**TNO report**

**Industrial Innovation**
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10
infodesk@tno.nl

# Project summary JIP "Synthetic Fibre Slings"

| | |
|---|---|
| Date | 31 January 2013 |
| Author(s) | Sjoerd van der Putten |
| Number of pages | 8 |
| Customer | Allseas Engineering<br>Heerema Marine Contractors<br>Jumbo Shipping<br>Seaway Heavy Lifting Engineering |
| Project participants | Bexco<br>DSM Dyneema<br>Endenburg<br>Samson Ropes<br>GL Noble Denton<br>Lankhorst Ropes<br>Lloyd's Register<br>Cortland<br>Selantic<br>Teijin Aramid |
| Project name | Improving Safety Factors of Fibre Slings & Grommets |

**Introduction**

This project summary gives an overview of the results of the Joint Industry Project “Synthetic Fibre Slings”. This JIP was initiated to develop a procedure to recommend on the required factors of safety for synthetic fibre slings and grommets to be used in engineered lifting operations.

Offshore contractors operate heavy lift vessels with capacities varying from 2,000 mt up to 14,000 mt. Boundaries are shifting and even larger capacities are required. Synthetic fibre rope slings are used for the heaviest lifting operations. But due to the relatively limited material knowledge of fibre ropes that is available today, the safety factors for fibre slings and grommets are highly conservative compared to those for wire rope slings.

The JIP outcome has led to a generally accepted guideline, representing the first step toward a better overall understanding of the failure mechanisms in fibre slings. This leads to increased safety of lifting operations, using fibre slings and grommets with an improved safety factor

The project has been a joint effort of several members in the value chain of synthetic fibre slings:

- High-performance fibre manufacturers (DSM Dyneema and Teijin Aramid);
- Rope/Sling manufacturers (Bexco, Cortland/Selantic, Lankhorst Ropes, Samson Ropes/Endenburg);
- Notified bodies (GL Noble Denton and Lloyd's Register);
- Offshore contractors (Allseas, Heerema Marine Contractors, Jumbo Shipping and Seaway Heavy Lifting); and
- Research organisation TNO.

The summary can be read by project participants to have all executed parts presented together in a logical order, and can be used by interested people from outside the project to get an overall picture of the work that has been carried out.

**Project timeline**

The synthetic fibre slings project was started in beginning of 2010 with a project definition phase. Offshore contractors and synthetic fibre slings users Allseas, Heerema Marine Contractors, Jumbo Shipping and Seaway Heavy Lifting took the initiative to set up a project with the objective to develop a procedure to recommend on the required factors of safety for synthetic fibre slings and grommets to be used in engineered lifting operations. Result of the project definition phase was to set up a JIP including several synthetic fibre manufacturers, rope suppliers and classification societies.

In April 2011 the contours of the JIP were set, and the value chain members committed to the project: Bexco, Cortland/Selantic, Lankhorst Ropes, Samson Ropes/Endenburg, DSM Dyneema, Teijin Aramid, GL Noble Denton and Lloyd’s Register. The synthetic fibre sling users (the JIP partners) asked TNO as a research contractor to coordinate the project. A project meeting was organized on the 24$^{th}$ of May 2011 to discuss the project scope, the draft literature study and desired input from project participants. After this meeting all parties agreed on an NDA with TNO in order to ensure confidentiality. A next version of the literature study, with four lift cases incorporated, was issued in June 2011 [1].

Based on this document and the four lift cases a first risk workshop was held on August 25th 2011. A second risk workshop took place on September 30th. Conclusion of the two workshops was the risk workshop report [2], comprising a failure mode and risk ranking, and an indication of relevant evidence lacking. This led to a discussion on the approach of a test program to gather consistent quantitative information. This discussion was part of the progress meeting on November 3rd 2011. After several reviews and another meeting on January 21st of 2012, a final test program was issued on January 26th 2012 [3].

Testing started mid-February and ended in May 2012. Test reports were issued to the individual fibre sling and grommet suppliers [4], and an overall test report [5] was sent to all project parties. In April and in May progress meetings were organized. During the meeting in May several small group sessions were held to come to a project advice on a Guidance Note, which functions as a conclusive document of the synthetic fibre slings project. A first complete issue of the Guidance Note was sent around on June 1st 2012. Another version followed on September 1st and after a progress meeting on the 1st of November, a final version [6] of the Guidance Note was issued on December 15th 2012.

On the 8th of June 2012 the project was presented on the “Maritieme Innovatie Programma” conference.

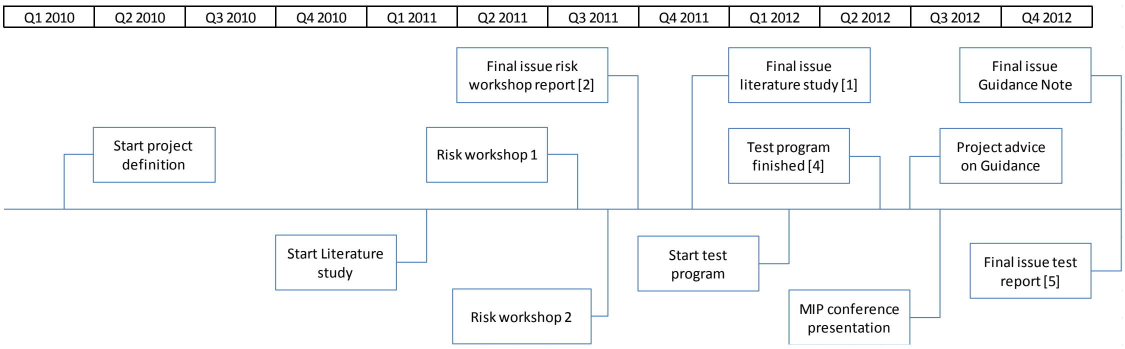


Figure 1: Project timeline

**Literature Study**

The literature study was the result of a literature survey that focused on failure modes and mechanisms of synthetic fibre slings, with the goal to find the critical parameters. This was done by not only studying the failure modes and mechanisms, but also the maintenance philosophies, condition monitoring and possible modification effects for a broad range of synthetic fibre slings, suited for a broad range of (engineered) lifting operations. The study was updated a number of times to include new available information from project participants and publications.

A recommended practice issued by Det Norske Veritas (DNV RP A203) prescribes a strategy to come to the qualification of new technology. This recommended practice has been used as a guidance for the project. The four categories of system parameters used to express uncertainties were: functional use, environmental conditions, fibre properties, and type of sling construction/assembly. The availability of data for the identified failure modes and mechanisms have been concluded in the table below.

| Failure mechanisms | Available literature (0-5) |
|---|---|
| Functional use | |
| Interfaces with other equipment | 0 |
| Static use | 1 |
| Dynamic use | 2 |
| Load range | 0 |
| Compressive loading | 0 |
| Bending | 0 |
| Hockle, twist, kink and corkscrew | 2 |
| Inspection | 0 |
| Monitoring | 0 |
| Training / knowledge of riggers | 0 |
| Load spreading | 0 |
| Environmental conditions | |
| Temperature | 3 |
| UV | 2 |
| Dirt / ingress inside rope | 0 |
| Contact with water | 1 |
| Contact with seawater | 1 |
| Contamination by chemicals | 3 |
| Mildew | 1 |
| Water depth / pressure | 0 |
| Radio activity | 0 |
| Lightning | 0 |
| Fire | 0 |

| Failure mechanisms | Available literature (0-5) |
|---|---|
| Fibre and fibre rope effects | |
| Hysteresis | 0 |
| Elongation | 1 |
| Creep | 2 |
| External abrasion | 1 |
| Internal abrasion | 5 |
| Ageing | 0 |
| Thermal expansion | 0 |

| Failure modes | Available literature (0-5) |
|---|---|
| Break (static) | |
| Overload | 2 |
| Shock load | 0 |
| Creep rupture | 2 |
| Fatigue (cyclic loading) | |
| Tensile fatigue | 1 |
| Bending fatigue | 2 |
| Axial compression fatigue | 1 |
| Hysteresis heating | 1 |
| Abrasive break / cutting | 1 |
| Failure of end connection | 0 |

Table 1: Failure modes and mechanisms

The results of the literature study focussed on the quality and quantity of the available data. Terminology has been explained, failure modes and mechanisms have been described, and available data has been presented by means of graphs and summarizing tables.

The literature study focussed somewhat less on the relevance of the data for a certain specific lift case. This is why four lift cases were defined in consultancy with the JIP partners. The lift cases were scrutinized during the risk workshops and provided more detailed insights on the relevance of the failure modes and mechanisms. The results of the subsequent additional literature survey were included in the final version of the literature study [1].

**Risk workshops**

The goal of the workshops was to identify and quantify the risks of a synthetic fibre sling or grommet during marine lifting operations, based known failure modes and mechanisms. The technique used for this was a Failure Mode and Effect Analysis (FMEA).

Preparation included the definition of four lift cases as a representation of marine lifting operations in general. The four lift cases were defined by the fibre sling users, including drawings and risk identification reports. The specified slings were evaluated by all experts and participants as a preparation for the workshop. Also a sample risk analysis was worked out and sent to all workshop participants. In the below table a summary of the lift cases is presented.

Table 2: Lift cases

| | SHL: Lift case 1 | HMC: Lift case 2 | Allseas: Lift case 3 | JUMBO: Lift case 4 |
|---|---|---|---|---|
| **Intended application** | Lifting offshore wind foundation | Lifting Drilling Deck | Abandonment and Recovery of pipeline | Lifting of large structure in sheltered waters |
| **Load range (SWL)** | 300 [mT] | 2052 [mT] | mean load 600 [mT], load variation +/- 400 [mT] | |
| **Lifting configuration** | Single sling basket | Single Crane four point lift | 2 x 500 t Grommet parralel | Grommet basket, dual lift; see drawing case 4 |
| **Effective work length** | Sling 20 [m] | Slings up to 30 [m] | Grommet 10 [m] | |
| **Accidental loading** | | | Snapload: 0 t to 1000 t in 2 s | |
| **Temperature range:** | 0 through +30 | 0 through +60 | 0 through +40 | -20 through +60 |
| **Contamination/particle ingress** | All which are relevant for offshore/subsea/on deck, no chemicals | All which are relevant for offshore/subsea/on deck, no chemicals | All which are relevant for offshore/subsea/on deck and on seabed | Possible contact with deck |
| **Usage** | Multiple | 5 times | 40 times | Multiple |

A group of 15-20 experts from industry provided input and together assessed the design, fabrication, transport and installation, operation and decommissioning of synthetic fibre slings. The group of experts included fibre manufacturers, fibre sling suppliers, fibre sling users, classification societies, and a TNO risk expert to facilitate the workshop.

A significant number of high and medium risk activities were identified, either caused by high potential consequence, or by large (or unknown) probability of occurrence. Some of the high risk items were: abrasive break, dynamic use and splice integrity. Medium risk items were: elongation and load distribution, temperature and D over d ratio.

The parameters that are the drivers for the identified failure mechanisms were investigated after the risk workshops. Project participants were requested to contribute to the project by delivering test data for the parameters. The availability of the test data from literature and project participants resulted in the conclusion that the following items had to be studied to come to more accurately quantified failure mechanisms:

- Elongation of sling in life time leads to a loss of functionality.
- Strength reduction caused by loss of splice integrity.
- Reduced strength by multiple use and dynamic environment.
- Strength reduction caused by bending.
- Elevated temperatures may induce permanent strength reduction.

**Test programs**

Nine test programs were carried out to further quantify the relevant failure mechanisms for typical rope sling or grommet constructions made from specific synthetic fibre materials. Rope sling and rope grommet constructions made of coated para-Aramid and HMPE were tested. The diameters of the constructions tested were small compared to the large diameters slings that can be applied in heavy lift operations. Because of the relatively small size a large number of specimens could be tested in a cost effective way, resulting in conclusions based on repetitive tests.

The base case was a 30 [mm] construction tested at room temperature. Next to this tests were carried out with an ambient temperature of 50 degrees Celsius and on samples with a rope diameter of 40 [mm]. In the test program for rope grommets different pin diameters were applied. The test programs comprised dry and wet static load tests and dynamic load tests.

A main conclusion was that the performance of fibre slings and grommets is predictable and constant, especially in static load tests. During these static load tests it appeared that the variation of the obtained breaking loads within individual programs (and thus products) was relatively small. Location of failure of the slings occurred at the transition from splice to undisturbed rope in most of the tests.

During dynamic load testing the performance of the constructions was again very good, but slightly less predictable. Break of the different constructions in the different programs occurred between 50% and 80% of the Minimum Breaking Strength (MBS) for both fast and slow cyclic testing. This level of loading is extreme and to put it in perspective, the maximum level of loading is 25% MBS if a very low safety factor of 4 is used. During dynamic loading heat is developed by friction between fibres. Conclusion was that no relation was found between temperature levels and break load levels. However, in the fast cyclic tests (in which the cyclic period is 10 seconds) and loads above 50%-60% of MBS, temperatures can occur that will have influence on the fibre properties like strength and modulus.

The break location of failed slings and grommets tested in a cyclic load test was less predictable compared to the static load tests. Break occurred in the splice, at the end of splice, and in the undisturbed rope for slings. Grommets failed on top of the pin, but also in the splice and at the end of splice.

**Guidance note**

The guidance note was the overall result of the project. The shared knowledge within the project and test program led to increased understanding on how to use synthetic fibre slings in a safe way. The overall result was presented – in a general way – in this guidance note. Sections include criteria for design, material, testing, manufacturing, and survey of synthetic fibre slings to be used for marine lifting operations.

**Conclusions and recommendations**

Fibre sling users who have initiated this JIP would like to have more insight in the parameters that determine safety factors for lifting operations with fibre slings and grommets. Safety factors are prescribed by notified bodies without having explained in detail how this factor has been determined. It is clear that the more information is available on the uncertainties in processes, equipment and materials, the less uncertainty should be compensated by conservatism. Fibre sling suppliers and material manufacturers have a great amount of information they can share with users of their products. This information, in combination with a description of their operations by users, can lead to a better understanding of the reliability of fibre slings and grommets in marine lifting operations.

One of the conclusions of the project is that, at this moment, setting up a generic reliability analysis tool for a nonspecific marine lifting operation is not feasible. A reason is that it is not possible to define environmental and operational boundary conditions in sufficient detail to come to a realistic load factor. Another reason is that there is no general mechanical or fatigue model available for synthetic fibre sling assemblies that can be used to determine generic material factors. This is not only because the sling construction is not standardized, but also because there are many different types of fibres with different characteristics in use and available.

Safety factors to be used are advised by certifying authorities like GL, DNV and LR. The authorities determine which possible event and its probability is acceptable. Evidence can be gathered to decrease uncertainties and as a result support a certain safety factor improvement, which is decided (or approved) by certifying authorities.

A qualitative, and if possible semi-quantitative, risk assessment for a certain marine lifting operation can be used to reduce parameter uncertainties. This risk assessment can be part of the synthetic fibre sling construction design procedure, see Figure 2.

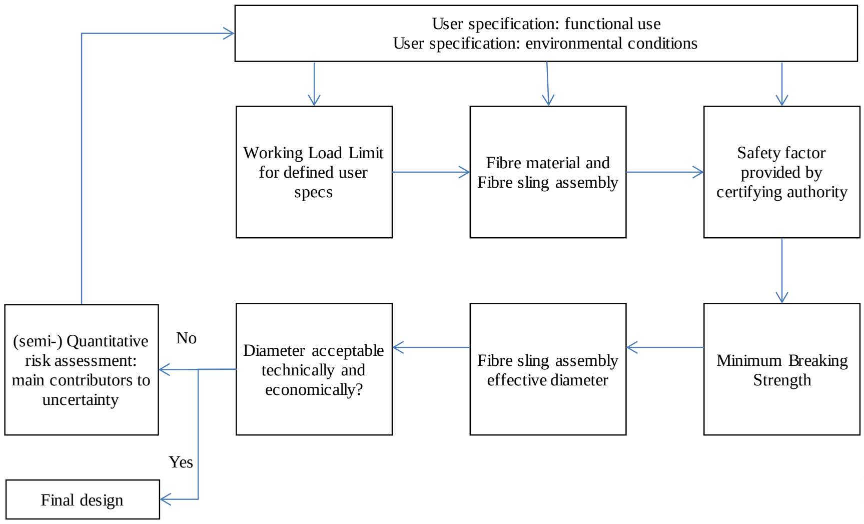


Figure 2: Design procedure including risk assessment

Quantification of characteristics of different fibre sling assemblies made of different materials will help users to reduce uncertainties. Evidence is key in improving safety factors. It is advised to suppliers and contractors to cooperate and set up projects to:

- Gather evidence via dedicated test programs on sling assemblies and materials.
- Build up a record for the residual break strength for (used) consumable synthetic fibre slings on board.
- Setup a system to monitor and re-certify the bigger synthetic fibre slings, specifically allocated for an engineered lift.

**References**

[1] Improving Safety Factors of Fibre Slings & Grommets: Literature Study V3, Sjoerd van der Putten, December 5, 2011
[2] Slings and Grommets Risk Workshop Report V2, Sjoerd van der Putten, November 4, 2011
[3] Fibre slings & grommets Test Plan V4, February 29, 2012

[4] Improving safety factors of fibre slings & grommets: Results of Test Program 1 – 9, May 2012
[5] Improving safety factors of fibre slings & grommets Phase III Test Program Results V4, December 1, 2012
[6] Guidance Note on the use of synthetic fibre slings V5, December 1, 2012