An Assessment of the Effects of Environmental Conditions on the Performance of Dynamic Climbing Ropes

Matthew Smith

200115773

Department of Mechanical Engineering

BEng Hons Mechanical Engineering

Supervisor: Dr A. J. McLaren

Project Number: 2004056

2005

Abstract

Research into the effects of environmental operating conditions on the breaking strength of dynamic climbing ropes has been limited. Studies have been carried out observing the effects of a small number of conditions. The aims of this study were to provide data for a number of other environmental conditions including: salt water treatments, high ambient temperatures, sand and varying fresh water and freezing treatments. This would then highlight conditions which are most degrading and require further research into the mechanisms of the degradation.

It was also intended to study two samples that had experienced real use and to compare their comparative conditions.

Shackles used for the testing of high strength fabric belts were used to test the ropes on a standard tensile testing machine. This allowed the testing of a large number of ropes such that a statistical analysis could be conducted. In total 87 tests were carried out on 14 different rope conditions.

It was found that some treatments degraded a ropes strength and extensibility characteristics markedly. Conclusions were also drawn as to the effect of appearance, treatment intensity, area of rope and dependence on sample set size. Mechanisms of degradation were suggested and areas for further study highlighted.

Nomenclature

N = sample size

$\sigma 1$ = first standard deviation

$\sigma 2$ = second standard deviation

X = sample mean average

1. Introduction

Data concerning the time at which a rope should be replaced is, at best, hazy. It is generally said to depend on the type, length and intensity of use. It has been found that few studies have been carried out into the effects that the environmental operating conditions may have on the degradation of a rope's performance. These studies have been fairly narrow in their scope and have not taken into account many obvious environmental hazards. They have looked mainly at the effects of UV degradation water treatments and ice contamination **[1]**. Must studies have been concerned with analysing a rope's performance as it falls over a sharp edge, the time at which failure is most likely to occur **[2][3]**. It is possible that the environmental conditions to which the rope has been exposed will have a bearing on this sharp edge performance. It is the intention of this study to produce data that will further the knowledge of how the environment affects the performance of what is, in most cases, a climber's only means of safety.

In order to produce a valid study it was necessary not only to conduct research on samples conditioned in the laboratory but also to examine ropes that have been exposed to real environmental regimes. To solve this shortfall a sample of ropes was subjected to a period of 13 weeks of a West coast of Scotland Winter. Two samples were also procured from the Royal Air Force Outdoor Activities Centre, Grantown-on-Spey, which had been used for the instruction of novice climbers. Both ropes were exactly the same save that their frequency of use and environmental operating conditions were different.

A study of these ropes would hopefully yield information as to how much effect the difference in operating conditions has had on the two ropes.

The study aimed to produce twelve different conditions in the laboratory from which it was hoped that the comparative level of degradation imposed by each treatment could be measured and ranked by use of a control sample. In total, 87 tests were carried out. It was desired to carry out more but time limitations meant that this would be impracticable. A statistical approach was employed to produce the ranking and judge whether a treatment was deemed to be significant.

Once a treatment is known to be significant it is clearly desirable to know by what mechanisms the treatment is causing the degradation. To this end it is endeavoured to suggest possible mechanisms for each degrading treatment and to suggest how this study may be modified, or another devised, such that these conjectures can be confirmed. Through the course of the study it was found that further studies had to be undertaken or that some studies had to be dropped, therefore whilst a plan was devised from the outset it was found that following this plan to the letter proved almost impossible.

2 Procedure

2.1 Sample preparation

All laboratory conditioned samples were produced from a 9mm, Polyamide 6, half rope manufactured by Edelrid (for the rope's technical data see appendix). A further two sample sets were produced from ropes procured from the R.A.F. Outdoor Activities Centre. Table 1 details all the samples that were tested. It shows which rope each sample set was made from, what condition they were subjected to, the relative time dependency of the treatment and the subsequent conditioning period.

Sample set	Rope	Condition	Relative time dependency	Condition period
0.1-0.6	Old half	10yr service life	0	0
1.1-1.6	Rocky half	None	0	0
2.1 -2.4	Rocky half	None	0	0
3.1-3.8	Rocky half	None	0	0
4.1-4.6	Rocky half	Dry frozen	2	7 days
5.1-5.6	Rocky half	Heat treated	5	14 days
6.1-6.8	RAF CC5	1yr service life	5	60 days
7.1-7.8	RAF CH8	1yr service life	5	19 days
8.1-8.6	Rocky half	Wet frozen	3	7 days
9.1-9.6	Rocky half	Wet dried	4	14 days
10.1-10.6	Rocky half	Roof samples	5	91 days
11.1-11.6	Rocky half	Wet salted	4	14 days
12.1-12.6	Rocky half	Dry salted	4	14 days
13.1-13.6	Rocky half	Sand treated	1	7 days
14.1-14.6	Rocky half	Core only	0	0
15.1-15.6	Rocky half	Aged samples	5	176 days
16.1-16.6	Rocky half	Fresh wet	4	7days

Table 1: listings of all samples tested with rope, condition time dependency and conditioning period

The relative time dependency determined how long each sample should be treated for. A low time dependency required little conditioning time to achieve its effect. The total time available for testing also had an influence on the conditioning period that could be used.

2.1.1 Old half rope

The old half rope was obtained from Dr A. J. McLaren. This rope was approximately 10 years old and contained many surface defects. It was used for configuration tests which determined the best way with which to constrain and load the samples.

2.1.2 Baseline tests

Samples 2.1-2.4 and 3.1-3.8 were tested in an "as new" condition. This allowed the measurement of the baseline performance of the rope in terms of load carrying capacity and extensibility.

2.1.3 Dry frozen

Sample set 4 was subjected to a 7 day freezing treatment. The samples were loaded into a chest freezer, again in an "as new" condition, which was set at a temperature of -25°C. After the conditioning period they were removed and immediately tested such that the minimum level of thawing was incurred

2.1.4 Heat treated

The heat treated sample set was subjected to a temperature equivalent to the maximum ambient temperature that a rope would likely encounter. A temperature of 50°C was set in a fan assisted oven. This treatment was deemed to be highly temperature dependent so a conditioning period of 14 days was applied.

2.1.5 Wet frozen

This set was subjected to the same freezing treatment detailed in section 2.1.3. However before freezing the samples were soaked in a container of fresh water for a period of 24 hours. Again it was important that the time between removal from the freezer and testing was kept to a minimum. The ambient laboratory temperature was also noted such that any effect from this may be noted.

2.1.6 Fresh wet and wet dried.

Both of these sample sets were subjected to a 7 day immersion in a container of fresh water. The only difference being that the fresh wet samples were tested immediately after removal from the water whereas the wet-dried samples were left to dry in a cool dark environment for a further 7 days.

2.1.7 Wet and dry salted

This treatment was carried out in exactly the same way as in 2.1.6. The only difference being that the water used for conditioning was salt water. This salt water was designed to replicate that which may be found around the shores of the U.K. As such an aquarium salt was used, mixed to a specific gravity of 1.022 using a hydrometer.

2.1.8 Sand treated samples

The sand conditioned samples were produced by firstly rubbing sand into the rope by hand and then leaving for a period of seven days entirely covered with sand before testing. The samples were removed from the sand environment 24 hours before testing and any excess sand on the sheath was shaken off.

2.1.9 Core only samples

In order to determine what proportion of load was carried by the core a set was prepared where a portion of sheath was removed from the centre of the sample. This left a section of sheath at either end so that the normal attachment method could be used. Care was taken not to damage any strands of the core such that the result would be invalidated.

2.1.10 Aged samples

In order to gauge any effects which ageing might have on the performance, a sample set was left untouched in a dark, dry cupboard for the period of the project. The samples were removed at the last available opportunity and tested as normal.

2.1.10 Roof samples

This sample set was left on the roof of the James Weir building for a period of 91 days. The conditions for the period were recorded using the University's weather station. The data deemed most relevant was that of the amount of rainfall recorded and the amount of UV radiation experienced. Ultra violet radiation was found to have a detrimental effect on a rope's performance in a study by Signoretti **[1]**. The total rainfall recorded was 505.4mm and a total radiation of 311762 kJ/m^2.

2.1.11 R.A.F. rope samples

Two rope samples were procured from the Royal Air Force Outdoor Activities Centre. These ropes were used in the instruction of novice climbers using a top roping technique. Both ropes were used for a period of exactly one year with rope cc5 being used a maximum of 63 times and ch8 a maximum of 19 times. Cc5 was used in a sea cliff environment and ch8 in an inshore cliff. These ropes were visually inspected and any defects noted with the use of a Macro Camera. They were then split into the appropriate lengths with the position of each rope in the original sample being noted. These ropes were both 11mm single ropes.

2.2 Test apparatus and method

The desired method for testing dynamic climbing ropes is detailed in British standard EN 892 **[4]**. This involves the use of a dynamic testing machine known as a DODERO. It was deemed that due to the expense and time required for the construction of such a rig it would be more suitable to use a slow speed tensile testing machine, a decision which is supported by a study by Casavola and Zanantoni **[5]**. In order to restrain the samples a pair of shackles was obtained, originally used for the testing of high strength fabric belts. Each shackle consisted of a solid steel drum of 110mm diameter. The drums were held in a pair of a parallel plates and a locking plate was attached to the plates. The ropes were secured to each shackle by wrapping the rope two times round the drum and using a locking knot to prevent the sample slipping through the locking plates, as shown in figure 1. The drums raised stresses in the ropes such that a true representation of the rope's strength was not obtained. It was not possible for the ropes to be restrained without applying stress but as this study aims to compare the relative strengths of the conditions it was decided that these stresses were not to the detriment of the study.

The shackles were loaded into testing machine **MOM35** and a distance of 200mm was set between the two shackles and two marks made 100mm apart in the centre of the gauge length. The sample was loaded to 1000Lbs and the distance between the two marks re-measured. This was used to compare the relative extensibilities of the samples. The samples were then loaded to failure. The failure load was recorded from the both the analogue and digital readings from the apparatus.

Fig 1: testing rig set up and shackle detail

3 Results and discussions

3.1 Analysis method

The breaking loads and extensions were recorded for each of the samples tested. The values for the breaking load were taken from an analogue scale as the digital readings were taken only once every 3 seconds such that it was unlikely that a reading would be taken at the precise moment of failure.

The mean breaking loads and extensions were calculated from the data. It was decided that in order to determine whether a result returned was significant then the standard deviations in the sample sets should be compared. Charts were then constructed using the standard deviations as error bars; this allowed the comparison of each result against the baseline.

The standard deviation calculation was taken as the following **[6]**:

$$\sigma_1 = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}} \qquad (1)$$

If there was no overlap between the first standard deviations of two sample sets then a confidence level of 68% could be applied. If the second standard deviation errors displayed no overlap then this confidence rose to a level of 95%. It was decided that a confidence level of 68% would be satisfactory.

3.2 Results

The results returned from the analysis are described in the charts below. The data from which these charts have been drawn are shown in the appendix. A data number was allocated to each treatment to allow for easier data manipulation.

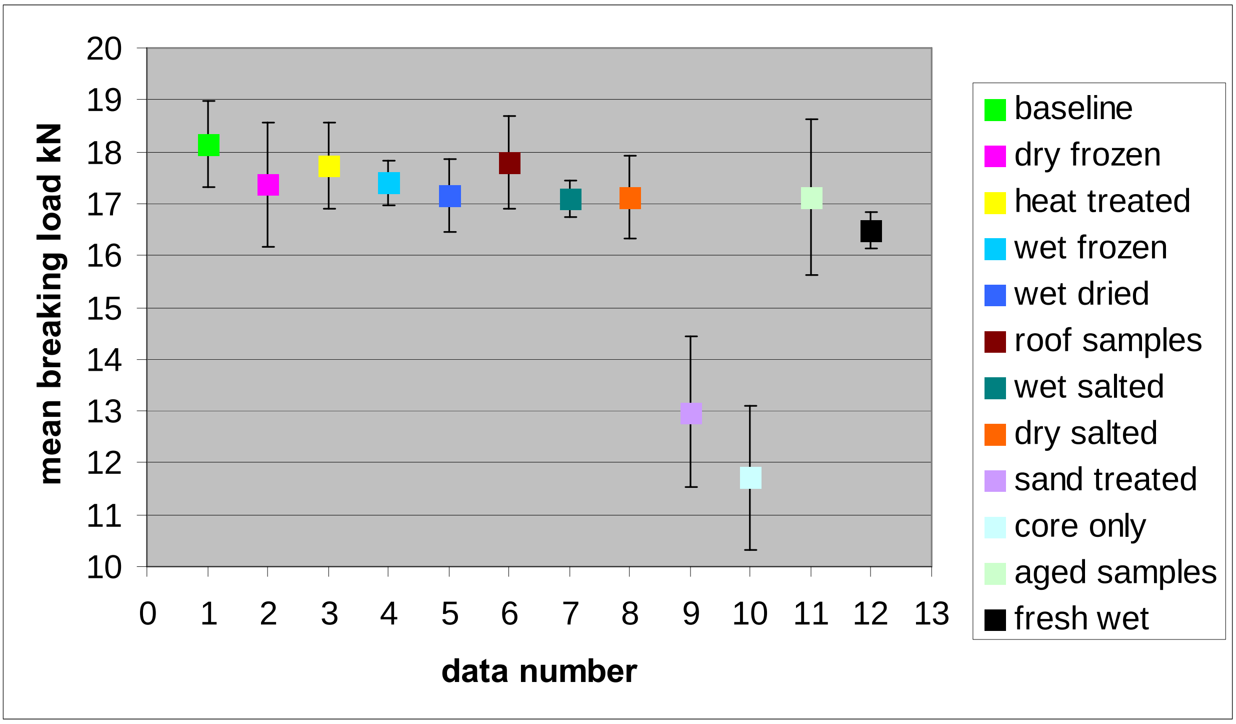

Chart 1: mean breaking loads of laboratory conditioned samples with error bars corresponding to 1 standard deviation

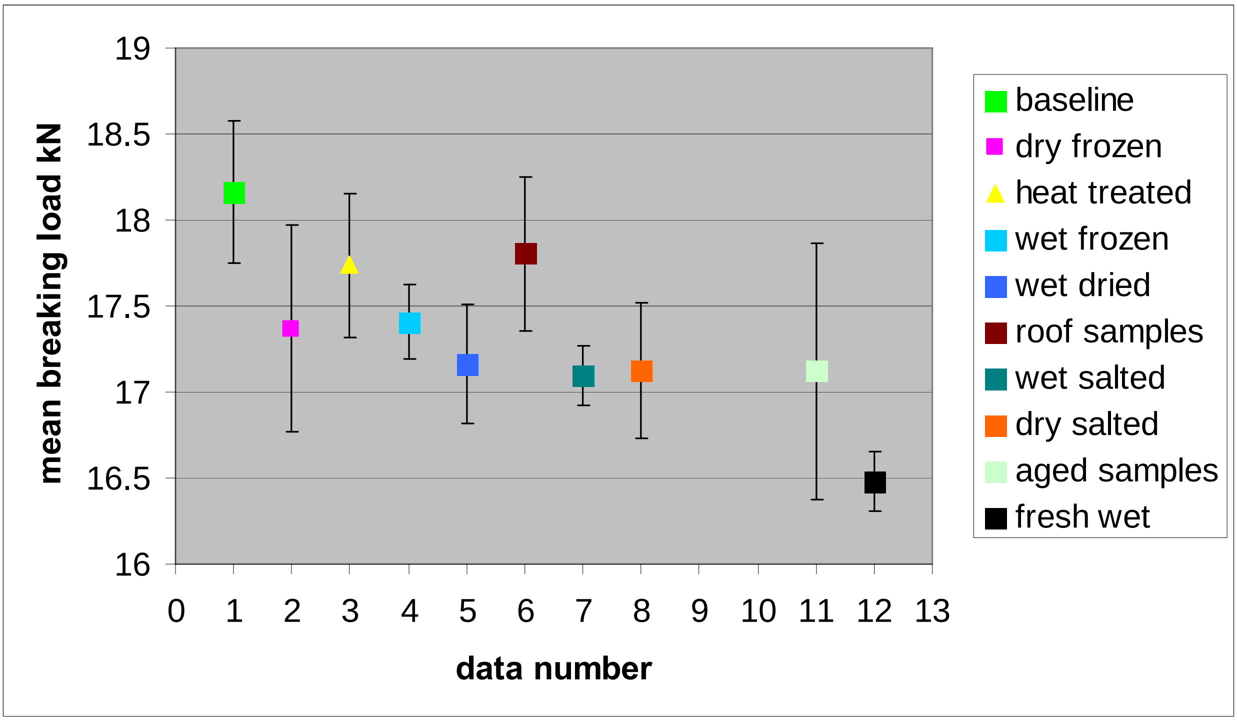

Chart 2: mean breaking loads with error bars corresponding to 1 standard deviation, not showing sand treated and core only samples

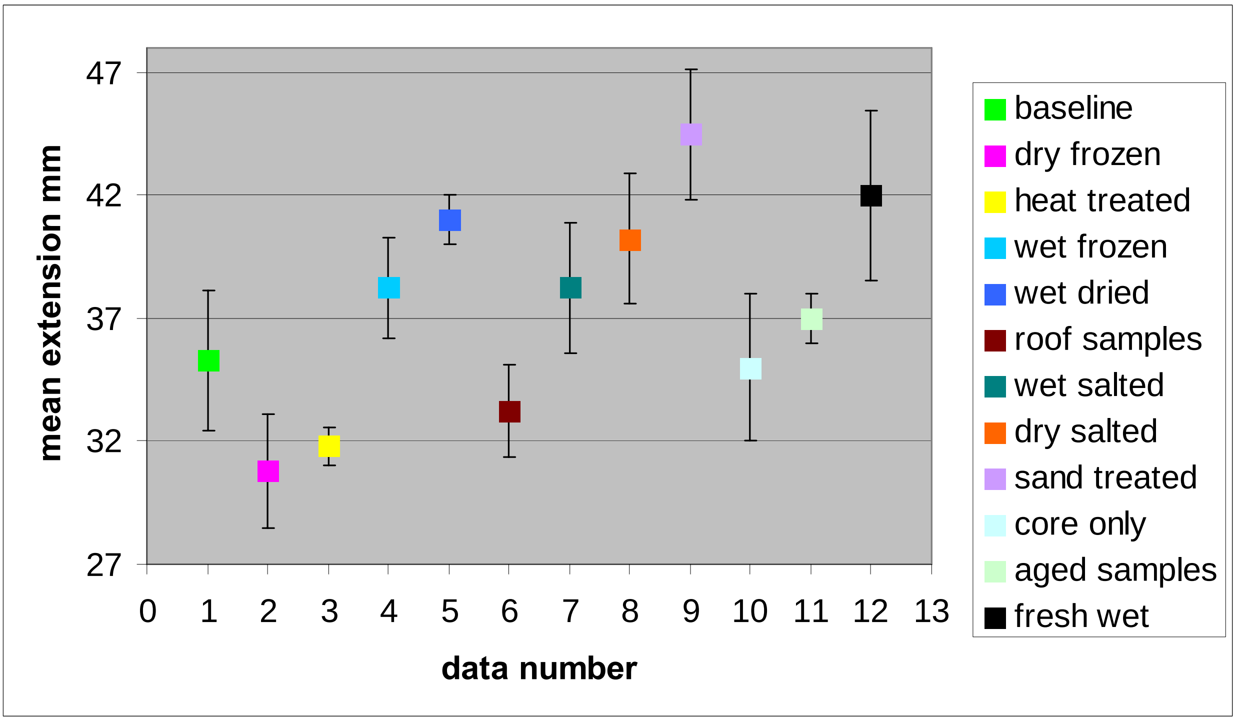

Chart 3: mean extensions at 1000lbs with error bars corresponding to 1 standard deviation

3.3 Discussions

3.3.1 Dry-frozen and heat-treated samples

From charts 2 and 3 it can be seen that the error bars of the mean breaking loads and extensibilities of both the heat-treated and dry-frozen samples overlap with those of the baseline sample. The difference in extension displayed by the heat-treated sample is on the verge of being significant and a larger sample set may have returned this result. However from the data gathered it should be said that neither the dry freezing of the rope nor a high ambient temperature produces a significant change in performance from a baseline sample.

3.3.2 Wet-frozen samples

From studies on wet-frozen ropes carried out on the DODERO **[1]** it was found that the thawing of the rope due to friction influenced the results obtained. It was hoped that a slow speed test may improve the accuracy of these results. However it was found that the use of a slow speed machine proved more problematic. Due to the difficulties in working the rope it was found impossible to break within the travel of the testing machine. It was decided that the ropes should be thawed entirely and dried so that any differences between this rope and the wet-dried samples could then be said to be due to the freezing process. From charts 2 and 3 it can be seen that the performance of the wet-frozen rope is significantly worse than the baseline, but not significantly different to that of the wet-dried samples. It can be seen that the mean values for the wet-frozen rope are closer to the mean baseline load than the wet-dried; this may be due to the freezing action inhibiting the plasticization effect that water has on polyamide 6 structures **[7]**.

3.3.3 Wet-dried and fresh-wet samples

It can be said with 95% confidence that the fresh-wet sample produces a significantly worse load carrying performance than the baseline. It can also be said that the fresh-wet samples produce a significantly worse load carrying performance than the wet-dried (68% confidence). This implies that the plasticization effects of the water are to some extent reversible. If it is assumed that the fresh-wet samples are to be 100% plasticized it can be inferred that the drying of a wet rope brings the polymers back to a level of being only 56% plasticized. This would then imply that if a rope becomes more than 44% plasticized then this plasticization is then permanent and non-reversible.

3.3.4 Wet and dry salted samples

It was found that both these samples performed worse than the baseline in load carrying capacity (68% confidence) but with no significant difference in extensibility. The fresh-wet sample had a significantly lower breaking load than the wet-salted set (68% confidence) this may imply that there is some mechanism which prevents the water plasticizing the polymers. The wet-salted and wet-dried are not significantly different from each other. This may imply that the plasticization which has occurred in the rope is still recoverable (it has not gone above 44%).

It is possible that there is an osmotic action in operation due to the high salt concentration in the solvent. The rope may act as a selectively permeable membrane, hindering the passage of salt into the core. This will mean that the salt is at a lower concentration in the rope and as such the fresh water which has penetrated the rope will seek to dilute the salt in the solution thereby leaving the rope. This could be confirmed by testing the rate of water absorption in fresh water and salt water solutions.

3.3.5 Sand-treated and core-only samples

The sand-treated and core-only samples' results were very similar, with both mean loads varying significantly from the baseline (95% confidence). The core did not return a significantly different extension, as may be expected, but the sand treated did. This could be accounted for by the fact that moisture from the sand was absorbed and that some plasticization may have occurred.

The difference in load can be accounted for in the core-only sample as only 62% of the rope proportion is carrying the load (for the rope's technical data see the appendix). Manufacturers guide books **[8]** warn against the effects of sand having a detrimental effect on the core of the rope. However this study found that it was in fact the sheath that suffers most from sand contamination. In all other tests it was found that the samples failed catastrophically, with sand however the sheath failed first and the core failed progressively after. This implies that in all the other samples the core was reaching its limit load before the sheath (this would be expected from the way the sheath is constructed) however here it is the sheath that is determining the strength of the rope.

The cause for this may be due to the increased friction between the drum and the rope caused by the sand. This friction may restrict the movement of the sheath whilst allowing the core to slip. There may also be a serration effect on the polymers due to the sharp, granular nature of the sand particles.

3.3.6 Roof and aged samples

Neither the roof nor aged samples returned significant differences in load or extension. This was as expected for the aged samples as previous studies **[9]** have shown age to have no effect. However a treatment period of 91 days of winter conditions may be expected to cause some degradation. This lack of degradation could be explained by the fact that the samples were held clear of the ground and so there was no prolonged exposure to water. The degradation due to UV light would be minimal at this time of year due to sky conditions and the position of the sun. This then may imply that it is not only the type of treatment that is applied to the rope but more the intensity of this treatment which determines the amount of degradation in performance.

3.3.7 R.A.F. rope samples

The data returned for the R.A.F. rope samples are shown in the appendix.

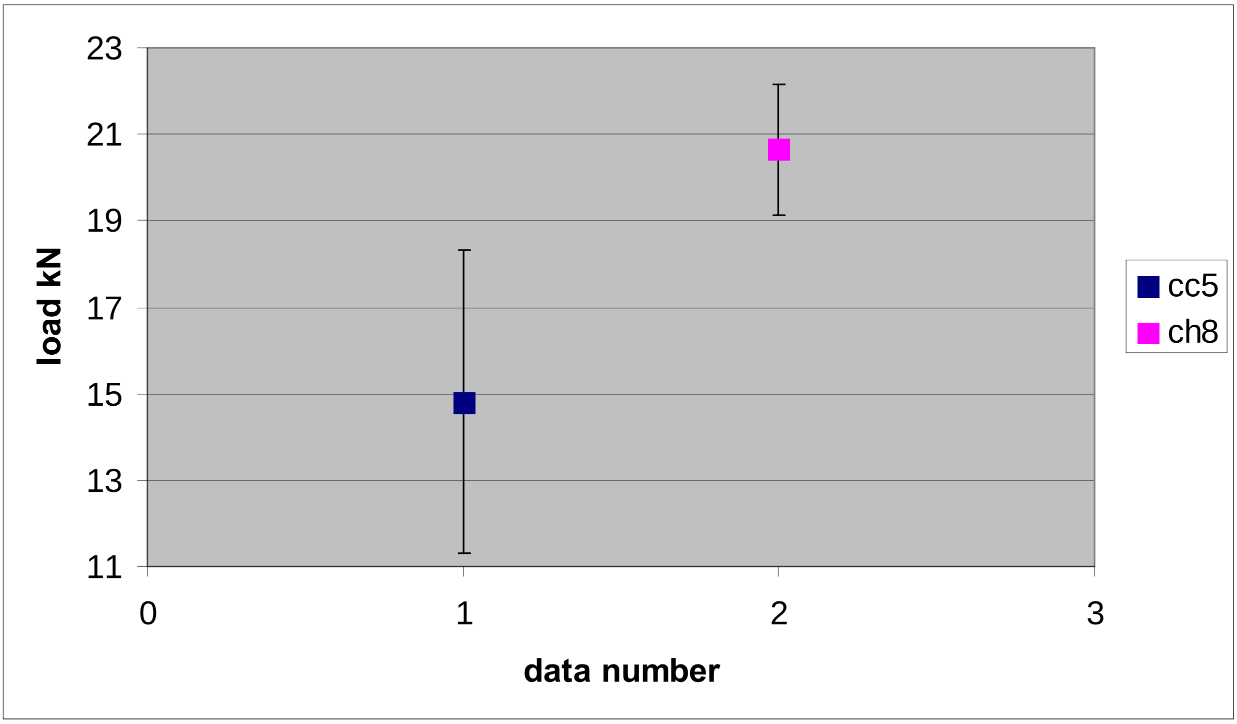

Chart 4: mean breaking loads of RAF rope samples with error bars corresponding to 2 standard deviations

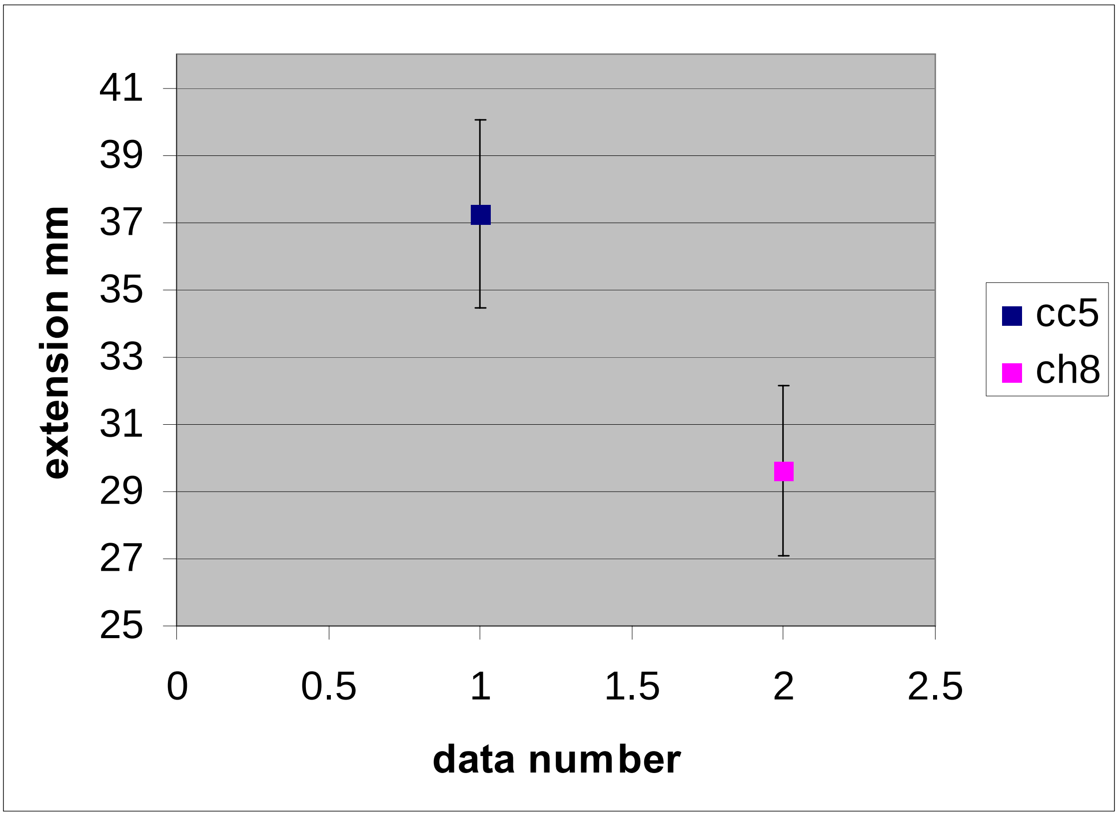

Chart 5: mean extensions of RAF rope samples with error bars corresponding to 1 standard deviation

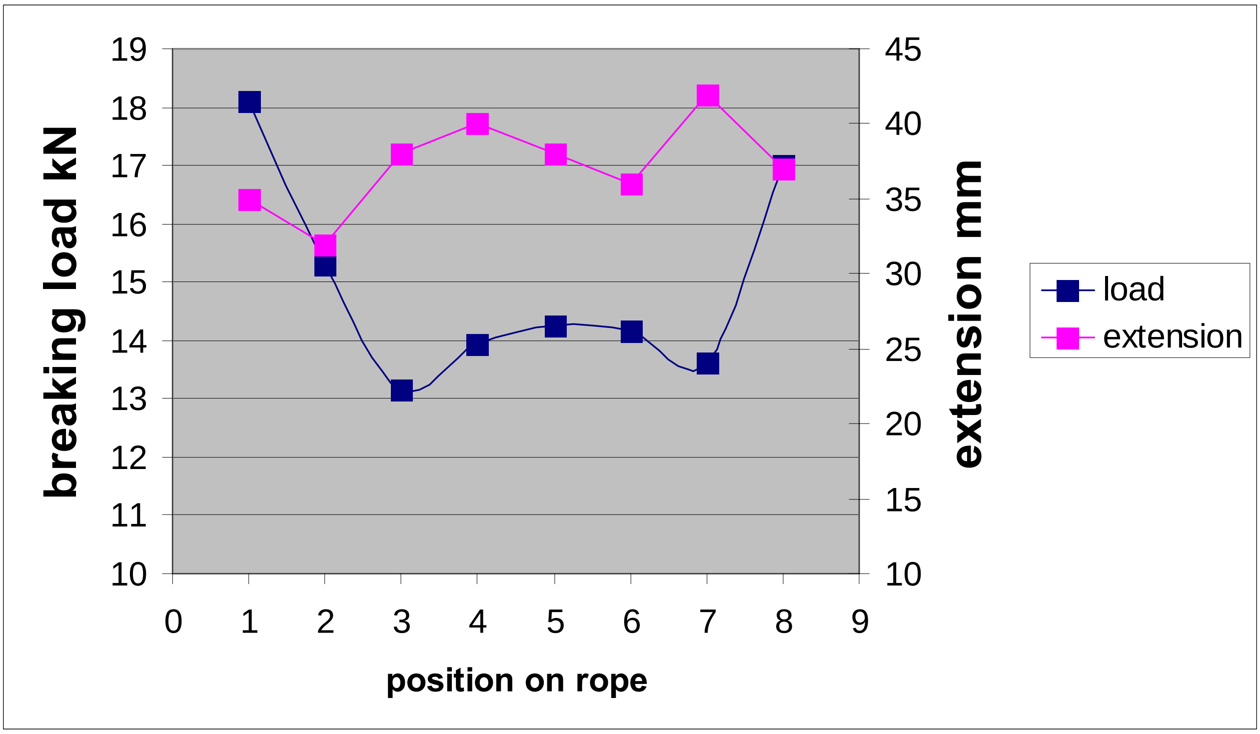

Chart 6: variance of load and extension through the length of rope cc5

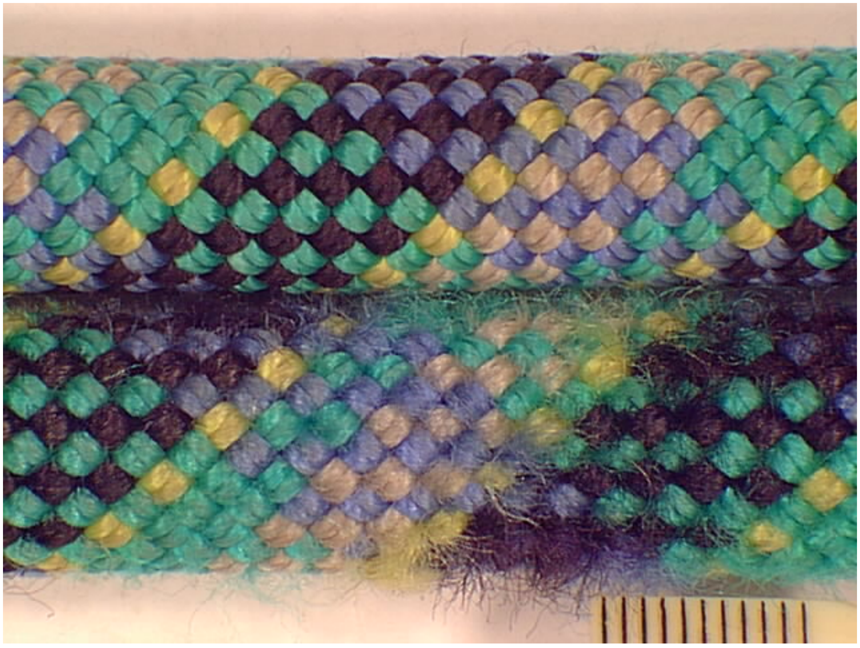

Figure 2: comparison of sheath damage between area 3 (top rope) and area 7(bottom rope)

It is clear that there is a marked difference in both load carrying capacity and extensibility between the ropes. This difference is most likely due to cc5 being used more than three times more often than ch8. The differing conditions experienced by both ropes, sea and inland, will also have an effect. It would be expected that the sand treatment that cc5 has experienced will have lowered the strength, but to what extent is uncertain. The significance of salt water treatment can be discounted, as it would be expected that the fresh water contacted by ch8 would produce more degradation than any salt water contamination in cc5.

The strength of the rope varies greatly through its length. Chart 3 shows that there is a possible correlation between the strength and extensibility of the rope. A low strength seems to be associated with a high extension, this compares well with the laboratory conditioned samples. The difference in strength could be due to the different loading regimes each area has encountered.

The most significant result returned comes from the comparison of figure 2 with chart 6. It can be seen that the sample from area 7 has suffered greatly from abrasion to the sheath and the sample from area 3 appears to be in good order. From chart 6 it is seen that area 3 is weaker than area 7. When compared with area 1, area 3 also appears less abraded but it is seen that area 1 is the strongest part of the rope. This implies that a poor sheath condition indicated a weak rope but the converse is not true, a good looking sheath does not necessarily indicate a strong rope.

4 Conclusions

The project was limited in its scope mainly due to time constraints. Given more time it is recommended that more samples be tested to decrease the effect of scatter in the data. It would also be beneficial to test more “real world” ropes such as the Air Force ropes, as these returned significant results. Whilst it is probable that the conditions tested will not weaken the strength of a rope by more than 10% it should be well noted that these factors, when combined with a fall situation, could lead to rope failure. This applies mainly to fresh water contamination and especially sand contamination where only 70% of the strength of the rope was maintained. Further studies may wish to investigate the mechanisms for these degradations including: osmosis in salt water treated ropes, plasticization and rate of water absorption in fresh water and salt water treatments and the failure of sheaths at low load due to sand contamination.

The most significant results returned were:

i. That the degradation due to environmental conditions depends on type, time and intensity.
ii. Intense fresh water treatment produces up to a 10% loss of strength almost immediately
iii. Some of the degradation is recoverable by drying the rope, although a portion will be permanently plasticized
iv. Water degradation is inhibited by the freezing of a rope

v. Water degradation is inhibited by the presence of salt

vi. Dry freezing or high ambient operating temperatures have no discernible effect on a rope’s performance

vii. The scatter in results is due largely to the variability of the treatment process.

viii. Samples treated with water exhibit less scatter than other treatments

ix. Sand contamination produces the biggest loss in performance

x. It is more harmful for sand to be in the sheath than in the core, which apparently contradict statements made in manufacturer’s guide books **[8]**

xi. Strength varies greatly through the length of a used rope

xii. Sheath damage may indicate low strength but perfect appearance does not indicate good performance.

Appendix

Material	Polyamide 6 (Nylon)
Diameter	9mm
Weight per meter	51g/m
Number of falls	12
Impact force	6.6Kn
Sheath slippage	0mm
Elongation in use	8.8%
Proportion of sheath	38%
Knotability	0.7

Table 1: Technical data for the Edelrid rocky half rope used for laboratory conditioning

Condition	Data Number	Mean Breaking Load kN (anlg)	σ1	σ2
Baseline	1	18.159876	0.41436111	0.82872222
Dry frozen	2	17.3691	0.60183963	1.20367926
Heat treated	3	17.73576	0.41770625	0.8354125
Wet frozen	4	17.4069	0.217144468	0.434288936
Wet dried	5	17.1612	0.34644272	0.69288544
Roof Samples	6	17.8038	0.44404946	0.88809892
Wet Salted	7	17.09505	0.1701	0.3402
Dry Salted	8	17.1234	0.39282912	0.78565824
Sand Treated	9	12.9843	0.726114289	1.452228578
Core Only	10	11.718	0.69288545	1.3857709
Aged Samples	11	17.1234	0.74361353	1.48722706
Wet Samples	12	16.4808	0.17322136	0.34644272

Table 2: mean breaking load and standard deviation r*esults returned for all laboratory conditions tested*

Condition	Data Number	Extension mm	σ1	σ2
Baseline	1	35.3	2.87	5.74
Dry Frozen	2	30.8	2.32	4.64
Heat Treated	3	31.8	0.75	1.5
Wet Frozen	4	38.25	2.061553	4.123106
Wet Dried	5	41	1	2
Roof Samples	6	33.25	1.892969	3.785939
Wet Salted	7	38.25	2.629956	5.259911
Dry Salted	8	40.25	2.629956	5.259911
Sand Treated	9	44.5	2.645751	5.291503
Core Only	10	35	3	6
Aged Samples	11	37	1	2
Wet Ropes	12	42	3.464102	6.928203

Table 3: extensibility results returned for all laboratory conditioned samples

Rope label	CC5	CH8
Start date	17-11-03	21-10-03
End date	16-11-04	20-10-04
Times used (max)	63	19

Table 4: R.A.F. rope information

sample	mean breaking load kN	1 st dev	s st dev
cc5	14.81382	1.74870987	3.49742
ch8	20.6577	0.75703879	1.514078
sample	**mean extension mm**	**1 st dev**	**2 st dev**
cc5	37.25	2.810694	5.621388
ch8	29.625	2.529822	5.059644

Table 5: results returned for the mean breaking load and extension of RAF rope samples

Acknowledgments

The author would like to thank his supervisor, Dr. A.J McLaren, for his continual help and guidance over the course of the study.

Thanks are extended to Mr. A. Crockett who helped to run the testing machinery throughout the whole of the study.

Sgt. P. Gray of the Universities of Glasgow and Strathclyde Air Squadron and Mr A. Wells of the R.A.F. Outdoor Activities Centre, Grantown, for their advice and generosity in providing materials for the study

Mr. E. Duncan, Mr C. Cameron and the technicians who provided advice and support with laboratory equipment and testing facilities.

Ms. S. Mcvie, student, and Mr. G Bartlett of the national meteorological Library and Archive for the environmental information they kindly provided.

References

[1] SIGNORETTI, G., “The Influence of Water, Ice and Sunlight on the Dynamic Performance of Climbing Ropes”, La Rivista del Club Alpino Italiano, January/February 2001

[2] ZANANTONI, C. “Sharp-Edge Rope Testing: Status and Prospects”, Commissione Centrale Materiali e Tecniche, Torino March 2002

[3] Henkel, O. “Sharp Edge Testing of Rope”, Commissione Centrale Materiali e Tecniche, Torino March 2002

[4] BS EN 897 “Mountaineering equipment, Dynamic mountaineering ropes, Safety requirements and test methods”, October 1996

[5] CASAVOLA, P., ZANANTONI, C., “Rope Testing and Wear: Equipment of the CMT”, Commissione Centrale Materiali e Tecniche, 2003

[6] BOWKER, A.H. and LIEBERMAN, G.J., “Engineering Statistics”, Prentice Hall, 1972, 2nd Edition

[7] CALLISTER, W.D., “Fundamentals of Materials Science and Engineering”, John Wiley and Sons, 2001

[8] MAMMUT, “ROPE”, MAMMUT Sports Group AG, 2004

[9] BRESSAN, G., “Rope Wear in Climbing and in the Laboratory”, Commissione Centrale Materiali e Tecniche, Torino March 2002