An Assessment of the Effect of Water Absorption on the Mechanical Properties of Dynamic Climbing Ropes

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Abstract

From previous research it was found that dynamic climbing rope became plasticized during water soaking treatments, but this effect was partially reversed during drying. The aims of this study were to determine whether the plasticization of the rope becomes permanent over repeated wetting and drying cycles and what effect this has on the mechanical properties of the climbing rope. Absorption tests were also carried out to investigate the water absorption of the ropes during the wetting and drying cycles.

Two different samples of rope, one with dry treatment coating and one without were studied. The non-dry treated samples were conditioned in salt and fresh water, whereas the dry treated samples were only conditioned in fresh water. Dry treated samples were also subjected to wear conditioning. All samples were tested in Tinius Olsen 81000 slow tensile testing machine. Strength and extension results were obtained, from which strain and strand modulus results were calculated.

The results suggest the plasticization of nylon becomes permanent with repeated wetting and drying lowering the strength of the samples. Salt water samples retain the salt content of the water after drying though it does not adversely affect the strength of the rope. Dry treated samples do not seem to be affected by wear and water conditioning although it is felt further study in this area would be beneficial.

Nomenclature

n = Sample size

s = Standard deviation

x = Sample data

$\bar{x}$ = Sample mean

1.0 Introduction

A climber's lifeline is his rope, it is his only protection should he fall. The rope absorbs the energy from the fall, by stretching and reduces the force transmitted to the climber's body, saving him from injury. Modern climbing ropes are constructed from nylon 6 or nylon 66. From research it is known that water has detrimental effects on the strength of nylon **[1]**. However, there is little known about how water absorption affects dynamic climbing ropes and even less about the effects of usage on water absorption on dry treated climbing ropes, and the associated consequences for the mechanical properties.

Climbing can be split into three main activities: top roping, lead climbing and abseiling. A short explanation of each will be given for clarity. For top roping a fixed anchor point is set at the top of the climb, a rope is attached and the two halves are dropped to the bottom. The climber is tied into one end via his harness and his partner, known as belayer, secures the other end to his harness via a friction device, known as a belay device. In lead climbing the lead climber ties in to one end of the rope and the belayer passes a few metres of rope through the belay device before attaching himself to it. As the lead climber climbs he places gear or protection, temporary anchor points, which the rope is clipped into. These are designed to take the weight should the climber fall, figure 1. Abseiling is the controlled descent on a rope using friction devices to over come steep ground, often used by climbers at the end of a climb **[2]**.

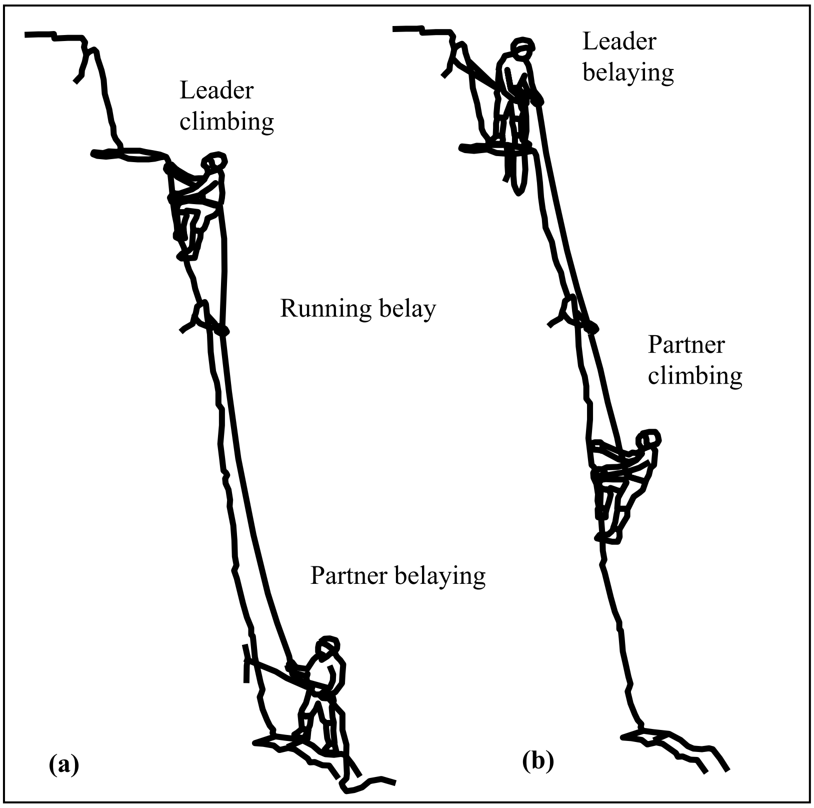

Figure 1 - Set up of lead climbing

The early climbing ropes were originally made from natural fibres such as hemp or manila, twisted and 'hawser laid' **[3]**. Modern climbing ropes are made from nylon with a kernmantel construction. In this construction, a sheath (the mantle) is tightly braided about a core (the kern). Modern mountaineering ropes are classified into four classes, single, half, twin and tour rope, which are approved by the UIAA (Union International des Associations d'Alpinisme). Each rope must be clearly marked with a standard label indicating which class it belongs to **[2]**. Single ropes are designed to be used on their own, to protect leader falls. Classically they have diameter 11mm. Half ropes are used doubled up to protect leader falls; rope drag can be reduced by clipping into protection selectively with either rope. Diameters range from 9mm-8.1mm. Twin ropes are used in a similar way to half ropes, but both ropes have to be clipped into all pieces of protection. Tour ropes are used for mountain walking and are not suitable for rock climbing.

Nylon 6 or polyamide 6 has been used to make climbing ropes since the 1950's. Research suggests that exposure to water environments induce permanent changes in the polymer matrix. The main effects of water on polymer matrices are; plasticization, changes in physical properties, i.e. decrease of mechanical moduli, decrease of yield strength, change of yield/deformation mechanisms, hydrothermal degradation, i.e. microcracks, ageing, chain scission through hydrolysis **[1]**. However nylon has many qualities essential for climbing rope production. These include the modulus of elasticity and flexion being specifically qualified for mountaineering ropes, high abrasion resistance, low density, low water absorbency, quick drying, yarn is rot resistant, good resistance to alkalis and has good dye ability **[4]**.

It is important for climbing ropes not to be overly adversely affected by water, as ropes get wet from days climbing in the rain and exposure to snow during winter mountaineering trips. They are also subjected to salt water when climbing on sea cliffs and stacks. It is thought that the salt left in the rope after drying, after exposure to sea water could possibly act similarly to sand particles. Both particles have sharp edges and could cut the filaments of the nylon strands, although there is no evidence to suggest this of salt particles. Signoretti **[5]** has conducted research investigating how wet and frozen ropes dynamically perform, but there appears to be very little research done on the long term effects of repeated wetting and drying on the ropes mechanical properties. Even less research has been done on the effectiveness of new generation dry treated ropes. These ropes have a special coating applied to the sheath or individual fibres to inhibit water absorption. There is no standardized test and different manufacturers use different coatings, meaning comparing them is difficult. It has been found that different coatings behave differently in different tests **[6]**. It is not known whether the coatings wear off with use, although it is a common belief among climbers. These ropes come at a premium, often costing 25% more than their non-dry treated counterparts and climbers want to know whether they are worth the money.

2.0 Procedure

2.1 Sample Preparation

All laboratory conditioned samples were produced from an 8.5mm diameter, Nylon 6, half rope manufactured by Mammut (for the rope's technical specification see the appendix). Eleven sample sets were produced from a rope without any chemical dry coating; while a further ten sample sets were produced from a rope with a special dry coat treatment. Each set consisted of six samples and a total of 108 samples were tested. Table 1 details all the samples that were tested. It shows what rope each sample set was made from, what condition they were subjected to and the number of cycles they were conditioned for.

Sample Set	Rope	Conditioning			Cycles	
		Fresh Water	Salt Water	Wear	Water	Wear
AA-AF	Non Dry	No	No	No	0	0
C1A-C1F	Non Dry	Yes	No	No	16	0
C2A-C2F	Non Dry	No	Yes	No	16	0
D1A-D1F	Non Dry	Yes	No	No	8	0
D2A-D2F	Non Dry	No	Yes	No	8	0
E1A-E1F	Non Dry	Yes	No	No	4	0
E2A-E2F	Non Dry	No	Yes	No	4	0
F1A-F1F	Non Dry	Yes	No	No	2	0
F2A-F2F	Non Dry	No	Yes	No	2	0
G1A-G1F	Non Dry	Yes	No	No	1	0
G2A-G2F	Non Dry	No	Yes	No	1	0
HA-HF	Dry	No	No	No	0	0
IA-IF	Dry	Yes	No	No	1	0
JA-JF	Dry	Yes	No	Yes	1	50
KA-KF	Dry	Yes	No	Yes	1	100
LA-LF	Dry	Yes	No	No	4	0
MA-MF	Dry	Yes	No	Yes	4	50
NA-NF	Dry	Yes	No	Yes	4	100
OA-OF	Dry	Yes	No	No	8	0
PA-PF	Dry	Yes	No	Yes	8	50
QA-QF	Dry	Yes	No	Yes	8	100

Table 1 - Listing of all sample sets, rope type and conditioning type and period

The number of cycles indicates how many times the rope was conditioned; this was heavily influenced by the total time available for testing. Water cycles consisted of the samples being submerged in water for 8 hrs, then taken out and dried naturally for 40 hrs. This cycle length was chosen as 8 hrs of wetting would simulate a long day of climbing in the rain. 40 hrs was found to give the rope adequate time to dry out completely. A cycle length of 48hrs was also chosen since this allowed for the wetting part of the cycle to be performed during the working day and allow two cycles to be completed per week.

2.1.1 Rope Preparation

From a previous study by Smith **[7]** it was found that the optimum rope length for testing was 2.5 m. Before conditioning, with exception to the wear conditioning, the ropes were cut to the appropriate length using a gas fuelled hot cutting knife.

2.1.2 Baseline Tests

Samples AA-AF and HA-HF were tested in an unconditioned state. This allowed for the measurement of baseline performance of the rope in terms of load capacity and extension.

2.1.3 Fresh Water Conditioning

The samples were immersed in a container of 40 litres of fresh water. De-chlorinating solution was added to the water to ensure the freshness of the water.

After immersion for 8 hrs the ropes were removed and hung out to dry on a drying rack at room temperature. The samples were tested in their dry state.

2.1.4 Salt Water Conditioning

This conditioning treatment was carried out in the same way as the fresh water conditioning, the only difference being the water was salt water. Instant Ocean aquarium salts were added to 40 litres of de-chlorinated water in a large plastic container. The salts produce water with the same salinity as the sea surrounding Scotland. The correct salinity was obtained by mixing the salt until a specific gravity in the range of 1.020-1.025 was obtained using a hydrometer.

2.1.5 Wear Conditioning

This treatment was applied to the dry treated ropes only. In the climbing community it is believed that these dry coatings are easily worn off with use, due to friction from belaying and abseiling, although there isn't any conclusive research to back up this common belief. The wear conditioning treatment was used to crudely simulate belaying. A karabiner was attached to a secure point, as if on a harness, the belay device with the rope threaded through it was then clipped into it, as with normal belaying practice. A knot was tied in either end of the rope to stop it running through. The rope was pulled through at a steady pace, using a hand over hand technique. Once the end of the rope was reached, it was pulled back through the belay system in the opposite direction. Once through the belay system was classed as one cycle.

2.2 Test Apparatus and Method

British Standard EN 892 **[8]** deals with safety standards for dynamic climbing ropes. The standardised procedure for testing dynamic climbing rope can be found within it. The procedure uses a dynamic test machine called a DODERO. Since access to one of these machines was not available, it was decided that building a dynamic test rig would not provide suitably accurate results compared to the DODERO. A study by Casavola and Zanantoni **[9]** put forward the idea that static testing can be substituted for dynamic as many tests suggest that elongation speed is independent of the force/elongation curve. The Tinius Olsen 81000 slow tensile testing machine was used for testing. The machine was used as it had a large amount of travel allowing for the large extension of the rope.

Shackles were used to restrain the rope at either end. They were originally designed for testing high strength fabric belts for flat bed lorries. Each shackle consisted of a solid steel drum 110mm in diameter and a pair of parallel plates securing the assembly. The ropes were wound one and a half times around the drums. Locking clamps were attached to the end of the ropes to stop them slipping, a knot was tied in the end of the ropes to stop it slipping through the locking clamps, see figure 2. 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 the Tinius Olsen 81000 tensile testing machine. The ropes were marked at their midpoints and also 100mm either side of the midpoint. The ropes are loaded into the shackles with the 100mm marks aligned with the centre of the drums, the locking clamps are attached to the end of the ropes and an over hand knot tied to stop them slipping. The testing machine loaded the rope to 1000 lbs, this was approximately 25% of breaking load, it was then stopped and a measure of elongation was taken by measuring the distance between the two 100 mm marks. The ropes were subsequently loaded until failure occurred. The failure load was noted from both the analogue and digital readings from the equipment.

Figure 2 - Test rig set up and shackle assembly

The absorption samples were weighed immediately before and after the submersion part of the water cycle. The samples were coiled loosely and weighed on a Precisa 1212M Superbal balance. The samples removed from the water were lightly shaken to remove any surface water before weighing. Mass readings were taken in kilograms to 4 significant figures.

3.0 Results

3.1 Analysis Method

The breaking load and extensions for each sample were noted. The breaking loads used for calculating average values were taken from the analogue readings since the digital measurements were only taken every 3 seconds. The digital system did not always take readings at the precise point where the ropes failed. However the most appropriate analogue scale was unavailable for the non-dry treated sample tests, as it was broken, so these results were not as accurate as they could have been. All readings were taken in pounds; these were converted to Newtons for the analysis.

The mean breaking loads and strain were calculated from the data. Strand modulus is the rope and wire equivalent of Young's modulus for solids. The mean strand modulus was calculated from the digital data at 1800 lbs.

It was decided to use the standard deviations of sample sets to compare the significance of the results. A 95% confidence level for the sample size was thought to be adequate, this equates to ±2.5 standard deviations. Graphs were then produced incorporating the standard deviation as error bars, to compare the sample results to the baseline results.

The sample standard deviation was taken as follows from a statistics book by Montgomery **[10]**.

$$s^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$$

The mean values for each cycle of absorption data was calculated and graphed. Wet and dry results were graphed on separate diagrams.

3.2 Results

The results from the analysis can be found in the figures below. The data from which these figures were produced can be seen in the appendix.

3.2.1 Non-Dry Treated Samples

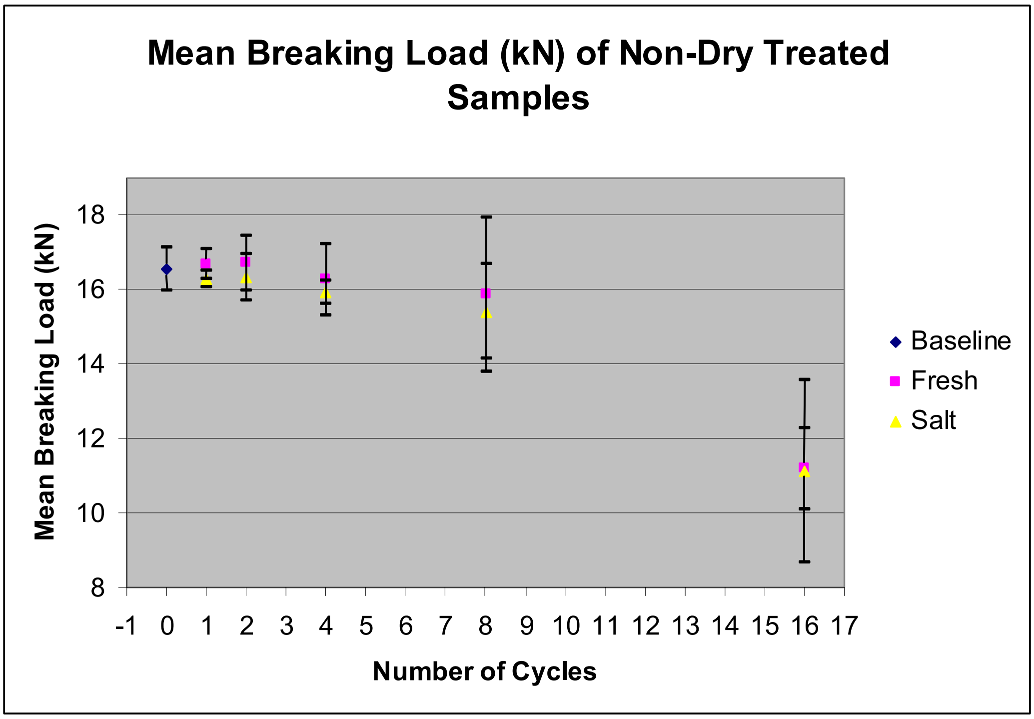

Figure 3 - Mean breaking loads of non-dry treated conditioned samples

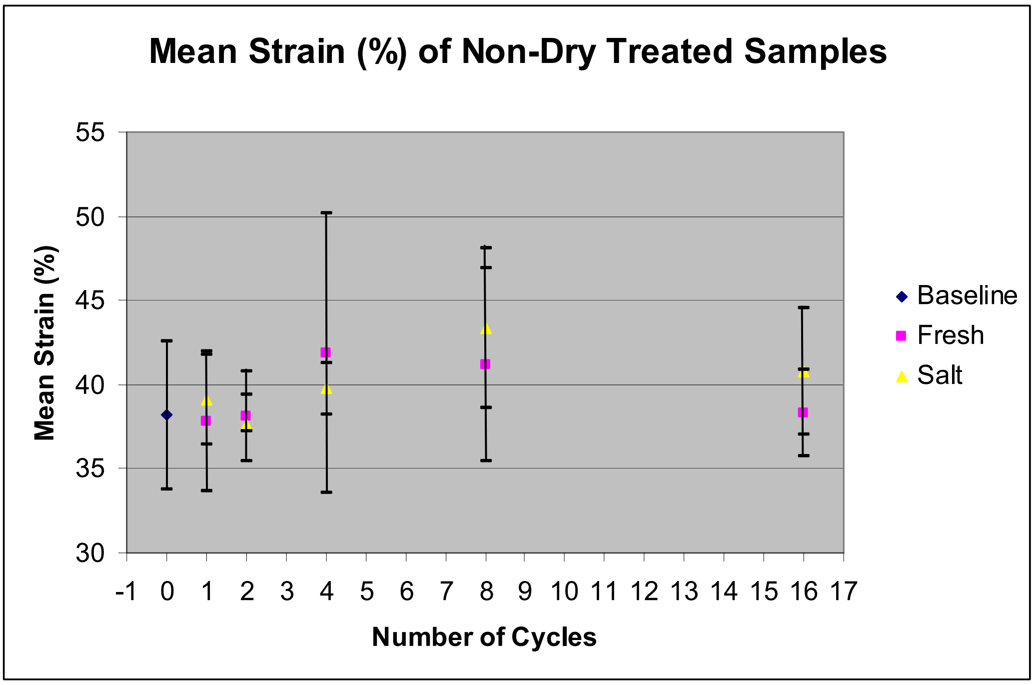

Figure 4 - Mean strain (%) at a pre-load of 1000lbs of non-dry treated samples

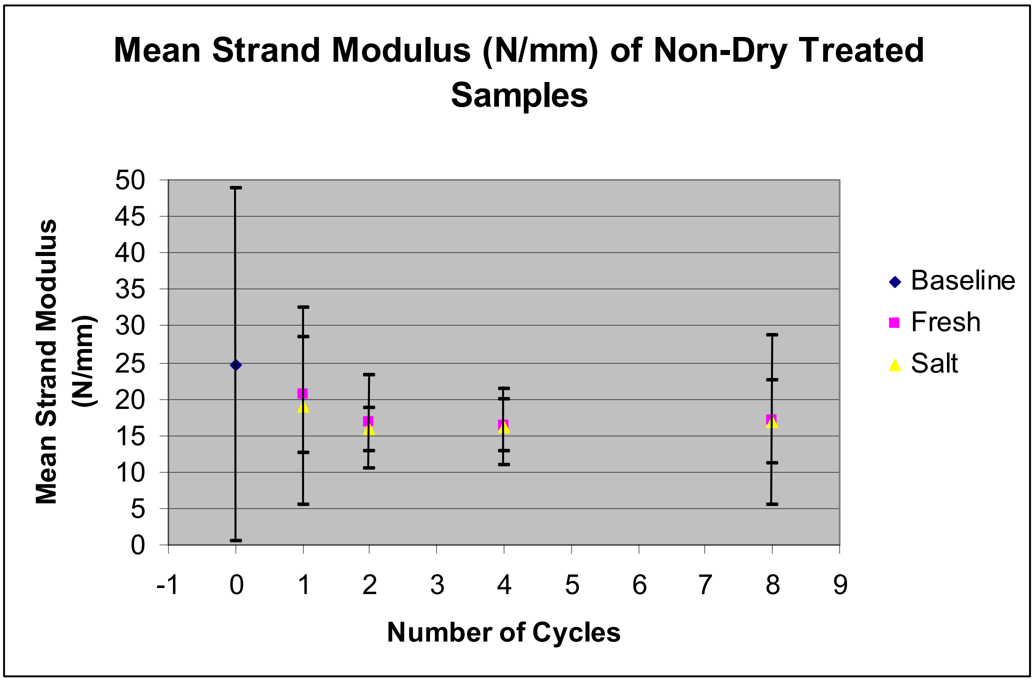

Figure 5 - Mean strand modulus measured at 1800lbs for non-dry treated samples, excluding sample sets C1 and C2

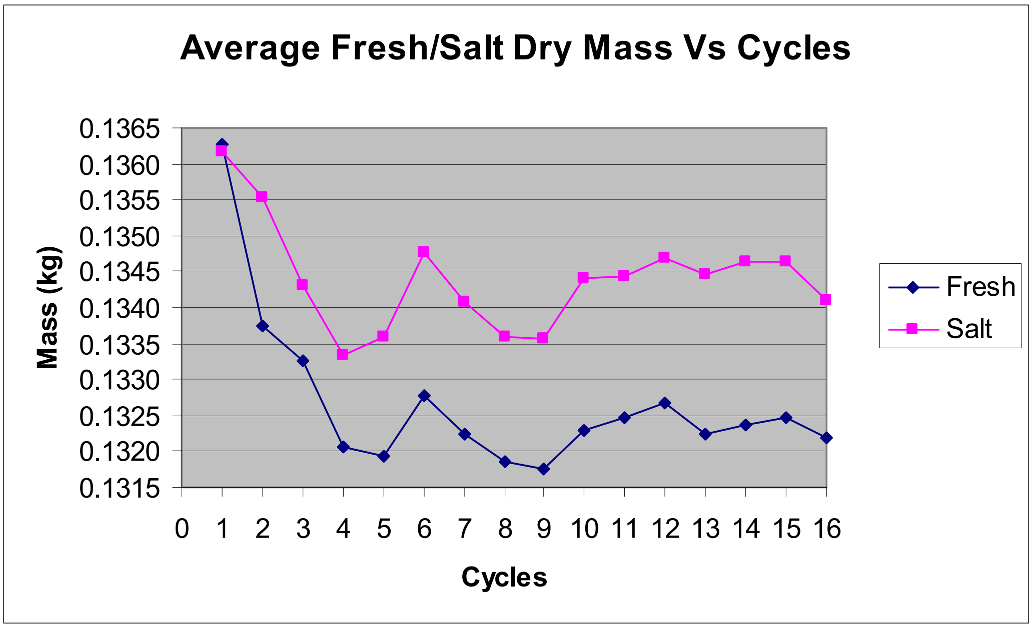

Figure 6 - Average dry mass for fresh and salt water non-dry treated samples for each conditioning cycle

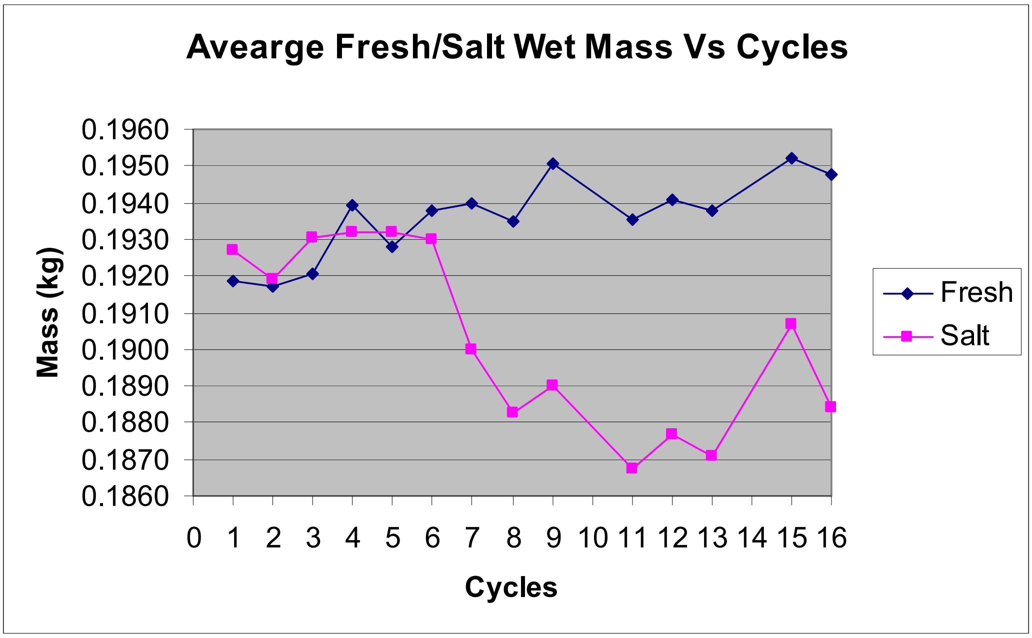

Figure 7 - Average wet mass for fresh and salt water non-dry treated samples for each conditioning cycle

3.2.2 Dry Treated Samples

Tests on samples sets I, J and K were not carried out due to a lack of time. This occurred when the Tinius Olsen 81000 tensile testing machine was moved location. It meant that it was more difficult than usual to get testing time with Mr. A. Crockett as the move had put him behind with his own work. From reviewing the results from the non-dry treated samples it was decided that sample sets I, J and K were not likely to give any remarkable results.

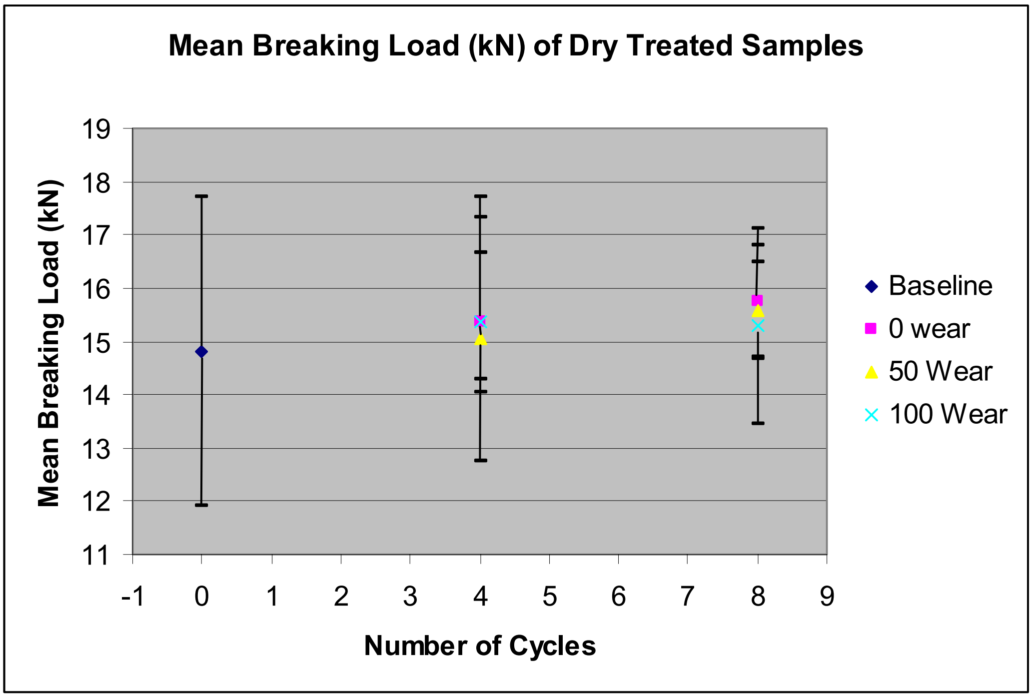

Figure 8 - Mean breaking loads of dry treated conditioned samples

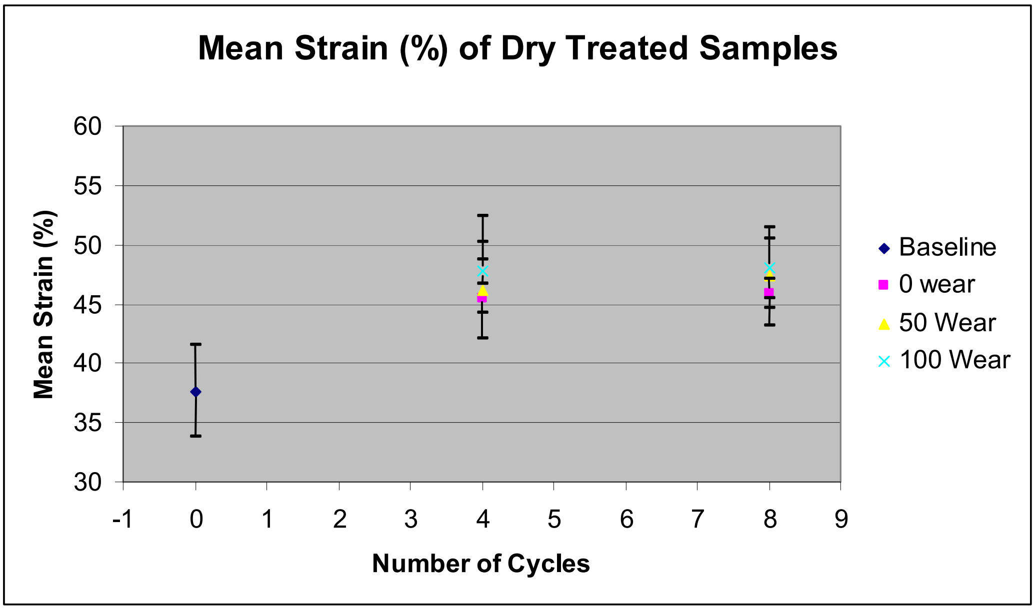

Figure 9 - Mean strain (%) at a pre-load of 1000lbs of dry treated samples

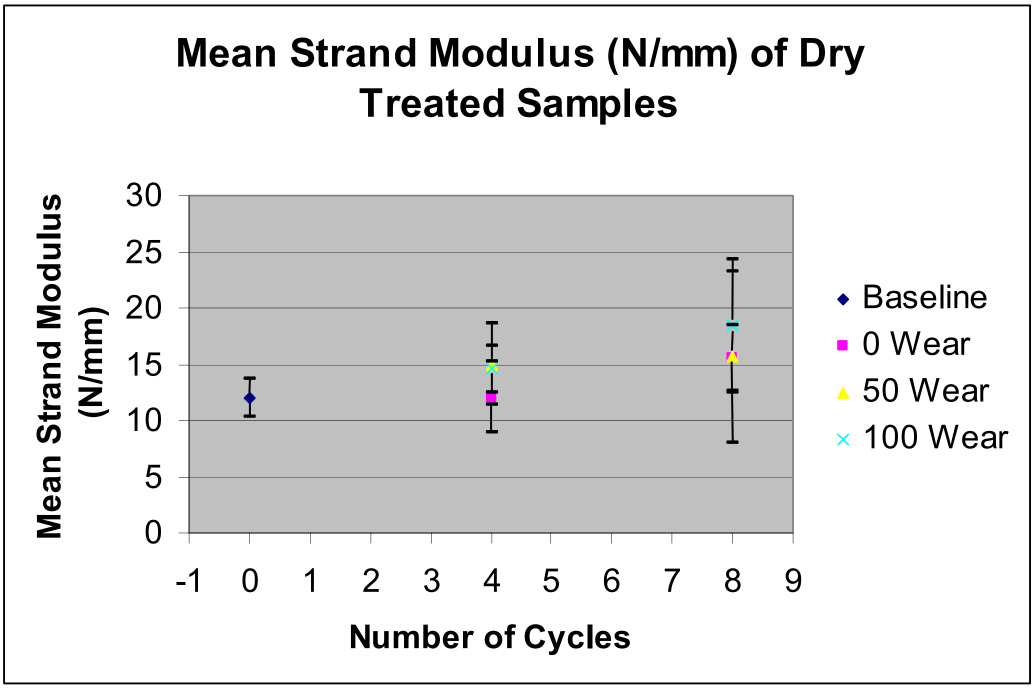

Figure 10 - Mean strand modulus measured at 1800lbs for dry treated samples

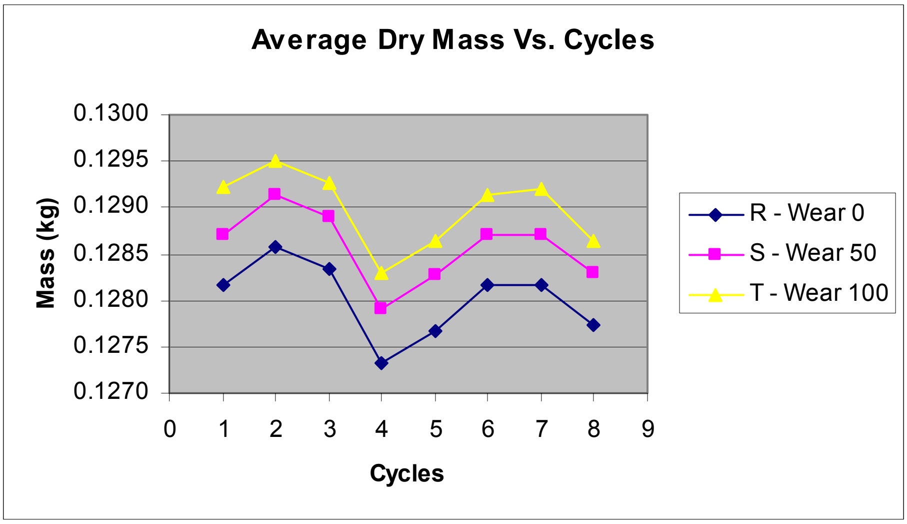

Figure 11 - Average dry mass for dry treated samples for each conditioning cycle

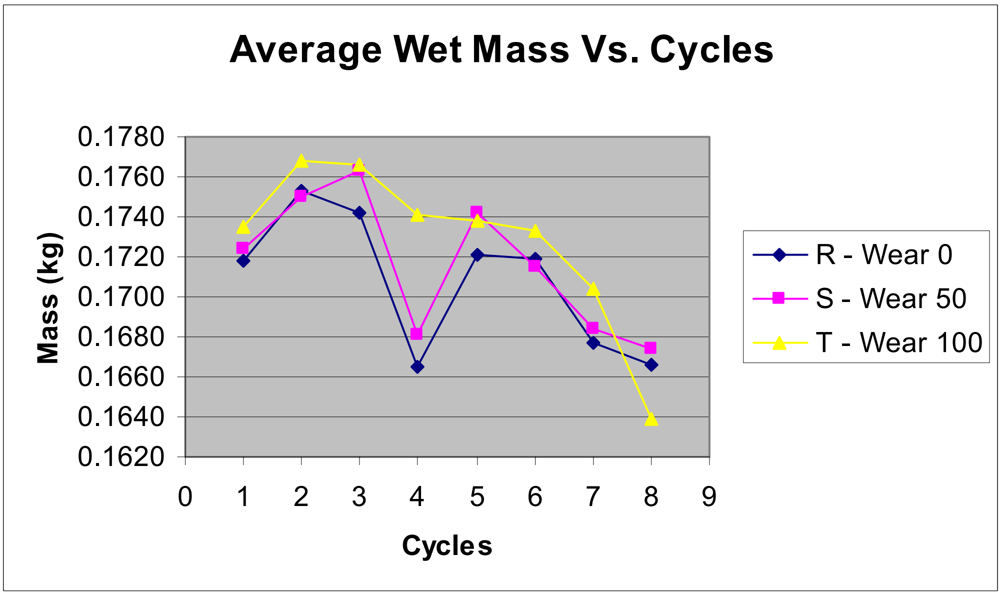

Figure 12 - Average wet mass for dry treated samples for each conditioning cycle

4.0 Discussions

4.1 Non-Dry Treated Samples

4.1.1 Fresh Water Samples

It can be seen from figure 3 that the first 8 water cycles have very little effect on the mean breaking load of the samples. After the 8th cycle the mean breaking load has lowered by only 0.7 kN which is deemed to be fairly insignificant. After 16 cycles the ropes have lost 32.3% of their strength. This suggests that the plasticization of the nylon when wet, which reverses during drying **[7]**, becomes permanent over repeated wetting and drying cycles. Climbers should not be too concerned by this discovery, as no known rope has ever failed due to over loading. Dynamic loading over sharp edges is said to have accounted for all but two of the reported rope failures in the past 35 years **[2]**.

The mean extension over the 200mm gauge measurement at 1000 lbs increases up to 8 cycles and returns to baseline values at 16 cycles. At 8 cycles the mean elongation is only 6mm longer than baseline. In figure 4, with 95% confidence level, there is no difference in the results of mean strain for the various water cycles.

Figure 5 shows mean strand modulus at 1800lbs, which appears to lower over cycles 1 to 4 and levels out by cycle 8, but with 95% confidence levels these results become insignificant. Data for cycle 16 was not included since during testing there was considerably more friction in the system which caused the ropes to stretch unsteadily while the load was being applied. This meant that the load being applied was constantly changing and smooth load/extension graphs were not obtained, and thus a tangent relating to strand modulus could not be obtained.

The absorption data results in figures 6 and 7 shows that the ropes lose mass over the first few cycles of the conditioning before levelling out and also that the ropes gradually increase water absorption. In the first 4 cycles something appears to be washing out of the ropes. After consulting the Mammut product literature it was found that the ropes have a Teflon coating. This coating is applied to the individual rope strands in order to minimise chafing and improve friction co-efficiency. Loading e.g. through a fall, is uniformly distributed through each individual filament, thereby optimising performance **[11]**. From the results it would seem that this Teflon coating is washing off the rope filaments. Over the 16 cycles the samples lose 3% of there original mass.

In figure 6 a small peak in the mass can be seen at cycle 6. Cycle 5 was when the majority of the samples started conditioning, so there would have been a much higher concentration of Teflon in the water, which could have been absorbed by the absorption samples. This would then have shown up in the dry mass of cycle 6.

Figure 7 shows the samples gradually absorbing more water with the increase of cycles. This could be due to the removal of Teflon allowing for the nylon to absorb more water, but that does not explain the gradual nature by which it happens, since the Teflon appears to be washed out in the first 4-5 cycles.

4.1.2 Salt Water Samples

The good news for climbers is shown in figure 3; the results indicate that the salt in sea water is not critical to the strength of the rope. On average salt water samples were only 0.34 kN weaker than their fresh water counterparts. This means that climbing on sea cliffs is no more harmful to ropes than climbing on inland crags.

As with fresh water samples the mean strain data, shown in figure 4, only varies slightly from baseline and with 95% confidence levels do not produce significant results. The same is true for the mean strand modulus results in figure 5.

The salt water results in figure 6 show that they follow the exact same pattern as the fresh water results, again likely due to the removal of Teflon, but on average they only lose 1.5% of their original mass. Investigating mean mass between cycles 4-16 finds the dry mass is 0.1342 kg, wet mass is 0.1897 kg and mass of water absorbed is 0.0555 kg. The salinity of the water was an average of 0.0305 kg/litre **[12]**, so every litre of water contained 3.05% salt, this equates to 0.0017 kg per rope sample. The difference in mean mass between the dry salt and fresh samples is 0.0018 kg. In actual fact the salt samples do not lose less mass than the fresh samples, instead they lose the same amount of mass, but then gain 1.5% of their original weight in salt and minerals from the sea water solution. There is also the possibility that the salt water samples do not fully dry out in the core due to the hydroscopic properties of the salt.

Figure 7 shows the wet mass of the salt samples, up until cycle 6 the water uptake of the samples is fairly steady, it then drops suddenly and becomes quite erratic. No explanation can be found for the results.

4.2 Dry Treated Samples

There are insignificant differences in the mean breaking load, figure 8, between the baseline and conditioned samples. The wear and water conditioning can be said to have had no effect on the strength of the samples. One possible reason for this is very likely to be the crudeness of the wear conditioning treatment. The treatment was a very poor simulation of belaying/abseiling as there was no load on the rope and thus very little friction in the system, friction is the most damaging aspect of normal use on rope. This was recognised as a possible problem and the number of cycles was increased to try and combat this, however this seems to have failed. It was beyond the scope of this study to design a system that would accurately simulate belaying/abseiling; this could be an area of further study. The baseline strength is almost 2 kN lower that the baseline samples of the non-dry treated rope. Both ropes have exactly the same mass per unit length, 48 g/m. For the dry treated rope to still have the same weight as the non-dry treated rope, it must have fractionally less mass of nylon. With having slightly less material to carry the load, it would be expected that the rope would be slightly weaker.

Even with the poor wear conditioning treatment, mean strain results, figure 9, seem to be significant. After 4 cycles the mean strain has increased from 37.7% to 46.5%, a 8.8% increase, this must be attributed to the water conditioning.

There was a slight increase in the mean strand modulus, but again nothing significant, figure 10.

From the average dry mass data, figure 11, it appears that the wear conditioning somehow altered the mass per unit length. The more wear cycles the rope underwent, the more positive the effect on the sample mass. No explanation can be found for this occurrence. Apart from this difference in initial mass, the samples have an identical dry mass versus cycle's plot. There is also no apparent explanation for the behaviour of the samples absorption characteristics, figure 12. Initially, the samples wet mass increases before decreasing after cycle 3. A reason for the sudden trough experienced by the 0 wear and 50 wear samples at cycle 4 can not be rationalized.

5.0 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.

Further studies may wish to investigate how similarly conditioned samples behave when dynamically tested. A more extensive study of dry treated ropes could also be undertaken, examining how wear affects water absorption in the long term. This would involve the development of a system to accurately simulate belaying and abseiling.

The most significant results returned were:

1. Plasticization of nylon when wet becomes permanent with repeated wetting and drying cycles.
2. Strain in non-dry treated rope is unaffected by water conditioning.
3. Non-dry treated ropes lose mass with water conditioning, 3% in fresh water and 1.5% in salt water of their original mass.
4. Mass loss of non-dry treated ropes can be accounted for by the removal of Teflon from individual nylon fibres.
5. Rope samples retain salt content of salt water absorbed when dried.
6. The presence of salt in non-dry treated samples had no effect on strength.
7. Over repeated water conditioning, fresh water samples increase absorbency and salt water samples decrease absorbency.
8. Combined wear and water conditioning has no effect on strength of dry treated ropes.

9. Combined wear and water conditioning caused a 8.8% increase in strain over 4 water cycles in dry treated ropes.
10. Wear conditioning altered the mass per unit length of dry treated samples.
11. None of the conditioning treatments had any effect on the strand modulus of either the non-dry or dry treated samples.

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References

1 Contugo, S., Mensitieri, G., Musto, P. and Nicolais, L., “Water Sorption and Transport in Polymers”, In Proceedings of Nylon and Ropes Conference, Turin, 8-9 March 2002

2 McLaren, A., J., “Design and Performance of Ropes for Climbing and Sailing”, Paper submitted to Special Issue of the Journal of Materials: Design and Applications, 16th September 2005

3 Blackford, J., R., “Materials in Mountaineering”, Materials in Sports Equipment, Woodhead Publishing Ltd., Cambridge, 2003

4 Ernst, E., “Polyamide 6. The Right Raw Material for Ropes: It’s Production and Technical Characteristics”, In Proceedings of Nylon and Ropes Conference, Turin, 8-9 March 2002

5 Signoretti, G., “The Influence of Water, Ice and Sunlight on the Dynamic Performance of Mountaineering Ropes”, Commission for Materials and Techniques, Italian Alpine Club, March 2002

6 Fronzaglia, W., J., “Determination of Dry Coating: Effectiveness against Water Impregnation. An Examination of Various Testing Methods”, In Proceedings of Nylon and Ropes Conference, Turin, 8-9 March 2002

7 Smith, M., “An Assessment of the Effects of Environmental Conditions on the Performance of Dynamic Climbing Ropes”, 2005

8 BS EN 892, “Mountaineering equipment - Dynamic mountaineering ropes - Safety requirements and test methods”, June 1997

9 Casavola, P. and Zanantoni, C., “Rope testing and wear: equipment of the CMT”, Commission for Materials and Techniques, Italian Alpine Club, March 2002

10 Montgomery, D., Runger, G. and Hubele, N., “Engineering Statistics”, Chichester: Wiley, 2004

11 Mammut, “Rope”, Mammut Sports Group AG, Switzerland, 2004

12 Seahorse Aquarium Supplies Company website, http://www.seahorse-nw.com/Specific_gravity.html

Appendix - Tables

Material	Polyamide 6 (Nylon)
Nominal diameter	8.5 mm
Number of UIAA falls	12-13
Weight per metre	48 g/m
Impact force	6.4 kN
Elongation in use	9.00%
Elongation at 1st fall	30%
Sheath slippage	0 mm
Proportion of sheath	49%

Table 2 - Technical data for Mammut Genesis non-dry treated and superDRY half rope used for conditioning

Sample	Mean Breaking Load (kN)	2.5*s	Mean Strain %	2.5*s
A	16.54	0.57	38.2	4.4
G1	16.69	0.39	37.8	4.2
G2	16.28	0.23	39.1	2.7
F1	16.72	0.74	38.1	2.7
F2	16.33	0.63	37.6	1.8
E1	16.28	0.96	41.8	8.3
E2	15.93	0.30	39.8	1.5
D1	15.87	2.07	41.2	5.7
D2	15.40	1.27	43.3	4.7
C1	11.20	1.09	38.3	2.6
C2	11.12	2.46	40.8	3.8

Table 3 - Mean breaking loads and strain, with 2.5 times standard deviation for non-dry treated samples

Cycle	Dry		Wet	
	Fresh	Salt	Fresh	Salt
1	0.1363	0.1362	0.1919	0.1927
2	0.1337	0.1355	0.1917	0.1919
3	0.1333	0.1343	0.1921	0.1931
4	0.1321	0.1333	0.1939	0.1932
5	0.1319	0.1336	0.1928	0.1932
6	0.1328	0.1348	0.1938	0.1930
7	0.1322	0.1341	0.1940	0.1900
8	0.1319	0.1336	0.1935	0.1883
9	0.1318	0.1336	0.1951	0.1890
10	0.1323	0.1344	0.0000	0.0000
11	0.1325	0.1344	0.1935	0.1867
12	0.1327	0.1347	0.1941	0.1877
13	0.1322	0.1345	0.1938	0.1871
14	0.1324	0.1346	0.0000	0.0000
15	0.1325	0.1346	0.1952	0.1907
16	0.1322	0.1341	0.1948	0.1884

Table 4 – Average wet and dry mass (kg) of non-dry treated samples

Sample	Mean Breaking Load (kN)	2.5*s	Mean Strain (%)	2.5*s
H - Baseline	14.80	2.90	37.67	3.93
L - Water 4 Wear 0	15.35	2.35	45.42	7.05
M - Water 4 Wear 50	15.04	2.29	46.17	4.08
N - Water 4 Wear 100	15.35	1.32	47.75	1.05
O - Water 8 Wear 0	15.75	1.05	45.92	1.23
P - Water 8 Wear 50	15.58	0.92	47.33	4.16
Q - Water 8 Wear 100	15.29	1.84	48.00	2.50

Table 5 – Mean breaking loads and strain, with 2.5 times standard deviation for dry treated samples

Cycle	Average Dry Mass (kg)			Average Wet Mass (kg)		
	R - Wear 0	S - Wear 50	T - Wear 100	R - Wear 0	S - Wear 50	T - Wear 100
1	0.1282	0.1287	0.1292	0.1718	0.1724	0.1735
2	0.1286	0.1291	0.1295	0.1753	0.1750	0.1768
3	0.1283	0.1289	0.1293	0.1742	0.1763	0.1766
4	0.1273	0.1279	0.1283	0.1665	0.1681	0.1741
5	0.1277	0.1283	0.1286	0.1721	0.1742	0.1738
6	0.1282	0.1287	0.1291	0.1719	0.1715	0.1733
7	0.1282	0.1287	0.1292	0.1677	0.1684	0.1704
8	0.1277	0.1283	0.1286	0.1666	0.1674	0.1639

Table 6 – Average wet and dry mass (kg) of dry treated samples