Steel Coil Lifting Using Synthetic Slings With Dyneema®: Reliable, Economic and Safe

High modulus polyethylene (HMPE) fibers have been introduced in lifting slings as an alternative to steel wire, chain or polyester slings because of their lower weight (ease of handling), higher stiffness (no elastic response while lifting), smaller diameter (easier to use in hooks) and excellent long-term properties (tension and bending fatigue, UV and chemical resistance).

Port operators in the port of Antwerp, Belgium, requested a new type of synthetic slings to be used for repetitive lifting of steel coils, while maintaining low weight and ease of use. In response to this demand, DSM Dyneema has helped sling manufacturing companies develop a new, patented type of sling that demonstrates very good resistance against sharp edges and abrasive surfaces, while maintaining good performance when lifting steel coils.

DSM Dyneema is the inventor of the HMPE gel spinning process and manufacturer of Dyneema® fiber, and works in partnership with its direct customers, the sling manufacturers, to develop new and improved lifting products that address end-user needs.

Market Challenge

For repetitive handling of heavy goods, such as loading and unloading of bulk cargo (in which case the term "stevedoring" is frequently used), wire rope slings, steel hoisting mats or chain slings are still commonly used. The use of steel-based slings, however, presents some serious disadvantages. First of all, their high mass hampers ergonomic handling, and often requires two workmen to handle them (to comply with health and safety regulations). Nevertheless, shoulder and back complaints are very common for harbor workers. In addition, broken steel wires may protrude from the sling, and such "meat hooks" pose a high risk for hand and other body injuries. The use of steel-based slings can also damage the goods that are being handled.

Heavy-duty roundslings based on synthetic fibers that are currently in use can replace wire rope slings in some cases, but problems are still encountered upon handling of, for example, heavy goods that are highly abrasive or have sharp edges, such as unpacked steel coils. In such cases, the synthetic roundslings generally have a short service lifetime: after only a limited number of lifting jobs, damage — such as tears or rips, or even cuts in the cover of the roundsling — is frequently observed. Safety regulations generally require that roundslings with a damaged cover be removed from service for repairs or even disposal. Therefore, this renders the use of such synthetic slings as unviable, for safety and economic reasons.

A new sling type for hoisting steel coils results in fewer injuries, faster rigging, higher safety and greater cost savings. This paper focuses on the development of the sling, assuring safe use, and discard criteria.

One way of increasing the service lifetime of a roundsling is to use additional protective pads between the roundsling and the goods. Such pads, however, need to be manually placed at critical spots, thereby increasing labor and handling time, and consequently reducing the average number of lifts per time unit significantly. In addition, such pads may be placed at the incorrect spot, or may shift during use, resulting in inadequate or even unsafe lifting performance.

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Figure 1

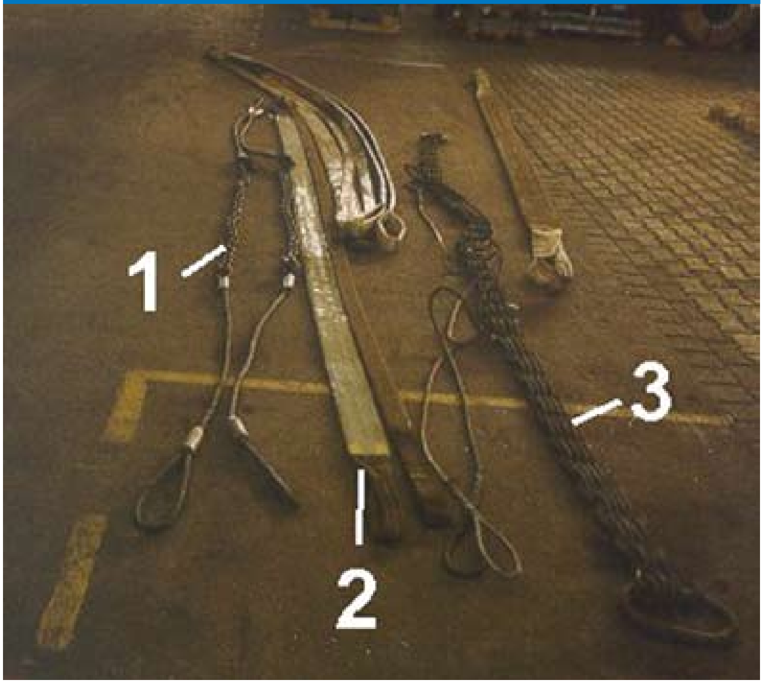
Steel coil.

the repetitive lifting of steel coils with sharp edges, while maintaining the low weight and their ease of use.

Steel companies had been experiencing problems with damaged loads when loading and unloading their cargo, specifically with the use of metal-based lifting equipment to lift steel coils. Only because of the lack of a good alternative were the steel companies still accepting traditional lifting slings.

Stevedores in several ports in Europe had been looking for solutions, trying everything from polyester webbings protected by extra sleeves, to solid polyurethane coatings on polyester webbing slings. None of these proved to be a viable alternative to chain or wire (see Figure 2 for various kinds of slinging equipment used for lifting steel coils).[1] Polyester slings, even with extra-heavy-duty polyester covers, are cut through too easily, and solid polyurethane coatings render the slings too stiff.

Figure 2



Various kinds of slinging equipment are used for handling sheet metal coils: (1) wire rope sling combined with central chain sling; (2) webbing sling made from polyester with solid polyurethane coating; and (3) chain sling.[1]

Design Considerations of the Roundsling

Roundslings made with synthetic fiber consist of a core and a cover. Typically, an endless roundsling consists of a load-bearing core that is fully enclosed within a protective cover. The cover is typically made of webbing with the ends overlapped and sewn.

Polyester roundslings are manufactured throughout the world and are covered by national or international standards. No standard that is currently available completely covers the new roundsling concept that is discussed in this paper. The two most relevant norms that were available and could be used as a reference are EN-1492-2[2] and WSTDA RS1.[3] Since the concept was developed in Europe, the EN-1492-2 norm was used as a reference and guidance norm.

After consultation with the distributor and end-user in the port of Antwerp, a vertical rated load of 20 tonnes (44,092 pounds) and a sling length of 4 m (13.1 feet) were chosen. All trial slings were tested with these design values, and only the cover quality was changed over time to accomplish a large number of lifts with each sling. With a safety factor (SF) of 7, the minimum break load of the slings should be 140 tonnes (308,642 pounds).

Cut- and Abrasion-resistant Cover

The Dyneema fiber is highly cut- and abrasion-resistant. It has been used in cut-resistant gloves for many years. The same yarn properties that provide the cut resistance in gloves were used to design a highly cut-resistant protection cover.

This fiber was used to make a sleeve that would deliver high resistance against cutting and abrasive surfaces. Several types of sleeves using the Dyneema fiber were manufactured. Additionally, protection sleeves readily available on the market were also evaluated.

Test Samples — Several cover materials were tested on laboratory scale for abrasion and cut resistance. Some samples are used as covers on commercially available sling products:

- Sample A is a plain woven fabric based on polyamide 66 (PA 66) fibers (used by Slingmax®, USA).
- Sample B is a standard sleeve as used in roundsling protection: a plain woven made from polyester (PET) fibers (obtained from Unitex Holding BV, The Netherlands).
- Sample C is a woven made from HMPE fibers provided with a plastic coating, and marketed by Samson Rope Technologies (USA) as Pro-Gard eye and rope protector (also called chafe gear).
- Samples D and E are hollow tubular 3-D wovens, consisting of four woven plies constructed into a hollow tubular format with two layers forming the wall, which were made by spirally interweaving a single multi-stranded and twisted weft yarn within a multiplicity of warp yarns. The two woven layers forming the wall are held together using a multi-stranded and twisted binder yarn technique to create structural integrity. In sample D, PET yarns are used in the warp, weft and binder threads. For sample E, Dyneema SK75 1600 denier yarns were used in the warp, weft and binder threads.

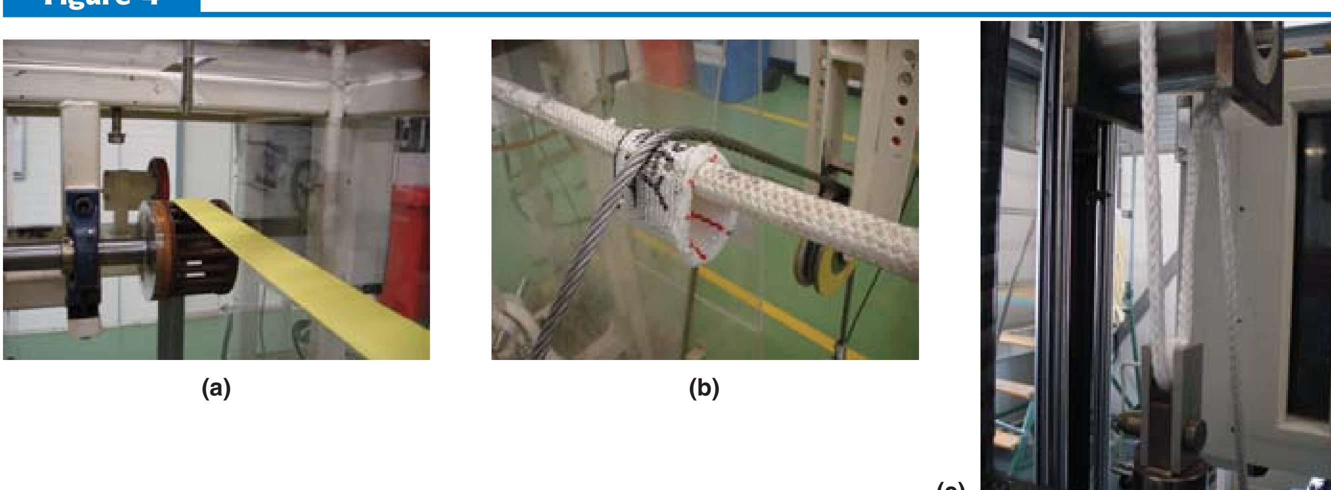
Test Methods —

1. Tensile properties of yarn: tensile strength (or tenacity) and elongation at break are defined and determined on multi-filament yarns with a procedure compliant with ASTM D885,[5] using a nominal gauge length of the fiber of 500 mm, a crosshead speed of 50%/minute, and Instron 2714 clamps of type Fiber Grip D5618C. On the basis of the measured stress-strain curve, the modulus is determined as the gradient between 0.3 and 1% strain. To calculate the tenacity, the tensile forces measured are divided by the titer, as determined by weighing 10 m of yarn.
2. Abrasion resistance of the covers was tested by mounting a cover sample on a support belt of about 6 cm wide, placing the combination at 90° angle around a wheel of 145 mm diameter, the outer surface of which is formed by 18 spokes of 12 mm diameter, while keeping the rope under constant tension with a load of about 1,300 kg. The

Figure 3

Cut-resistant gloves with Dyneema®.[4]

Figure 4



(a) (b) (c)

Test machines used in laboratory tests: (a) abrasion resistance, (b) sawing resistance and (c) cutting resistance.

Table 1

Overview of Laboratory Test Results

Sample	Type of fibers	Construction	Specific mass (gram/m^2)	Thickness (mm)	Abrasion resistance (rotations)	Abrasion resistance (motions)	Cutting resistance (N)
A	PA66	Plain woven	1,497	3.7	32	2,200	6,965
B	PET	Plain woven	742	1.2	3	361	3,663
C	HMPE	Coated woven	1,046	1.5	21	12,308	8,589
D	PET	Multi-layered 3-D woven	3,616	4.8	49	5,381	9,235
E	HMPE	Multi-layered 3-D woven	3,398	4.8	325	80,898	11,711

wheel was rotated at 4 rpm, and the number of rotations was determined by noting when the first contact of the supporting belt occurred with the spokes of the wheel (visual determination).

3. Sawing resistance of the covers was determined by a saw movement, using a steel wire rope of 10 mm diameter, back and forward with an amplitude of 140 mm at an angle of 120° and with a load on the steel wire of 40 kg over a cover mounted on a 20-mm support rope. The support rope was held under a constant load of 575 kg. The number of motions was determined when the first contact between steel wire and support rope occurred (visual determination).
4. Cutting resistance of the covers was measured by mounting a length of the cover material around a support rope, bending the cover over the edge of a stainless steel knife, and tensioning both ends of the rope at 150 mm/minute in a tensile tester until the cover was cut. The result is reported as the force applied at cutting. The knife has a thickness of 10 mm, and an edged part of 6 mm, which was sharpened before each test with a Sandvik #3 file.

From the results listed in Table 1, it can be concluded that sample E demonstrates the best overall performance, although the cutting resistance test results indicate smaller differences between the cover samples when compared with the abrasion and sawing tests.

Sling: Behavior of the Core Under Load

The HMPE multi-layered 3-D woven cover outperforms all others. As this cover is based on Dyneema fiber, it does not stretch much when under load. The core is also manufactured from high-modulus Dyneema fiber. Samples of a complete sling were tested to determine behavior under load.

The stretch of a sling containing a core with Dyneema is in linear relation with the load applied. Only when loaded for the first time does the sling show a non-linear "construction stretch" (as seen in many rope and sling constructions from synthetic yarns), which is removed from the sling during the first load. Every consecutive loading will show a linear behavior between zero load and full load applied.

Figure 5 shows a break test, in which a sling is preloaded three times and then broken. The sling is a 20-ton (196 kN) work load sling with a length of 3.8 m, designed with a safety factor of 7. It is preloaded three times to 50% of the minimum required break strength of 140 tons (1,372 kN). The first load, including the construction stretch, starts at the 40-mm mark and ends at 123 mm, showing a stretch of 83 mm at 50% break load. The second and all subsequent loads start at the 85-mm mark and show a stretch up to the 165-mm mark, showing a stretch of 80 mm up to break load, recalculated to 2.1% (safety factor 7).

The overall result is a sling construction that will stretch only 0.3% at the rated working load, showing an elongation performance that is very similar to wire rope–based lifting slings.

Creep

A deterioration mechanism generally linked to the Dyneema fiber is creep. Creep is an irreversible deformation of a rope or sling when a constant load is applied to it. DSM Dyneema has issued a paper dealing with creep in HMPE in mooring applications.[6] This paper presents an updated creep model that models the creep behavior of ropes. The same model can also be used to simulate creep behavior in sling applications. The model has been verified for yarn level and rope/sling use.

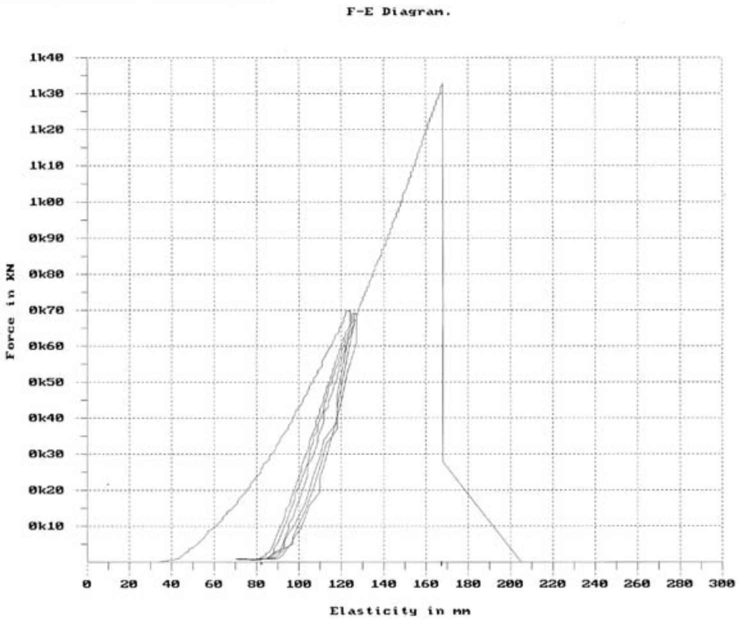
Creep behavior of HMPE fibers is dependent on:

- Type of HMPE fiber.
- Load: the percentage of the break load that is applied.
- Temperature of the fiber.

This updated creep model calculates the creep lifetime, being the time after which a rope or sling, subjected to a constant creep load, should be discarded. In general, creep is not an issue in sling applications due to the combination of high safety values involved and a limited total time of exposure to a load. As an illustration of the effects of time and temperature on the creep lifetime, Table 2 illustrates the percentage of the creep lifetime that has passed after applying the creep load for a specified time.

The calculations have been done on a roundsling, as described in this paper, of a WLL of 20 tons (196 kN) having a safety factor of minimum 7 (Case 4: 1,000 lifts at 104°F). These slings will normally be used to lift steel coils. Each lift will take about 3–5 minutes maximum, and at 1,000 lifts the load will have

Figure 5



Typical elongation behavior of a 20-ton (SF 7), 3.8-m sling under load.

Table 2

Calculated Effect of Creep for a 20-ton WLL (SF 7) Sling With Dyneema® SK 75 Yarns

Creep conditions	Case 1	Case 2	Case 3	Case 4: 1,000 lifts at 104°F
Load (kN)	196	196	196	196
Time the load is applied constantly (days)	30	30	20	3.5
Temperature of the sling (°C)	20	40	60	40
Temperature of the sling (°F)	68	104	140	104
Expected elongation of the sling at end (%)	0.6	1.0	5.7	0.6
Creep lifetime used (% of total)	8	12	71	6

Figure 6

The two lifting products compared: steel hoisting mat made from wire rope (left) and roundsling with Dyneema® (right).

Figure 7

Red indicator yarns.

been applied to the sling for 5,000 minutes maximum, comparable to 3.5 days. Maximum temperature in use will be 40°C (104°F). For this case, reflecting normal use, the percentage of the creep lifetime that has been used is only 6%, at a calculated elongation of the sling due to creep effects of 0.6%.

Tests in the Port of Antwerp

The 13-kg roundsling, made completely with Dyneema fiber, was evaluated against equally long standard steel hoisting mats with a mass range 70–100 kg, in lifting steel coils of mass 15–35 tons per coil (Figure 6). In practice, about half of the coils are packaged; the remainder is transported in non-packaged form, which means the slings are in direct contact with the sharp edges of coils during lifting operations.

The steel hoisting mats have such a high mass that handling needs to be performed by two workers. Steel hoisting mats were found to have a typical service lifetime of 150–200 lift jobs (on packaged and unpackaged coils).

The roundsling made from HMPE fibers could be handled by one worker during stevedoring, and showed hardly any visible damage after 521 lifting jobs (of which about 50% were on unprotected steel coils). This is a much longer service life than standard steel-based products. The roundsling was further inspected by removing the cover, to reveal no visible damage to the core fibers.

The average residual strength of the core was subsequently measured to be more than 70% of its initial strength. The roundsling being tested could have safely performed many more lifting jobs.

Earlier comparative tests had already revealed that roundslings with a core based on HMPE fibers, and with various covers made from polyamide 66 or polyester fibers, had to be taken out of service because of unacceptable damage to the covers after only a few lifting jobs, which does relate to the laboratory test results.

Determining Cover Damage Versus Core Strength Loss

Any sling requires a clearly defined criterion to determine when it should be discarded. When looking at roundslings, the discard criterion that is generally accepted is damage to the sleeve. In this design, it was decided to incorporate a special design feature in the sleeve. The sleeve contains red indicator yarns on the inside of the weft. The user instructions need to clearly state that the sling should be discarded when the red yarns become visible.

As the discard criterion is visibility of the red yarns, a clear relationship between the retention strength of the core of the sling and the deterioration of the cover should be established. Therefore, an additional set of tests was conducted in several ports. Several slings were made available to the port, and coils were lifted using these slings. The port operator counted the number of lifts that each of the slings had performed, and slings

Figure 8

Tests in the port of Antwerp.

were taken out of service after a specified number of lifts. The slings were break-tested to establish the retention strength of the core in relation to the number of lifts.

The retention strength of the sling decreases as the number of lifts increases. Cover damage normally occurs after about 1,000 lifts. It can be concluded that, even at this high amount of lifts, the retention strength of the core is considerably more than 50% of the original strength under conditions similar to these tests.

Summary

Roundslings made from HMPE fiber have been introduced as an alternative to steel wire and chain for lifting steel coils by stevedoring companies in ports. This paper discussed the design criteria and the tests performed to establish an adequate design for lifting these coils.

The patented low-weight slings based on Dyneema fiber have demonstrated as an alternative to chain or wire, allowing the port operator to work faster, reduce damage to the coils, and increase safety and ease of handling for the operators.

Acknowledgments

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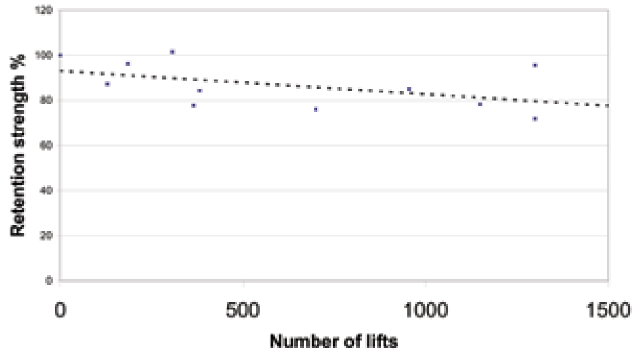
Figure 9



Retention strength of sling versus number of lifts.

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