Evaluating the effect of particle intrusion in deep water mooring ropes

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Nomenclature

ABBREVIATIONS

Y-O-Y	Yarn-on-yarn
CTF	Cycles to failure
SEM	Scanning Electron Microscopy

DEFINITIONS

FILAMENT	Smallest fibre component around 10-20µm diameter
TEXTILE YARN	Assembly of filaments (typically 200 to 800 - in a yarn)
ROPEYARN	Assembly of twisted textile yarns
STRAND	Assembly of twisted yarns
SUB-ROPE	Assembly of strands, braided or twisted

SUMMARY

For the purpose of evaluating particle intrusion in fibre ropes, two types of tests were conducted. Firstly, Y-O-Y abrasion tests were conducted on textile yarns to establish effects of different particle sizes, materials and concentrations. Secondly, cyclic loading of small ropes in various concentrations of seabed sediment and measurement of residual strength was conducted.

There is significant reduction in Y-O-Y abrasion life due to small particles penetrating between filaments in a textile yarn. The reduction in Y-O-Y abrasion life was around 26 times when tested in the presence of seabed sediment compared with reference tests without particles. The abrasion increases with increasing concentration of particles.

This reduction in life is of a similar order of magnitude whether silica or seabed sediment is used. This infers that the mechanical properties of the abrasive particles are not key parameters for abrasion life.

The key parameter in determining Y-O-Y abrasion life from this study was found to be particle size where the smaller particles, possibly with a limiting size, have the worst effect.

This is probably associated with the depth of particle penetration where smaller particles can migrate further into the yarn structure, thereby abrading more of the yarn cross section.

Significant strength loss was found on small scale ropes when subjected to cyclic loadings submersed in a tank with a seawater and seabed clay environment.

The results from these tests infer that there could be a significant long term strength reduction due to internal abrasion in permanent fibre mooring ropes if particles penetrate the rope. Rope strength reduction will be dependent on particle size and depth of penetration.

INTRODUCTION

Synthetic fibre ropes for deepwater mooring require installation under controlled conditions. One of the most practical installation methods currently used for conventional chain/steel wire rope mooring systems is to preinstall the mooring lines on the seabed before the vessel arrives at the field. This preinstallation may take place up to a year before the vessel arrives at the field. However, this installation method subjects the fibre ropes to seabed particle ingress that may have a detrimental effect on long term rope durability.

This paper presents the results on a series of tests conducted to determine the magnitude of reduction in Y-O-Y abrasion life of a textile yarn immersed in various particle sizes and types. Residual strength fatigue tests were conducted on scale ropes without jacket to investigate the effect of clay particle intrusion under realistic conditions inside a rope.

SAMPLES AND TEST METHOD

Y-O-Y Abrasion - Textile yarns

Tension Technology International Ltd tested a 1000 denier marine finish polyester textile yarn for Y-O-Y abrasion. The fibre manufacturer's specification breaking load was 92N (940gms).

The yarn was tested in two types of particles, crushed silica and seabed sediment.

Two sizes of crushed silica were used, 6-35 µm and 35-70 µm and each tested in two types of carrier. One carrier type was total immersion in silica with water filling the interstices and the other 17% by volume silica in a paste made from carboxy methyl cellulose. It was not possible to maintain the particles in suspension in water, even with various stirring methods tried, due to the high density of silica.

The total immersion in silica was tested to represent worse case whereas the 17% by volume simulates a rope with partial particle penetration.

Sediment particles were tested in 17% by volume in paste only. As for the silica, the sediment could not be held in suspension in water, so paste was used as the carrier. Two almost identical sediment samples A and B were supplied by the Norwegian Geotechnical Institute from deep water in the Norwegian North Sea[1].

Reference tests were run in water and paste, with no particles added.

The Draft ASTM standard test method was used[2].

The yarn was interwrapped in contact with itself between three pulleys, and drawn back and forth under tension until it failed as shown in figure 1. The interwrapped region and the lower pulley were immersed in the media to be tested. The number of cycles to failure for each test station was recorded. The cycles to failure for several tests at a given applied load level were statistically analyzed to determine mean and standard deviation. These statistics were calculated and plotted on a log-normal basis.

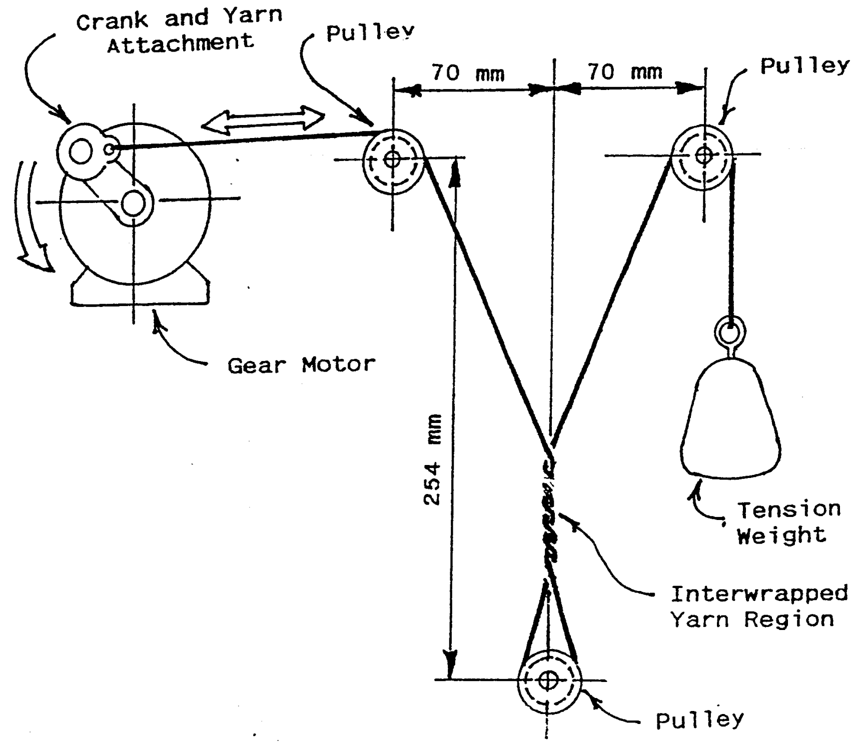

Figure 1. General Arrangement of the Yarn-on-Yarn Abrasion Test Apparatus

Residual strength fatigue testing of small scale ropes

For the purpose of assessing the effect of clay ingress on the fatigue life of polyester fibre ropes, Det Norske Veritas AS performed cyclic testing with subsequent test of residual strength of polyester ropes:

- Both laid and steel wire rope constructions were tested.
- The ropes were of breaking strength in the order of 25 - 35 tonnes.
- Each rope sample was subject to 100,000 load cycles between 10 and 50 kN prior to the break test.
- An onshore clay with properties very close to that found in deep water offshore was used.

After the cyclic loading, the samples were tested to break according to *OCIMF Prototype Rope Testing, Chapter 8.*

For each test run to 100,000 cycles, three samples were mounted in series in the test machine. The cyclic frequency was 0.12 Hz.

During the cyclic loading, one of the following test conditions was used:

Sea Water (Condition 1)

For the purpose of obtaining reference results, two runs were made with the samples submerged in natural sea water only. No clay was added.

Clay, with pre-soaking (Condition 2)

The ropes were soaked in the emulsified clay prior to the test, approximately 350 mm deep in the bottom of the machine tub. The ropes were then tested in the natural sea water above, containing dispersed clay particles. Clay particle dispersion was ensured by a mud pump. Reference is made to Figure 2.

Clay, without pre-soaking (Condition 3)

Natural sea water containing dispersed clay particles. No soaking of the ropes in the emulsified clay prior to cyclic testing.

Clay, with extended pre-soaking (Condition 4)

Same as condition 2, with soaking of the ropes in the emulsified clay on the bottom whilst the cyclic testing was performed for condition 3.

The clay particle dispersion was such that after each 100,000 cycles, a layer of approximately 5 mm depth had settled on top of everything inside the machine tub including the ropes.

Figure 2 below shows a sketch of the test set-up.

Figure 3 shows ropes and connecting shackles covered by settled clay particles.

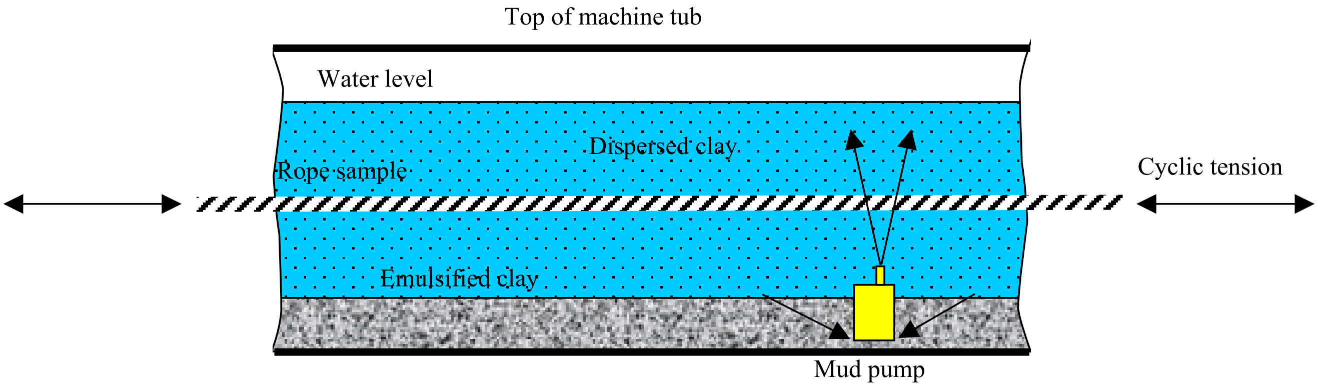

Figure 2. Schematic of small scale rope test set-up.

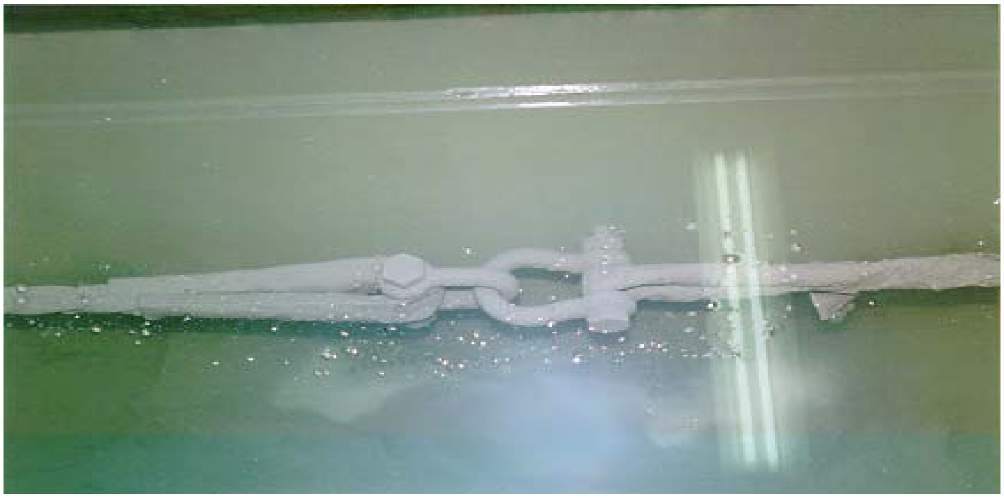

Figure 3.Ropes and connecting shackles covered with settled clay particles in test condition 3.

RESULTS AND DISCUSSION

Y-O-Y abrasion – textile yarns

The abrasion life cycles to failure versus applied load are graphically presented in Figures 4 to 11 with 95% confidence limits.

The 300gm load level results are summarised in Table 1 and the reduction in life expressed as a ratio relative to the respective water and paste references. There was a reduction in life due to the paste by a factor of 5 compared with the water. The various silicas in different carriers range from 18 to 57 times reduction compared with the reference results. The smaller particle sizes had significantly higher reduction whether in paste or in water carrier. For comparable particle size the total immersion in silica gave around twice the reduction in life compared with the 17% silica in paste.

Sediment 'B' appeared to show finer particles due to non-settling in a water mixture when left to stand compared to complete settling of sediment 'A'. The 400gm and 500gm runs in sediment B gave a stick-slip motion in the inter wrap region rather than the usual smooth sliding motion for the other runs.

The sediment samples A and B gave 26 and 17 times reduction in life respectively. They gave similar reduction in life as the crushed silica. From figures 10 and 11 for the sediment A and B samples it is interesting to note that the variability increased dramatically at the higher loads that is indicative of a different abrasion damage mechanism. This was corroborated by observation of stick-slip during these tests. In contrast, all the other figures do not exhibit this trend. The exception is Figure 6 where a very low CTF at the higher load gave difficulties running this test.

TEST	LOAD gms	CTF	REDUCTION IN LIFE RELATIVE TO REFERENCE
WATER (REFERENCE)	300	12131	1
PASTE (REFERENCE)	300	2502	5
SILICA 6-35 TOTAL IMMERSION + WATER	300	214	57
SILICA 35-70 TOTAL IMMERSION + WATER	300	370	33
SILICA 6-35 17% PASTE	300	96	26
SILICA 35-70 17%PASTE	300	138	18
SEDIMENT ‘A’ 17% PASTE	300	95	26
SEDIMENT ‘B’ 17% PASTE	300	146	17

Table 1. Summary of 300gm Y-O-Y abrasion CTF test results

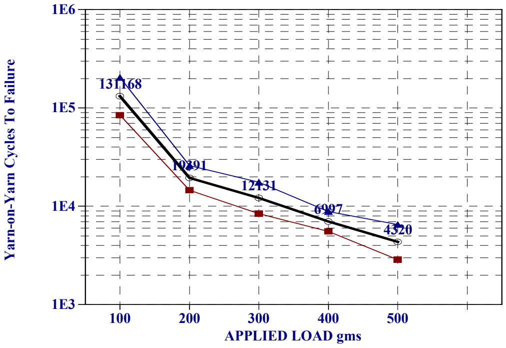

Figure 4 Water (reference)

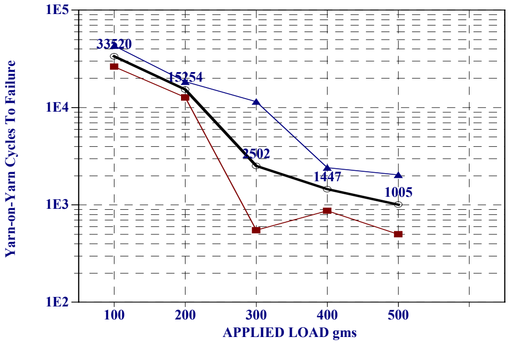

Figure 5 Paste (reference)

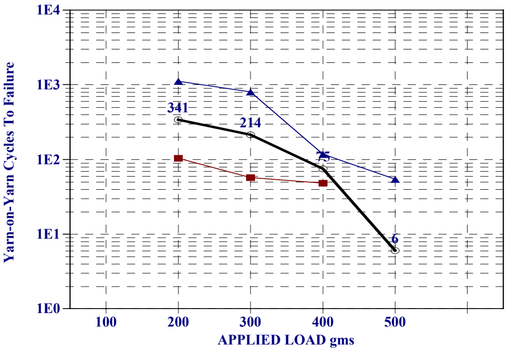

Figure 6 Water immersed silica 6-35μm

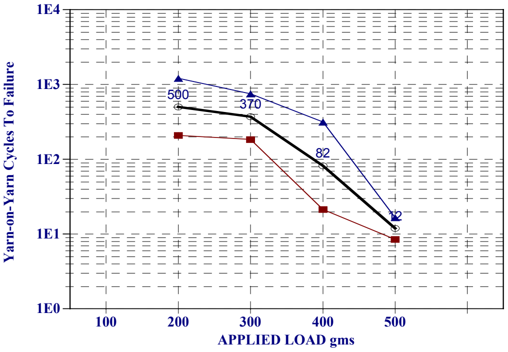

Figure 7 Total immersion in silica 35-70:m

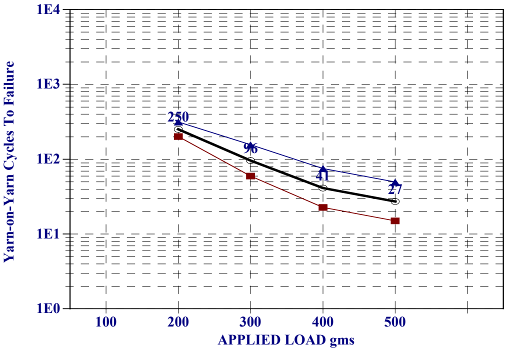

Figure 8 Silica 6-35 in paste

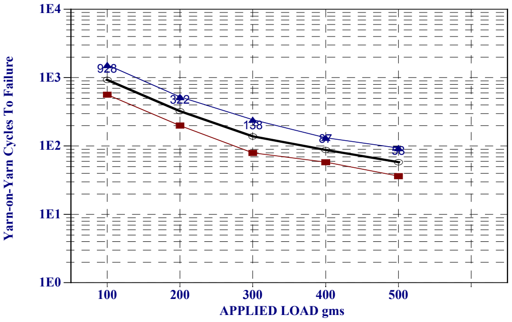

Figure 9 Silica 35-70 paste

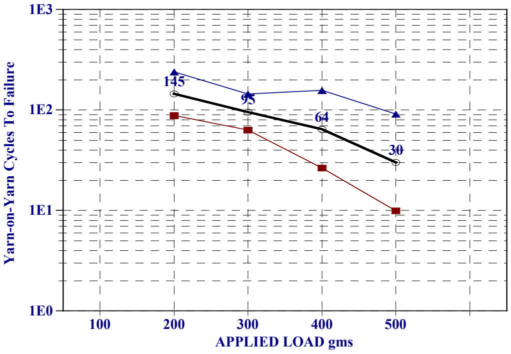

Figure 10 Seabed sediment A in paste

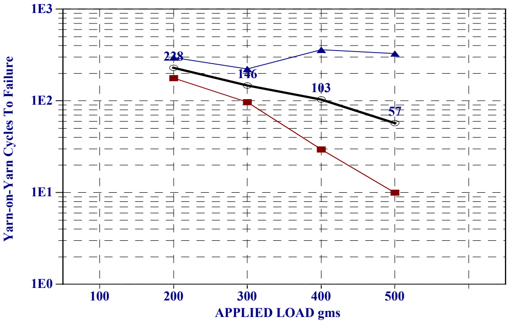

Figure 11 Seabed sediment B in paste

Residual strength fatigue tests

Table 2 shows the average percentage residual strength for the ropes in each clay exposure condition, as compared with condition 1 without clay exposure.

Table 2. Average residual break strength for each category.

Test condition	Average residual break strength
Condition 1, reference:	100 %
Condition 2:	64 %
Condition 3:	79 %
Condition 4:	69 %

The results clearly indicate that clay intrusion affects the residual breaking strength of polyester ropes subject to cyclic loading. The cyclic load levels and number of fatigue cycles were selected to obtain realistic load levels for all rope samples, and test duration long enough to detect possible effects whilst minimising total test duration as much as possible.

Microscope examinations of tested ropes

In order to study the suspected abrasive mechanism, yarn samples were extracted and examined microscopically. Two scanning microscope images are shown in Figure 12.

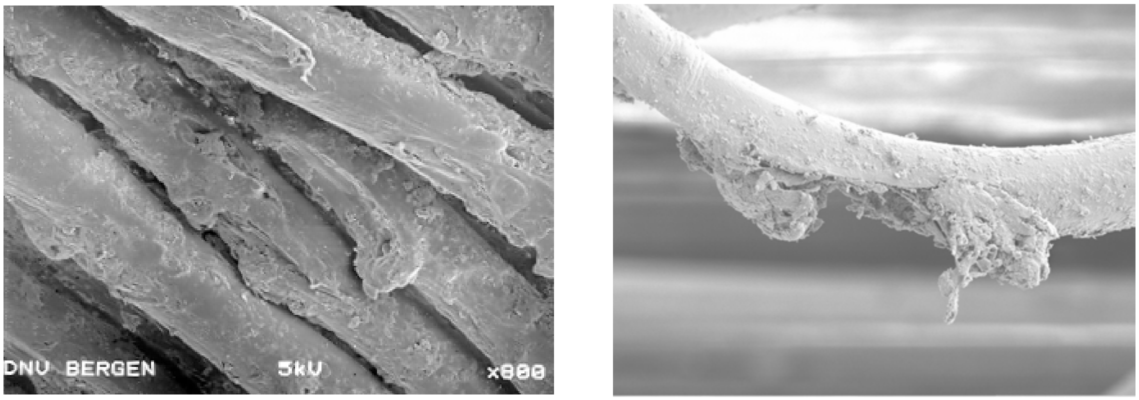

Figure 12 a and b. SEM images of polyester fibres extracted from ropes subject to clay exposure and 100,000 load cycles. (Conditions 2 and 4.)

The findings clearly indicate abrasion as the main damaging mechanism.

CONCLUSIONS

There was a significant effect of particles reducing abrasion life. The results from these tests infer that there could be a significant strength reduction over longer term due to internal Y-O-Y abrasion in the presence of particles within permanent fibre mooring ropes. Previous SEM work[3] conducted on yarns removed from cyclic loaded ropes and Y-O-Y abrasion tests have shown identical abrasion damage.

It is well known that ropes that have had prior immersion in seawater, dried out, and then subjected to cyclic loading results in a dramatic reduction in life due to the internal abrasion from salt crystals. This has been verified by Y-O-Y tests on seawater immersed yarns tested in dried out condition[4]. No less than 100/1 reduction in life was found compared to water control.

It is interesting to note that, silica and seabed sediment gave a similar order of magnitude reduction in Y-O-Y abrasion life when tested at the same concentration. Since there is a large difference in mechanical properties between these particles, this infers that the type of abrasive media is not a key property in determining abrasion life.

As particle size decreases abrasion damage increases, although there appears to be a limiting particle size as discussed below. This may be due to the smaller particles penetrating further into the yarn. Therefore, abrading more of the cross section of the yarn compared with larger particles that would not penetrate so deeply.

Sediment A passes[1] around 45% of particles up to 2Φm and B passes 50%. Hence, there are more small particles in B compared to A. In addition, observations of the sediment B tests showed stick-slip motion in the Y-O-Y wrap region and the sediment solution in water did not settle. Thus we conclude that there is a difference between the two sediment samples and B has more finer particles, which may explain the higher variability at the higher loads when compared with A. In contrast, the silica is graded into a particle size range and is all of the same material and the results show a more consistent pattern.

Paradoxically, B gives longer life than A. This may be due to the finer particles having a limited or even beneficial effect, and could be an indication that the minimum particle size is 2Φm for a filtering protective jacket.

The residual strength fatigue test programme shows that clay affects the fatigue life of polyester ropes. A 20-40% strength reduction compared to the reference test was observed for the various test conditions.

The Scanning Electron Microscope examination confirms that abrasion is the main damaging mechanism.

These findings are not a threat to the use of fibre ropes for mooring systems but more a reminder that fibre ropes must be treated differently than chain and steel wire rope. Installation of fibre ropes must be done in a way that they do not come in contact with the seabed or an effective jacket must be covering the rope.

Acknowledgement

The authors gratefully acknowledge the support of BP Amoco, Conoco, Elf, Norsk Hydro, Saga, Shell and Statoil that funded these tests in the NFR Project “Alternative Configurations and Materials for Mooring/Anchoring”.

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3. Parsey, M.R., Street, A., and Banfield, S.J. ‘Dynamic Behaviour of Marine Hawsers.’ Offshore Technology Conference, OTC 5009 Houston, Texas May 6-9 1985.
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