Investigation into the Effectiveness and Durability of Waterproof Coatings and Heat Treatments of Dynamic Climbing Ropes.

Technical Paper

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Abstract

Previous research has shown the detrimental effect that water has on the properties of climbing ropes. Rope manufacturers are now adding dry treatments which they claim are effective and durable methods of reducing the amount of water ropes absorb. Very little research exists into these claims, therefore this study aims to produce of this study to produce results validate these claims.

Three ropes were tested; a rope that was heat treated, a rope that was dry-treated and a rope that had no treatment were all compared. Three types were conditioned in water to examine the effectiveness of different the waterproof treatments and also to examine how the ropes water absorption characteristics are affected by repeated wetting and drying. The heat treated and dry treated samples underwent wear conditioning to investigate how durable the treatments were. The samples were also tested on an Tinius Olsen 81000 slow tensile machine, which allowed for the observation of any change in the tensile strength and strain due to wear of the samples.

The results suggested that the treatments significantly reduced the amount of water absorbed by the sample ropes. The effectiveness of the treatment was not affected by repeated soaking and drying cycles. However the effect of wear conditioning deuced the effectiveness of the dry treated and heat treated samples.

Nomenclature

s=Standard deviation

x =Sample data

$\bar{x}$ =Sample mean

n=Sample size

1.0 Introduction

Modern climbing ropes are designed not only to arrest a falling climber but also to reduce the impact force. The rope absorbs the energy generated in a fall by stretching. Today’s climbing ropes are manufactured from either nylon 6 or nylon 66. The material properties of these types of nylon are very suitable for the production of ropes. They have high tenacity, good abrasion resistance, low density, rotting resistance, and are quick drying [1]. The elastic properties of ropes arise from both the elastic properties of nylon and the methods used in constructing the rope.

Recent research has shown that a rope holds less falls when wet [2], this reduction in rope strengths is due plasticisation. This has a number of effects on nylon fibres including a decrease in the mechanical moduli, a decrease in yield strength, a change of deformation characteristics, ageing and scission [3]. Wet ropes are heavy which makes it harder to use, it can also be dangerous in low temperatures where it will freeze.

Rope manufacturers are now producing ropes which have treatments added to their sheaths or individual fibers which they claim inhibit water absorption by the rope. There is no industry standard whereby the effectiveness and durability of the treatments can be tested. Ropes with these treatments are generally more expensive with some manufacturers charging up to 25 % more than for treated ropes.

2.0 Procedure

2.1 Rope Selection

The ropes used for the investigation were all Mammut Genesis 8.5mm, the technical properties of the rope are located in table 1 located in the Appendix. Three different ropes types were investigated, one with dry treatment one with heat treatment and one with no treatment.

2.1 Water Conditioning Procedure

Rope Sample Preparation

The rope samples were cut using a gas powered hot knife which cut through the rope by melting the nylon fibres. This sealed the ends of the samples and prevented them from fraying and deteriorating. Seven 1 m samples were cut from each of the three different ropes. Three of the samples were kept intact while the core and sheaths were separated from the other three samples.

Labelling

The labelling system used to identify rope samples can be found in table 2 located in the Appendix. The labels were attached using tie grips which allowed the labels to be removed and reattached easily when ropes were being put through the soaking and drying cycles. The labels had to be removed prior to the rope samples being soaked to prevent interference with the results produced by the mass spectrometer.

Water Conditioning Duration

A soaking duration of eight hours was selected, this simulated a full days climbing in wet conditions. Each sample was placed in separate containers to soak. A drying length of 40 hours was used to give the rope adequate drying time. The total time taken for one full soaking and drying cycle was 48 hours. This time scale allowed three cycles to be completed per week. The rope samples were dried on a wire rack in the laboratory. This was not the ideal due to varying environmental factors in the laboratory but was the most suitable method available.

Number Cycles

It was found that during the investigation by Andrew [4], that the mass decrease of the non dry treated rope occurred over the first six cycles and then levelled off between cycles 8 to 16. For this reason only seven cycles were investigated. This number was also deemed adequate to test if soaking or drying cycles affected the ability of the treatments to absorb water.

Decontamination

The apparatus used during the water conditioning stage of the investigation was decontaminated before to every cycle. A 1% concentration DECON solution was poured into each of the containers and left to soak for 24 hours. The containers were then rinsed six times with running water and three times with distilled water. A similar decontamination process was used for the container lids and pipettes.

Soaking Cycle

The glass containers were then filled with 1.8 ltrs of double distilled water and the 2.5 m sample groups placed into the containers for a soaking cycle of eight hours. Double distilled water was used to ensure that the most accurate results would be obtained from the Mass Spectrometry. After the rope samples had been removed from the containers they were emptied and the decontamination process was repeated. This ensured that the containers were decontaminated and ready for the next soaking cycle.

Sample Collection

Three 5 ml samples were collected from each container and placed into screw-top bottles. One sample was used for mass spectrometry, one sample was left to evaporate and one sample was kept spare in case further analysis was required.

Rope Testing

The initial weight of all the ropes was recorded prior to beginning of each cycle; the wet weight was recorded after the ropes had been allowed to sit for three minutes which allowed for excess surface water to drip off. After 40 hours of drying time the ropes were weighed again to assess if there was any change in the dry mass. The weights were measured using a Pricisa 1212M Superbal balance; this allowed the sample masses to be measured in kilograms with an accuracy of 5 decimal places.

Mass Spectrometry

To examine the sample solutions removed from the containers a mass spectrometer machine was used. The machine used was an LCQ Duo Electrospray Ion

Trap Mass Spectrometer. 0.5 ml was removed from each sample and mixed with 0.5 ml of methanol. The methanol was added to aid the vaporisation of the solution. The entire procedure was fully automated after the samples had been loaded into the machine.

2.3 Wear Conditioning Procedure

Wear Machine Design and Manufacture

To investigate the durability of the treatments applied to climbing ropes a wear machine was constructed. The machine was designed to replicate the conditions experienced by climbing ropes during belaying. Belaying is the process through which the control of climbing rope is achieved through the application of friction. A diagram of the machine is shown below in Figure 1. It was powered by a 12 V windscreen wiper motor attached to a pulley wheel. The rope was passed through a figure of eight belay device. To ensure that the tension in the system remained constant, a mechanism was designed using a spring balance and turnbuckle. A constant tension of 80 N was maintained on every sample.

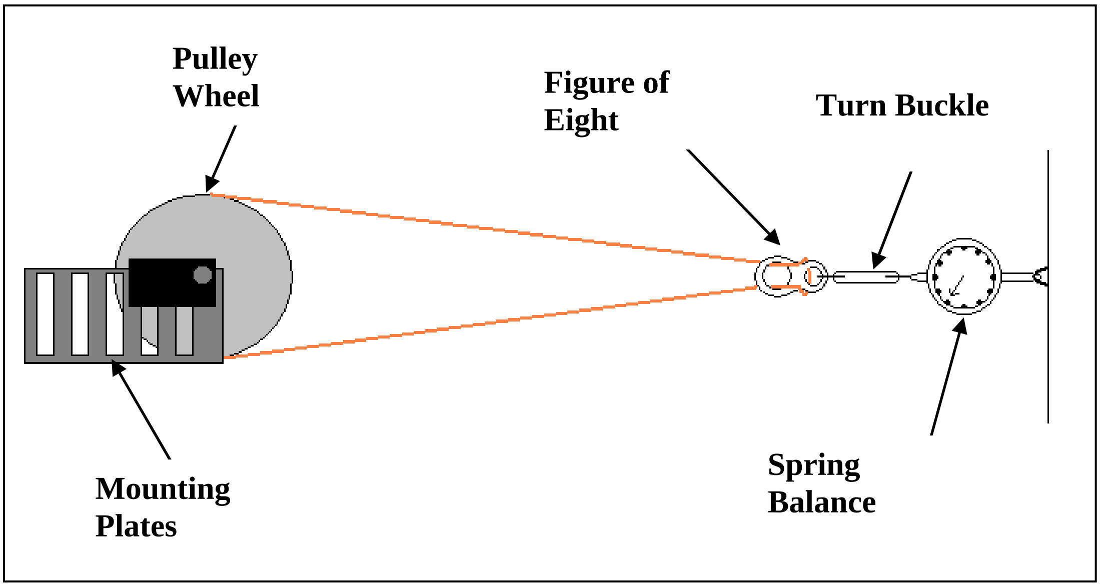

Figure 1: Diagram showing the configuration of the wear machine

It was decided that three different cycle lengths of 250, 500 and 750 revolutions would be tested through the figure of eight.

Cycle Speed

The speed at which the rope passed through the figure of eight device played a very important factor on the wear of the rope. Research has proven that when a rope is subjected to very high temperatures then the quality of the rope degrades [5]. If the rope were to pass through the figure of eight too quickly then the temperature produced could damage the rope and therefore affect the results. It was decided that the actions of a belayer feeding the rope through the figure of eight, a rope speed of roughly 1m/s would be adequate. The motor speed was measured to be 66 rpm. The diameter of the pulley wheel was designed to produce the required speed of the rope. The machine was switched off every 50 cycles for 2 minutes to allow any heat generated to dissipate and also to prevent the motor from over heating.

Sample Preparation

The sample length was selected to be 2.5 m, as previous investigations found this was the optimum length for the tensile testing machine. Before being placed into the wear machine, the sample ends were sewn together to form a loop. Twenty samples were produced from the heat treated rope and twenty samples were produced from the dry treated rope.

Labelling

The samples were labelled using a similar method as used in water conditioning procedure whereby the labels could be removed and reattached to the samples after their conditioning had been completed. The labels applied to each of the samples and the number of cycles each sample set endured can be found in Table 3 in the Appendix.

Tensile Strength and Elongation Testing Procedure

The British Standard test for climbing ropes is to measure the number of falls held on a DODERO machine, however due to the unavailability of such a machine, the tests were carried out on a Tinius Olsen tensile testing machine. The samples were secured to the tensile machine using two large shackles which had previously been used to test high strength fabric belts used for securing loads onto lorries but also served this purpose well. These shackles were solid steel drums of 300 mm diameter welded between two parallel plates. The shackles were loaded into the top and bottom cross hairs of the machine. The samples were each wound around the top and bottom shackles once in order to secure them to the tensile machine. To ensure the samples did not slip clamps were applied and securing knots were tied in the ends of the samples.

It was noted that the shackles did not produce constant stress across the diameter of the rope due to the circular drums, however as the samples were being compared under the same conditions, this was deemed acceptable.

Once the rope had been loaded into the shackles the mid-point of the rope was marked and a further two marks were made 100 mm either side of mid-point. These marks were used to calculate the elongation of the sample. Initially the samples were loaded to 400 lb and then unloaded again, in order to exercise the rope prior to the testing. The samples were then loaded up to 1000 lb which is roughly 25% of their maximum load. The elongation of rope was then measured against the marks and was

recorded. The samples were then loaded to failure and the breaking load was recorded.

Baseline Test

The two different rope types were tested to establish a baseline standard on which the rest of the experiments could be compared. Sample sets A1-4 and B1-4 were soaked in water for eight hours then removed and placed onto a drying rack for three minutes. The samples were then tested on the tensile machine using the procedure out lined above.

3.0 Results

3.1 Analysis Method

The mean values for the wet and dry weights for both the water and the wear conditioning cycles were calculated and graphed.

The elongation and tensile strength values for the wear conditioning cycles were taken from the analogue reading on the slow tensile machine. The machine produced digital readings every three seconds, however it did not always record the exact load at which the samples failed. The analogue readings were recorded in pounds and were then converted into newtons.

The mean breaking loads and percentage strains were calculated from the data. The standard deviation of each data set was calculated to discover if the results produced were significant. From Engineering Statistics by Bowker [6] it is shown that if the standard deviations from the mean of two sample sets are not coincident, then there is approximately a 68% likelihood that the sample means are different. This likelihood rises to 95% if the means remain incoincident with an error of two standard deviations. This 95% is equivalent to 2.5 standard deviations. The standard deviation of a sample set was calculated using the following equation:

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

The graphs were then plotted incorporating the standard deviations as error bars, to allow for the easy comparison of the effects of wear on the samples.

3.2 Water Conditioning Results

3.2.1 Dry Weight after Water Conditioning

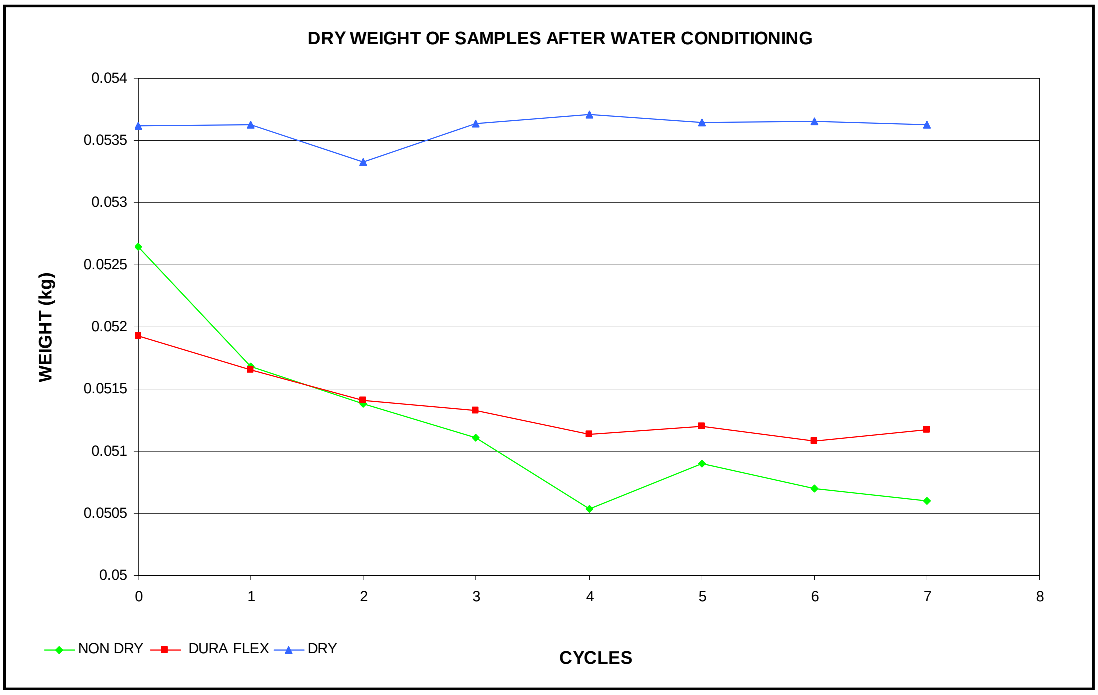

Figure 2: Average dry mass of samples after water conditioning cycles

3.2.3 Dry Weight of Sheath and Cores after Water Conditioning

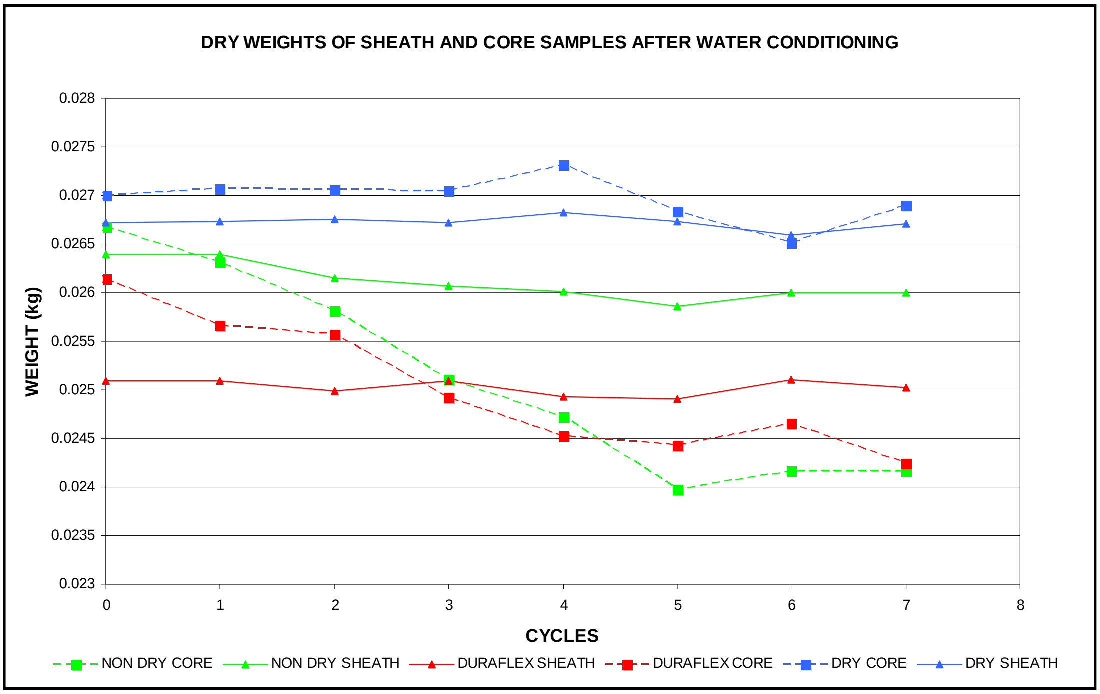

Figure 3: Dry weight of sheath and cores

3.2.4 Mass Spectrometry Results

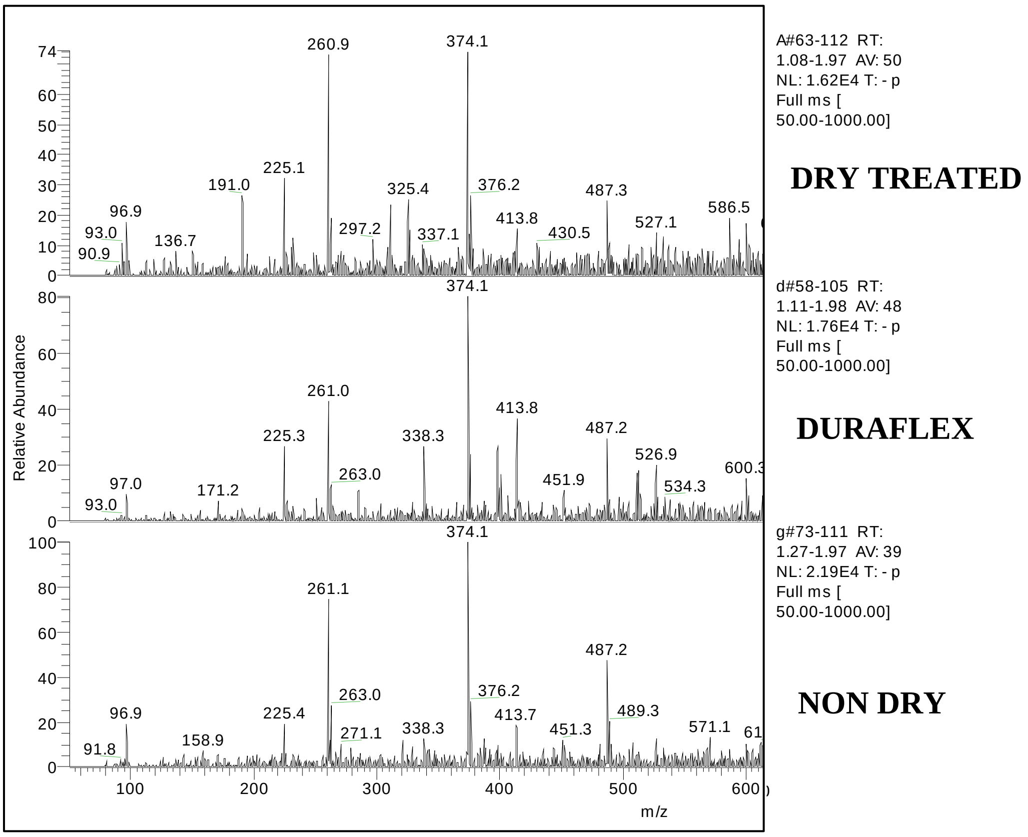

Figure 4: Negative ions results of samples taken after 1st soaking cycles

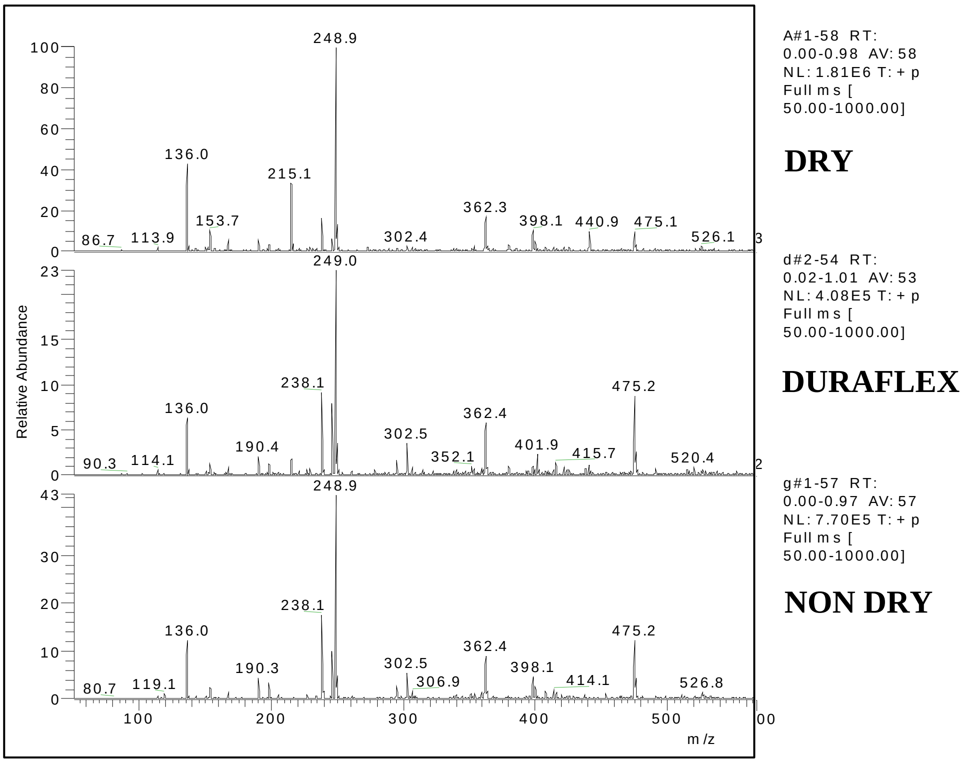

Figure 5: Positive ions Mass Spectra results of Samples taken after 1st soaking cycles

3.2.5 Wet Weight after Water Conditioning

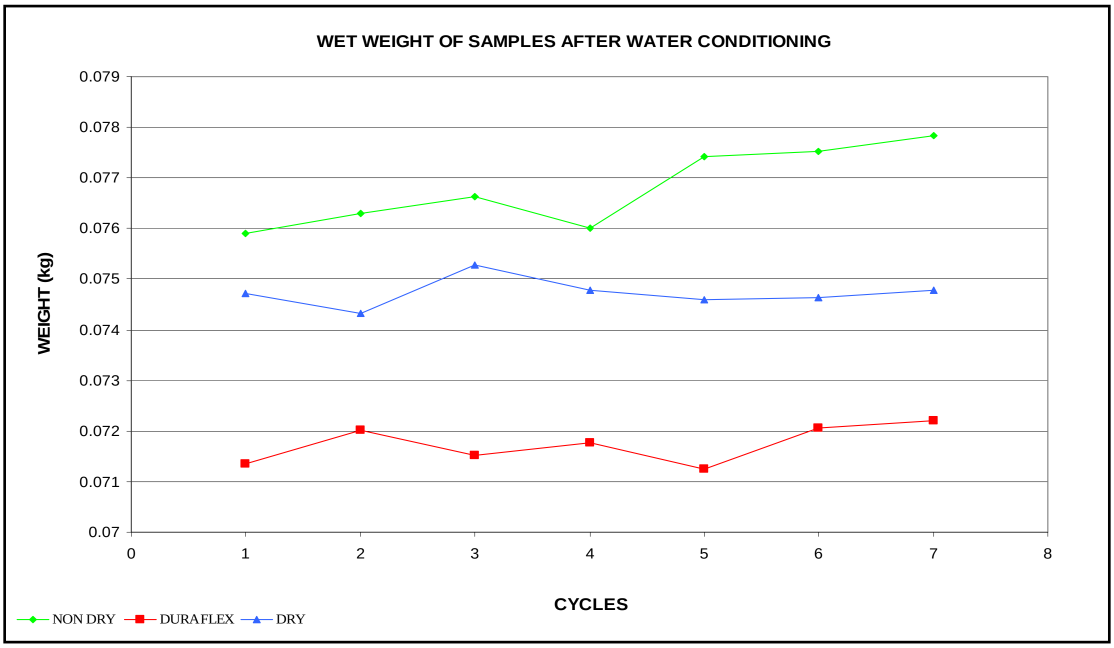

Figure 6: Average wet mass of samples after water conditioning cycles

3.2.6 Percentage Change of Dry and Wet Weights after Water Conditioning Cycles

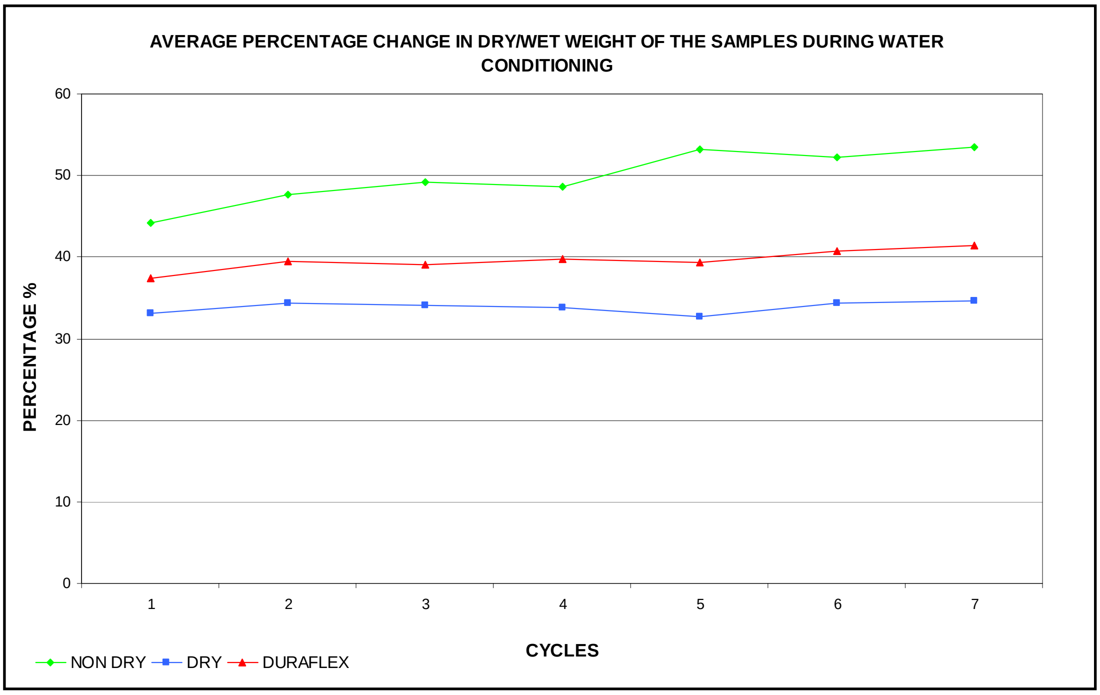

Figure 7: Percentage change in dry and wet weights of samples after water conditioning

3.3 Wear Conditioning Results

3.3.1 Dry Weight after Wear Conditioning

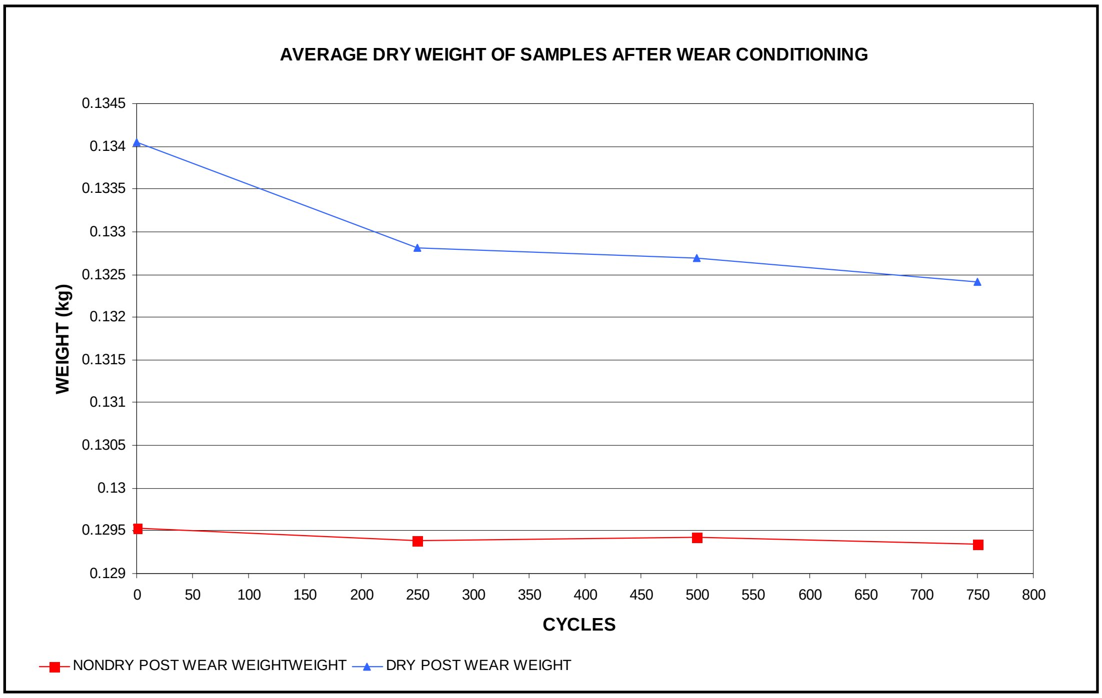

Figure 8: Average dry weight of samples after wear conditioning cycles

3.3.2 Wet Weight of Samples after Wear Conditioning

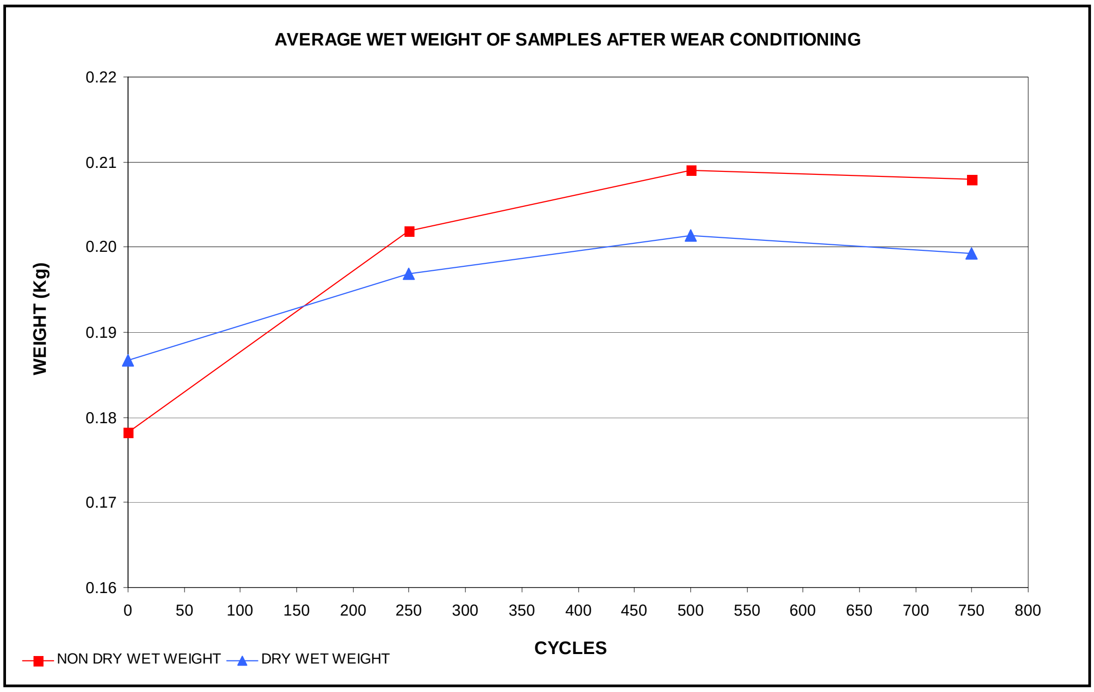

Figure 9: Average wet weight after wear conditioning cycles

3.3.3 Percentage Strain of Samples

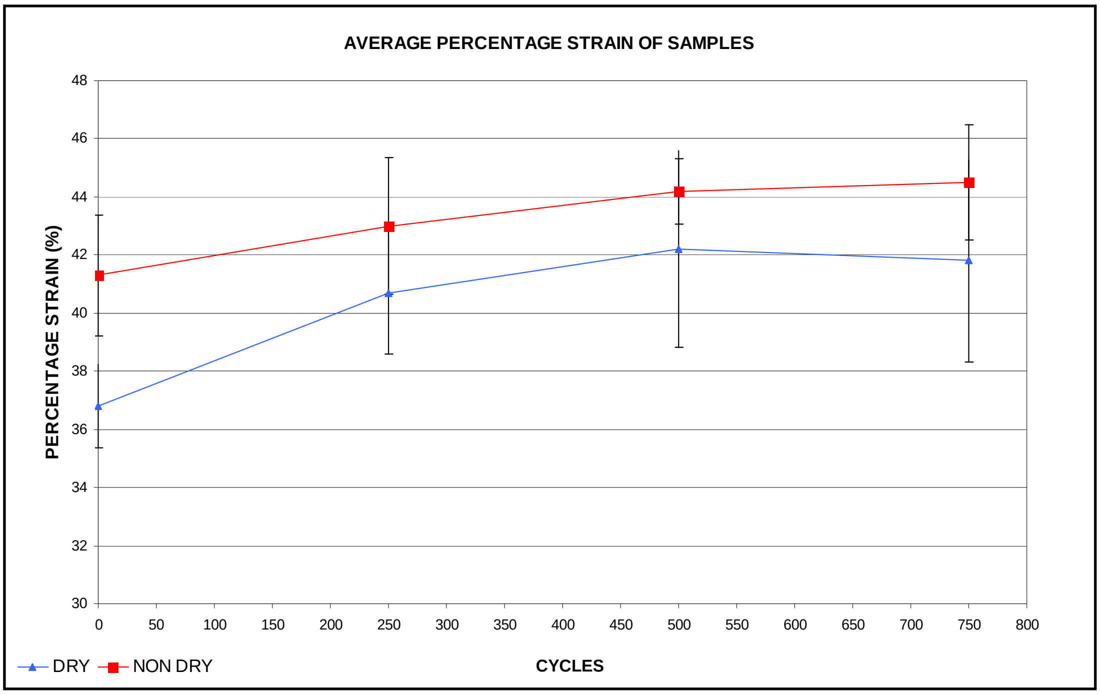

Figure 10: Average percentage strain of samples at a load of 1000lb

3.3.4 Average Breaking Loads of Samples

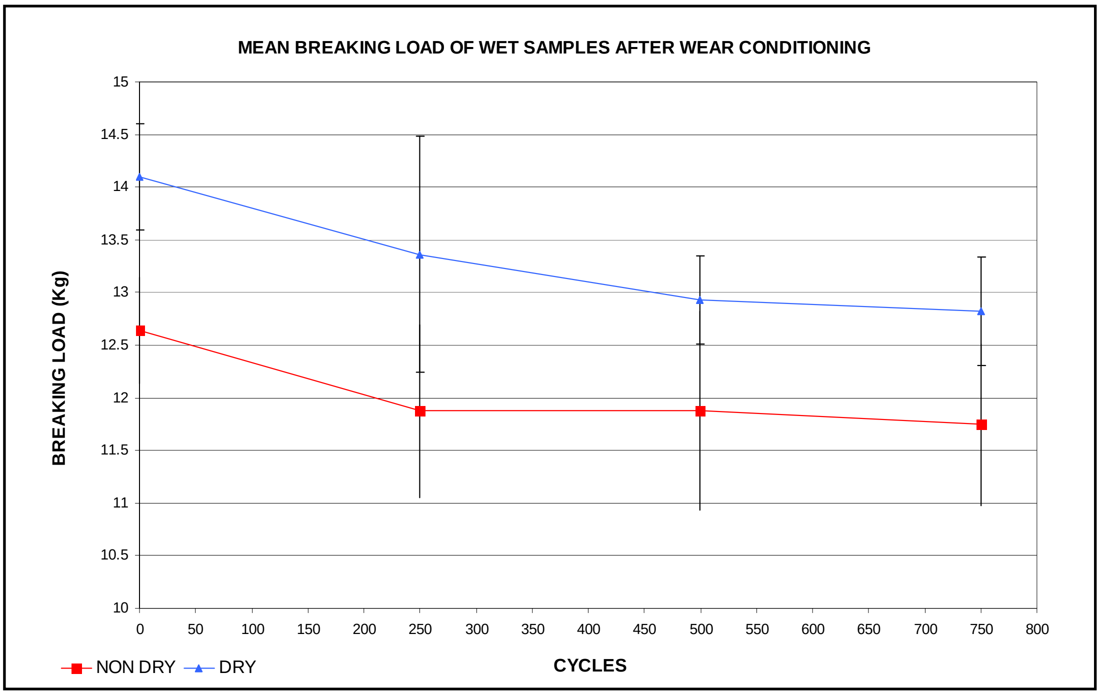

Figure 11: Average breaking load of samples after wear conditioning

4.0 Discussions

4.1 Water Conditioning

The initial dry masses of the three different rope types can be seen in tables 4, 5 and 6 in the Tables section. Weight per metre of rope is one of the tests performed by Mammut [7]. The weight of the Genesis rope is stated as 0.48 g/m. When this value is compared with the recorded values, it is apparent that the experimental values are heavier. The dry treated rope is over 5 g heavier. The inconsistency between the manufacturer's weight and the actual weight may be because the rope is weighed immediately after manufacture before moisture from the air has entered the rope. The lightest rope was the duraFLEX sample. This may have been lighter because of the heat treatment which binds the fibres of the rope together, effectively sealing the rope off from any moisture which could penetrate it.

Figure 2 shows the average dry mass of the samples after each water conditioning cycle. The results show that the dry-treated rope samples do not lose any mass during the conditioning cycles. However, duraFLEX and non dry-treated samples do lose mass. The non-dry samples lost an average of 4% of their mass over eight cycles while the duraFLEX samples lost 1.5% of their initial mass over eight cycles. Figure 3 demonstrates that this mass loss described above only occurred from the core. The sheath samples remained at a constant weight throughout the conditioning.

It was hoped that the mass spectrometer results would be able to identify what substance was actually being removed from the non-dry and duraFLEX cores. The results however were disappointing as they proved inconclusive. Figures 4 and 5.

Although identification of the substance was not achieved the results did prove that the same molecules awere being removed from all the rope samples during the soaking phase. This can be seen from the similarites in the bar graphs. The molecular

masses of the largest peaks are exactly the same for all three samples. This suggests that the treated samples prevented the loss of mass occurring in the same magnitude in comparison to what occurs with the non-dry treated samples.
The largest peak in the negative ion results was the molecule with mass 374 and the largest peak in the positive ion results was a molecule with molecular mass 148. These two masses were investigated further using the mass spectrometers built in search facility to find any possible matches. The results returned from the library were non-conclusive.

Figures 6 and 7 indicate the effectiveness of treatments. Figure 6 illustrates the wet masses of the samples throughout the water conditioning. The non-dry treated samples had the highest wet mass, the duraFLEX samples were the lightest samples and the wet weights of the dry treated samples remained virtually constant. The duraFLEX samples showed a very gradual increase in their wet mass over the water conditioning. The average amount of water being absorbed by the non-dry treated samples increased by 2 g over the course of the seven cycles. A possible reason for this may be due to the COATINGfinish being removed during the soaking cycle there by allowing more water to be absorbed by the rope. The most conclusive findings regarding the effectiveness of the treatments can be made from figure 7. The graph plots the average percentage increase of mass due to water absorption for each of the samples. The dry treated samples had the lowest percentage increase of mass, the sample showed a 33% increase from the dry mass. The duraFLEX samples had a 38% increase during the first cycle, compared to the non dry treated samples increase of 43%. This mean that after the first soaking cycle there was only a 10% difference in the percentage mass change of dry treated and non-dry treated samples. After seven cycles the percentage mass change of the non-dry treated samples has increased to 53%. This graph proves that the amount of water that the treated samples absorb over the course of the conditioning remains constant. This reinforces the fact that the treatments are not affected by water conditioning.

4.2 Wear Conditioning

It was confirmed that mass was lost from the dry treated samples during wear conditioning, figure 8. The samples lost 1.6 g of their mass over the course of the cycles. The majority of the loss of mass occurred during the first wear set of 250 cycles with an average 1.2 g of mass lost. A possible reason for this loss of mass may be due to the removal of the dry coating from the surface of the sheath due to wear. The post wear mass of the duraFLEX treatment shows no change in mass due to wear.

Figure 9 suggests that the treatments have been affected by the wear conditioning. The dry treated baseline samples had a wet mass of 0.187kg. The samples that underwent 250 cycles on the wear machine absorbed the wet mass increased to 0.197kg. This is an increase of 10g which is equivalent to 5% of the initial mass. After 750 cycles the mass difference between the baseline and worn samples increased to 7%. The duraFLEX samples showed a similar trend to the dry treated samples with a large difference between the baseline samples and the wear conditioned samples. The wet mass increased by 13% after the first wear set of 250 cycles. This implies that the duraFLEX treatment was affected more adversely by wear than the dry treated samples. The duraFlex is a heat treatment which binds the fibres tightly together. However after samples experience wear conditioning, the benefits of duraFLEX begin to disappear.

There are insignificant differences between the baseline elongation and the elongation of samples that have underwent wear conditioning. Although the amount of water absorbed by the samples increased there was no significant change in the elongation properties. An increase in the number of samples in each set may have improved the significance of these results.

There was a significant decrease in the mean breaking load of the dry treated samples. It was found that the sample sets that were exposed to 500 and 750 revolutions had tensile strengths of 12.97 kN and 12.78 kN respectively. The baseline samples were calculated to have mean of 14.28 kN. The largest decrease in tensile strength occurred in the 750 cycle sample set with a decrease of 1.5 kN. This decrease in the tensile strength is thought to have occurred due to the non dry treatment being removed from the surface of the ropes sheath. This allowed water to penetrate into the fibres of the sheath resulting in plasticising to occur. This plasticisation led to a decrease in the tensile strength.

5.0.Conclusions

It was realised that to improve the accuracy and reliability of the investigation more sample sets should be used with larger number of samples in each set. However due to the limited time and budget available this was not possible.

The most significant results found during this investigation were:

1. The treatments added to protect ropes against the affect of water were effective. The dry treated samples absorbed 20% less water over eight soaking and drying cycles than a non dry treated rope. The heat treated rope absorbsed 13% less water than the non dry treated samples.
2. The mass lost from non dry and heat treatment sample during the water conditioning was lost only from the cores of the samples
3. The molecular masses of molecules being removed from the core during the water conditioning were found. However it was beyond the limits of this investigation to identify exactly what the molecules were.
4. The effectiveness of the dry coatings were not altered by repetitive water conditioning.
5. Wear conditioning caused a decrease in the dry mass per unit length of the dry treated rope. This loss of mass was assumed to be due to removal of waterproofing chemicals from the surface of the sheath.
6. Wear conditioning did not alter the dry mass per unit length of the heated treated rope
7. Wear conditioning caused an increase in the amount of water that the dry treated and heat treated samples absorbed.
8. Effectiveness of waterproof coatings are reduced with wear conditioning

9. Dry treated rope that underwent wear conditioning had a lower tensile breaking load when wet than a baseline that had not experienced any wear.
10. It was concluded that this was because the waterproof coating was removed by the wearing cycles therefore increasing plasticisation.
11. There was no significant change to the elongation of dry treated sample due to wear conditioning.

6.0 Further Studies

Initially it had been desired to test a number of ropes from different manufacturers to allow for comparison of durability of the treatments. Due to time and budget constraints that this would not be possible, however this is an area where further investigation is required.

If similar research is planned then it is strongly urged by the author to use a larger, more powerful motor. The 12 V motor used during this investigation was adequate to turn the pulley wheel with 80 N of tension applied to the system, however this was the upper limit of motor.

Rope samples could be placed in a container of dirt or sand and then undergo wear cycles to investigate the effect this have on the dry treatment.

7.0 References

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8.0 Appendix

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 1: Material Properties of Mammut Genesis 8.5mm Rope

SAMPLE	ROPE TYPE
AA1-4	**NON DRY**
AS1-3	**NON DRY SHEATH ONLY**
AC1-3	**NON DRY CORE ONLY**
BA1-4	**DURAFLEX NON DRY**
BS1-3	**DURAFLEX NON DRY SHEATH ONLY**
BC1-3	**DURAFLEX NON DRY CORE ONLY**
CA1-4	**DRY**
CS1-3	**DRY SHEATH ONLY**
CC1-3	**DRY CORE ONLY**

Table 2: Shows the samples labelling system for soaking and drying cycles

Sample	Rope	Cycle Length
A1-4	**NON DRY**	**0**
B1-4	**DRY**	**0**
C1-4	**DRY**	**250**
D1-4	**DRY**	**500**
E1-4	**DRY**	**750**
F1-4	**NON DRY**	**250**
G1-4	**NON DRY**	**500**
H1-4	**NON DRY**	**750**

Table 3: Shows the samples labeling system wear cycle

9.0 Results Tables-Water Conditioning

Cycle	Rope Section	Initial Weight	Wet Weight	Dry Weight
Cycle 1	Rope	0.052643333	0.075895667	0.051681
	Sheath	0.0263985	0.0462175	0.0263915
	Core	0.0266705	0.039136	0.0263095
Cycle 2	Rope	0.051681	0.076293	0.051382
	Sheath	0.0263565		0.0261465
	Core	0.0263095		0.025816
Cycle 3	Rope	0.051382	0.076636	0.051110333
	Sheath	0.0261315		0.026066
	Core	0.025816		0.025107
Cycle 4	Rope	0.051110333	0.076003333	0.050534
	Sheath	0.026096		0.0260085
	Core	0.025107		0.0247174
Cycle 5	Rope	0.050534	0.077416	0.050779667
	Sheath	0.0260585		0.025856
	Core	0.0247174		0.0239775
Cycle 6	Rope	0.050779667	0.077522667	0.050518
	Sheath	0.025956		0.02599973
	Core	0.0239775		0.024165
Cycle 7	Rope	0.050518	0.077838667	0.050567333
	Sheath	0.02599973		0.025995
	Core	0.024165		0.024165

Table 4 – Non-Dry Rope Conditioning Testing Results

Cycle	Rope Section	Initial Weight	Wet Weight	Dry Weight
Cycle 1	Rope	0.051923333	0.071341667	0.051653
	Sheath	0.0250955		0.025088
	Core	0.026145		0.025665
Cycle 2	Rope	0.051653	0.072016333	0.051404853
	Sheath	0.025088		0.02499327
	Core	0.025665		0.02557455
Cycle 3	Rope	0.051404853	0.071508	0.051330667
	Sheath	0.0250786		0.0250945
	Core	0.02557455		0.024917
Cycle 4	Rope	0.051330667	0.071775333	0.051136
	Sheath	0.0250945		0.02493015
	Core	0.024917		0.0245185
Cycle 5	Rope	0.051136	0.071256133	0.051204
	Sheath	0.02493015		0.0249038
	Core	0.0245185		0.0244295
Cycle 6	Rope	0.051204	0.072052133	0.051080967
	Sheath	0.0249038		0.02510015
	Core	0.0244295		0.02465
Cycle 7	Rope	0.051080967	0.072212667	0.051175667
	Sheath	0.02510015		0.0250235
	Core	0.02465		0.0242385

Table 5 – Duraflex Rope Conditioning Testing Result

Cycle	Rope Section	Initial Weight	Wet Weight	Dry Weight
Cycle 1	Rope	0.053614667	0.074710667	0.053624667
	Sheath	0.02671965		0.026733
	Core	0.0269955		0.027073
Cycle 2	Rope	0.053624667	0.074322333	0.053325333
	Sheath	0.026733		0.0267547
	Core	0.027073		0.027063
Cycle 3	Rope	0.053325333	0.075281	0.0536343
	Sheath	0.0267547		0.0267213
	Core	0.027063		0.0270485
Cycle 4	Rope	0.0536343	0.074772	0.053705667
	Sheath	0.0267213		0.02682425
	Core	0.0270485		0.027319
Cycle 5	Rope	0.053572333	0.074593	0.053643333
	Sheath	0.02682425		0.0267383
	Core	0.027319		0.0268375
Cycle 6	Rope	0.053643333	0.074643333	0.053650667
	Sheath	0.0267383		0.0265875
	Core	0.0268375		0.0265097
Cycle 7	Rope	0.053650667	0.074789667	0.053627667
	Sheath	0.0265875		0.026715
	Core	0.0265097		0.0268941

Table 6 – Dry Treated Rope Testing Results

Results Tables-Wear Conditioning

Cycles	Initial Weight (kg)	Post-wear Weight (kg)	Wet Weight (kg)	Strain (%)	Break Load (kN)
0	0.13404436	N/A	0.1866585	36.8	14.27908781
250	0.1339644	0.1328156	0.19691	40.7	13.58055556
500	0.1340658	0.1326954	0.2013332	42.2	12.92738255
750	0.1340412	0.1324162	0.1993042	41.8	12.78223299

Table 7: Shows the samples labelling system wear cycle

Cycles	Initial Weight (kg)	Post-wear Weight (kg)	Wet Weight (kg)	Strain (%)	Break Load (kN)
0	0.1295248	N/A	0.1782766	41.3	12.51007756
250	0.1294636	0.1293896	0.2018654	43	11.82061716
500	0.1294992	0.1294242	0.2090102	44.2	11.87504825
750	0.129498	0.12934	0.2079902	44.5	11.60289282

Table 8: Shows the samples labelling system wear cycle