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Synthetic Rope for Use in Cable Logging: A Review of the Literature

Summary

The logging industry makes extensive use of steel wire rope in harvesting operations. As an alternative, high performance synthetic ropes such as those made from high modulus polyethylene (HMPE) may be an excellent replacement for wire rope in various logging applications.

Given the major advances in fibre technology over the last 30 years, a review of alternatives to wire rope in logging applications is important. Synthetic ropes have the equivalent strength of the same diameter wire rope but only one-seventh of the weight of wire rope.

In this review, several papers discuss the overall benefits and potential of synthetic ropes to the logging industry in terms of workload, safety and productivity improvements. High strength, light weight synthetic ropes have the potential to dramatically improve ease of handling, reduce set-up times and increase efficiency without compromising strength.

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Introduction

Overview of Fibres for Rope Applications

There are several commercially available fibres and wire in use in rope applications (McKenna *et al.*, 2004; Hearle, 2001):

- **Steel wire rope**: there is a history of practical experience going back for over 150 years; the rope constructions and terminations are proven technology. Steel has a well-known simple elastic-plastic response compared to the more complicated (temperature dependent) load-elongation properties of synthetic fibres. The steel wire ropes are made of a limited number of thick wires, whereas synthetic ropes consist of millions of fine filaments. Corrosion and metal fatigue are the potential problem areas for steel wire ropes. Lubrication may be of concern for environmental reasons. Steel wire ropes can wear grooves in fairleads and other equipment. Steel rope is not easy to handle because of its weight and is hazardous should it break. Broken wires ("sprags" or "jaggers") also cause injuries while handling.

- **Polyamide**: The first man-made fibre to be used in cordage, polyamide (nylon) was invented in the early part of the last century. Polyamide ropes will stretch approximately 15% under normal working load, which can be desirable for some applications. Surface and internal abrasion resistance is good. Polyamide has a good resistance to most chemicals, bacterial decay and mildew. Polyamide fibre absorbs water and will shrink in a wet environment with a strength reduction of 10-15%.

- **Polyester:** the attributes of industrial grade polyester fibre are relatively lower stretch (approximately 5-10% under normal working load), no water absorption (no cold water shrinkage), good ultraviolet (UV) resistance, and good abrasion resistance, particularly when wet. Polyester has a slightly lower strength-to-weight ratio than polyamide.

- **Aramids**: were the first high performance fibres developed and commercialized by Du Pont and Akzo (now Teijin Aramid). The fibre is based on an aromatic polyamide structure (PPTA, or polyphenylene terephtalamide). In the last few decades, more fibres have been developed in the same chemical class and these are also showing identical generic properties but with improvements in bending fatigue. The fibre can withstand temperatures up to 425°C, has low elongation to break and relatively low creep. Aramid fibres are prone to abrasion, sensitive to UV light and some chemicals, and have a low resistance to axial compression fatigue, making them less suitable for dynamic rope applications.

- **Liquid crystal polymers (LCP)**: further developments in polyester chemistry resulted in a fully aromatic polyester developed by Celanese (now Kuraray). LCP fibre exhibits low creep and relatively good temperature resistance. As with aramids, abrasion, bending fatigue, flex fatigue and UV resistance are limited.

- **High modulus polyethylene (HMPE)**: in the late 1970s, DSM, a Dutch chemical company, patented the production process to manufacture HMPE fibres under the brand name Dyneema®, based on their own UHMWPE (ultra high molecular weight polyethylene) feedstock. Ropes with HMPE fibre are seven times stronger than steel wire ropes on a weight-for-weight basis. They float, have excellent abrasion, bending fatigue and tension fatigue properties and chemical resistance. UV resistance is among the best within synthetic fibres. Limitations are in the higher temperature applications or static applications, where elongation due to creep may be an issue. With the development of HMPE fibres (such as Dyneema®), a material has become available that is stronger than steel on an area basis and about 10 times stronger on a weight basis. Table 1 shows data for HMPE and polyester fibre (PET) as a well-known commodity fibre for comparison.

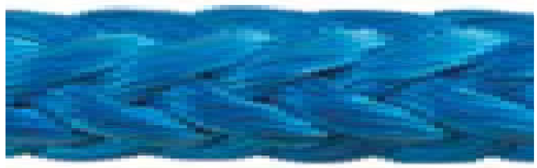

Figure 1: AmSteel®-Blue 12-Strand braided rope using Dyneema® SK-75 fiber.

HMPE is one of the high performance fibres which has become established on a large scale in all kind of applications like ballistic protection (bullet resistant vests, car armouring, helmets), sports (yachting lines, fishing lines, para lines) and in netting and large diameter engineered ropes. Due to their high strength per weight, good UV-resistance and excellent dynamic fatigue properties like tension and bending fatigue, HMPE-based ropes have replaced other synthetic and steel wire ropes in a number of predominantly dynamic applications. Currently HMPE ropes are in use in a large number of offshore, marine and on-land applications.

Quantity	Unit	Steel wire	HMPE	PET
Density	[g/cm³]	7.85	0.97	1.38
Strength/unit area	[MPa]~[N/mm²]	2600	3400	1130
Strength/Weight (tenacity)	[cN/tex]	33	350	82

Table 1: Tensile properties of steel wire, HMPE and polyester fibres (McKenna *et al*., 2004).

In logging applications, the most important wear mechanisms may be summarised as bending fatigue, tension fatigue, torsion and abrasion (McKenna *et al.*, 2004):

- ***Bending fatigue*** (also flex fatigue) means the effect of bending the rope structure (e.g. when guy lines run over sheaves at the top of the yarder). The rope is subject to compression forces on the inside radius of a bend and to tension on the outside radius. Flex fatigue depends on many variables like fibre material, sheave surface material, rope construction, load levels and frequency. Probably the strongest influence on bending fatigue is the ratio of D, the diameter of the sheave, to d, the diameter of the rope. Large D/d ratios increase rope life.

- ***Tension fatigue*** refers to rope wear due to cyclic loading and unloading, which primarily leads to internal fibre abrasion followed by filament breakage and therefore loss of strength. Tension fatigue is again dependent on fibre material as well as load difference (between minimum and maximum load), load level (mean load) and load frequency. Internal abrasion is the key to tension fatigue, the performance of the fibres is strongly influenced by fibre finishes.

- ***Torsion*** reduces rope strength as it leads to unbalanced loads on rope strands. Tests showing the influence of torsion on rope strength from one study showed that with a twist of 1 turn/linear metre the residual rope strength was 96% and with a twist of 5.5 turns/linear metre that strength was 56% (Tension Technology

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International - funded by the Marine Accident Investigation Board).

- ***Abrasion resistance***: ropes in logging are confronted with rough abrading conditions (e.g. rock, tree bark, branches etc.), most likely under high loads. This holds true for both steel wire and synthetic fibre ropes. While abrasion and wear of steel wire ropes can be assessed on the basis of a specified number of broken wires, synthetic ropes become fuzzy and eventually this fuzziness may become so prominent as to hide the initial braid structure.

Previous Research on use of Synthetic Fibres in Logging

One application in which weight plays a major role is logging, and especially steep country logging. The subject of synthetic ropes in logging applications is by no means a new area of research in New Zealand.

Early work looking at polypropylene fibre rope noted the strength, light weight, and ease of handling and splicing (Terlesk, 1975). Disadvantages of polypropylene rope were noted as lower abrasion resistance than wire rope, and the fact that life of polypropylene strops had not yet been established.

Other trials were undertaken with polypropylene logging strops by the Kaingaroa Logging Company Limited and the Logging Industry Research Association, LIRA (Gaskin, 1980). In these trials, 20mm polypropylene rope was used, which had a minimum breaking load of 5330kg. In comparison, modern HMPE Dyneema® fibre rope of the same diameter has a minimum breaking load of over 40000 kg.

In 1985, LIRA looked at the application of polyester round slings in a cable logging pre-stropping operation (Prebble, 1986). Results showed no productivity advantages, and the strops tested failed after 7.5 days of operation, due to physical damage to the polyester casing.

On studying more recent overseas literature, it is obvious that modern synthetic rope could offer advantages over wire rope for certain operations.

Kirth *et al.*, (2007) found the use of HMPE fibre ropes as a substitute for steel wire rope has the potential to:

- lead to a significant reduction of work loads (ergonomic aspect)
- reduce the potential for accidents, as it both eliminates wire breakage that may lead to puncture-type injuries and reduces fatigue which is often the cause of accidents
- reduce harvesting costs per m^3 (economic aspect), as task times may be significantly reduced, shortening preparation delays and increasing productive time

Pilkerton *et al.* (2001) reported the results of field trials limited to ergonomic, health, and safety issues in completing typical logging activities. Heart rates and time to complete tasks were measured for line pulling, tree rigging, and carrying guy lines. Not only was the task time less when using synthetic rope, but the first results also indicated that maximum heart rate was less for tasks using synthetic rope than tasks using steel wire rope. Furthermore, the recovery time for heart rates was significantly less with tasks using synthetic rope.

Garland *et al.* (2002) performed laboratory tests to further understand the characteristics of UHMWPE and to determine failure values. Samples were loaded according to the Cordage Institute's standards by cycling to 20 percent of breaking strength 10 times and then loaded to failure. These tests yielded breaking strengths at acceptable levels. A second set of tests was conducted after discussions with the manufacturer. Samples were cycle loaded to 50% of the breaking strength and then pulled to failure. These initial trials indicated that UHMWPE 12-strand braided rope was suitable for logging applications.

Leonard *et al.* (2003) studied the use of synthetic rope as guy lines, intermediate support lines, tree straps, and snap guy lines. In all four applications, the synthetic rope was found comparable in performance to steel wire rope. However, because the rope is lightweight, workable, and easy to bend, set-up times in the field were much lower than with steel wire rope. Although it took approximately the same time for descending steep terrain with synthetic rope and steel wire rope, carrying steel wire rope uphill took twice as long. Fewer trips to carry gear to the rigging tree were needed because more gear per load could be taken into the bush.

Pilkerton *et al.* (2003) investigated the use of synthetic rope in winching applications. Five case studies (three skidder winch lines, a carriage dropline, and a carriage mainline) were conducted to determine the effectiveness of the rope in logging.

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Figure 2: AmSteel®-Blue synthetic rope used as a guyline (Leonard *et al.* (2003)

Operators were pleased with the lightweight line and the ease of pulling line through the bush. Operational times and thus cycle time decreased. The authors also commented that visual evidence from abrasion, corrosion, crushing, diameter reductions, stranding, bending and shock loading for wire and synthetic ropes differed as follows:

- ***Abrasion*** – Abrasion in wire rope causes broken wires and replacement is based on a specified number of broken wires. Synthetic rope initially fuzzes up from broken filaments that produce a protective cushion but when braided rope is worn 25% from abrasion it should be replaced. Powder inside the rope indicates internal abrasion (The American Group 1997).
- ***Corrosion*** – With wire rope, pitted wire surfaces and breaks indicate corrosion, and corrosion is difficult to assess for interior damage. AmSteel-Blue synthetic rope is not affected by corrosion with the chemicals typically encountered on logging operations.
- ***Crushing*** – With wire rope, flattening of strands from poor spooling and other causes damages the rope and reduces its strength. Synthetic rope may flatten and glaze due to tension around pins and sheaves but will return to a round shape when worked by hand.
- ***Diameter reductions*** – Wire rope diameter reduction is a critical retirement factor due to excessive abrasion, loss of core support and inner wire failure. Synthetic ropes may actually increase in apparent diameter from braided filaments and material inside the rope itself. Localized diameter reductions, flat areas, and lumps and bumps in the synthetic rope are of concern for replacement, as well as ropes built up with dirt and debris.
- ***Stranding*** – Wire rope stranding occurs from various causes including kinking, twisting, or tight grooves leading to exposed broken wires ("sprags" or "jaggers") to such a degree the rope is unusable. Synthetic rope will have broken filaments and strands but no "sprags" or "jaggers".
- ***Bending*** – Wire rope manufacturers' recommended ratios of bending to rope diameters have seldom been met for wire rope in logging. Synthetic rope ratio recommendations are also larger than those found in logging practice.
- ***Shock loading*** – In wire rope, core protrusion ("bird caging") is evidence of shock loading and seriously degrades rope strength. Synthetic rope is less subject to shock loading, but fibres may have "memory" and may retain effects of shock loading during normal loads.

Hartter *et al.* (2006) reported several potential benefits of synthetic rope adoption within the logging industry: ergonomic potentials, workforce benefits, environmental benefits and, probably the most important, increased productivity. The authors also outlined some of the drawbacks of synthetic ropes such as end connector limitations, susceptibility to cuts by sharp objects and potential need for changing the system to suit the "new" concept of using synthetic ropes.

Garland and Pilkerton (2007) reported that their research demonstrated ergonomic and efficiency gains from replacing steel wire rope with synthetic rope in logging applications. Workloads as measured by heart rates were reduced and task times were lowered as well. The lighter materials could eliminate some hazardous and exertive tasks such as extra trips needed to rig up cable harvesting operations. Anecdotal evidence by synthetic rope users confirmed designed experimental results in dramatic terms. Tree climbing tasks needed further study for direct comparisons between the two materials.

Kirth *et al.* (2007) reported results of lab and practice tests for fibre ropes made of Dyneema® combined with other synthetic fibres. They concluded that these newly developed ropes performed well in the rough conditions of logging, maintaining the technical properties of Dyneema® for a longer time while improving abrasion resistance and providing an

indication of rope wear and rope life. Their data indicated that bending fatigue, tension fatigue and torsion were relevant wear mechanisms in logging, but tension fatigue of HMPE ropes was reportedly better than that of steel wire ropes. The amount of bending on a guy line did not affect the rope and torsion was not likely to be so high as to lead to a deterioration of rope strength. Work also focused on the design of end terminations/connectors with little compression force. End connections and terminations based on splicing and sewing had stood the test especially in static applications. They also stated that more work needed to be done to optimise choker ends. The use of synthetic ropes in logging has become practicable and leads to productivity/cost savings that make them pay off. They reported that in the use of synthetic rope as a guy line for a yarder, overall preparation time is reduced by 50%, estimated to provide gains of 36 hours per year or 300 cubic metres of solid timber more to be harvested. Additionally, installation may be done by two workers instead of four.

Costs

Cost is an important consideration in the evaluation of synthetic rope in forest operations. Cost of HMPE ropes 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 (Garland *et al.*, 2003). Synthetic rope costs two to five times more than comparable steel wire ropes (Garland *et al.*, 2004). However, logging contractors have been willing to purchase synthetic ropes for the benefits to their workers and the efficiency gains. Efficiency gains have been shown to provide pay back periods for the additional cost within one month of usage or sooner (Garland and Pilkerton 2005).

Hartter *et al.* (2006) outlined one of the drawbacks of synthetic ropes being its higher cost. Despite this the authors concluded that synthetic rope appeared to be on the way to adoption within the forestry sector, with over 200 operators throughout the US and Canada using it in various applications, and research and field trials being under way around the United States, Canada, and Europe. They suggested that adoption of synthetic rope in the forestry sector might follow a process through stages of interest, evaluation, trial and adoption by groups of early adopters, early majority, late majority and laggards in a more or less normal distribution over time.

As use of synthetic rope increases within the logging sector, prices may become more competitive. Hartter *et al.* (2006) reported that*:*

> *"The cost of synthetic rope in logging applications runs two to five times that of domestic steel wire rope depending on the application. For rigging straps and prepared rigging, the cost is about three times that of steel. A winch line of 150 feet (36m) might cost five times more. Small diameter lines in long quantities like those used for rig-up (e.g. 10mm straw line) may be only twice as expensive. Synthetic "wrappers" (throw over strops) for log trucks may be three times as expensive as wire rope strops. Synthetic rope costs per hour or production unit over time have not been developed. However, one contractor, independent of our studies, estimated a cost of US$1.00 per operating hour for his synthetic winch line."*

Cost of the synthetic rope is an initial drawback for most logging contractors. However, the benefits of using synthetic rope for static rigging applications in cable logging seem to outweigh this concern. Benefits such as decreased rigging times, reduced workloads due to lighter weight materials, ease of use, and a potential to increase production are factors to consider when assessing the cost-benefit ratio between steel wire rope and synthetic rope (Leonard *et al.*, (2003).

Conclusions

In general, most logging researchers see ergonomic and efficiency benefits in the use of synthetic rope for logging applications, but some individual logging and trucking contractors in the research expressed a preference for steel rope in their judgment. By summary of applications, results showed:

- Use as static lines in cable logging (guy lines, intermediate support lines, and block strops) showed efficiency and ergonomic benefits
- Use as guy line extensions showed ergonomic benefits, but needed sizing determinants for yarders
- Use as skyline extensions showed ergonomic and efficiency benefits, but further study was needed
- Use as skidding line on a carriage showed ergonomic benefits, but both carriage and operations needed modifications to use synthetic rope effectively
- Use as winch lines on tractors/skidders showed ergonomic, efficiency and potential environmental benefits

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• Use as chokers/winch line on a tractor showed ergonomic benefits, but efficiencies were still under evaluation.

In summary, synthetic rope is not the same as wire rope, and the differences provide ergonomic benefits. Logging operators will need to change their practices to use synthetic rope to its fullest benefits. Synthetic rope will not take the same abuse operators give wire rope in logging applications, however it does stand up comparably when used appropriately.

Future research overseas may involve trials using synthetic rope as a skyline where the weight advantage could be significant in low deflection circumstances. The question of how a carriage might affect the skyline is still open for trial (Pilkerton *et al.* 2003).

Further research of synthetic ropes available in New Zealand will investigate the cost of synthetic ropes versus that of steel wire ropes, the economic gains and other benefits that may offset the higher reported purchase cost.

References

Garland, J., Sessions, J., Pilkerton, S., and Stringham B.(2002): Using Synthetic Rope to Reduce Workloads in Logging. Final Report Worksite Redesign Program. Oregon Occupational Safety and Health Administration:. 27p.

Garland, J., Sessions, J., Pilkerton, S. and Hartter, J. (2003): Synthetic Rope to Replace Wire Rope in Mountain Logging Operations. Proceedings of Austro2003 – High Tech Forest Operations for Mountainous Terrain, Schlägl. Austria.

Garland, J., Pilkerton, S. and Leonard, J. (2004): Field Testing of Synthetic Rope in Logging Applications to Reduce Workloads. Final Report, Worksite Redesign Grant, Oregon Occupational Safety and Health Administration, Oregon, US.

Garland, J. and Pilkerton, S. (2005): Use of Synthetic Rope as a Skidder Winch line for Designated Skid Trails. USDA Forest Service Gen. Tech. Rep. PSW-GTR-194. in Proc. of Council On Forest Engineering. Annual Meeting, July 11-14. Fortuna, CA.

Garland, J. and Pilkerton, S. (2007): Synthetic rope reduces workloads in logging. The International Mountain Logging and 13th Pacific Northwest Skyline Symposium. April 1-6, 2007, Corvallis, OR.

Gaskin, J.E. (1980) A Look at Polypropylene Strops. LIRA Report Vol. 5 No.3 1980. Logging Industry Research Association, New Zealand.

Hartter, J., Leonard, J., Garland, J., and Pilkerton, S. (2006) Research on synthetic rope and its future in timber harvesting. NZ Journal of Forestry (August 2006): 23-30.

Hearle, J.W.S. (2001) High-performance fibres. Woodhead Publishing Ltd. Cambridge.

Kirth, R., Schiemer, S., Nemestothy, N., Sperrer, S. (2007) Further developments of synthetic ropes for logging applications in forestry. Austro2007 /FORMEC'07: Meeting the needs of tomorrow's forests – New developments in Forest Engineering, October 7-11, 2007, Vienna and Heiligenkreuz, Austria.

Leonard, J., Garland, J., and Pilkerton, S. (2003) Evaluation of Synthetic Rope for Static Rigging Applications in Cable Logging. Proceedings 26th Annual Council on Forest Engineering. Sept. 7-10, 2003. Bar Harbor, Maine.

McKenna, H.A., Hearle, J.W.S., O'Hear, N. (2004) Handbook of Fibre Rope Technology, Woodhead Publishing Ltd., Cambridge, UK.

Pilkerton, S., Garland, J., Sessions, J., and Stringham, B. (2001) Prospects for Using Synthetic Rope in Logging: First Look and Future Research. The International Mountain Logging and 11th Pacific Northwest Skyline Symposium.

Pilkerton, S., Garland, J., Leonard, J., and Sessions, J. (2003) Synthetic Rope Use in Logging Winching Applications. Proceedings 26th Annual Council on Forest Engineering. Sept. 7-10, 2003. Bar Harbor, Maine.

Prebble, R.L. (1986) Polyester Roundslings as Strops. LIRA Report Vol. 11 No.4 1986. Logging Industry Research Association, New Zealand.

Terlesk, C. J., The Mercedes Benz tractor production thinning *P.radiata*. Economics of Silviculture Report No.86, 1975 (unpublished). NZFS Forest Research Institute, Rotorua New Zealand.

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