Should I Use a Polypropylene Lifeline?

Bob Mehew, Roy Rodgers and Steve Richards

(Reproduced from text of article published in Speleology, Issue 17, April 2011)

This article arose from a simple question on the UK Caving forum about the use of polypropylene hawser laid rope as a lifeline. The British Caving Association's Rope Test Rig was used to run a quick drop test on a dry 12mm diameter sample of polypropylene hawser laid rope which demonstrated that the rope could not hold a single 80cm Fall Factor (FF) 1.0 drop of a 100kg test mass. Unfortunately this single test provided no data on the margin of failure; did the rope only just fail, or was it totally inadequate for the task? Further tests were required. Toward the end of a day's work on the recently upgraded Bradford Pothole Club (BPC) rope test rig another drop test was run on an 80cm length of 12mm diameter polypropylene rope. Figure 1 shows the resultant force/time plot. The test mass was 100kg, and the Fall Factor 1.0. This three peak curve was new to us, as previously we had limited our testing to kernmantle ropes.

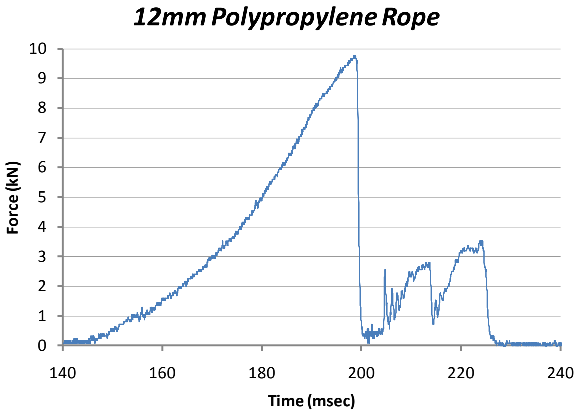


Figure 1

Note that all the tests reported in this article used dry but otherwise unconditioned rope.

Figure 2

A look at the broken ends of the rope (Figure 2) revealed a number of interesting details.

The rope consisted of three strands. Two of the strands had parted at a similar length whilst the third had straightened from its lay in the hawser rope and extended further. The third strand exhibited two distinct lengths, both extending beyond the first two strands. The rope had parted at the knot, as predicted by both practical experience and theory (Ref 1).

Since the test mass keeps moving in the same direction it seems reasonable that the more extended strands broke later in the sequence. If we postulate that the three strands did not share the load equally the following chronological sequence of events seems likely (of course other interpretations are possible):

1. Two strands take the lion's share of the load. They are well-matched and break at about the same time, giving rise to the first peak.
2. As the load on the third strand increases a subgroup of the strand's fibres assume a disproportionate share of the load. They break, causing the second peak.
3. The load on the remaining fibres of the third strand increases until they break. This is the third and final peak.

This curious result prompted us to look at a range of hawser based ropes to contrast them with the kernmantle rope experience we had gained so far. Three lengths of 10mm diameter hawser rope were purchased from Timko Ltd (www.ropesandtwines.com) made from polypropylene, polyester and nylon, see Table 1 for properties.

Material	***Polypropylene***	***Polyester***	***Nylon***	***Nylon***
Lay	***Hawser***	***Hawser***	***Hawser***	***Kernmantle***
Diameter mm	10	10	10	10
Weight g/m	36	75	68	65
Cost £/m	0.14	1.10	0.45	1.10 (1)
Breaking Load kg (2)	1400	1590	2080	2700
Samples used	3	4	2	1
Minimum Drops Survived	0	0	9	26
Peak Force kN (3)	7.0 (4)	10.9	7.6 / 13.7	8.4 / 16.4
Peak Rise Time ms	40	90	140	120
Jolt kN/sec (5)	175	121	54.3 / 97.9	70 / 137
Heat Capacity J/kg °K (6)	1925	1850	1310	1310
Heat Capacity J/°K meter of rope (7)	69	140	89	85
Thermal Conductivity W/m °K	0.1 – 0.22	0.42 – 0.51	0.25	0.25
Deflection Temperature °C (8)	100	70 (9)	160	160

Notes to Table 1

1 – Approximate price.
2 – Data from supplier, believed to be for testing without knot terminations.
3 – First value is peak load from first drop; second value is peak load from penultimate drop.
4 – Rope failed.
5 – Calculated by dividing Peak Force by Peak Rise Time.
6 – For the bulk material. Sources http://www.matsceng.ohio-state.edu/mse205/lectures/chapter20/chap20.pdf and http://www.kayelaby.npl.co.uk/general_physics/2_3/2_3_6.html
7 – Rope diameter 10mm. Source http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html
8 – Source http://www.matweb.com/reference/deflection-temperature.aspx based on 0.46MPa load per BS EN ISO 75-2:2004 Method B.
9 – Used PET value (alternative name for Polyester).

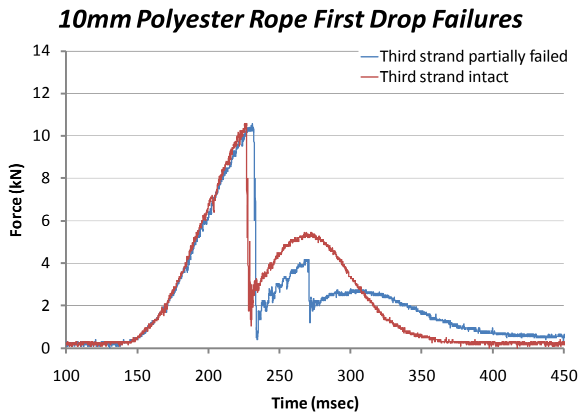


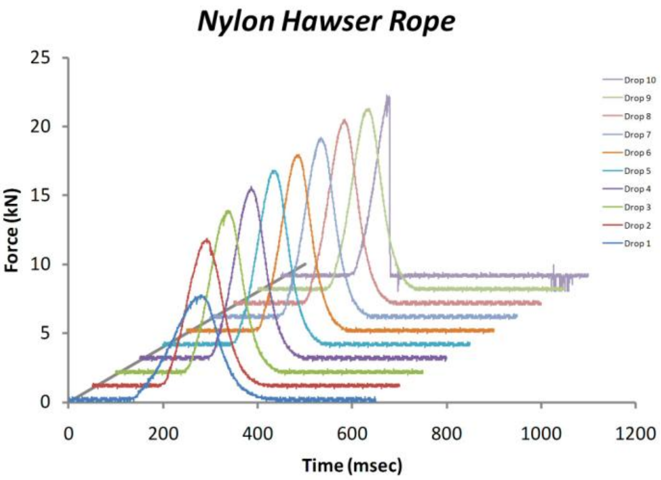
Figure 3

Rope Drop Test Results

All of the drop tests used an 80cm drop, a Fall Factor of 1.0, and a 100kg test mass. The results of the polypropylene and polyester hawser tests have many features in common. All three polypropylene samples failed on the first drop; all of the failures showed the multiple peaks on the force/time plot characteristic of uneven load sharing. Two of the four polyester samples failed on the first drop, with the remainder failing on the second. Both of the first drop failures exhibited the symptoms of uneven load sharing. Both of the

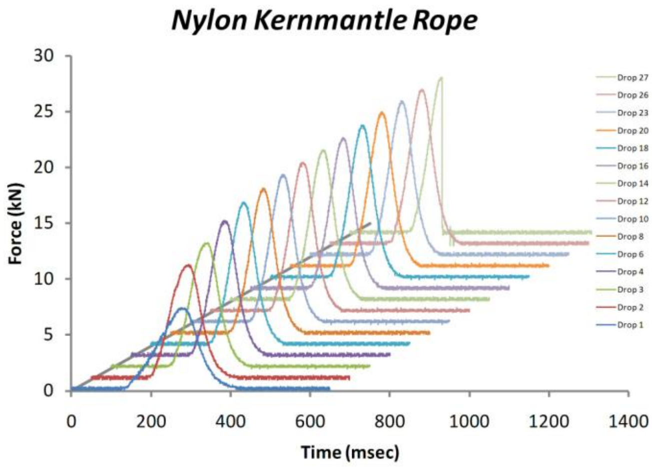
Figure 4. Partial Third Strand Failure

second drop failures were simple breaks, without evidence of uneven load sharing. The first drop failure polyester samples did not fail completely, but left one of the three strands either partially or completely intact due to the weight reaching the end of its travel before complete failure. The force/time plots for the first drop failures are shown in Figure 3, and the partial third strand failure in Figure 4. Interestingly the force/time plot for the drop that left the third strand intact does not exhibit the abrupt drop in force at 270 msec, which seems to support the chronological sequence of events suggested above.



The results of the nylon hawser and nylon kernmantle tests are shown in Figures 5 and 6 respectively. A single sample was tested in both cases. The nylon hawser rope survived nine drops; the nylon kernmantle survived 26.

Referring to Table 1, it can be seen that the lowest peak force for a survived drop is for hawser laid nylon, followed by kernmantle nylon and then polyester. The polypropylene value is discounted since the rope failed. These results show no correlation with the supplier's breaking load values, which may be attributed to the difference between the supplier's static testing technique and our dynamic approach. Jolt (the rate of change of force) is another characteristic of dynamic testing; the higher the jolt, the more abruptly the force is applied. Table 1 shows that, of the hawser laid ropes, polypropylene experienced the highest jolt, followed by polyester and finally nylon.



Thermal Factors

In 1974 the first UK caving fatal SRT accident occurred when abseiling with polypropylene rope (Ref 2). Though it is likely the rope parted due to a mixture of abrasion and shock loading, concern was raised at the time over the low melting point of polypropylene. Clearly, thermal properties are a vital factor in the rope selection process. In the interests of simplicity the discussion will be restricted to dry ropes.

Two key properties govern the temperature the rope's surface will attain when it is heated by friction. The first of these, heat capacity, is a measure of how much heat input is required for a given temperature rise. A lower heat capacity will result in higher temperatures. To compare heat capacities it is necessary to transform the bulk values (usually quoted per kilogram of material) into heat capacity per meter length of rope; both values are included in Table 1. As can be seen, polyester has the best (highest) value, followed by nylon and finally polypropylene. The second important thermal property is thermal conductivity, a measure of how easily the bulk material conducts heat. A material with a high thermal conductivity will quickly conduct heat away from the surface, lowering its temperature. Here again polyester has the best (highest) value, followed by nylon and finally polypropylene.

Both thermal properties rank our materials in the same order of desirability, so it will come as no surprise that for a given frictional load the polyester rope will be the coolest, the nylon rope will be in the midrange, and the polypropylene rope will be the hottest. However there is one more factor that influences our choice – the rope's ability to withstand high temperatures. This is characterized by its deflection temperature, the temperature at which the rope will start to deform (also included in Table 1). Nylon offers the best high temperature performance, followed by polypropylene and polyester. Of particular note is that polyester's 70°C deflection temperature means that it does not even gain the benefit of the energy sink when water is turned into steam.

Discussion

Polyester's deflection temperature is so low that it is effectively ruled out as a viable choice for abseiling or even life lining when using metal devices such as a stitch plate. Additionally, hawser laid polyester rope's price is similar to nylon kernmantle's, so there is no point in considering polyester further. The choice is between nylon and polypropylene. Polypropylene rope just does not have the strength of nylon in either static or dynamic measurements. The choice is clear – nylon rope is the one to use.

With the rope's material chosen, one choice remains; kernmantle or hawser laid rope? Referring to Table 1 for one last time we see that the kernmantle rope is stronger both statically and dynamically, and that it survived almost three times as many drops as the hawser laid rope. However this performance comes at a price; nylon kernmantle rope is more than twice the cost of nylon hawser laid rope.

The force/time plots for both hawser laid and kernmantle nylon ropes (Figures 5 and 6) show significant increases in peak force and jolt as the sequence of drops progresses. In both sequences the increase between the first and second drops is by far the largest, almost a factor of two. This may be attributed to knot tightening, and leads us to another important point of rope care; relax the knots after every trip, and, if a rope takes a fall during a trip, retie the knots before further use on that trip. If this precaution is taken consistently the safety margin will be increased by a factor of nearly two, an improvement well worth the effort required.

Three caveats:

1. All these deductions are based on results from new, dry ropes. Wet kernmantle is known to lose around half of its dynamic strength when measured in drops survived (Refs 3 and 4) and, as yet, no work has been done on wet hawser laid nylon rope. Nor has hawser laid nylon rope been tested to see how its strength is affected by usage. It is moderately well documented (Refs 5 and 6) that nylon kernmantle rope loses a considerable part of its drops survived performance after very few (less than 100) uses. This fall off in performance then abates and the rope's capability degrades very slowly over the remainder of its life.
2. The dynamic tests reported here used an 80cm sample length, while the Standard (Ref 7) specifies a 2m sample length. The influence of the knot on the behaviour of the sample is known to increase as the sample length decreases. The question of the relationship between a real-world falling caver and a 2m (or 80cm) Fall Factor 1 drop test remains.
3. Hawser laid rope is known to have a lot more bounce than kernmantle rope. Although we are still developing the rig to investigate this area, it has been accepted from the early days of SRT usage that one should not use hawser rope for this reason.

Conclusions

The clear answer to the title of this article is NO, you should not use hawser laid polypropylene rope either for SRTing or as a lifeline. It simply is not strong enough.

Acknowledgements

Thanks go to Bradford Pothole Club for the loan of their rope test rig and to Dave Elliot for his efforts in its design; also to Bob Mackin and Mike Sainsbury of the University of Lancaster for calibrating the load cell.

References

Ref 1 G. Dietler et al, "Localization of breakage points in knotted strings"; New Journal of Physics 3 (2001) 10.1–10.13, see http://iopscience.iop.org/1367-2630/3/1/310.

Ref 2 A. Eavis, "Gaping Ghyll : Why did the rope break?"; Descent No 31, p5 & 6, 1975.

Ref 3 G. Signoretti, "The influence of water, ice and sunlight on the dynamic performance of mountaineering ropes"; UIAA & Italian Climbing Club Conference, Turin, Italy, 2002.

Ref 4 R Mehew, unpublished work.

Ref 5 G. Bressan, "ROPE WEAR IN CLIMBING AND IN THE LABORATORY, Decay in dynamic performance of ropes due to wear"; UIAA & Italian Climbing Club Conference, Turin, Italy, 2002.

Ref 6 R Mehew, unpublished work, see http://british-caving.org.uk/equipment/LTRT.pdf , 2009.

Ref 7 British Standard "PPE for the prevention of falls from a height – Low Stretch kernmantle ropes", BS EN 1891:1998.