# SYNTHETIC ROPE TO REPLACE WIRE ROPE IN MOUNTAIN LOGGING OPERATIONS

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**Abstract:** *Describes research at the Forest Engineering Department of Oregon State University on synthetic rope to replace wire rope in mountain logging operations. The synthetic rope studied is made from ultra high molecular weight polyethylene (UHMWPE) and compares to steel in strength at the same diameter but weighs about one-ninth as much. Other synthetic rope characteristics are described. Ergonomic potentials for the logging workforce from using lighter ropes are discussed. Trials of synthetic rope in static lines, tractor winch lines, running lines, truck load securement lines, and other applications are outlined. Authors cite needed developments for end connectors, wear and replacement criteria, and carriage applications. Future potentials of synthetic rope for skylines, rigging lines and other running lines are briefly noted. References cite prior work by OSU and others.*

## 1. Introduction and Problem Statement

Since 1999, the OSU Forest Engineering Department has been studying synthetic rope to replace wire rope in logging with grants from the Worksite Redesign Program of the Oregon Occupational Safety and Health Administration. Three grants looked at the potential of synthetic rope, the end connectors and running lines, and trials of the rope usage by industry cooperators. Steel wire rope is the standard for cable and winch applications in logging and is used around the world in large quantities. However, while it is durable and has well-known properties, it is stiff and heavy to use and develops “jaggers” (broken wires that puncture workers) over time. Using heavy wire rope contributes to the high workloads in logging as measured by heart rates.

Concerns for reducing workloads in logging also come from the fact that the workforce is aging and young new recruits to the sector are not numerous. Fatigue is also implicated in Oregon accident statistics especially the most common injury of slips and falls. Truck drivers also suffer injuries similar to those of major league baseball pitchers from repeatedly throwing steel wrappers over loads on log trucks. The State Accident Insurance Fund (SAIF) found thirty six trucker injuries to cost over $267,718 USD and averaged 25 days lost per claim for one region over two years (SAIF, 2003).

Synthetic rope may also offer efficiency gains in ground-skidding operations, line pulling from cable carriages, cable rigging operations, use as a skyline or skyline extension, and other applications. Our research shows promise for synthetic rope but more research and development are needed.

## 2. Synthetic Rope as Potential Solutions

As a matter of policy, Oregon State University does not endorse any product to the exclusion of other suitable products; thus, mention of trade names is for information only. We selected one type of synthetic rope we thought would work in logging and conducted our trials with Amsteel Blue, an ultra high molecular weight polyethylene (UHMWPE) Dyneema fiber rope produced by Samson Rope Technologies of Ferndale, Washington, USA (www.samsonrope.com). Several of the rope's material properties are appealing for use in logging. The twelve strand braided rope is approximately as strong as steel at the same diameters commonly used in logging but weighs only about one-ninth as much. Figure 1. shows these comparisons for strength to some steel wire ropes.

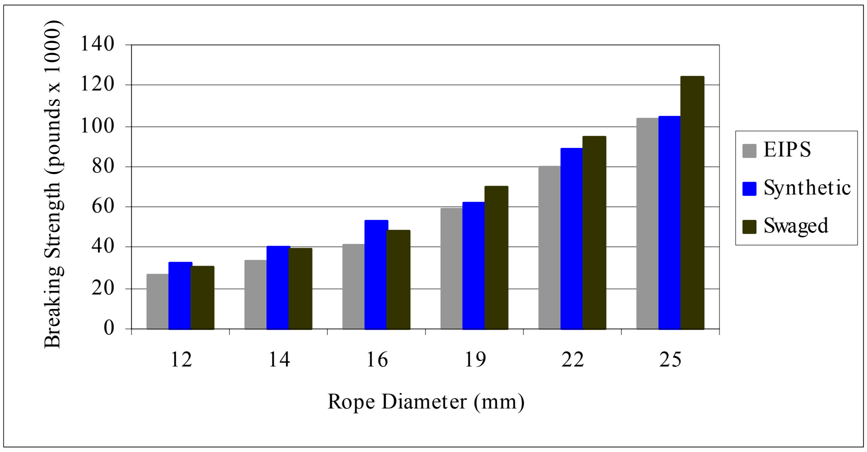


**Figure 1: Comparison of rope breaking strengths by diameter in pounds**

Amsteel Blue has little stretch or stored energy compared to other synthetic rope materials like nylon or polypropylene and is comparable to steel (about 2.5 times steel at 30% of breaking strength). The rope is not affected by many chemicals and the same material is commonly used for oil/gas containers in logging. A special coating protects the rope from the sun's ultraviolet light degradation. The rope has a low coefficient of friction, is resistant to abrasion, and most importantly, does not produce jaggers (the broken wires of steel rope that produce painful puncture wounds). Amsteel Blue has been used in marine towing and anchoring applications as further demonstration of its industrial suitability.

A property of concern is that the rope can be cut with sharp objects, especially chainsaws. In fact, scissors or knives are used to cut the rope for splicing. Plus, the rope cannot withstand high temperatures with its relatively low melting point compared to steel. Cost of the rope in quantities currently produced run two to four times that of steel wire rope, depending on the source and quality of the comparison steel wire rope. Data and experience on wear for logging applications are now being collected for understanding rope life in the non-expendable applications. While splicing of synthetic rope is remarkably easier than steel rope, especially for eye splices, other end-connectors have not been fully developed for connecting to steel rope or logging machinery as yet.

## 3. Ergonomic Potentials

### 3.1 Heart rate measures

Our first research project documented some of the ergonomic potentials of synthetic rope over wire rope in logging. We used heart rates and subjective measures to assess the differences between steel and synthetic rope in some common logging tasks such as pulling, carrying, and rigging trees.

The Student Logging Crew of the Forest Engineering Department used both steel and wire rope for specific tasks and with line pulling from a skidder winch in designed experiments on various slopes and terrain conditions. Differences were significant for heart rates among both male and female workers in most tasks. With the task of climbing and rigging tail or intermediate support trees, heart rates reached near maximum levels once the workers were about three meters off the ground and rope differences were masked although subjective measures showed synthetic rope much preferred over steel.

Figure 2. shows a typical heart rate trace for a worker using steel or synthetic rope in a task of carrying either a fifty kilogram steel strap or an eight kilogram synthetic strap down and up a twenty-five percent slope. Task duration is reduced and the heart rate trace for synthetic rope is typically lower and recovery after the task is shortened. While worker fitness is important for recovery, we think that faster recoveries with synthetic rope indicate less demanding tasks involved. Our research further documented the high workloads in logging as measured by the time heart rates are highly elevated. Direct fatigue measures were not possible but subjective responses indicate easier workloads with synthetic rope.

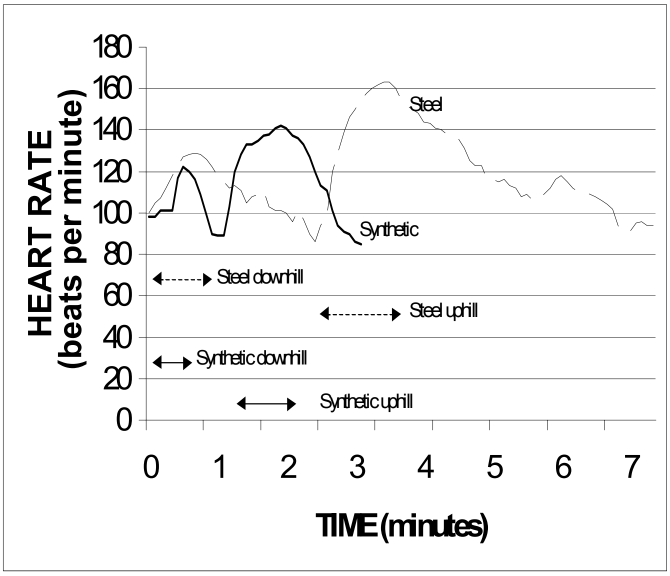


**Figure 2: Heart rate trace of male subject on 25% slope carrying steel and synthetic rope**

**3.2 Wrappers**

Until January 1, 2004 four steel wire rope wrappers are required to secure loads on the 4,300 log trucks transporting Oregon's timber harvest to the mills. Steel wire rope wrappers weigh 5-6 kilograms and many drivers suffer rotator cuff, shoulder or elbow injuries over time. We are investigating replacing steel wrappers with synthetic wrappers where the driver would only throw a kilogram or so over the load rather than the heavier steel wrappers. Part of our research involved providing the basis for changing safety codes of the Occupational Safety and Health Administration (OR-OSHA) in Oregon to allow synthetic rope to be used in logging applications (OR-OSHA, 2003).

## 4. Needed Developments

### 4.1 Trials in logging

Our initial evaluations of the synthetic rope identified several developments needed before such a rope could be highly useful to loggers. First, there are a number of applications that merited trials beyond what the OSU Student Logging Crew could accomplish with its mix of equipment and operations. Thus, it made sense to recruit industry cooperators in our research to try the synthetic rope in ways they might find useful. Their expansive trials would contribute to our efforts to see how the rope could both be used and abused. We monitored their rope use and when failures occurred, we learned how and why.

We supplied our cooperators with synthetic rope and replaced or repaired the rope when problems occurred. Most loggers were skeptical that such light rope would have the needed strength to do what the steel rope we replaced had done. In one case, the machine operator tried to pull the rope to failure and ended up breaking a steel choker and nearly pulling over a tree. In another case, the logging crew pulled a 35 cm diameter stump out of the ground trying to break the synthetic rope strap. In both cases, the synthetic rope performed well and made believers about its strength. Our cooperating loggers basically treated the rope like it was the same as the steel wire rope it replaced. Along with some abuse, we expected loggers to come up with both innovations and problems with using synthetic rope.

### 4.2 End connectors

Our pleasant surprise at the ease of splicing synthetic rope for use with eyes and shackles gave us at least one end termination commonly used by loggers. The buried eye splice (BES) is also the end connector used to test the ultimate strength of the synthetic rope itself. Thus, for a BES, no further strength reductions are needed, unlike wire rope where the eye splice can reduce rope strength by 5-15% depending on the splice. However, we needed end terminations to connect with drums on winches, wire rope itself, and to pass through carriages to load hooks. For many applications, it would be helpful if the rope would terminate in a nubbin (steel knob) or attach to itself to provide the appropriate line length (as in the case of cable clamps used with steel wire rope). The traditional use of knots in Amsteel Blue was quickly found to be unsuitable as the slipperiness of the rope made the knots unusable with any significant tension. One of our research objectives was to locate, invent/devise and test end connectors that could be used in logging applications.

### 4.3 Wear and damage

Industry is extremely interested in the wear of synthetic rope with its increased cost. The rope manufacturer offers some indicators for rope replacement but these were not developed from logging applications. We did laboratory tests by cutting the strands of the 12-strand rope and measuring the residual strength. With one strand cut, residual strength was 92%. Two strands cut yielded at 81% while three strands dropped to 60+%. For two cut strands, the loss was proportional to the number of strands lost which is much better than wire rope replacement criteria. Abrasion occurs with synthetic rope but residual strength declines are proportional to material lost as opposed to broken wires in steel wire rope. With synthetic rope, there is no rust or weather deterioration if protected from ultraviolet light. Rope users will need to distinguish between expendable ropes (chokers, winch line end sections, etc.) and those longer term uses (guylines, straps, etc.) as they compare wire rope and synthetic rope applications. We are testing synthetic ropes with known uses for their residual strengths. Direct tests on log truck wrappers comparing synthetic to steel at known uses are underway.

## 5. Industry Trials

Efforts to place synthetic rope in the hands of loggers for evaluation provided trials as follows:

- Static line applications such as tree and ground straps, guylines for yarders and trees, and intermediate support lines (11 firms)
- Winching applications for crawlers, skidders, and dropline carriages ( 6 firms)
- Wrappers used on Oregon and Washington log trucks (5 firms/locations)

While these trials were not designed studies, we attempted to gain some detailed time studies of the operations for short durations to assess statistical relationships and provide guidance for future designed studies. Leonard (2003) has summarized results from the static line and winching applications in greater detail in his Master's degree paper. Pilkerton, et al (2003) also provides results from the trials. Wrapper trials are still underway but some observations are useful. It is even more significant to note that loggers are choosing synthetic rope on their own for some trials based on our research (Crouse, 2002).

### 5.1 Static line applications

Static line uses for synthetic rope are highly successful in our estimation. Loggers who found the synthetic straps effective were more likely to try other uses and were able to use less labor to rig trees because of the weight reduction (Leonard, 2003). Even without more advanced line shortening devices, loggers were able to tighten and connect guylines effectively with the BES and a shackle. Guylines for yarders as back and snap guys were used and found to be helpful. One logger was able to rig an intermediate support tree entirely by himself (steel lines usually took two people) and used a rock climbing technique to lower himself from the tree rather than climbing down as usual.

The ergonomic benefits were apparent when loggers would be willing to pay twice (63%), three times (13%) or five times (13%) for the ergonomic benefits. Only one logger would not pay more for synthetic rope (Leonard, 2003). Other useful operating techniques were developed by industry cooperators as they experimented with the synthetic rope as static lines.

### 5.2 Winch lines

The steel winch line on a crawler or skidder is considered expendable during use as it becomes worn, corkscrews, breaks, or develops jaggers. When synthetic rope is used exactly like a steel winch line, problems developed that provided useful information. Synthetic winch line can be cut from sharp edges on the machine, damaged from running the winch line and steel chokers onto the drum, and broken from hard pulls over rimrock. When the appropriate end connectors to the chokers are used (ring/pear and toggles) and operating techniques are adjusted for the rope, synthetic rope provides both ergonomic benefits and efficiency gains to the machine operator setting chokers. Typically hook times are reduced, less time is spent maneuvering the machine, and longer winch distances are employed. In fact, one operator reported that a long downhill then uphill winch pull took five people for his prior one inch bull line where he alone could do the same with his current synthetic line.

While synthetic line will dive into the drum during pulls over loosely wound line, operators can pull the line out by hand unlike bound steel winch lines. When steel winch line is damaged it is shortened or replaced, synthetic lines can be spliced or easily up-ended to resolve problems. Environmental benefits of wider skid trail spacing are apparent and operators reported feeling fresher at days end when using synthetic versus steel winch lines. Efficiency gains for winching make it possible to pay off the extra winch line cost within a month of skidding (Garland, et al, 2001).

### 5.3 Dropline carriage

Our trial with a Boman motorized dropline carriage showed more problems than potentials for the operating circumstances we encountered. Poor deflection and rigging practices produced cut winch lines on sharp edges we did not foresee. Also, the powered spooling mechanism would backspool if the choker setter did not keep tension on the line as it spooled out. Plus, if logs are just under the skyline, the advantages of pulling the dropline to the side or uphill with synthetic line is not apparent to the chokersetters. The logging contractor would like to try the synthetic rope again on the carriage after our series of problems were diagnosed. We believe a designed study could really show differences between synthetic and steel droplines on carriages.

### 5.4 Wrapper trials

Initial wrapper trials in Oregon required drivers to throw an additional synthetic wrapper because the law required steel wrappers. However, both a male and female driver appreciated the potentials of the synthetic wrappers sufficiently for us to undertake expanded trials in Washington State where synthetic wrappers are legal. Wrappers in Oregon must now meet a strength requirement for the chain and rope of "15,000 pounds" ultimate strength which can be met by either steel or Amsteel Blue rope of 9.5 millimeters. Steel wrappers tend to bite into the logs and perhaps remain tighter as loads shift; however, the synthetic wrappers perform well and have caused drivers to remark how easy they are to throw over the load. The Oregon Department of Transportation provided a variance for a driver who had been injured earlier to use synthetic wrappers in our trial. One Washington driver who had chronic shoulder/arm pain with steel wrappers found it disappeared when he began using synthetic wrappers. We did have one wrapper cut by a chainsaw used to trim an overhanging limb from the load (a chainsaw practice not recommended). Wear of comparable steel wrappers is being measured in residual strength trials now underway. Synthetic wrappers may be the fastest application to gain acceptance if trials continue to be successful.

## 6. University Trials

Resources of the University labs and Student Logging Crew were directed at two field trials and numerous break tests. The field trials included using winch line on a John Deere 540 skidder over several summer logging seasons. We had a designed project to measure effects of using synthetic or steel winch lines plus some continuing trials to this date. Results parallel those above. We also are continuing a trial with a 9.5 mm synthetic mainline on a Koller K-300 yarder equipped with a Koller SK 2.5 carriage. These results are promising although with such light lines, ergonomic gains are not apparent for just the mainline replacement. The Student Logging Crew also uses synthetic rope for straps, guylines, intermediate support lines, and a snap guyline. We will soon try a synthetic rope skyline on this operation.

### 6.1 Rope properties

Much of our research at the University has been to understand the properties of the synthetic rope by testing and comparing to steel or the manufacturer's specifications. Several of these findings are listed below:

- Manufacturer's listed strengths may depend on testing procedures, splicing methods, or product quality variations. We did not achieve tabular strengths in many of our trials but the rope still is sufficiently strong for logging applications.

- Splicing is remarkably easy and various splices may only require a knife and 5-10 minutes for new synthetic rope. Some splicing of used rope will require more difficult and time consuming techniques.
- Failures most often occur at the end of the buried rope section in the eye splice and frequently one strand is left more or less intact and the rope breaks and compresses along that strand. Energy at break point is dissipated as heat and along the rope section without torsion induced flailing. One or more strands may fail before the rope ultimately breaks violently.
- The D/d ratio of pin/sheave diameter to rope diameter is much lower than with steel and we did not find breaks in the eye around the pin in our testing
- Rope soaked overnight did not absorb water and broke similarly to the dry rope.
- Knots of various types did not perform well with Amsteel Blue and either pulled out or broke when sharp bends were tightened on the rope itself. We have one more special knot to test.
- Manufacturers warn against using compression fittings on the rope but we achieved around 60% of ultimate strength when we tried common cable clamps. We did not assess damage to the rope from lower/repeated clamping however. We may try some clamping designs in the future.
- Our trials were limited to rope sizes commonly used: 9.5, 14, 16, & 22 millimeter ropes. Synthetic rope nominal diameters are measured differently and are not as precise as steel wire rope diameter measurements.

### 6.2 End connectors

Another line of research is centered around finding end connectors for synthetic rope. A series of designed trials are now underway and will be fully reported in Hartter's thesis. We have tested a variety of end connectors and believe new designs and new materials will be needed to efficiently connect synthetic rope to machines and steel wire rope. Connections to synthetic rope to shorten the line were also tested. Table 1. below indicates the concept tested and its use.

**Table 1: Synthetic rope connections tested**

| Connection | Use |
|---|---|
| Buried Eye Splice | End connector with shackle and basis for ultimate strength test of the rope |
| Long Splice | Connecting two synthetic rope sections |
| Cable Clamps (Crosby clamps) | Connecting two synthetic rope sections & to end connect rope to itself |
| Compression nubbin on synthetic rope | Nubbin attachment to allow end connections to machines or steel rope |
| OSU Patentable Pinned Nubbin Design | Nubbin attachment to allow end connections to machines or steel rope |
| SEFAC (proprietary, rope end connector) | Connections to steel or machinery |
| "Whoopie Sling" | Variable line length connection to synthetic |
| "Y Splice" | Infinitely variable line length connection to synthetic |
| Steel nubbins with poured epoxy | Nubbin attachment to allow end connections to machines or steel rope |
| UHMWPE nubbins with epoxy | Nubbin attachment to allow end connections to machines or steel rope |
| Special knot for Amsteel Blue | Connecting two synthetic rope sections & to end connect rope to itself |

Our preliminary findings show some connections achieve approximately 90%, 80% and around 60% of the rope's reported strength which allows for differential ratings for the connections depending on applications. Our OSU Design has potential and we are looking at patenting the design for a nubbin connection. We are both surprised and disappointed at some connections that we thought had promise but failed at low levels. We are confident that connections can be developed for synthetic rope but more trials and field applications are needed.

### 6. 3 New materials

Another research area is in the use of UHMWPE materials themselves to replace steel in logging applications such as rigging and sheaves. We will try some of these materials but further research designs are needed to make some applications for logging. Our efforts have been minimal considering the potentials of the types of ropes and end connectors that can be conceived and evaluated.

## 7. Future Potentials

The OSU Synthetic Rope Research Team is looking to the future for research support for a variety of projects that will enhance the adoption of synthetic rope in logging. The actual list of potential projects could be quite long but those below are indicative of needs.

- Use of synthetic rope in cable rigging applications, eg rigging lines, layout lines, etc.
- Further development of end connectors and connections to machinery
- Synthetic rope skylines and skyline analysis programs incorporating synthetic rope
- Chokers of synthetic rope forms
- Skyline extensions to steel skylines and carriages
- Carriage designs to accommodate synthetic rope clamping and spooling properties
- Replacing steel sheaves and rigging with UHMWPE materials to further lighten rigging
- Designed trials for skidders and crawlers to measure environmental benefits
- Testing of specialty rope designs for specific logging applications
- Use of synthetic rope in "Tong Tossing" by "Yoaders" (hydraulic excavators equipped with winches and capable of yarding, loading, and shove logging)
- Combining synthetic rope with traction carriages for cable logging

Certainly other opportunities will present themselves as users find new applications for synthetic rope in logging.

## 8. Summary

It is difficult not to become excited over the prospects of synthetic rope in logging from our four years of trials. Logging is known to be difficult, dirty and dangerous but synthetic rope offers one approach to reduce workloads in logging and bring additional high technology to an important industry sector. We look forward to future research and development with loggers and synthetic rope.

## 9. Acknowledgements

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