL TEST REPORT

8823299 1/16 ULTRACORE® 712A80-H PLUS 33SP 2,376 Lbs.

Supplied To: MACHINERY & WELDER CORP
2225 S. 116TH STREET
WEST ALLIS, WI 53227-1007

Customer PO: M3008
Q2 Lot®: 15288198

This material was manufactured under lot control in accordance with ASME Section II Part C SFA 5.01, lot class T4, and tested per Schedule I to the requirements of SFA 5.20 classification E71T-12M JH4. Material and testing in accordance with ASME Section II Part C, 2015 Edition. No weld splicing with filler material was conducted on this product. This product was manufactured in the U.S.A. using steel that was melted in Canada.

This product was manufactured in accordance with Lincoln Electric's Quality System Manual SSW50 Rev. R dated 1/12/17. Lincoln Electric's Quality System meets the requirements of ASME NCA-3800, conforms to all applicable requirements of 10CFR 50 Appendix B, and meets the basic requirements of NQA-1. 10CFR Part 21 and 10CFR 50.55(e) apply to this order.

The product stated herein was manufactured and supplied in accordance with the Quality System Program of The Lincoln Electric Co., Cleveland, Ohio, U.S.A., as outlined in our Quality Assurance Manual. The Quality System Program of The Lincoln Electric Company has been accredited by ASME as evidenced by Certificate Nos. QSC-489, QSC-489-1, and QSC-489-2 which expire on March 30, 2020, and is certified to ISO 9001 as evidenced by Certificate No. 30275.

Test Conditions

Electrode Size (Inches)	1/16
Process / Electrode Polarity	FCAW-G / DCEP
CTWD (Inches)	1
Wire Feed Speed (ipm)	300
Current (Amps)	320
Arc Voltage (Volts)	28
Heat Input (kJ/inch)	37
Passes/Layers	15/7
Preheat/Interpass Temp. (°F)	82/300
Gas Type	75% Argon/25% CO_2
Plate ID	84696

As-Welded Mechanical Properties[1]	Plate 84696	SFA 5.20
Yield Strength (psi), .2% Offset Method	66,000	58,000 psi minimum
Ultimate Tensile Strength (psi)	77,000	70,000 – 90,000 psi
% Elongation	29	22% minimum

[1] The strength and elongation properties were obtained from a tensile specimen artificially aged at 105°C (220°F) for 48 hours.

As-Welded Impact Properties	Plate 84696	SFA 5.20
CVN ft. lbs. @ -60°F	136, 111, 110 = 119 Avg.	20 ft-lbs. minimum Average

KNES
QUALITY

Q2 LOT® 15288198

Deposit Chemistry	Plate 84696	SFA 5.20
% Carbon	.05	.12 max.
% Manganese	1.39	1.75 max.
% Silicon	.41	.90 max.
% Sulfur	.01	.03 max.
% Phosphorus	.01	.03 max.
% Chromium	.02	.20 max.
% Nickel	.01	.50 max.
% Molybdenum	.01	.30 max.
% Vanadium	<.01	.08 max.
% Copper	.02	.35 max.

Diffusible Hydrogen

mL/100g of Weld Deposit	3.4, 3.9, 4.2, 4.0 = 3.9 Avg.	4.0mL/100g maximum

Radiographic Inspection Results: Met Requirements

This is to certify that the contents of this report are correct and accurate and that all test results and operations performed by The Lincoln Electric Company or its subcontractors are in compliance with the requirements of the material specification and the specific applicable requirements of the Code as specified by the customer. We do not use mercury in the design and formulation of our consumable products. In the manufacturing and testing of our products, our equipment meets mercury exclusion requirements.

Rajeev Katiyar — 1 Sep 2017
Rajeev Katiyar — DATE
Manager, Quality Assurance

Tim Peck — 1 Sep 2017
Tim Peck — DATE
Manager, Special Products

"Note: The recording of false, fictitious or fraudulent statements or entries on this document may be punished as a felony under Federal Statutes including Federal Law, Title 18, Chapter 47."

KONECRANES
Nuclear Equipment & Services

On Site-Surveillance:

Critical Characteristics for this surveillance as reviewed and approved by Engineering and Quality.

Engineering: [signature] Date: 11/13/17

Quality: [signature] Date: 11-13-17

Date: 11/14/2017 Supplier: Weldall Mfg. Inc.
2001 S. Prairie Ave
Waukesha, WI. 53189-7307

Scope of Survey/Surveillance:
Check weld wire Segregation, Markings, and Traceability

Konecranes/MMH Drawing reference: Lot# 15288198 Quantity: N/A

Critical characteristics to be verified during surveillance.	Acceptance Method	Comments (If any)	Accept/Reject
Checked for segregation	Visual	Skids were segregated	Accept
Checked for Lot number to match the CMTR's	Visual	Lot# SRI_15288198	Accept
Checked control of weld filler for jobs	Visual	Job routing has specific wire and lot noted	Accept
Checked for wire being exposed to the elements	Visual	All spools were contained and not exposed	Accept

Sign-Off for Completion of Surveillance.

Konecranes/MMH: [signature] Date: 11-14-17

Customer (If applicable): N/A Date: N/A

6

INSPECTION DATA COLLECTION FORM

Part Number:	Rev:	Qty:	Order Number:	Part Name:
54380723	00	4	US52-00222 4500950543	SRI-Welding Wire

CHARACTERISTICS	LOC	#1	#2	#3	#4	#5	#6	#7	#8	INSP	DATE	REMARKS
Inspected for suspect or counterfeit indications	N/A	OK	OK	OK	OK					J.F.	10/12/17	No signs of being suspect or counterfeit.
Inspect for the material number. 712A80-H PLUS	N/A	OK	OK	OK	OK					J.F.	10/12/17	Part number is written on the box tag.
Inspect for the lot number. 15288198	N/A	OK	OK	OK	OK					J.F.	10/12/17	Heat number is written on the box tag.

KONECRANES
Lifting Businesses

Weld Wire supplier surveillance "WELDALL" supporting evidence 11/14/17

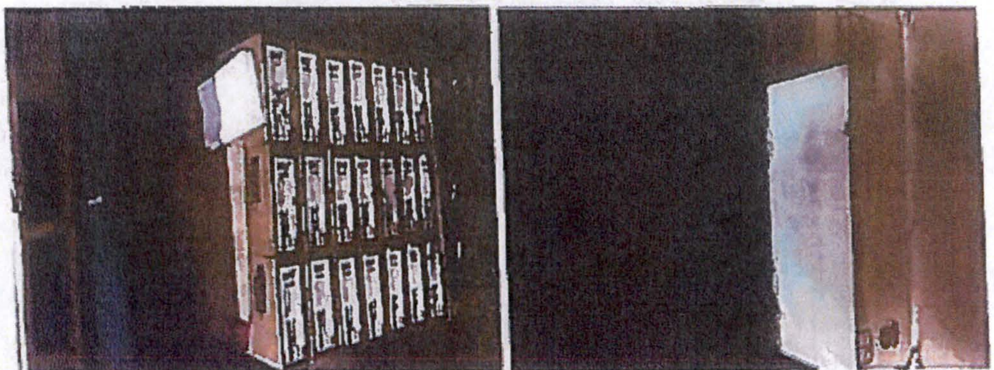
SRI Wire

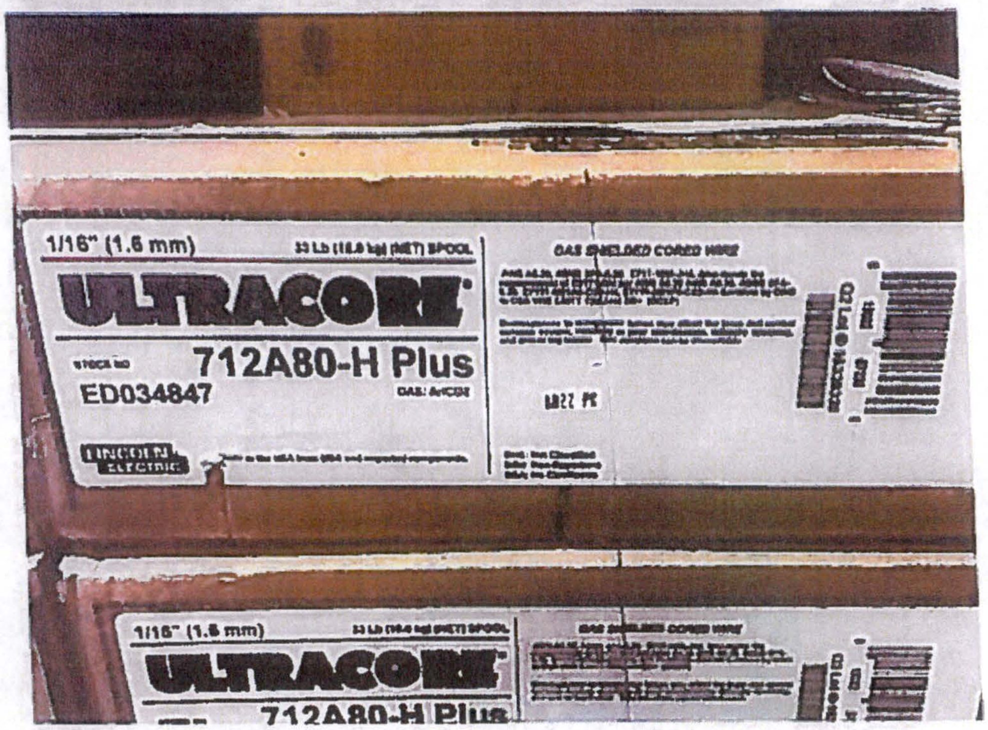
1/3

KONECRANES
Lifting Businesses

Weld Wire supplier surveillance "WELDALL" supporting evidence 11/14/17

NON-SRI Weld Wire





2/3

KONECRANES
Lifting Businesses

Weld Wire supplier surveillance "WELDALL" supporting evidence 11/14/17

Example Routing using SRI-Routing

```
Qty  Um  Operation Description              Crew    Cyc/Hr   Tot-Hours  Un
---  --  --------- -----------              ----    ------   ---------  --
          GAS: 75% - 25% AR - CO2

          > Weld Map Required - Reference Drawing QR95240

          > PRIOR TO WELD
            Weld Wire And Gas Verification Is Required
            By A Supervisor or Quality Representative
            BEFORE Welding Can Begin.

          > Welders MUST Mark Their KONECRANES Issued Number
            On ALL Welds They Complete. IN WHITE MARKER

          > 100% Fit-Up Inspection Required.
          > Record Dimensions On Prints.

          > Verify Requirements Prior To Heat Straightening.
          > ONLY Cold Straightening Allowed After S.R.

          > Send Weld Drawings Along With Weldments To Machining
          ...

1    EA  BAY 2 WELDING                        1.00       .0     18.8600

         - FOLLOW KONECRANES NOP 5.0.1 AND AWS D1.1
         ------------------------------------------------------------
         - PROCESS:

         WELDING PROCEDURE (SRI)

         WPS: 2T-10-4H-FC-14

         WPS: 2T-10-5H-FC-12

         WIRE: LINCOLN ULTRACORE 712A80-H PLUS .062"0
         QZ LOT: 15288198
         GAS: 75% - 25% AR - CO2
         ------------------------------------------------------------
         - WELD MAP REQUIRED - REF. DWG. QR95240
         ------------------------------------------------------------
         *** HOLD PRIOR TO WELD ***    Weld wire and gas
         verification is required by a Supervisor or Quality
         representative before welding can begin.
```

3/3