Abrasión y Fatiga de Fibra en Cuerdas de Alta Performance de Sintéticas para Asistencia del Remolque y amarrado

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SYNOPSIS

High Modulus PolyEthylene (HMPE) synthetic ropes have been used successfully in the towing industry for ship assist and vessel escort since the mid 1990s. Samson has been tracking these ropes in application and reported the studies of their performance. Important observations were made to understand both the short and long-term behaviors of HMPE ropes used in tug assist application in up to 4,000 jobs. Detailed residual strength determinations and laboratory analysis confirm that abrasion is the dominating factor affecting service life of HMPE ropes used for ship escort and berthing. This paper details the research and development efforts that have been made to provide solutions for problems experienced by tug operators regarding service life and reliability of tow lines. Specifically, it will describe the importance of rope design to abrasion resistance and other methods to increase service life of HMPE tow lines.

INTRODUCTION

High Modulus PolyEthylene (HMPE) fibre ropes replace wire cables in many working line applications because of the following three core benefits:

1. Safer to use – due to their high strength and light weight;
2. Cost effectiveness – due to lower labour requirements, decreased towing times and longer rope life;

Among all marine applications, tug assist is one of the most severe environments that a rope can experience. Comprehensive testing and field trials have been conducted, as shown in Figure 1, comparing residual strengths of HMPE lines against the number of jobs performed.

![Figure 1: Residual strength history; ropes of similar sizes performing similar jobs in harbour class tractor tugs in Puget Sound and Southern California.](image)

Lab simulation and field observation concluded that the most serious threat to the integrity of a tug's tow line is abrasion. In the following sections, we will quantify the effect of abrasion on rope and describe general inspection guidelines for HMPE tow lines. Most importantly, we will discuss how to overcome the effect of abrasion by understanding the effects of hardware conditions, rope design and chafe protection.

EFFECTS OF HARDWARE ON SERVICE LIFE

The majority of tractor tugs currently in use, as well as those under construction today, will likely have HMPE tow lines installed. Also, their design will have considerations of the proper deck hardware that would minimise unnecessary abrasion damage (ie, stainless steel staples and bitts). However, in vessel escort or berthing, there is often little or no control over the condition of the vessel's chocks and bitts. Along with other sources of abrasion, this is a major cause of damage affecting rope service life. To extend the life of the main tow line, the risk for this type of damage is often counteracted with the use of sacrificial pendants, which are used to endure most of the damage from ships' hardware.

In order to best protect from this unnecessary damage on board, it is recommended that surface hardware be kept at a maximum of 250 μm. This recommendation is supported with testing as shown in Figure 2, showing the effects of a rough surface on rope life.

![Figure 2: Surface roughness comparison.](image)
Most manufacturers provide new tugs with stainless steel staples and bitts, which typically meet or exceed these surface roughness recommendations; however special attention should also be given to the condition of any other potential contact surfaces. Some stainless steel-clad surfaces can be left unprotected in certain locations that may come into contact with the tow line as the lead angle changes in service. Some examples are shown in Figures 3a & b and 4a & b, where the roughness of the surface can damage the rope.

**Figures 3a & b: Bull nose contact surfaces; rough surfaces causing heavy surface abrasion.**

In Figures 3a & b, small amounts of fibre can be seen on the bull nose and lead edge of the tug where rough surfaces have worn the rope’s surface.

**Figures 4a (below left) & 4b, above: H-bitt comparison.**

*Figures 4a & b, below left, and above, show a comparison of a stainless steel-clad H-bitt to a typical ‘carbon steel’ H-bitt. Note the differences in surface roughness and pitting. Even after being painted, these locations on the H-bitt cause a noticeable difference in the condition of the lines that are used on them.*

**GENERAL GUIDANCE ON ROPE HANDLING AND INSPECTION**

One critical issue in maximising service life and safety is ensuring that all operators and rope handlers are well trained in the use of high performance tow lines as well as knowledgeable of retirement criteria. While the retirement criteria for tow lines are ultimately at the discretion of the tug companies, Figures 5-7 show some descriptions of warning signs to look for in ropes that have been in service or suffered damage from abnormal conditions.

**Figure 5: Cut strands.**

It is highly recommended that any rope that has suffered adjacent cut strands be retired or repaired by cutting out the damaged section and re-splicing. If a cut line cannot be repaired it should be treated with caution and replaced at the earliest convenience. Figure 5 shows an eight-strand
rope with a cut strand even though the rope was in otherwise good condition with only moderate surface abrasion.

Figure 6: Comparing internal and external yarn condition.

While a rope's outside surface may look rough or damaged, it is important to compare the inner yarns to determine how much abrasion damage has affected the rope's strength. Figure 6 shows internal yarns that are beginning to suffer from moderate internal abrasion, but are still in a serviceable condition.

With any HMPE line, melting damage is a concern. Quick slipping on hardware under high loads can generate a high amount of heat that can cause yarns or even strands to melt and fuse together, as seen in Figures 7a & b.

The fibres/yarns will have a glossy appearance and it will no longer be possible to separate them by hand. This situation should be carefully guarded against. If the yarns that make up a strand are found to be completely fused, that section of the rope should be removed or the entire rope retired.

ROPE DESIGN AND ABRASION RESISTANCE

To allow for comparison of several different rope designs, laboratory testing programmes were performed to establish baseline performance data in regards to abrasion resistance.

An important aspect of rope design that plays a critical role in the rope's abrasion resistance is the braid cycle length. The length of a single braid cycle in a rope, which is controlled by the braid angle, can vary greatly. This design factor will dictate, among other things, how flexible the rope is to handle. It is possible to adjust the weight and/or strength of a rope by changing the braid period. Figure 8 shows the comparison of single braid 12-strand ropes with different braid periods and twist levels.

- Sample A: Good firmness and abrasion resistance;
- Sample B: 10 per cent looser braid than Sample A;
- Sample C: Very loose braid, difficult to handle, likely to snag.

Figure 8: Rope construction comparison.

Using Sample A as the control sample, Figure 9 shows the difference in performance characteristics between the three samples tested. Each rope was cycled in a wet abrasion environment under tension until failure occurred. While the weight and strength specifications for each rope were very similar, there was a dramatic difference in abrasion resistance. The loose braid samples had a significant decrease in their ability to resist abrasion damage.

COMPARISON OF HMPE ROPE CONSTRUCTIONS

HMPE FIBRE SELECTION

In addition to the performance differences inherent in rope design, performance of different HMPE fibres can vary drastically. It is recommended that the user investigates and understands the differences before making rope selections.
PROTECTING AGAINST ABRASION

As tug operators become more and more familiar with the failure mechanisms of tow lines made of HMPE fibre, it is essential to continue to improve the defence mechanisms of the lines. Whether it is external chafe protection, hardware upgrades, rope construction or coating improvements, there are several options available that help to extend service life. The following issues will be detailed below to help describe possible benefits to taking extra steps to protect tow lines from abrasion damage.

- External vs Internal Abrasion
- Chafe Gear Benefits
- Coating Developments

EXTERNAL VS INTERNAL ABRASION

Abrasion, being the dominant factor in decreasing strength and service life, consists of external and internal abrasion. Figures 10 and 11 show examples of external and internal abrasion, respectively.

![Figure 10: Example of moderate external abrasion.](Image)

![Figure 11: Example of heavy internal abrasion.](Image)

After just a few weeks in service the outside surface of any rope made from HMPE fibre will begin to look rough and ‘fuzzy’ (Figure 10). This is due to external abrasion caused by unavoidable contact with rough surfaces such as chocks and/or the vessel’s deck. During service the strands of a braided rope are constantly being subjected to relative movement. This movement causes damage at the points in which strands cross each other, much like the damage caused at positions where the line crosses the chock (Figure 11).

EXTERNAL ABRASION

Figures 12-14 represent 30m pendants taken off two nearly identical 6,000hp tractor tugs operating within the same waters after approximately the same number of jobs (Tug C: 630 jobs, Tug D: 704 jobs). The two tugs were using the same product (12-strand braided rope made of HMPE fibre) with one exception: Tug C utilised chafe protection in and around the outboard eye of the line while Tug D did not use any chafe protection on the line. Several issues should be noted upon inspection of these lines.

Figures 12 and 13 show the lines just below the eye splice. Although both lines show some external wear, there is more severe abrasion on the line in Figure 13.

![Figure 12: Tug C pendant (moderate/heavy abrasion) – with chafe protection.](Image)

![Figure 13: Tug D pendant (extreme abrasion with cut strands) without chafe protection.](Image)

![Figure 14: Tug D pendant (cut strands).](Image)
When the line from Tug D was inspected it was evident that the surface abrasion had greatly affected the condition of the rope. The abrasion damage was so severe that a majority of the rope’s strands had been at least partially cut or worn through as shown in Figure 14 (previous page), with several cut yarns from throughout the lay length of the rope.

INTERNAL ABRASION

Figures 15 and 16 compare the internal abrasion of the ropes from Tug C and Tug D respectively. These images show a very important advantage to the proper use of chafe protection. While Tug C had performed over 10 per cent more jobs than Tug D, it is very clear that the chafe protection used in the eyes of the tow line on Tug C was able to greatly reduce the amount of both external and internal abrasion on the line. Looking at the internal strands of each line one can see the strands covered by chafe gear look close to new, while the unprotected strands are fuzzy and worn.

All the information described above is summarised by testing to determine the residual strength of the pendants to quantify their current safety factor based on residual strength. Table 1 shows the difference in average residual strength between the pendants off Tug C and Tug D. This difference in residual strength can be directly attributed to the use of chafe gear as well as differences in handling techniques between the two operators.

### Table 1: Residual strength comparison (Tug C and Tug D pendants)

<table>
<thead>
<tr>
<th># of Jobs</th>
<th>Tug C Pendant</th>
<th>Tug D Pendant</th>
</tr>
</thead>
<tbody>
<tr>
<td>630</td>
<td>704</td>
<td></td>
</tr>
<tr>
<td>Average Residual Strength (% Published MBS)</td>
<td>61%</td>
<td>41%</td>
</tr>
<tr>
<td>Remaining Safety Factor</td>
<td>3.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Several options are available to help prevent damage to synthetic ropes as well as personal injury. A summary of chafe protection options is listed in Table 2 (see next page).

PROTECTING AGAINST ABRASION WITH COATING TECHNOLOGY

The abrasion resistance of a rope can also be enhanced by coating technology that protects it. Samson has conducted extensive studies to find the next generation coating technology for improved abrasion protection.

Promising test results have lead to field sample evaluations on several tractor tugs to confirm performance enhancements. We will report at future conferences, as more test data and field experience become available.
CONCLUSION

Abrasion is the most dominant factor affecting the service life of HMPE tow lines. The methods to help mitigate normal wear to extend service life of rope include:

1. Providing acceptable hardware conditions;
2. Proper rope design;
3. Selecting the right product;
4. Use of chafe protection or coating technology to protect the rope.

As in many marine applications, mitigating risk is an important issue. Giving proper protection against the wear and abrasion of HMPE tow lines can help achieve significant service life.

REFERENCES


Table 2: Chafe options offered by Samson.
Mike Allen
Gentlemen, thank you very much. Rope performance is critical and your research on abrasion and fibre fatigue is extremely valuable to the industry. I’m sure that we are very grateful to you for your informative paper.

Steve Lewis, Prince William Sound Regional Citizens Advisory Council
I was wondering if you have done any work or have even anecdotal feeling about the effect of lower temperatures and in this case, I am thinking down to probably around -20 degrees F, on immediate strength and then also on ultimate service life.

Terry Crump
We’ve done extensive tests, not only on extreme cold, Steve, but also on extreme hot. We have technical bulletins on those that are available on our website. Just as a rule of thumb, as the temperature gets cooler, in fact the strength goes up a little bit. We’ve also done tenacity and flexibility, and it’s not reduced as the temperature falls – for example in Valdez Alaska, where I think is where you’re from, or maybe Saldovia where you get some extreme colds in the winter, it’s not impacted. In extreme hot conditions, of course, we’ve done a case study on some of the ambient temperatures in Khattar and in going through chocks due diligence needs to be taken care of that the temperature doesn’t get up too high. You can use protection as we’ve done here, but it’s not impacted either way, negatively.

Markus van der Laan, IMC Corporate Licencing
Thank you very much for sharing this valuable information on abrasion. Technically, I am interested in one relation that I don’t get from the paper. Perhaps you can extend on that. I would like to have a relation between abrasion and the load applied, and also load variations, because you refer to a typical tug and some typical loadings, but is there something more to tell about it, because I hear from many people that especially higher loads have a high influence on abrasion. What kind of relationship can we expect between load and load variations and abrasion? Is there anything you can tell and share with us?

Kris Volpenhein
We haven’t performed that testing to try to come up with a model to answer that question directly. I think your comment is accurate. In general, you would see an increased negative effect as far as abrasion is concerned when the load is increased, but to be honest, no, we don’t have that data right now. We could probably come up with it pretty quickly, at least to answer that question, but as far as a model is concerned, no.

Jarkko Toivola, Neste Shipping OY
Thanks for the very interesting paper. My question – actually there are two questions, the first being, in your drawings, I still saw the very rapid initial drop of approximately half of the initial strength on these lines. Could you comment on what is behind that, because that’s something that we’ve seen before and it looks like we have to buy double the strength of lines we need, because the life at the end of the rope seems to be staying as it is, but where is that 50 per cent going? Any comments on that?

Kris Volpenhein
One more note about that model. All those lines that were tested were unprotected, so there was no chafe gear used. If you compare the rapid drop on the shorter end – jobs under 700, let’s say – to the rest of the plot, those are all pendants and it’s just representative of the service condition that those lines are going to see. But in general, you can make almost a linear shift if chafe protection was used, and you can kind of see that in the case study between tug C and tug D. Other than that, I guess the general phenomenon is that, inherent in the application, there is a quick strength reduction because the lines are immediately, as soon as they are put into service, subjected to such severe service conditions, especially on the customer end. Because of that, the outside of the rope is quickly fuzzed and you would see that after, let’s say, 50 jobs almost. That strength reduction is inherent in any synthetic rope unless chafe protection is used.

Jarkko Toivola
You are saying that you consider that most of that loss of strength is because of the abrasion and not the rope failing – some yarns breaking due to initially being too tight or something like that.

Kris Volpenhein
Correct – abrasion. I don’t know if I understood that completely, but if you look at the chart also, you will see almost an increase in strength that happens initially from strand alignment and evening. Then as soon as that peak hits, the abrasion effects start to come into play. It is a fairly rapid drop off. Across the industry, I’ve seen several of these models, and they all fall pretty well in line with each other. It is worth noting that strategic use of chafe protection can create, like I said, almost a linear shift in that drop off, and likely even change the slope of that curve.

Jarkko Toivola
OK. The other part of my question is for connecting the pendants and the main lines, and the chafing – back where I come from, we are actually using three different types of connections in pretty similar conditions; one being just splicing the pendant pin and grommet. Then one being cow hitching and then one being lashing. Any comments on the preferred method from your point of view, any test experience, especially on the splicing eye-to-eye or lashing, where there is a possibility of chafing into the connection. Cow hitching tends to get so tight that there is no chafing into it. Any comments on that?

Kris Volpenhein
We have performed that testing. In general, the straightforward comment is that a spliced eye-to-eye connection would see effectively no strength reduction. A cow hitch connection, you could expect, if it’s a size for size cow hitch connection, you could expect anywhere from 10 to 20 per
cent strength reduction. A lot of it has to do with how evenly that cow hitch is set up and first tensioned. If you’re going to cow hitch a line, you’re probably going to have to cut it out anyway, unless you do the due diligence on the front end. Our recommendation would be to link eye to eye. We haven’t done any testing with the seizing of any type.

Jarkko Toivola
Yes, because the seizing is the fastest way of doing it in operational conditions. The cow hitching can be opened if you use some clever methods, but then again, it’s a bit more complicated in an operational situation.

Kris Volpenhein
Yes, one more comment is just to keep in mind that if you’re cow hitching different sized lines, that strength reduction can drop off pretty quickly – down to 30 or 40 per cent. It’s something to keep in mind.

Buck Baker, Ledge’s Diving Service Pty Ltd
Has there been any study done with regard to the effect of sand and grit on the ropes?

Kris Volpenhein
I guess not in particular. I know in the offshore industry, there is a lot of talk about ingress and the effect on strength, but I don’t think we’ve done any. I can’t say for sure – maybe some years back, but I don’t think there’s been any specific testing done to try to quantify what certain amounts of particle ingress would do to strength reduction.

Terry Crump
Part of what I think Robert Underhill touched on a couple of years ago, it gets down to examination. If there is egress of sand and dirt that is controllable, that the crews can monitor and figure out what the source is, then remove the source. So rust, particulate matter that needs to be cleaned off the deck and deck surfaces. But if we’ve got issues, for example in your business, underwater, then maybe perhaps a jacketed type of product or some type of chafe protection that would not allow that particulate matter to get in there, because you certainly would get internal abrasion from the yarns and the sand working against one another. It’s like sandpaper.

Geoff Grosskreutz, Maritime Industry Services
In the late ’90s, I was working for a tug company and we did a lot of testing on HMPE ropes as tails to a motherline. What we found was after about 1,500-2,000 jobs, that the HMPE rope would fail for no apparent reason. There would be no signs of excess chafing, but it appeared to be a cyclic loading problem and the rope would fail. We instituted procedures where, a bit like airplane wings, before the wing would fall off, we would change the wings. So we used to do about 1,000 jobs on a particular line, then take it away. Has that shown up in your research, that HMPE ropes after a certain amount of load being taken off, suffers from work hardening or cyclic loading problem?

Kris Volpenhein
It’s definitely a potential. There are two ways of looking at it, I think. One thing that should be addressed is that, like I mentioned with the inspection, the lines may appear to look quite similar to what they did at 800-1,400 jobs, and then all of a sudden you get to 1,500 and it fails. In that time, the inside of the rope might be just going to pieces from abrasion and that might be worth noting. As far as tension fatigue goes, HMPE is significantly better as a performer in fatigue life from wire or most other synthetics, but it is a potential problem. If a line is going to last that long, basically what that could mean is that you guys were doing such a good job of protecting against abrasion that you’ve introduced a different failure mechanism, which is a good thing to see, I guess. We don’t have data to compare when that happens, when that failure point would come. I know that’s the million dollar question – when can we tell when our line is going to fail? That’s something that we’re working on, I’ll put it that way. One thing to keep in mind for comparison’s sake, is that there is a test called T CLL testing, which is, for all intents and purposes, a comparative test between fibres and steel in construction, which allows you to compare a theoretical, and it’s pretty accurate, strictly tension fatigue life. So if you are looking at different products and different constructions, you can see that comparison straightforward. We have that data for most of our products.

Terry Crump
We can provide that to you.

Mike Allen
Gentlemen, thank you very much.