Abrasion and Fibre Fatigue in High Performance Synthetic Ropes for Ship Escort and Berthing

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SYNOPSIS

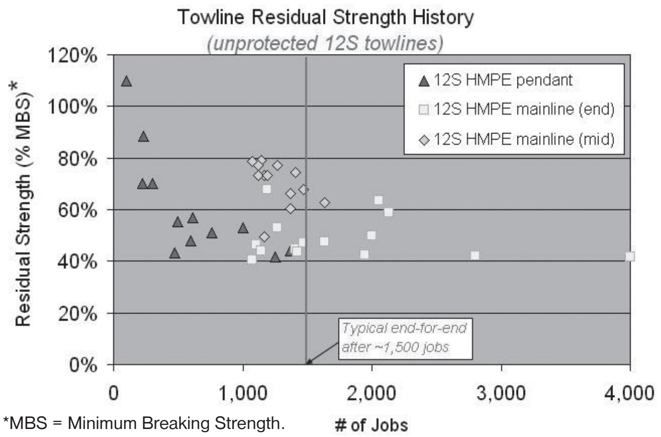
High Modulus PolyEthelene (HMPE) synthetic ropes have been used successfully in the towing industry for ship assist and vessel escort since the mid 1990s. Samson has been tracking these ropes in application and reported the studies of their performance[1]. Important observations were made to understand both the short and long-term behaviours of HMPE ropes used in tug assist application in up to 4,000 jobs. Detailed residual strength determination and laboratory analysis confirm that abrasion is the dominating factor affecting service life of 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;
3. Superior towing performance – high strength to diameter ratio and superior winch performance.

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.



*MBS = Minimum Breaking Strength.

Figure 1: Residual strength history; ropes of similar sizes performing similar jobs in harbour class tractor tugs in Puget Sound and Southern California[4].

Lab simulation and field observation concluded that the most serious threat to the integrity of a tug's tow line is abrasion[1]. 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 μ [2]. This recommendation is supported with testing as shown in *Figure 2*, showing the effects of a rough surface on rope life.

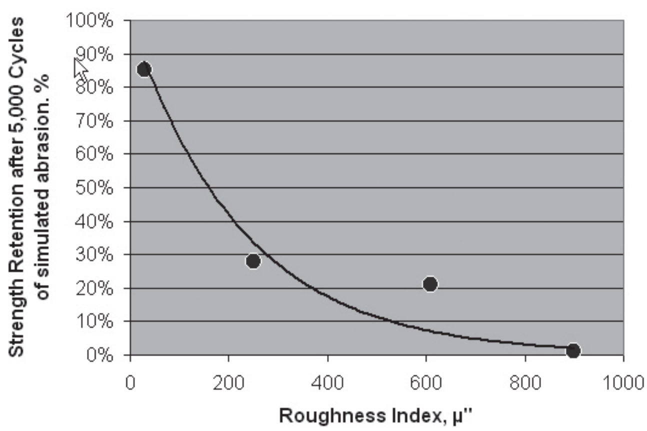
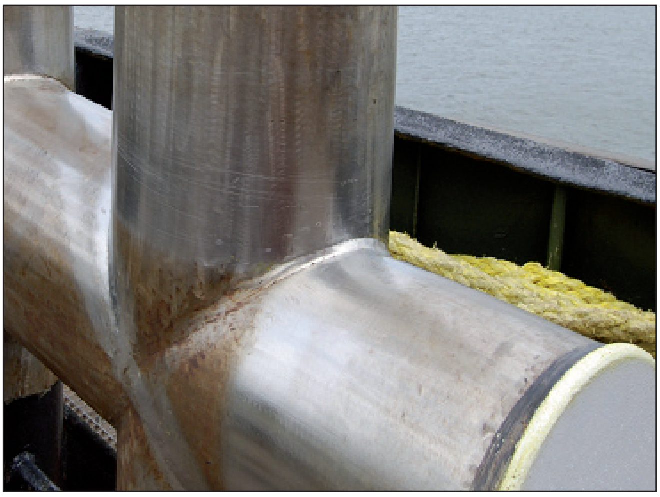


Figure 2: Surface roughness comparison[2,3].

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.

Figures 7a & b: Melted and fused fibre damage.

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 three samples that were tested in order to form a 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.

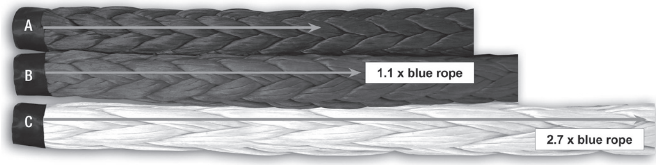


Figure 8: Rope construction comparison.

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.

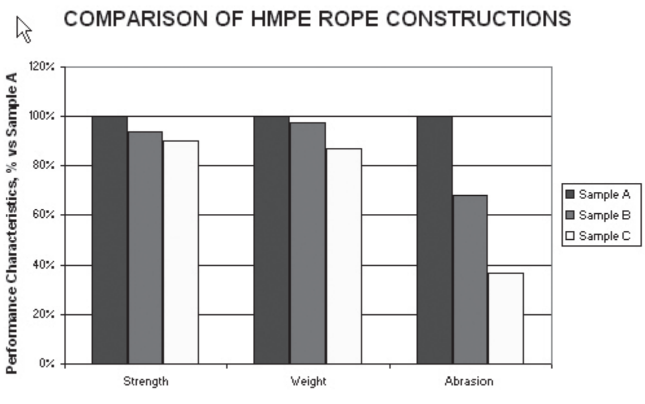


Figure 9: Construction comparison testing.

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.

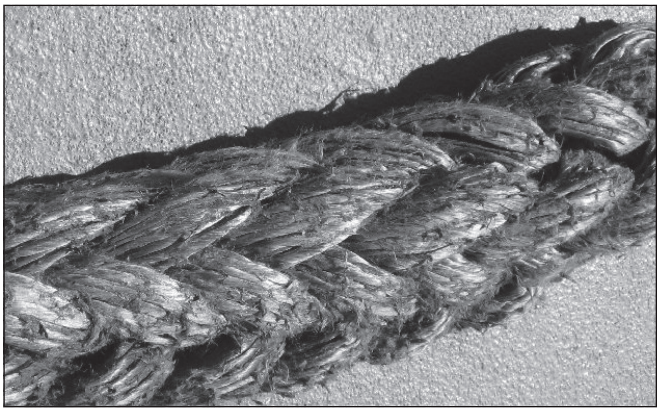


Figure 10: Example of moderate external abrasion.

Figure 11: Example of heavy internal abrasion.

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*.

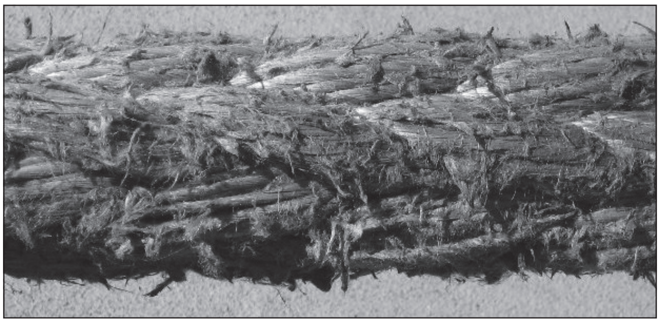


Figure 12: Tug C pendant (moderate/heavy abrasion) – with chafe protection.

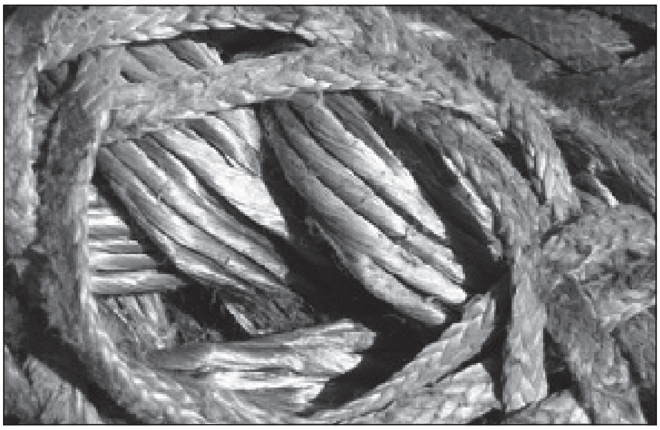
Figure 13: Tug D pendant (extreme abrasion with cut strands) – without chafe protection.

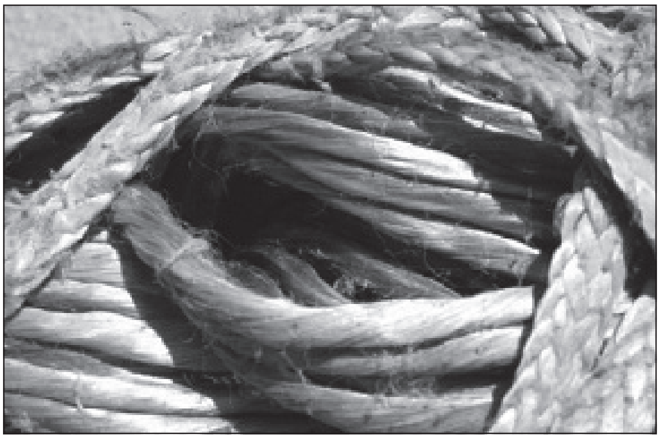
Figure 14: Tug D pendant (cut strands).

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.



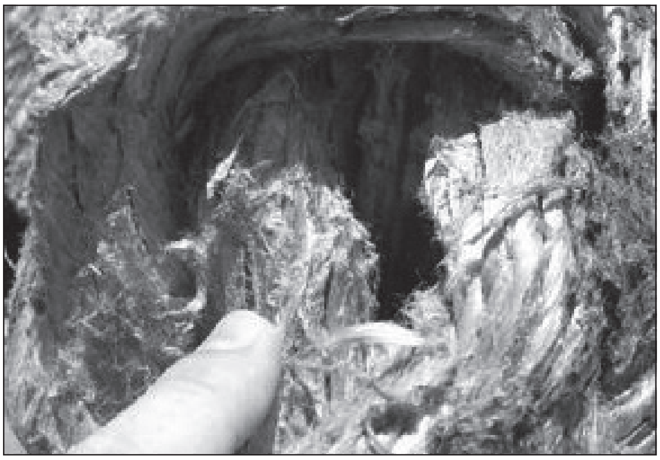


Figures 15a & b: Tug C – abrasion (with chafe protection).

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.

	Tug C Pendant	Tug D Pendant
# of Jobs	630	704
Average Residual Strength (% Published MBS)	61%	41%
Remaining Safety Factor	3:1	2:1

Table 1: Residual strength comparison (Tug C and Tug D pendants)[4].



Figures 16a and b: Tug D – abrasion (without chafe protection).

CHAFE GEAR BENEFITS

The internal abrasion damage shown above occurs from the internal 'cutting' action that takes place between strands/ yarns in all braided ropes and can be limited greatly through the use of chafe protection. This phenomenon is a result of the chafe gear allowing for the entire rope to slide and adjust inside the chafe protection while the chafe gear absorbs the frictional effects from surface contact. Conversely, without chafe protection the rope's surface yarns become the contact surface with hardware. This increases the amount of relative motion between surface yarns and internal yarns and in turn increases the damage done by internal abrasion. This makes it critical to know how and where to utilise effective chafe gear in order to maximise the life of a tow line and mitigate risks involved with the application.

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.

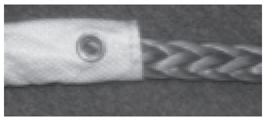
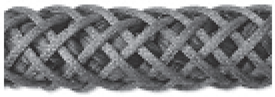
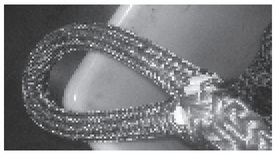
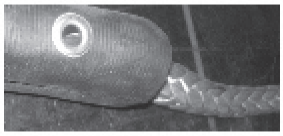
Description	Application	Pros and Cons	Image
Sewn Woven HMPE Sleeve	Working lines body	Moderate cost Good durability Fixed to rope or hardware Install pre-splicing	
Pliable or Straight Velcro Woven HMPE Sleeve	Working lines eye or body	Moderate cost Good durability Easy to install on spliced rope	
Chafe sleeve Open construction	Tug/Mooring eye and body	Higher cost Excellent durability Fixed to rope Install during splicing	
Braided HMPE Jacket Woven Construction	Tug-body up to apex of eye	Highest cost Excellent durability Fixed to rope or hardware Install during splicing	
inverted hose-Rubber and polyester or nylon fiber	Mooring lines body	Low cost Fair durability Fix to hardware Install pre-splicing	
Nylon Jacket	Mooring lines eye or body	Lowest cost Least durable Fix to rope Install pre-splicing	

Table 2: Chafe options offered by Samson.

CONCLUSION

Abrasion is the most dominant factor affecting the service life of HMPE tug 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

[1] E McCorkle, R Chou, D Stenvers, Paul Smeets, Martin Vlasblom and Edwin Grootendorst. *Abrasion and Residual Strength of Fibre Tuglines*, *ITS Convention* proceedings, 2004.
[2] J Gilmore, J Miller, R Chou. *Mooring with High Modulus PolyEthylene Fibre Lines*, *OSEA Convention* proceedings, 2006.
[3] Samson Internal Report, TR-100, 2005.
[4] Cordage Institute (CI) 1500 – Standard Test Method for Fibre Ropes.