

Abrasion and Twist Effects on High-Performance Synthetic Ropes for Towing Applications

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ABSTRACT

High modulus polyethelene (HMPE) synthetic ropes have been used successfully in the towing industry for ship assist and vessel escort since the mid1990s. Samson has been tracking these ropes in applications and has reported the studies of their performance [1]. Important observations have been made that helps to understand both the short- and long-term behaviors of HMPE ropes used in tug assists in up to 4,000 jobs. Detailed determination of residual strength and laboratory analysis confirmed that abrasion is the dominating factor that effects the 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 towlines. Specifically, it will describe the importance of rope design in relation to abrasion resistance and other methods to increase service life of HMPE towlines.

INTRODUCTION

High modulus polyethylene (HMPE) fiber 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 effective – due to lower labor 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.

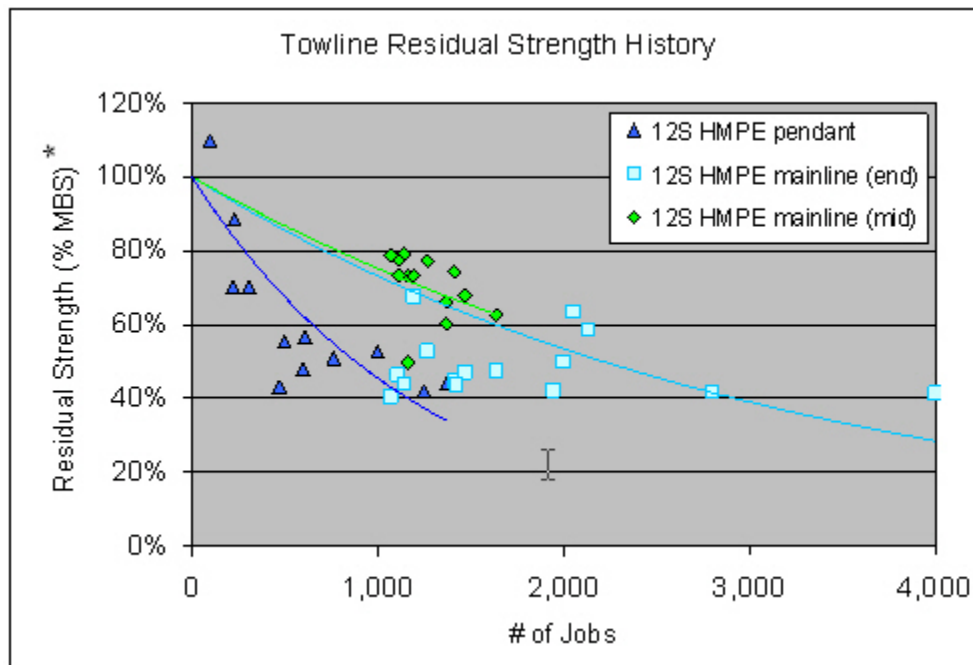


Figure 1. Residual strength history of similar sized ropes similar sizes performing similar jobs in harbor-class tractor tugs in Puget Sound and Southern California. (*MBS = minimum breaking strength.)[3]

Lab simulation and field observation concluded that the most serious threat to the integrity of a tug's towline is abrasion [1]. In the following sections, we will quantify the effect of abrasion on rope and describe general inspection guidelines for HMPE towlines. 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 towlines installed. Also, their design will have considerations of the proper deck hardware that minimize unnecessary abrasion damage (i.e., stainless-steel staples and bitts). However, often times in vessel escort or berthing, there is little or no control over the condition of the vessel's chocks and bitts. This is a major cause of damage that effects rope service life, along with other sources of abrasion. In order to extend the life of the main towline, the risk for this type of damage is often counteracted with the use of sacrificial pendants that are used to endure the majority of the damage from ship's hardware.

In order to protect from this unnecessary damage on board it is recommended that surface roughness of 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.

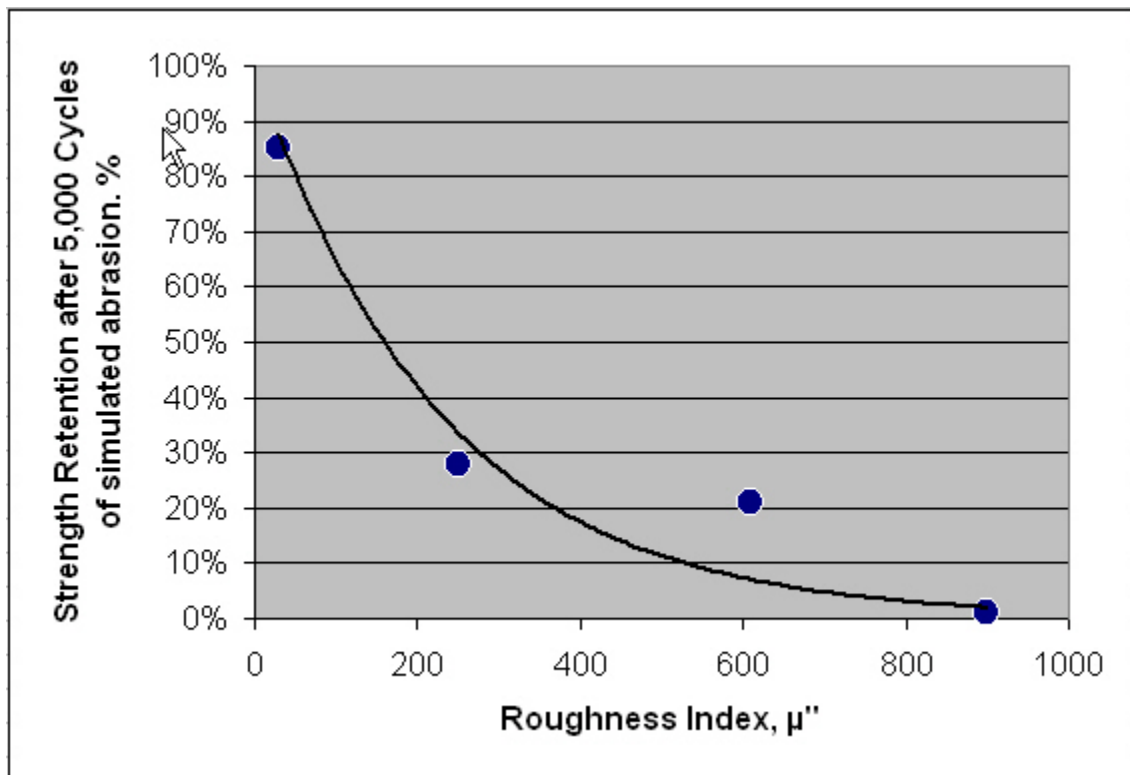


Figure 2. Surface roughness comparison. [2]

Most manufacturers provide new tugs with stainless-steel staples and bitts that 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 towline as the lead angle changes in service. Some examples are shown in Figures 3 and 4, where the roughness of the surface can damage the rope.



Figure 3. Bull-nose contact surfaces. Rough surfaces cause heavy surface abrasion. [4]

In Figure 3, small amounts of fiber can be seen on the bull nose and lead edge of the tug where rough surfaces have worn the rope's surface. Figure 4 shows a comparison of a stainless-steel-clad staple 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.



Figure 4. H-bitt comparison. [4]

GENERAL GUIDANCE FOR ROPE HANDLING AND INSPECTION

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



Figure 5. Cut strands. [4]

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 as soon as possible. Figure 5 shows an 8-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. [4]

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 effected 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.



Figure 7. Melted and fused fiber damage. [4]

With any HMPE line, melting damage is a concern. Quick slipping on hardware under high loads can generate a high amount of heat, which can cause yarns or even strands to melt and fuse together, as seen in Figure 7. The fibers/yarns have a glossy appearance and it is no longer 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 a comparison of several different rope designs, laboratory-testing programs were performed to establish baseline performance data with regard to abrasion resistance.

An important aspect of rope design that plays a critical role in the rope's abrasion resistance is the braid's 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.



Figure 8. Rope construction comparison. (A) Good firmness and abrasion resistance; (B) 10% looser braid than Sample A; and (C) a very loose braid, difficult to handle, and likely to snag. [4]

Figure 9 shows the difference in performance characteristics between the three samples tested. Using Sample A as the control sample, 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.

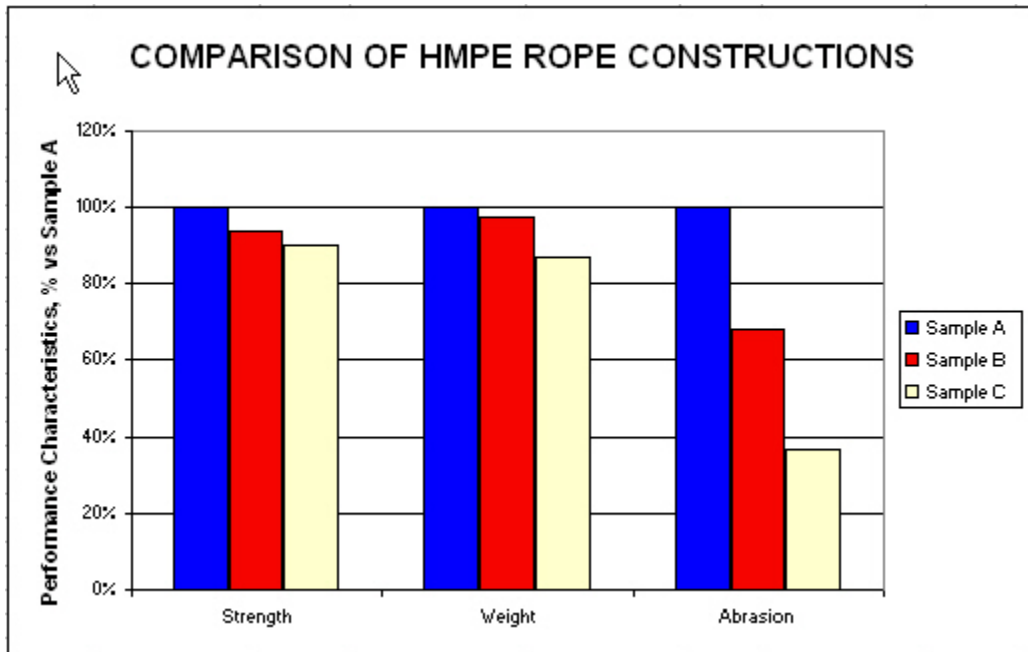


Figure 9. Construction comparison testing. [4]

IMPACT OF TWIST ON TOWLINE STRENGTH

While abrasion is the primary deterioration mechanism of towline strength, operators should have a high awareness of the negative effects twisting synthetic toelines can have on strength and therefore safety. Figure 10 shows the results of testing to represent the expected strength reduction for HMPE lines when twist is imparted.

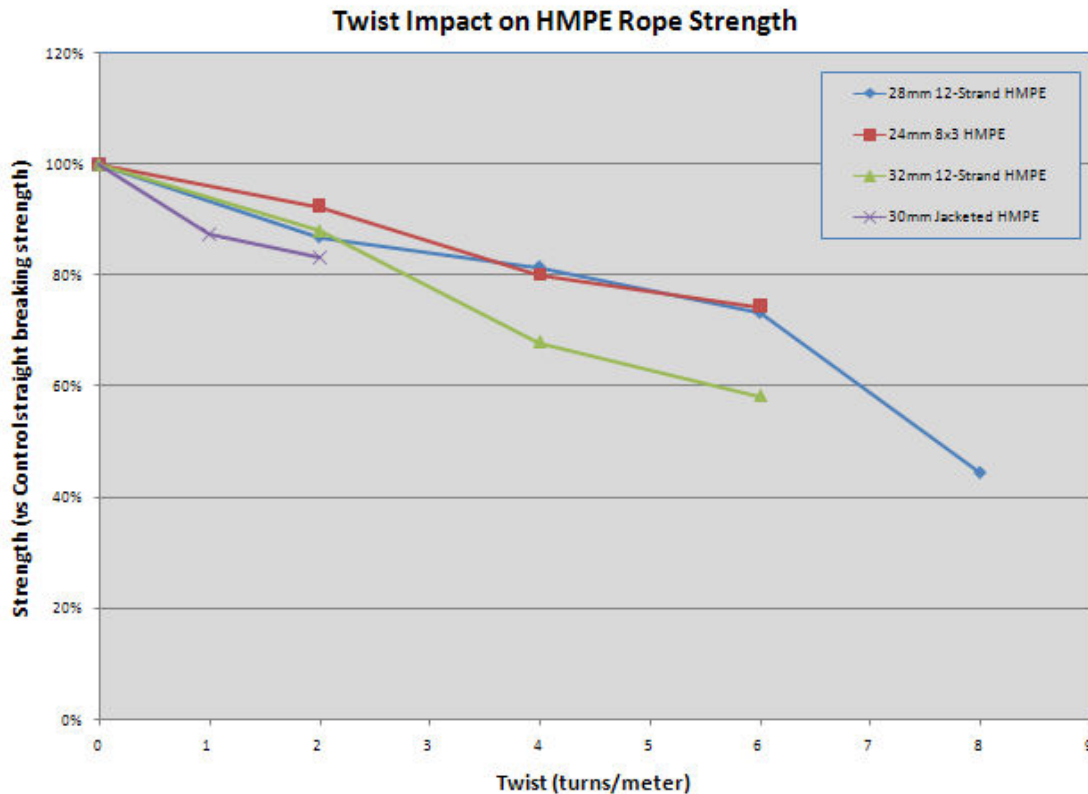


Figure 10. Twist impact on HMPE rope strength.

It should be noted that while the strength reduction is significant (10–30% for a realistic amount of twist in a typical towline) the problem is even further compounded by the always-present threat from abrasion during standard service.

PROTECTING AGAINST ABRASION

As tug operators become more and more familiar with the failure mechanisms of towlines made of HMPE fiber, it is essential to continue to improve the defense 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 next sections detail possible benefits to taking extra steps to protect towlines from abrasion damage.

EXTERNAL VS. INTERNAL ABRASION

Abrasion, being the dominant factor in decreasing strength and service life, consists of external and internal abrasion. Figures 11 and 12 show examples of external and internal abrasion, respectively.



Figure 10 Example of moderate external abrasion. [4]



Figure 11. Example of heavy internal abrasion. [4]

After just a few weeks in service the outside surface of any rope made from HMPE fiber will begin to appear rough and “fuzzy” (Figure 11). 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 where strands cross each other, much like the damage caused at positions where the line crosses the chock (Figure 12).

EXTERNAL ABRASION

Figures 13–15 represent 30-m pendants taken off two nearly identical 6,000-hp tractor tugs operating in 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 ropes made of HMPE fiber) with one exception—Tug C used 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 were observed upon inspection of these lines.

Figures 13 and 14 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 14.



Figure 12. Tug C pendant with chafe protection. This rope has moderate to heavy abrasion damage. [4]



Figure 13. Tug D pendant without chafe protection. This rope has extreme abrasion damage with cut strands. [4]

When the line from Tug D was inspected, it was evident that the surface abrasion had greatly effected 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 15, with several cut yarns throughout the lay length of the rope.



Figure 14. Tug D pendant with cut strands. [4]

INTERNAL ABRASION

Figures 16 and 17 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 10% fewer jobs than Tug D, it is very clear that the chafe protection used in the eyes of the towline on Tug C significantly reduced 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 almost new, while the unprotected strands are fuzzy and worn.



Figure 15. Tug C: Abrasion with chafe protection. [4]



Figure 16. Tug D: Abrasion without chafe protection. [4]

All the information described above is summarized by testing to determine the residual strength of the pendants to quantify their safety factor based on their residual strength. Table 1 shows the difference in average residual strength between the pendants off Tugs C and 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 of Tug C and Tug D Pendants.







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

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 that allows 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 utilize effective chafe gear in order to maximize the life of a towline 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 are listed in Table 2.

Table 2 – Chafe options. [4]

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	

PROTECTING AGAINST ABRASION WITH COATING TECHNOLOGY

Abrasion resistance of a rope can also be enhanced by coating technology that protects the rope from both internal and external abrasion. Extensive studies have been conducted to find the next generation coating technology for improved abrasion protection due to normal “wear and tear” during service.

Testing has been conducted on several harbor-class tractor-tug towlines that use optimized coating technologies for the purpose of establishing the baseline for a new residual strength model. These lines have proven to be the best performers of chafe-protection-free ropes in terms of abrasion resistance. Figure 18 shows this updated model, which demonstrates that an improvement of approximately 15% in the towline’s residual strength can be expected for these pendants being used with no additional forms of chafe protection.



Figure 18. Residual Strength Comparison (coating development).

Further qualification and verification of this model is ongoing, and updates of these efforts will be forthcoming.

CONCLUSION

Abrasion is the most dominant factor effecting 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. Using proper rope design
3. Selecting the right product
4. Using chafe protection and/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 towlines can help achieve significant service life.

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