The influence of water, ice and sunlight on the dynamic performance of mountaineering ropes

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Introductory notes

As generally known, modern mountaineering ropes are composed by a core and a surrounding sheath; both components are made of very fine nylon threads – most frequently polyamide 6 - with a diameter of 30 micron (equivalent to the 30 thousandth part of a millimetre or half the size of a normal hair). A "simple" UIAA rope contains as many as 60 – 70 thousand [1] threads.

Nylon is the best material for mountaineering ropes, on account of its excellent tensile properties: high breaking strength, large elongation at rupture and good elastic recovery (in general, capacity to retain its mechanical and dimensional properties even after a large strain), and a very good manageability which implies good functionality of the rope. However, it cannot be said that the ultimate solution for the composition of mountaineering ropes has been found yet. Indeed the nylon threads are very sensitive to side-pressure (tight knots, sharp edges, etc.), their filaments break easily by rubbing against rock, their physical and mechanical properties are strongly affected by the UV radiation of sunlight; in addition, water intake causes reduction of the dynamic performance of ropes (number of falls held in the Dodero test[a]).

These properties – common to all synthetic fibres - are qualitatively well known, but their quantitative aspects require further investigation, particularly so for mountaineering equipment. Consequently, the Safety Commission of the Italian Alpine Club has programmed a wide research on some of the mentioned problems. Experiments are being carried out in laboratory and in the field, i.e. mountains or crags and rock faces.

Part 1 - Ropes and sunlight: a matter of ... colour[2]

As already mentioned, exposure of nylon ropes to the sun causes an irreversible deterioration of their physical and mechanical properties due to reactions induced by UV radiation. Photo-oxidation modifies the chemical structure of the nylon macromolecules, since it initiates their de-polymerisation, which leads to loss of resistance and elasticity of the material. This process can be reproduced in laboratory using a suitable artificial light.

It is possible to reduce these reactions by means of photo-chemical stabilization of the nylon fibres; this can be accomplished using either UV protecting agents similar to those used in sun creams (products that act as filters for a radiation of specific wavelengths), or anti-oxidation products [3] [4].

These processes - photo degradation of nylon and its stabilization - have been well studied, but it is still very difficult to clearly anticipate their development. Particularly on materials used for mountaineering knowledge is very scarce, so that mountaineers cannot answer questions such as: How big is the reduction of the mechanical characteristics of the core and sheath of a rope due to sunlight, as a function of usage? What is the influence of this degradation in terms of resistance to wear and dynamic behaviour of the rope ?

Laboratory experiments

Ropes of five different makes, chosen among the most commonly used, where exposed to artificial light as well as to natural sunlight.

The exposure to artificial light was performed by means of an apparatus usually employed in specialised laboratories to produce accelerated photo chemical degradation, the so called *xenotest*. This apparatus contains a xenon lamp, which produces a radiation spectrum nearly identical to the solar one; its radiation flux is about 10 times that obtained by natural sunlight at sea level.

Experiments in-the-field

Exposure to natural sunlight occurred:

- at an altitude of 2550 m, on a wall of the Kostner hut in Vallon (Sella group),
- at an altitude of 1843 m, on a wall of the Carestiato hut (Moiazza group),

two representative places in the Dolomites area, very popular with mountaineers.

Rope samples with a length of 15-16 m were wound in a spiral within a metallic structure, a sort of cage with a diameter of approximately 1 m. The resulting "piece of folk art" (**see PHOTOS 1 and 2**) was exposed on the southern wall of the huts during the whole summer season, from June to the end of September. To ensure a homogeneous exposure of the ropes to sunlight, the hut keepers kindly agreed to give the cage half a turn once a week.

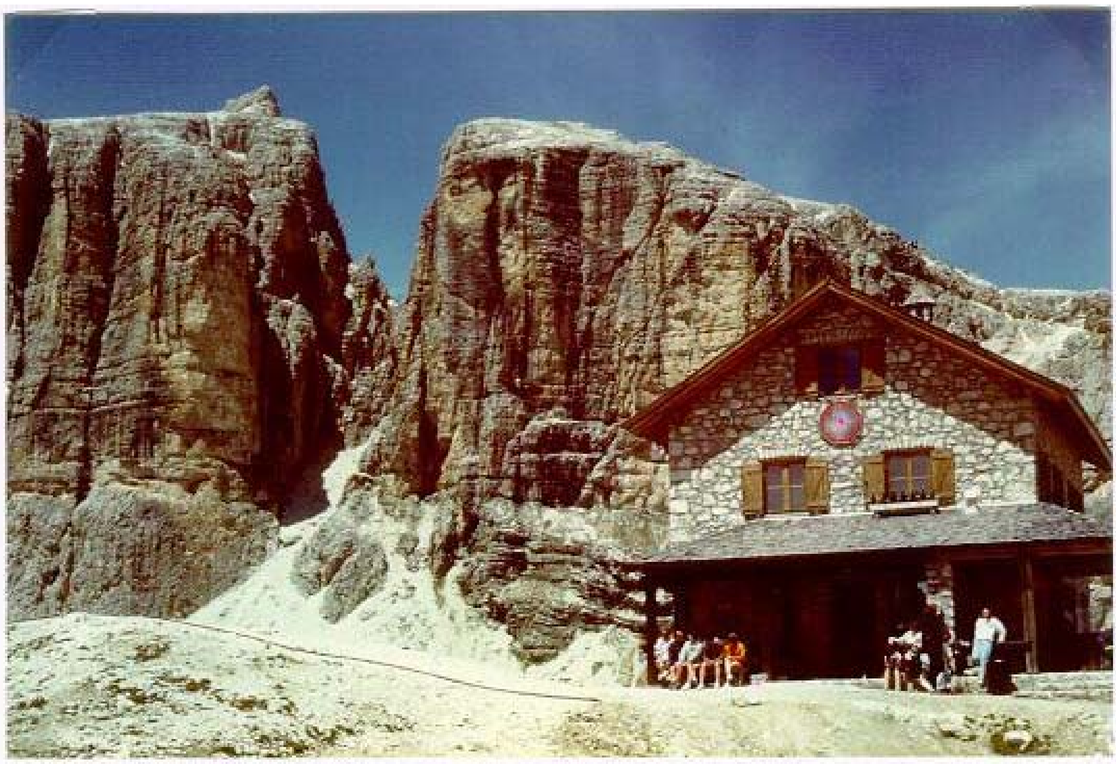


Photo 1. Kostner hut

<u>The tests</u>

At the end of the season, the performance of the ropes on the Dodero (number of sustained falls) as well as the mechanical properties of sheath and core filaments were tested.
It was obvious that the degradation of core filaments was going to be small compared to sheath filaments, due to the protection provided by the sheath.

Photo 2. The piece of folk art.

Synthesis of the results

Colour degradation.
The following general remarks apply:
- ropes decolourise much more rapidly under irradiation with the xenon lamp than under natural sunlight (**PHOTO 3)**
- on some ropes all colours fade uniformly whereas on other types of rope some colours remain stable and others disappear nearly completely (**PHOTO 4**)
- the ropes exposed at 2550 m on the Kostner hut lost more colour compared to those exposed at 1834 m on the Carestiato hut (**PHOTO 5**).

Decay in mechanical properties of the filaments.
A correlation was found – as expected - between the fading of colour and the mechanical properties of the filaments: the higher the loss of colour, the higher the degradation of the mechanical characteristics. This seems to concern mainly the brilliant colours and the colours a-la-mode, say acid green and fuchsia. This may be caused by either a rather vaguely described catalytic action due to the chemical structure of the colour itself, a process mentioned in literature [5], or by the reduction of the filtering action of the colour against UV.

Core and sheath.
The degradation of filaments due to UV radiation is more contained and more uniform throughout the core than in the sheath, irrespective of the type of exposure (sun/rain or xenotest). The larger sensitivity of the sheath fibres to radiation is due not only to the

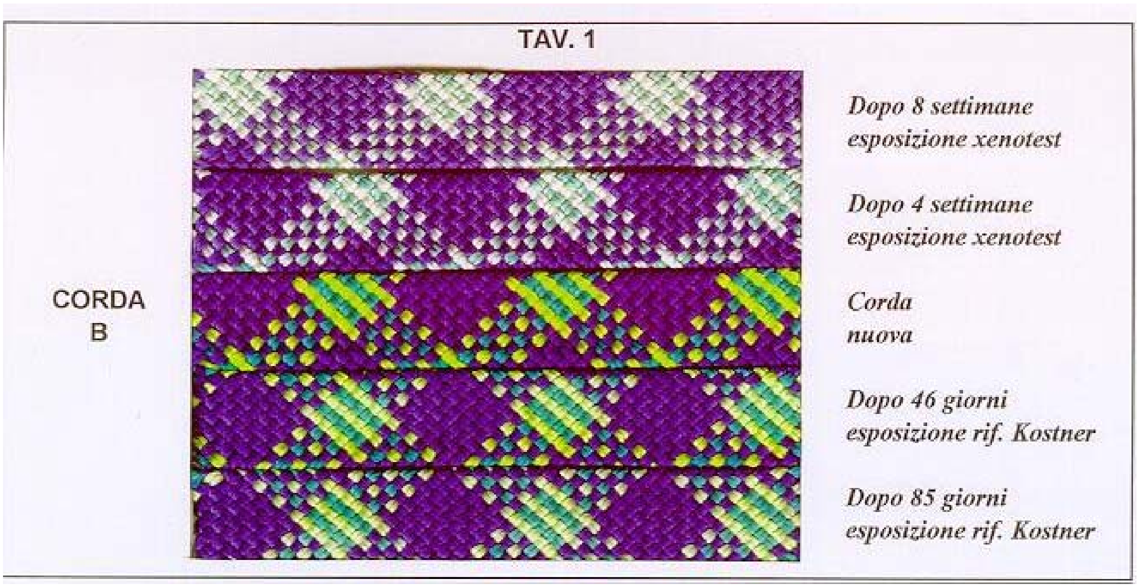


Photo 3. Rope 1.

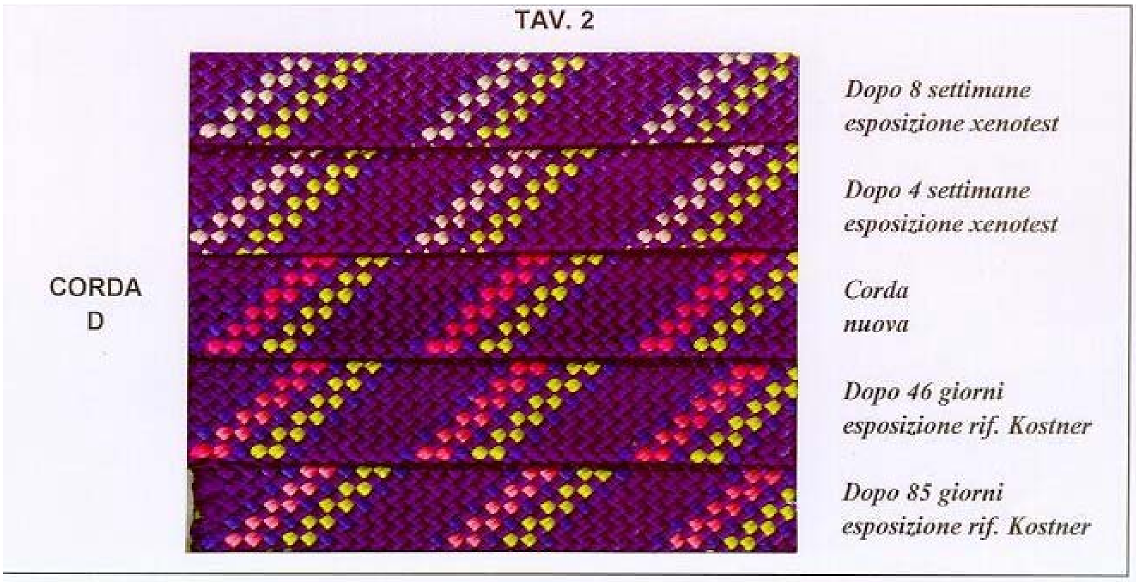
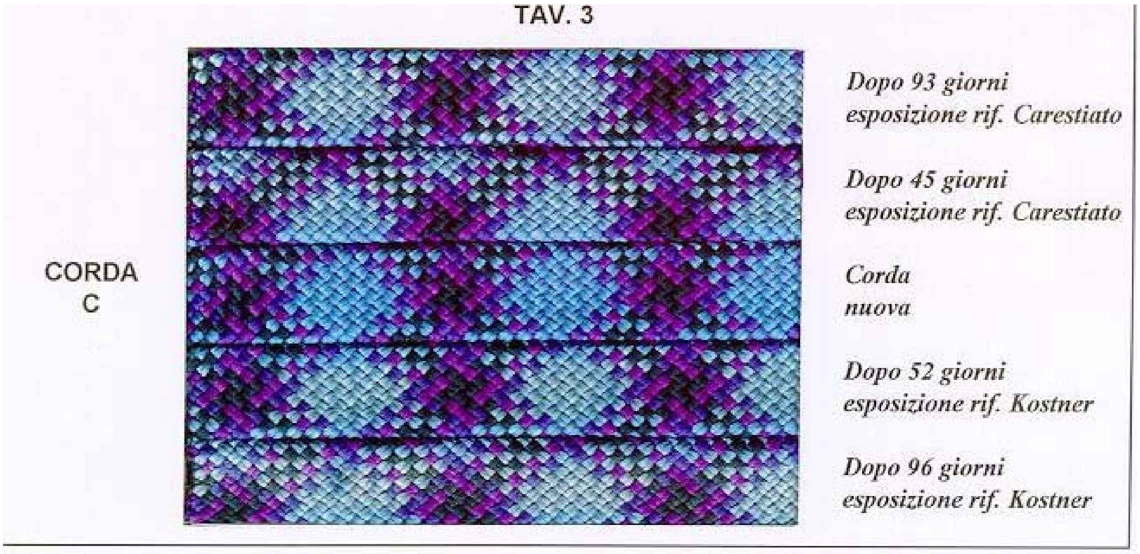


Photo 4. Rope 2

direct exposure to the sun but also, as already mentioned, to the characteristics of the colours present on the fibres.
As for the speed of photo degradation, it can be stated that one day exposure to xenon lamp is equivalent to about 5 to 10 days exposure to sunlight (see plots of **Figs 1a** and **1b**).

Degradation of the filaments and dynamic performance of the rope.
The obvious question of a mountaineer is, at this stage, how the degradation of the mechanical characteristics of the filaments affects the dynamic performance of a rope, i.e. the number of falls held on the Dodero. The answer is given by **Fig.2** which, notwithstanding the remarkable scattering of the data, shows a clear tendency: a relatively low degradation of the mechanical properties of the filaments (e.g. 10%) is sufficient to generate a large reduction in the number of falls (say 50%).

Photo 5. Rope 3.



The reduction of dynamic performance of the ropes is clearly shown in **Tab.1**, where the results of the Dodero tests (impact force, number of held falls and their variation in percentage) on the rope samples exposed on the Kostner and Carestiato huts are presented: after a three month exposure on the Kostner hut (altitude 2250 m) the ropes are still capable to hold an average 65% of falls; those exposed on the Carestiato hut (altitude 1834) on average hold about 85%: a lower degradation, consistent with the lower intensity of the UV radiation at lower altitude.

The comparison of **Tab.1** with **Fig.1a** shows that the decrease in dynamic performance of the ropes is larger than the difference in static strength of their filaments.
A tentative explanation of this behaviour can be given on the basis of observations of the Dodero tests: on the first fall, there is no significant difference in holding force (the maximum value of the force registered during the fall), compared to the new rope. This means that the ability of the rope to absorb energy on the first fall is about the same. However, a higher damage to the rope (compared to the new rope) must occur, which cumulates in the subsequent falls, leading to an overall lower number of falls sustained. This is quite probably due to an increased fragility of the filaments, due to sun/rain exposure.

This is cause of concern for mountaineers, since they must conclude that exposure to the sun is not only dangerous in itself, but also weakens the resistance to abrasion, which is not very good even in the new rope. However, it must be pointed out that in the case of high quality ropes, as the ones tested in our case (ropes designed to hold 9 – 10 falls on the Dodero) the general "health conditions" after three months of exposure are still good, i.e. the number of falls held on the Dodero is still higher than 5, the minimum number required by UIAA standards.

Part 2 - Wet and icy ropes may be dangerous [6]

The loss in performance of wet and/or icy ropes was already studied at the end of the sixties by the Spanish mountaineer Prof Josè A. Odriozola , and some years later by Pit Schubert, the Safety Officer of the German Alpine

Club (DAV). The results they obtained can be considered similar to the ones presented in this paper. In particular in his two studies on ropes which were saturated with water and then frozen, Odrionzola observed a reduction of 30% in **static resistance** in relation to the initial performance of the dry rope[7][8]. The fear that similar reductions could occur in wet ropes led the Austrian company Teufelberger to conduct tests, **this time dynamic, on the Dodero**, on ropes that were only soaked in water. The result: ropes that held 2 falls when new (the minimum imposed by the standards at that time) held only one, or even none, when wet[9].

Further research on this matter is now reported here, after thirty years. "Simple" ropes of three different makes, with a diameter of 10.5 cm, new as well as used, normal as well "everdry"(protected by water-repellent substances), were used.
Samples of these ropes underwent tests on the Dodero machine, to asses their dynamic performance, after the following treatments:
not treated (reference rope)
wet (at normal temperature)
soaked in water, then frozen
soaked, then dried.
The soaking time was 48 hours. After each treatment, weight and length of each sample were measured in order to investigate correlations with the dynamic performance of the sample.

<u>Results</u>

Wet ropes

The results, given in **Table 2**, highlight the alarming effect of water contents on the dynamic performance of the ropes. The presence of water notably affects the number of falls held on the Dodero, which is reduced to about **1/3** of the initial value. This relative decrease in performance was found on new as well as used ropes, and also in both normal and "water-proof" ropes ("waterproofing" seems to prevent water from sticking to the surface of the threads but not to stop water from being absorbed in the polymer molecules). It is interesting that the effect of water is remarkable also in case of brief immersion (2 hours) and even – though not so strong - in the case of a simple splashing of the rope with water.

Such a behaviour is in accordance with literature[10]: the presence of water in nylon greatly lowers its Tg [b] ,the "glass temperature", i.e. the glass transition temperature of the material: water acts like a plasticiser, since it deeply modifies both the mobility of the amorphous part of the macromolecule and the characteristic temperature of mechanical relaxation of the material. This means that, as expressed in relevant literature [10], *"in many respects, the addition of water to nylon is equivalent to raising its temperature substantially"*. In other words: testing a wet rope on the Dodero at normal temperature is about equivalent to testing a dry rope at 70 – 80 °C, conditions which lead to a loss in performance.

It is interesting that the impact force on the first Dodero fall is significantly larger (5 – 10 %) after wetting, as if the rope had become "more rigid" than the dry one. This could be due to increased fibre-fibre friction (not to be undervalued in the presence of water) as well as to the elongation of the rope [the average is 3 – 5%] found in the wet ropes immediately after removal from water (a rope that is already slightly stretched is more resistant to strain; on the Dodero a rope is stretched by 30 – 35%, therefore a stretching of 3 – 5 % is not negligible).

Frozen ropes

The results have been notably better compared to wet ropes. There is a smaller reduction ("only" about 50%) of the dynamic performances and a reduction (about 10%) of the impact force at first fall. A warning must be given here concerning the meaning of this test: the ropes could be kept in a frozen state only during the initial phase of the test, due to the warming up caused by the heat developed during the fall arrest and the influence of the surrounding temperature (20°C).

We may dare to guess that if we had been able to maintain the rope frozen during the whole test the performance could have been even better, maybe almost as good as that of the dry ropes. The sample would in fact have been tested at a low temperature, such that the crystalline structure of the wet rope, in particular the mobility of its amorphous part, would have been the same as that of a dry rope at normal temperature.

Last but not least, a word of comfort to the mountaineers. After being soaked and dried, the rope seem to reacquire almost completely its original characteristic, as described in literature. The number of falls held on the Dodero goes back to the initial value, whereas the impact force diminishes a little, due to the slight shrinking of the rope (4%).

It is interesting to note that the almost complete recovery of the initial performance takes place also after repeated soaking and drying, as long as the ropes are dried in a cool, aired and shaded place; if they are dried under direct sun light a notable loss of performance occurs, obviously due to the influence of UV radiation discussed previously. It has to be pointed out that complete drying required the exposure to sunshine for 4 weeks, a non-negligible period concerning sun radiation.

The effects of wetting and freezing are summarised in the attached **HISTOGRAM**.

<u>Conclusions</u>

It is hoped that the mountaineers grasp the importance of the phenomena described here.

It must be taken into account that the presence of water and/or ice in ropes used for mountaineering can seriously impair their performance. A rope considered in "good conditions", maybe because it is supposed to still hold 4 – 5 falls on the Dodero when dry, can only hold 1 or 2 falls when soaked with water, for example due to a brief downpour, a quite frequent event in the mountains.

Less critical seems to be the effect of sunlight; however, it is likely that the UV radiation reduces the already scarce resistance to abrasion, thus favouring the breakage of sheath filaments by rubbing on rocks and of core filaments by penetration of micro crystals, let alone the damage done by abseiling and belying devices.

The mountaineer should realise that it is mandatory not only to use ropes which are good or in perfect conditions, but also to substitute his old, trusted rope much more often than we are now in the habit of doing!

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[6] Gigi Signoretti - *L'acqua che non ti aspetti* - Rivista del CAI, genn-febbr 2001, pp. 74-79.

[7] Josè A.. Odriozola - *Estudios previos para ensayos de cuerdas a baja temperatura* - Revista Peñalara, abril-junio 1968, pp. 37-40.

[8] Josè A. Odriozola - *Comportamiento de una cuerda de montaña a baja temperatura* - Revista Peñalara, enero-marzo 1969, pp. 14-21.

[9] Pit Schubert - *Was halten nasse und vereiste Seile?* - Sicherheitskreis im DAV; Tätigkeitsbericht 1971-1973, pp. 197-206.

[10] *Nylon Plastics*, edited by Melvin I. Kohan - Plastic Department; E.I. du Pont De Nemours and Co., Inc.

Notes

[a] The Dodero machine is used to test the dynamic performance of mountaineering ropes according to UIAA standards. A minimum number of 5 falls of a standard mass must be sustained.

[b] 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°C, but for wet nylon it goes down to about 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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TABLE 1 - INFLUENCE OF SUNLIGHT ON THE DYNAMIC PERFORMANCE OF ROPES

Exposure during summer season at Carestiato hut, 1834 m, and at Kostner hut , 2550 m

Rope	DODERO TEST	NEW ROPE (REF.)	CARESTIATO HUT		KOSTNER HUT	
			AFTER 45 DAYS	AFTER 93 DAYS	AFTER 52 DAYS	AFTER 96 DAYS
A	Impact force daN	784	778	772	781	759
	Nr. of falls	**13,0**	**11,5**	**11,0**	**12,0**	**10,0**
	Residual nr. of falls %	100,0	88,5	84,6	92,3	76,9
B	Impact force daN	967	977	977	949	960
	Nr. of falls	**10,0**	**9,5**	**9,0**	**7,0**	**5,5**
	Residual nr. of falls %	100,0	95,0	90,0	70,0	55,0
C	Impact force daN	937	945	953	944	933
	Nr. of falls	**13,0**	**10,5**	**9,5**	**7,0**	**6,5**
	Residual nr. of falls %	100,0	80,8	73,1	53,8	50,0
D	Impact force daN	1003	990	1002	1010	981
	Nr. of falls	**12,0**	**12,0**	**10,5**	**8,5**	**6,5**
	Residual nr. of falls %	100,0	100,0	87,5	70,8	54,2
E	Impact force daN	860	851	854	828	852
	Nr. of falls	**12,7**	**11,0**	**10,5**	**9,5**	**9,0**
	Residual nr. of falls %	100,0	86,6	82,7	74,8	70,9

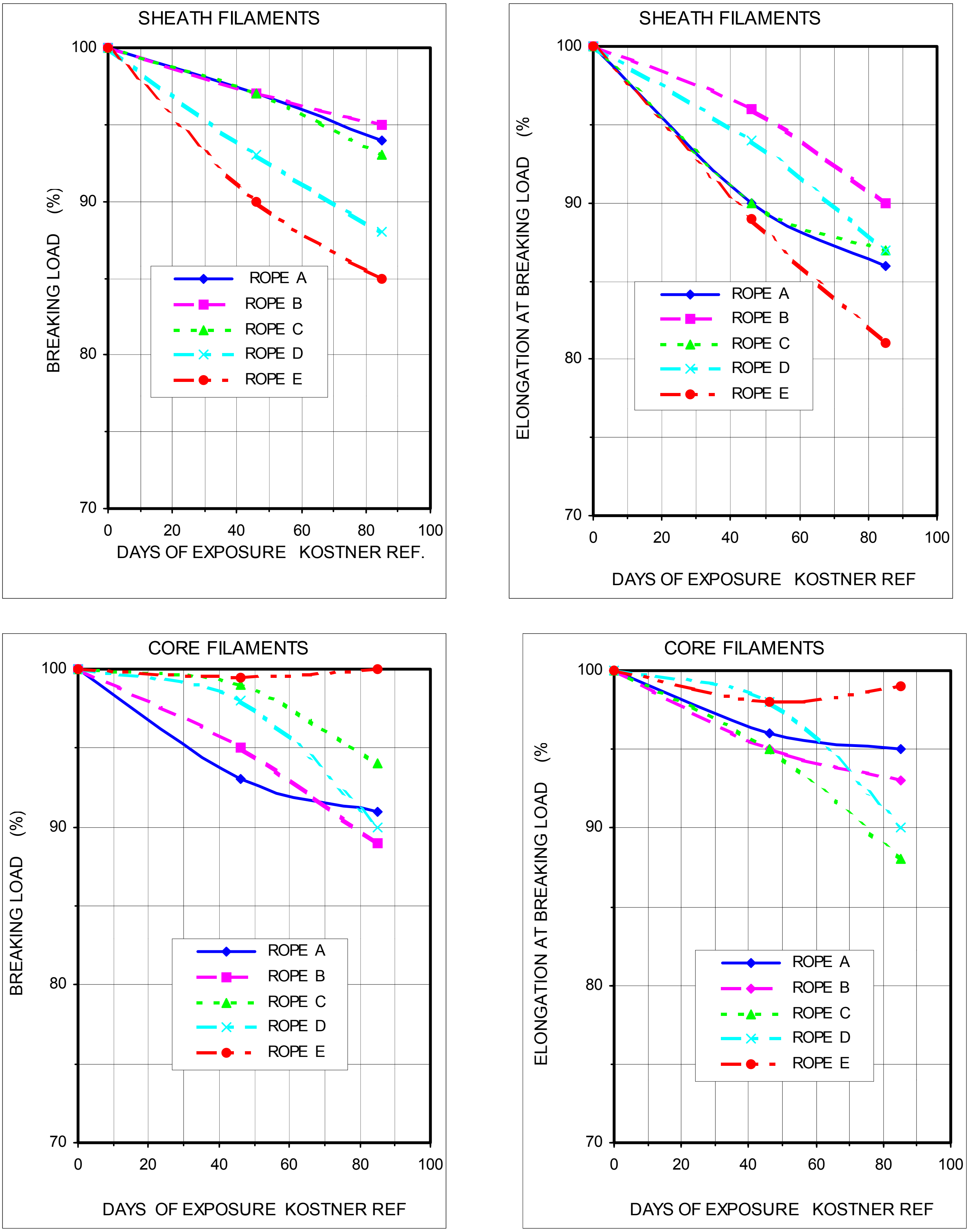


Figure 1a. Deterioration of the mechanichal characteristics of the threads of sheath and core, due to the influence of sunlight. Exposure at Kostner refuge at Vallon, 2550 m.

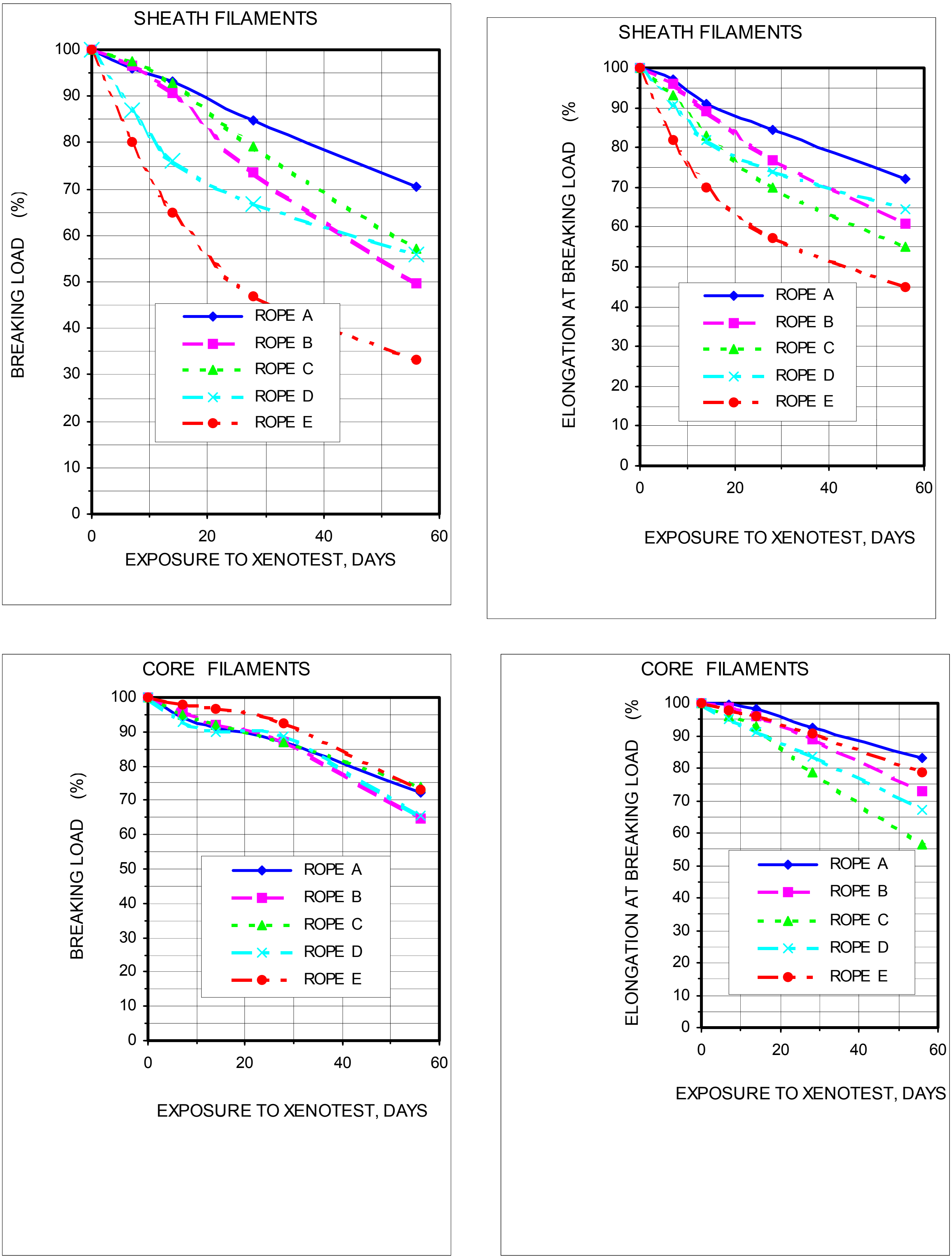


Fig. 1b. Deterioration of the mechanical characteristics of the threads of the sheath and the core after the xeno test

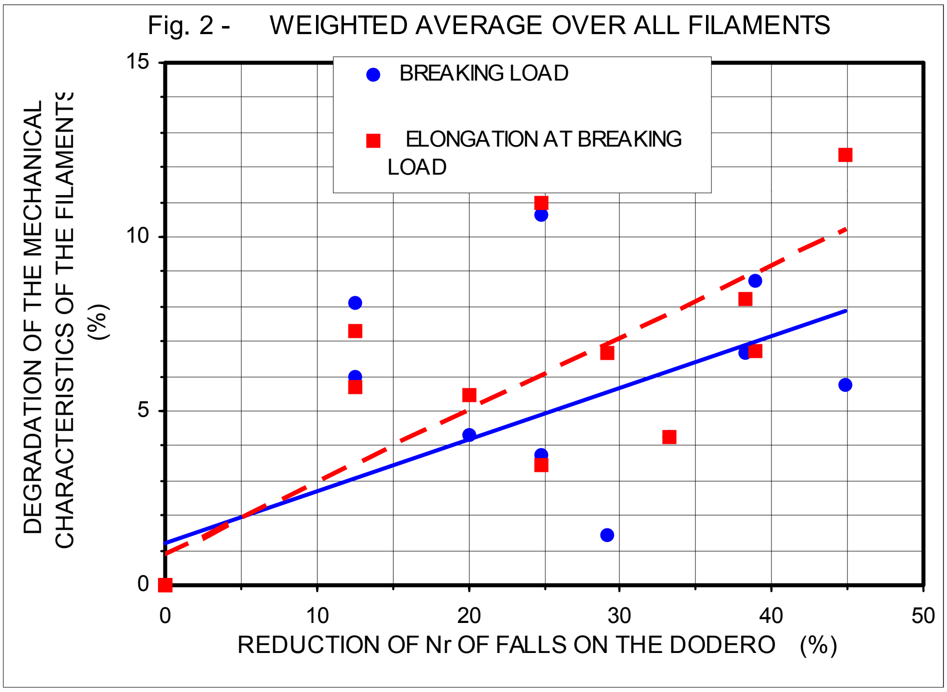
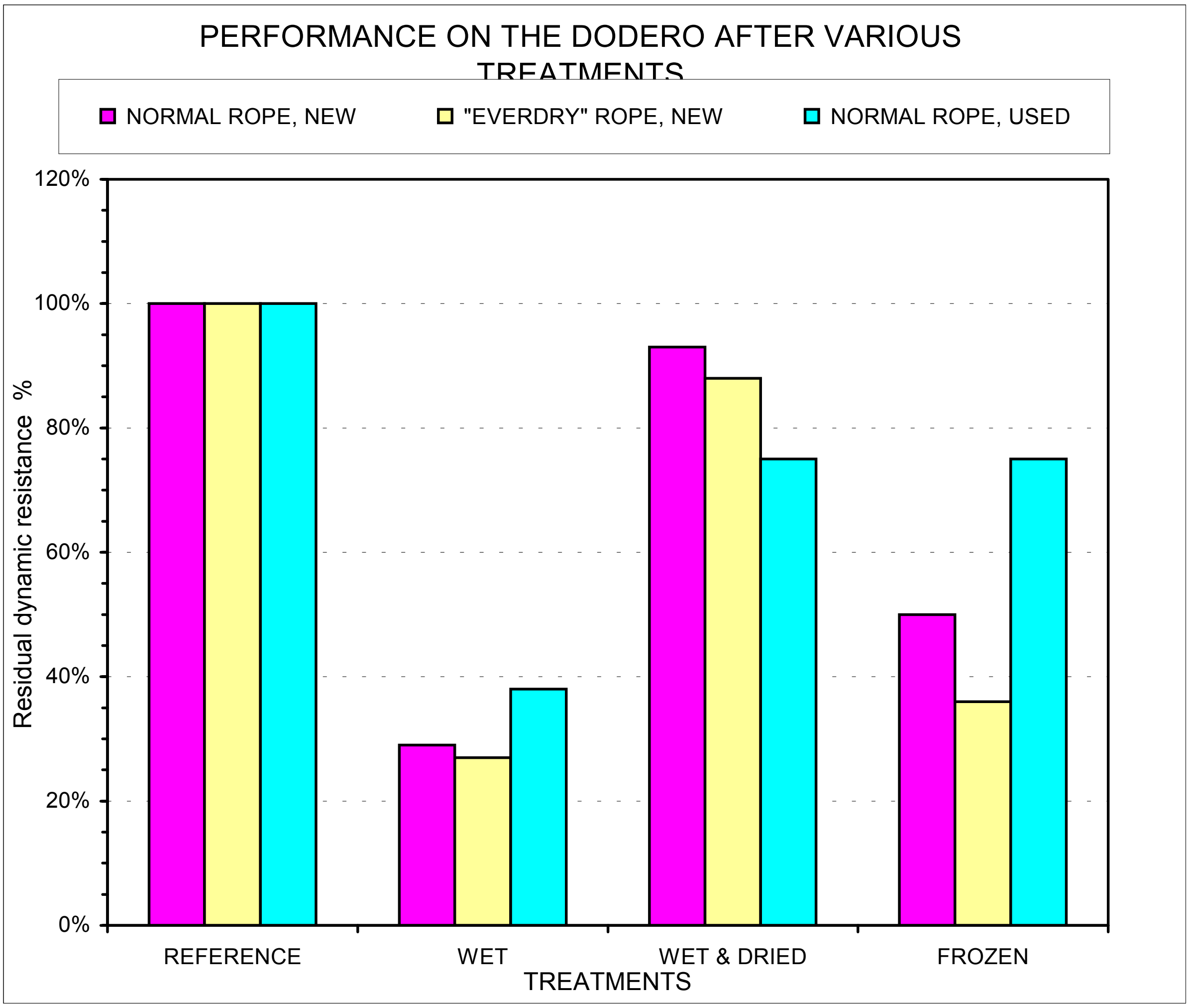


Fig. 2 - WEIGHTED AVERAGE OVER ALL FILAMENTS
BREAKING LOAD
ELONGATION AT BREAKING LOAD
DEGRADATION OF THE MECHANICAL CHARACTERISTICS OF THE FILAMENTS (%)
0
5
10
15
0
10
20
30
40
50
REDUCTION OF Nr OF FALLS ON THE DODERO (%)

	TEST	Rope NEW	Rope NEW	Rope USED
NOT TREATRED	**Falls on the Dodero**	**8**	**11**	**4**
(reference)	**Impact force daN**	**886**	**946**	**950**
WET	**Falls on the Dodero nr**	**2,3**	**3**	**1,5**
	Impact force daN	**926**	**1022**	**1052**
In water for 48 hours	Falls variation	-71%	-73%	-62%
	Impact force variation	+5%	+8%	+11%
	Weight variation	+45%	+42%	+59%
	Length variation	+4%	+2%	+5%
	Falls on the Dodero nr		**3**	
WET	**Impact force daN**		**984**	
Soaked for 2 hours	Falls variation		-73%	
	Impact force variation		+1%	
	Falls on the Dodero nr		**5**	
WET	**Impact force daN**		**990**	
With splashes of water	Falls variation		-55%	
	Impact force variation		+2%	
WET & DRIED IN NORMAL CONDITIONS	**Falls on the Dodero nr**	**6**	**9,4**	
	Impact force daN	**867**	**812**	
	Falls variation	-25%	-15%	
	Impact force variation	-2%	-4%	
	Weight variation	-	-1%	
	Length variation	-	-4%	
WET & DRIED IN "EXTRA-DRY" CONDITIONS	**Falls on the Dodero nr**	**9**	**10**	**3**
	Impact force daN	**785**	**826**	**861**
	Falls variation	+12%	-9%	-25%
	Impact force variation	-11%	-13%	-9%
	'Weight variation	-3%	-3%	-3%
	Length variation	-7%	-8%	-3,5%
4 CYCLES OF SOAKING	**Falls on the Dodero nr**		**12**	
	Impact force daN		**860**	
AND DRYING UNDER COVER	Falls variation		+9%	
	Impact force variation		-7%	
4 CYCLES OF SOAKING AND DRYING IN SUNLIGHT	**Falls on the Dodero nr**		**8**	
	Impact force daN		**860**	
	Falls variation		-27%	
	Impact force variation		-9%	
FROZEN Wet and kept at -30°C for 48 houts	**Falls on the Dodero nr**	**4**	**5**	**3**
	Impact force daN	**805**	**898**	**819**
	Falls variation	-50%	-64%	-25%
	Impact force variation	-9%	-5%	-14%

Note: these data are the average over three specimen


PERFORMANCE ON THE DODERO AFTER VARIOUS TREATMENTS
NORMAL ROPE, NEW
"EVERDRY" ROPE, NEW
NORMAL ROPE, USED
Residual dynamic resistance %
120%
100%
80%
60%
40%
20%
0%
REFERENCE
WET
WET & DRIED
FROZEN
TREATMENTS