Synthetic Rope Properties and End Connector Concepts For Use in Timber Harvesting Applications

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ABSTRACT

Steel wire rope is the accepted standard in logging because it is strong, durable, stiff, and dependable. However, steel wire rope has disadvantages: its strength to weight ratio is low; it is difficult and time-consuming to splice; and used wire ropes develop jaggers. UHMW-PE (ultra-high molecular weight polyethylene) braided rope has potential to replace steel wire rope. It has been appreciated in the offshore mooring and shipping industries for years. Characteristics such as a specific gravity less than one (it floats!), high flexibility, low stretch, and ease of splicing make the synthetic rope useful. UHMW-PE rope has a higher breaking strength to weight ratio than steel wire rope by a factor of 10 for breaking strengths compared diameter by diameter for steel wire rope.

Research is underway to incorporate UHMW-PE rope into timber harvesting systems. One such application is the use of eye splices, which can achieve the catalogue breaking strengths of the rope. However, other typical steel end connectors are not suitable for synthetic rope due to the properties of the material. Solutions were developed to incorporate end connections for static guylines, running lines and truck wrappers.

This paper outlines the unique physical, mechanical, and thermal properties of UHMW-PE fibers and 12-strand braided rope for use in logging applications. Additionally, it describes new end connection concepts being investigated for use with synthetic rope as well as performance in laboratory tests. Information in this paper is derived from current research of the Synthetic Rope Project at Oregon State University funded by Oregon's Occupational Safety and Health Administration.

INTRODUCTION

Currently, wire rope is used universally in timber harvesting for skylines, guylines, winchlines, support lines, truck wrappers, chokers, and running lines. It has advanced cable logging and it is employed around the world in millions of miles annually. However, wire rope is heavy, corrodes, and is difficult and time-consuming to splice. Additionally, used wire ropes develop jaggers that puncture the hands of woodsworkers.

The opportunity exists to replace steel wire rope with ultra-high molecular weight polyethylene (UHMW-PE). The braided rope has the strength of steel, lower weight, low stretch, and high flexibility. UHMW-PE rope has a higher breaking strength to weight ratio than steel wire rope by a factor of ten for breaking strengths when compared diameter by diameter for steel wire rope. Synthetic rope does not kink, corrode, or absorb chemicals and water. It is the same material commonly used for oil and fuel containers. Figure 1 compares breaking strengths for corresponding rope weights for synthetic rope, EIPS wire rope, and swaged wire rope. UHMW-PE braided rope has proven itself in the offshore drilling, mooring, tugline, and powerline industries. The US Navy (Flory et al., 1992) and Canadian Coastguard (Fisheries and Oceans

Canada and the Canadian Coast Guard Search and Rescue, 2000) have approved it for use within their maritime operations and deep-sea salvage.

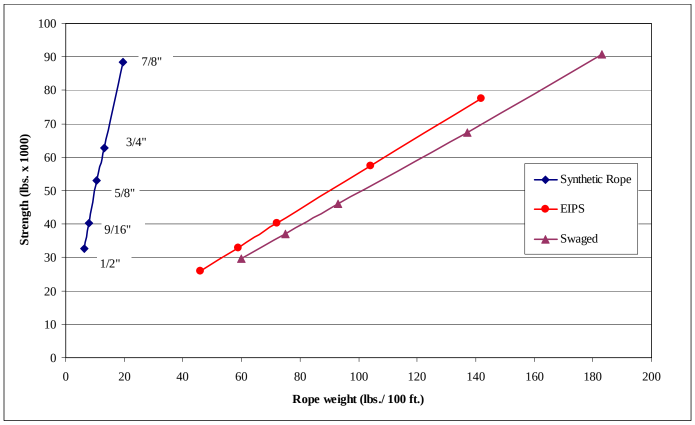

Figure 1. Breaking strength vs. rope weight

One of the major difficulties with synthetic rope is adapting it to current end connections for use with harvesting systems. Because of the low coefficient of friction, standard wire rope clamps, fist grips, etc. that would yield 90%+ breaking strength with steel wire rope, only yield 50-60% breaking strength with synthetic rope (Garland et al., 2002). Synthetic rope has a much lower critical temperature compared to steel rope and is intolerant of heated connections. Finally, the low coefficient of friction makes pressed connections difficult. Essentially, the rope's physical, chemical, and mechanical properties that make it an excellent substitute for wire rope in timber harvesting also make it difficult to couple with existing cable systems.

Although some steel wire rope end connections are not suitable in their traditional form, the concepts may be modified for synthetic rope. Wire rope clamps and pressed nubbins are two examples of adapted technology. Splicing an eye is one of the most common end connectors for wire rope. However, splicing steel wire rope is tiring, cumbersome work. Synthetic rope manufacturers have developed quick splicing techniques that yield nearly 100% of the rope's ultimate breaking strength. For this project, new end connections were developed to meet requirements unfulfilled by splices or modified wire rope hardware.

The OSU research was the first extensive study on end connections specifically designed for synthetic rope. The objective was to determine suitable end connections and terminations for use with synthetic rope (Hartter, 2004). This study assesses the strength of the synthetic rope end connections under cycled loading at ambient temperature. Without proper end connections and terminations, synthetic rope's advantages over steel wire rope cannot be fully appreciated in the woods.

METHODS

The pilot study determined which concepts are suitable for use in timber harvesting. The study design required rope samples of the diameter classes common to many logging applications: 3/8", 9/16", and 5/8" diameters were tested. However, only the 9/16" and 5/8" Amsteel®-Blue[1] diameter classes will be discussed in this paper.

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[1] Amsteel®-Blue is a product of Samson Rope Technologies, Ferndale, WA. Mention of trade names does not constitute an endorsement by Oregon State University.

The rope manufacturer identifies the buried eye splice (BES) as retaining the highest breaking strength when the rope is modified. It is a simple splice to construct and is used in all diameter classes, but specifically for the 9/16”, and 5/8” nominal diameters. Figure 2 shows a diagram of a rope segment with buried eye splices.

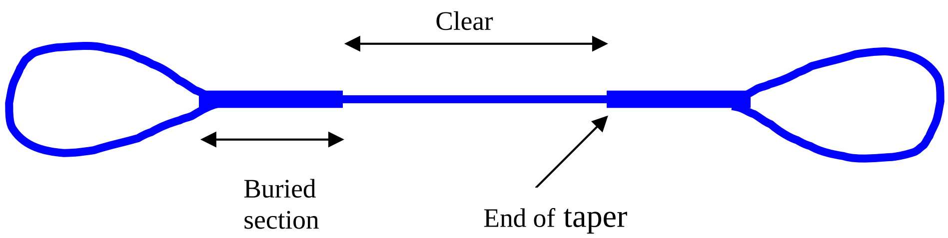

Figure 2. Diagram of buried eye splice

In this project, the buried eye splice was the control treatment, or benchmark to compare all end connector concepts and represents the ultimate breaking strength of the rope. Each of the additional splices shown in Figure 3 utilizes unique splicing configurations developed by the rope manufacturer. The splice is a concept similar to the common children’s finger puzzle where the harder the pull, the tighter the device grips the fingers (Pilkerton et al., 2001). Similarly, as tension is applied to the rope segment, the rope constricts on the buried length of the rope to lock it into position.

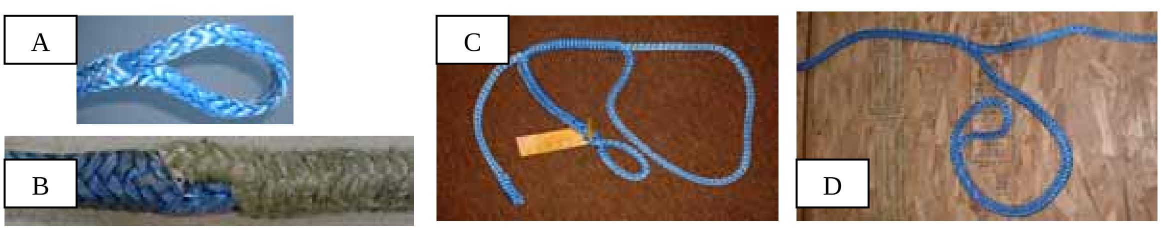

Figure 3. Spiced end connections: A) Buried eye splice B) Long splice C) Whoopie Sling D) Y-splice

The following end connections were evaluated: buried eye splice, long splice, Whoopie Sling, Y-splice, pinned nubbin, knuckle link, and pressed nubbin. Figure 3 shows these spliced end connections. The knuckle link and pinned nubbin were designed by the researcher and fabricated specifically for this pilot study. The pressed nubbin was a straightforward adaptation of steel end termination techniques. Figure 4 shows these hardware connections.

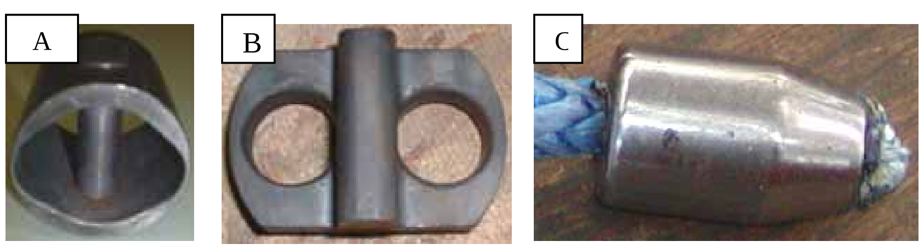

Figure 4. End connections with hardware: A) Pinned nubbin B) Knuckle link C) Pressed nubbin

All test specimens were prepared in accordance with Cordage Institute Standards CI 1500-99 §6 (Cordage Institute, 1999) and tested with the synthetic rope manufacturer’s Test Methods for Fiber Rope (SRT Test

Method-001-02) in the Knudsen Structural Laboratory in Richardson Hall at Oregon State University. The procedure was standardized for all end connector tests to reduce variability.

RESULTS TO DATE

As expected, the buried eye splice had the highest breaking strength of the rope splices (see Figures 5 and 6). The buried eye splice averaged 50,187 pounds and 94% of the catalogue minimum value (CMV) in the 5/8" diameter and 39,377 pounds and 96% of the CMV in the 9/16" diameter (see Figures 3 and 4). The long splice is used to join two pieces of new or used synthetic rope together by burying tapered sections in each segment. The long splice was the next strongest splice connection at 47,354 pounds and 89% of the CMV for the 9/16" diameter and 38,314 pounds and 95% of the CMV for the 5/8" diameter.

The Whoopie Sling is an adjustable strap with an eye at both ends designed for static line applications such as guylines and intermediate support lines. It had mean breaking strengths of 85-86% of the CMV for the 9/16" and 5/8" diameters. Test samples were consistent for breaking strengths and exhibited a single failure mode. The Whoopie Sling broke at the exit point of the adjustable tail with the butt splice.

The Y-splice was developed as another solution to adjusting rope lengths to meet various job conditions. A Y-splice is a separate section of rope with an eye splice that can be inserted at any point on the main rope segment to change the length to fit particular requirements. For the 5/8" diameter, the Y-splice had a mean breaking strength of 36,438 pounds and 69% of the CMV. The 9/16" Y-splice performed more consistently than the 5/8" rope samples with and average breaking strength of 35,956 pounds, 89% of CMV. The issue with the Y-splice is its performance and consistency. The rope must be slowly and carefully loaded, so the main section of the rope can constrict and hold the Y-splice section. Without this practice, the Y-splice segment can simply pull out of the main section.

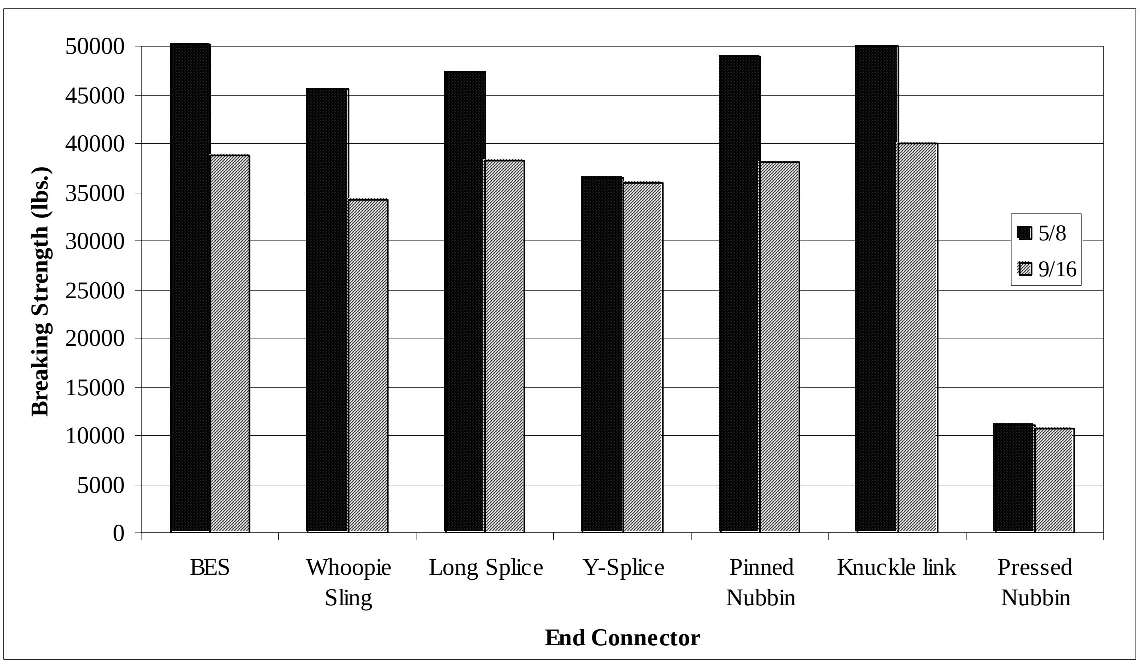

Figure 5. Mean end connection breaking strength

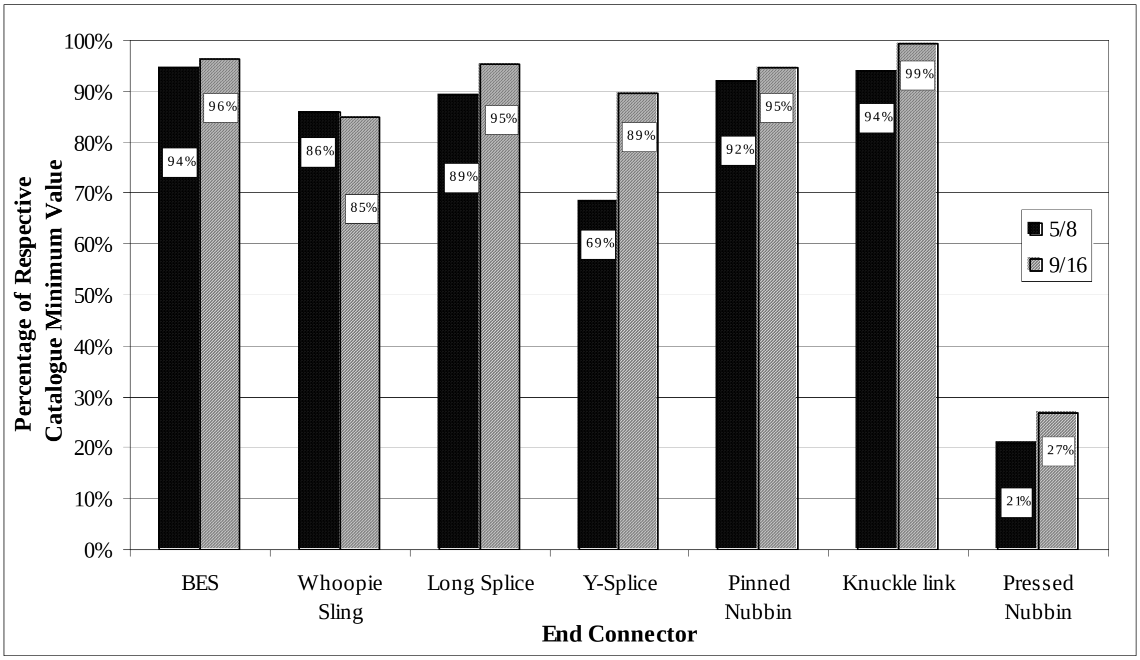

Figure 6. Mean breaking strength as a percent of catalogue minimum value (CMV).

In addition to the four spliced end connections, three end connections with hardware were tested. The knuckle link had the highest breaking strength in the 9/16" diameter class at 39,944 pounds and 99% of the CMV. The pinned nubbin had a mean breaking strength of 48,868 pounds for the 5/8" diameter and 38,067 pounds for the 9/16" diameter, representing 92% and 95% of the CMV respectively. Both the pinned nubbin and knuckle link concepts performed consistently with low variability in breaking among the samples.

The knuckle link and pinned nubbin were designed to attach to the synthetic rope using an eye splice and for use with static and running line applications. For the knuckle link, as the rope is spliced, it is first passed up through one hole, over the bar, and passed back down through the other hole. When the rope is pulled, the strands of the rope are highly stressed, and the top of the eye becomes one of the common failure modes. The second failure mode common to the knuckle link and pinned nubbin is at the end of the splice taper.

Finally, the pressed nubbin concept was derived directly from steel wire rope applications where a hydraulic press compresses the steel nubbin onto the wire rope. A similar procedure was used to compress the steel nubbin on to the synthetic rope. The pressed nubbin for both diameter classes performed consistently to within a 5% standard deviation. Although consistent and a potentially useful end connection for use with breakaway drum connections, it only achieved 21% (11,066 pounds) and 27% (10,724 pounds) of the CMV for the 5/8" and 9/16" diameters respectively.

DISCUSSION

Six of the seven end connections show promise for use with timber harvesting systems. Other end connection concepts were developed and tested, but none consistently achieved more than 60% for both diameter classes. Other concepts tested were wire rope clamps and nubbins with adhesives. The adhesives were weak and inconsistent in breaking strengths. The wire rope clamps provided 57% of the CMV for the 9/16" and 65% of the CMV for the 5/8" diameters and merit further investigation.

This study developed and tested different end connection and termination concepts suitable for timber harvesting. Not all end connection concepts tested achieved acceptable breaking strengths. Instead, the variability among end connections was substantial. Sometimes, the end connection that has the highest breaking strength may not be the most suitable for an operation. The pressed nubbin may be an option to attach the synthetic rope to tractor winch drums. For example, if a load suddenly began to roll over a cliff, the end connection on the drum should break before the skidder is upset.

Further research and development needs to be conducted on end connector concepts. This research has identified some suitable end connections for synthetic rope. Not all forest operations require maximum breaking strength for certain rope applications. End connections have been tested that break at lower strengths, but can be used in such systems when their breaking strengths are known and considered. Some end connectors attain nearly 100% breaking strength of synthetic rope.

End connections and termination concepts from this pilot study have been developed through controlled laboratory testing and engineering analysis. Materials selected and fabricated for the hardware are not only essential to the strength of the end connection, but also to the safety of the workers. Furthermore, when fabricating hardware, one should know the material properties and the effects of welding and heat-treating. It is not advisable to simply use any material available, weld a bolt on, and put it into use in the field. Such actions jeopardize the safety of the entire crew. The rope manufacturer's splicing directions should be carefully implemented. In all cases, the appropriate safety rules should be followed.

FUTURE RESEARCH

Although this particular study is concluded, it is just the beginning for formalized end connection and termination research for synthetic rope. This project was a pilot study and has identified seven end connectors for future research and testing with larger sample sizes. End connections could be adapted and tested on more rope diameters. Although 3/8", 9/16", and 5/8" diameters are commonly used rope sizes, larger diameters up to 1 ½" could be tested. Another concept of interest is a synthetic rope choker design. Synthetic chokers will not only decrease weight, but more importantly, they will reduce the safety hazards and hardships of carrying them into the brush. Research could also investigate the operational performance of synthetic rope with other lightweight materials, such as UHMW-PE or nylon sheaves. Finally, the end connectors should be subjected to various environmental conditions.

CONCLUSION

Synthetic rope has many advantages that make it attractive to logging, specifically in static line and running line applications. Each application is governed by operating regulations, material and strength requirements. For current logging uses, it may be important that synthetic rope performance be held to similar standards as for steel wire rope. As with steel wire rope, the synthetic rope is only as strong as its end connection. It is therefore essential that suitable end connections be developed and tested.

This project was one of the first studies on end connections specifically designed for synthetic rope. New end connections were developed and steel wire rope connections were modified to meet the strength and usability criteria for timber harvesting operations. Future research should modify or refine the designs and test larger sample sizes.

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