Wet and Icy Ropes May be Dangerous!

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Foreword

It is well known that modern mountaineering ropes are made of very thin continuous filaments of polyamide-6, known as nylon-6. This synthetic fibre is characterized by excellent mechanical properties, such as high breaking strength, large elongation at rupture and good elastic recovery. It is less known that its breaking strength is greatly decreased by water absorption (4). The dangers that might occur when using wet and frozen ropes in mountaineering can be inferred from the data presented here.

The loss in performance of wet/frozen ropes was first studied at the end of the sixties by a Spanish mountaineer, Prof. José A. Odriozola, and, after a couple of years, by Fa. Teufelberger and by Pit Schubert, Leader of Safety Research of the German Alpine Club (DAV). The results they obtained are similar to those presented here. In particular, in Odriozola's two studies on the *static* strength of wet and frozen ropes a reduction of about 30% in static resistance, as compared to dry ropes, was reported [1] [2]. This prompted the Austrian manufacturer Teufelberger (EDELWEISS ropes) as well as Pit Schubert to investigate to what extent such a reduction might occur for wet ropes in *dynamic* conditions. Tests on wet ropes were carried out on the Dodero machine (UIAA drop test). Result: ropes that held 2 falls when dry (the minimum imposed by the standards at that time) only held up to 1 fall, or none, when wet [3].
It is astonishing that such a problem hasn't been studied further for thirty years, although the reduction of resistance in wet ropes may be equal to and even more important than the loss caused by a long rope wear in mountaineering.
In order to know more about it, a set of tests were made by the author for the Safety Commission (Commissione Materiali e Tecniche, CMT) of the Italian Alpine Club (CAl). They concern new and used ropes, of normal and 'dry' type (i.e. treated with waterproofing substances). The purpose of the tests was to assess the dynamic performance - on the Dodero machine - of a **wet**, **frozen**, and **wet and dried** rope compared to a reference rope.

Description of the tests.

The tests were executed on samples of rope of three different makes A, B, C (three specimens per sample), with the following characteristics:

- **A. NEW** rope, diameter 10,5 mm, version **normal**
- **B. NEW** rope, diameter 10,5 mm, version **ever dry**
- **C. USED** rope, diameter 10,5 mm, version **normal**

The following samples were subjected to the UIAA test on a Dodero machine:

- **non-treated** (reference)
- **wet** (by immersion in water for at least 48 hours, at normal temperature);
- **frozen** (wet as above, then kept for at least 48 hours in a freezer at -30^{0}C);
- **wet, then dried normally** (wet as above, then laid out in an airy and shady place, as it is convenient to do with your own rope);
- **wet and dried "extra dry"** (wet as above, then centrifuged, then dried at normal temperature in an ventilated room, and finally vacuum-dried in presence of a chemical dehydrator).

A few tests were made on ropes submitted to a shorter soaking, to simulate mountaineering conditions:
- immersion in water for a couple of hours
- brief treatment with splashes of water under a shower

Furthermore, the effect of numerous soaking/drying cycles was studied, drying the ropes under cover (as normally recommended) as well as in direct sunlight.

After each treatment the variations in weight and length of each specimen were checked, in order to investigate possible correlations with the dynamic tests.

Results

The results obtained, listed in TABLE 1 are briefly discussed here.

Wet Ropes

The alarming effect of water content on the dynamic performances of a rope has emerged from the tests: the number of falls held on the Dodero is reduced to about one third of the initial value. Such a decrease of performance has been noted on both new and used ropes, and also on both normal and waterproof treated ropes (apparently, the waterproofing additive seems to prevent water from sticking to the surface of the sheath, but doesn't stop water from entering the core of the rope). It is interesting that the effect of water is remarkable also in case of brief immersion (2 hours) and even in the case of a simple splash.

Such a behaviour is in accordance with literature [4]: the presence of water in nylon greatly lowers its Tg [a], the Glass Temperature (glass transition temperature of the material). Water acts like a real plasticizer, since it deeply modifies both the mobility of the amorphous part of the macromolecule as well as the characteristic temperature of mechanical relaxation of the material. This means that "*in many respects, the addition of water to nylon is equivalent to raising its temperature by a substantial amount"* (literature). In other words: testing a wet rope on the Dodero at normal temperature is about equivalent to testing the dry rope at 70-80^{0}C, conditions that cause a loss in performance.

It has also been noted that the impact force at the first fall with the wet rope is significantly larger (5-10%), as if the rope had become more rigid than the dry one. This could be due to increased fibre-fibre friction as well as to the increased length of the rope. A rope that is already stretched is indeed more resistant to strain, more "rigid". The stretching - average 3-5% - measured on wet ropes just after removal from water is not negligible compared to the strain that occurs in the Dodero test (30-35%).

Another unexpected result: the amount of water retained by new ropes is 40-45% of the weight of the dry rope, independent of the waterproofing treatment (the long soaking time - 48 hours - renders the additive ineffective).

In the case of a used rope, the quantity of water retained is much greater, about 60%; this is probably caused by the great quantity of broken filaments existing on the rope surface.

Frozen Ropes

A warning must be made here concerning the meaning of the tests: it is not possible to keep the rope icy during the whole test. This is due to the time necessary to mount the rope on the Dodero machine and to the long waiting time required by the standard testing procedure (a succession of falls at intervals of 5 minutes). In addition, the rope is warmed up by the heat due to the energy developed at each fall and to the higher ambient temperature. As a consequence, only during the initial phases of the test were the ropes frozen. Therefore the results must be read critically, trying to extrapolate the results of the ice-effect from our tests.
In spite of these uncertainties, it can be stated that the Dodero tests prove that frozen ropes behave slightly better than wet ropes: there is a smaller reduction ("only" about 50%) of the dynamic performances, and even a reduction (about -10%) of the impact force at the first fall.
As a conclusion, we may dare to guess that if we were able to maintain the rope frozen during the whole test, the results may show reasonable performances of frozen ropes; maybe almost as good as for dry ropes! At low temperature, in fact, the crystalline structure of the wet/frozen rope, in particular the mobility of its amorphous part, would be the same as that of a dry rope at normal temperature.

Wet Ropes - Dried Normally

Here at least is some good news for climbers. After soaking and drying, the ropes seem to regain their characteristics, as quoted in literature for nylon fibres. The number of falls on the Dodero machine reaches its original value, while the impact force decreases a little, since the rope is slightly (4%) shorter.
It is also interesting that the return to the original performance is granted even after various cycles of soaking-drying, as long as the ropes are dried in a cool, airy and shady place. If, however, they are dried in sunlight there is a decrease of performance at the Dodero test, due to the negative effect of the UV radiation [5]. In our case the ropes had been kept in sunlight for 4 weeks, long enough to see these effects.

Wet Ropes - Dried Extra-Dry

These tests confirm the results reported above. The complete drying of the rope reduces its weight by about 3% compared to the reference case. This thorough drying process leads to an almost complete recovery of the dynamic resistance of the rope - be it new or used, normal or waterproofed - and to a reduction of the impact force at the first fall by about 10-12% (the rope is about 4-8% shorter).

Conclusions

The presence of water or ice in climbing ropes produces important modifications in their performances, such as:

1. The dynamic resistance of the ropes (i.e. the number of falls held on the Dodero) decreases enormously - down to 30% of the initial value - when they are soaked with water, be they new or used, normal or waterproofed.
2. After soaking in water a rope becomes 4-5% longer, which can be correlated to the 5-10% increase of the impact force at the first fall on the Dodero machine.
3. The negative effects of water on the dynamic performance of ropes are remarkable even in the case of a brief soaking time, even after being splashed under a shower.
4. This behaviour seems to be due to the interaction of water with the structure of the nylon macromolecule (according to literature).
5. Such behaviour lasts as long as the rope is wet, but after drying - in a cool, airy and shady place, as recommended - the rope recovers almost completely its original dynamic performance, even after various soaking/drying cycles.
6. Depending on the drying grade (normal or thorough), the rope can become shorter by 4% to 8%, which seems to be correlated to the decrease by 6-12% of the impact force at the first fall on the Dodero machine.
7. Even in the case of soaked and frozen ropes the dynamic resistance decreases, but less than in wet ropes.

In conclusion, a used rope in good conditions, say a rope which can still hold 4-5 faIls in the UIAA test on the Dodero machine when dry, might only hold 1 or 2 faIls when soaked after a sudden rain fall, as often occurs in the mountains.
This may not be too much of a serious problem when climbing in a *Klettergarten*, where falls are usually less dangerous and it takes little time to pull the rope down and go home. But mountaineers must demand the maximum security from their rope, even when wet, since it might snap on a rough edge during a fall. This risk is lower when the rope is in good conditions. The problem can be less critical when climbing a glacier or an ice-fall, because the ropes are frozen, but even in this case the temperature is very important: if it goes over 0^0C, the rope returns to be wet!
In conclusion, it would be a good idea to change our ropes more often!

Bibliography

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[3] Pit Schubert - *Was halten nasse und vereiste Seile?* - Sicherheitskreis im DAV; Tätigkeitsbericht 1971 - 73, pages 197-206.[4] *Nylon Plastics,* edited by Melvin I. Kohan - Plastics Department, E.I. Du Pont De Nemours and Co., Inc.

[5] Gigi Signoretti - *Corde e luce solare* - La Rivista del Club Alpino Italiano, Luglio-Agosto 1999, pages 76-84.

Notes

[a] The Tg, or Glass Temperature, is the glass transition temperature of the material. Polymers, as nylon, are made of macromolecules, where crystal parts (i.e. perfectly orderly chain structures) alternate casually with amorphous parts (i.e. disorderly structures with tangled chains). The temperature at which the mobility of the amorphous part is modified is called glass transition temperature (Tg, Glass Temperature), since the behaviour of the material is similar to that of glass (typical amorphous solid) when it is taken to softening/fusion. The amorphous part of the material goes from a rigid state to a plastic state, with greater mobility; generally all polymers above Tg can be deformed due to their greater plasticity. It has been proved that the presence of water in nylon lowers considerably its glass transition temperature: according to literature, the Tg of dry nylon is 60-80^{0}C, but for wet nylon it goes down to about 0^{0}C! This lower Tg in presence of water means that the mechanical properties of the nylon filaments of the rope are strongly modified.

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