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An Analysis of the Impact of Environmental Conditions on Webbing Strength

Landon Wright, Caleb Duncan, and John L Salmon

ABSTRACT

Nylon webbing was subjected to four simulated environmental conditions which were hypothesized to drastically decrease its strength. The conditions were: water saturated webbing, webbing intermittently exposed to water, webbing exposed to freezing temperatures, and webbing exposed to both freezing temperatures and water saturation. Following the exposure to these simulated environmental conditions a tensile testing machine was used to determine the ultimate breaking strength of the webbing. Each condition was simulated on 20 segments of 3 ft ($\approx$ 1 m) webbing tied with a water knot. In addition, testing was performed on a control group of 30 segments of 3 ft dry, unused webbing at room temperature with the same water knot to serve as a benchmark for comparison across the four environmental conditions.

The experimental testing suggests that water exposure or saturation has a statistically significant effect on the strength of the webbing. We observed greatest strength reduction in webbing that had been soaked for 30 min of 7.9% compared to the benchmark results. A 5.7% reduction in strength for webbing was observed that was soaked for 5 minutes and then allowed to dry each day for one week. A similar reduction in strength of 5.4% was measured for webbing undergoing the same daily soak-dry cycle, in addition to freezing the webbing during the night immediately after the 5 minute soak. Thawing and drying occurred during the day time hours over the seven day cycle.

The fourth environmental condition was simulating cold exposure of webbing without water saturation. The webbing was frozen overnight and then allowed to thaw during the day. The webbing was refroze every night for one week. This webbing showed a slight decrease in the mean strength (1.9%), but it was not a statistically significant amount.

We noticed during testing that the webbing rarely broke at the water knot. Rather we observed that the weak point was frequently at the point where the webbing was slung around the metal bars of the tensile testing machine. We observed this trend in almost all of the test cases, with the exception of the webbing that was soaked for 30 minutes. Since this webbing was pulled while it was still wet, we suspect that the water reduced the friction at the sling connection points which resulted in the knot becoming the weakest point in the webbing specimen.

Beyond the laboratory testing, we collected webbing from Cassidy Arch Canyon in Capital Reef National Park to evaluate and test potential strength reduction in actual use environments. Since there was no record of the webbing history, such as past exposure that may have occurred or how long the webbing was left in place, the samples are insufficient for rigorous analytic explorations. It does however provide some insights into how webbing decreases in strength when left exposed to the elements. This enables the comparison between the strength of webbing collected in the field with the artificially weathered webbing in the laboratory to determine the efficacy of our process.

When we compared the strength of the webbing samples collected from the canyon we found that they had an average of 27.8% reduction in the ultimate breaking strength compared with the control group. This represents roughly four times the reduction in strength that we observed in the weakest condition from the laboratory experiments. Although all the factors that contributed to the decrease in strength of this webbing are unknown, we suspect that the effects of UV radiation may have played a significant role.

From our testing we were able to conclude that exposing webbing to water has a statistically significant effect on its ultimate breaking strength. We also determined that freezing webbing in the absence of water seems to have a negligible effect on the strength of the webbing. By collecting webbing from a canyon we were able to establish that our simulated weather exposure processes did not fully recreate the conditions that webbing left in actual outdoor environments experience. However, the collected webbing does show that strength is lost through environmental exposure. We suspect that an extended time period of simulated weather, including UV exposure, would results in laboratory tests more closely reflecting the strength of the collected webbing samples.

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AN ANALYSIS OF THE IMPACT OF ENVIRONMENTAL CONDITIONS ON WEBBING STRENGTH

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INTRODUCTION

Webbing left in slot canyons for recreational canyoneering is often used with no knowledge of its history or what kind of environmental conditions it may have been exposed to. Typically, webbing is only replaced if it looks excessively sun-bleached or worn. Ideally webbing would be replaced at every use or have its exposure tracked to facilitate replacement when necessary. While this is highly desirable it is relatively impractical.

We set out to quantify how various environmental conditions affect the ultimate breaking strength of webbing. We identified four environmental conditions that we hypothesized would have a significant impact on the strength of the webbing. We examined the impact of: water saturation, intermittent water saturation followed by drying, exposure to overnight freezing temperatures followed by thawing, and exposure to both overnight freezing temperatures and water saturation followed by thawing and drying. We simulated these different types of exposure under controlled conditions and evaluated their impact on the ultimate breaking strength of the webbing. From this testing we have been able to determine that saturating webbing with water has a statistically significant, although minor, impact on its strength. However freezing webbing does not have a statistically significant impact on its strength.

The results of this testing were then compared with the strength of several lengths of webbing that were removed from Cassidy Arch Canyon (seen in Figure 1)[N 38.26109 W -111.22585] and Wife 5 Canyon[N 38.28037 W -111.24037] in Southern Utah. From this comparison we observed a 28% reduction in strength compared to the control group.

PRIOR RESEARCH

The topic of webbing strength has been previously researched in both backyard and laboratory settings. Thomas Evans published an excellent review of the current state of webbing research in 2015 [1]. McKently and Parker performed tests in 2000 to determine the strength characteristics of webbing made on different types of looms [2]. This was mainly a comparison between MIL-spec webbing and climb-spec webbing. Evans performed an extensive study on the strength of old and retired webbing consisting of samples donated by various search and rescue organizations [3]. David Pylman and Phillip Spinelli performed a 2013 study to compare the breaking strength of webbing in slow-pull and dynamic drop-testing

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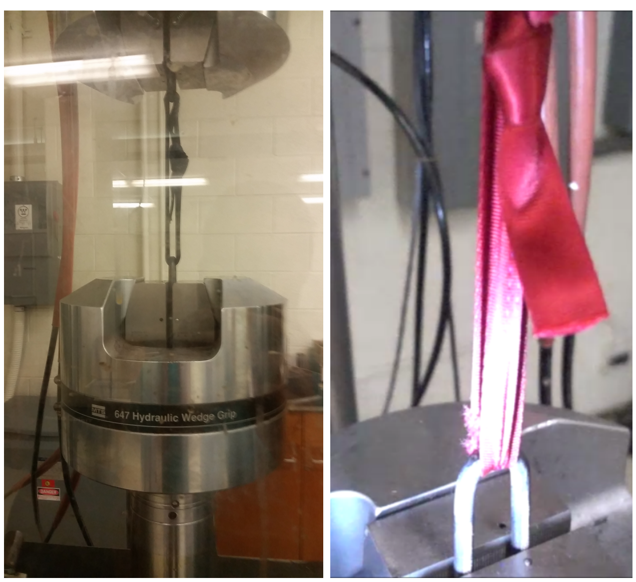
FIGURE 1: Cassidy Arch Canyon as seen from the approach trail.

conditions. They concluded that on average the breaking strength in dynamic loading situations is similar to the breaking strength under slow-pull loading [4]. The topic of the effects of water on nylon rope and webbing has also been visited multiple times [5, 6]. However we were unable to find any research regarding the effect of freezing temperatures, with or without water saturation, on webbing strength.

METHODOLOGY

In an effort to examine only the strength of the webbing, and not any effects that might be introduced from the anchoring method, we tested the webbing in a simple loop configuration pulled on a hydraulic tensile test machine at a rate of about 1 in/s as shown in Figure 2. With the exception of the webbing that was removed from the canyons, all of the webbing that we



(a). (b).

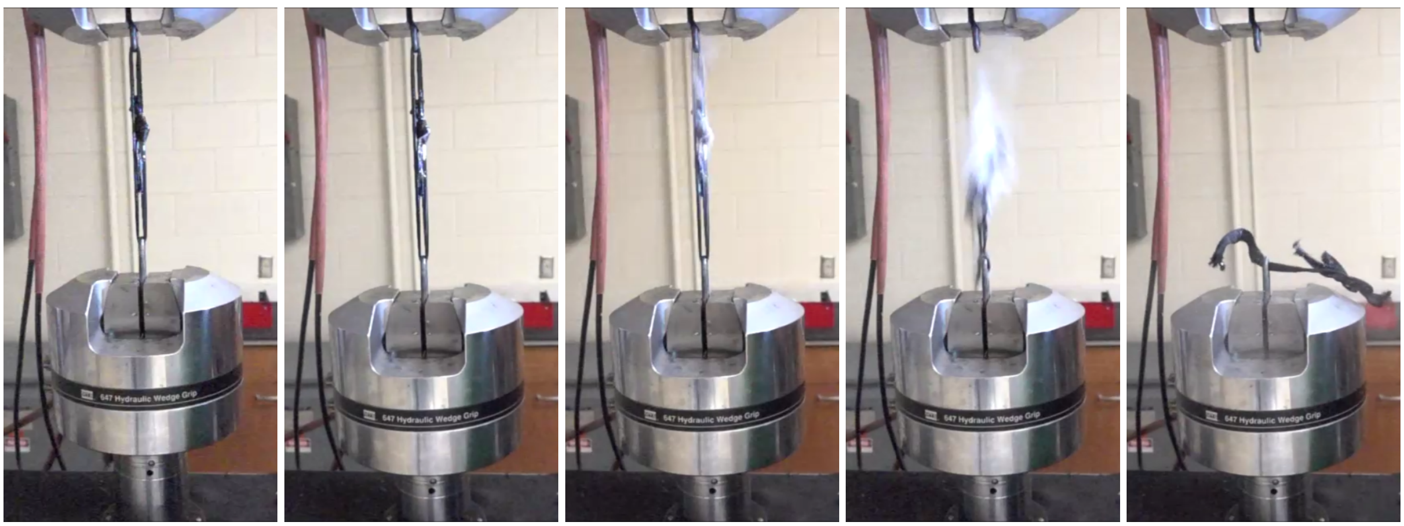
FIGURE 2: (a). Webbing specimen being subjected to load in the tensile tester. (b). Tearing of webbing close to the U-bar anchor before fracturing

tested was new BlueWater one-inch tubular climb-spec webbing cut from the same 100-yard spool [7].

Each test specimen was cut to three foot long segments and tied in a loop with a water knot by the authors. We were careful to ensure that the webbing was tied without twists and that the tails of the knot were consistently 3.5 inches long. The webbing that was removed from the canyons was a mixture of MIL-spec and climb-spec webbing from unknown manufacturers, but it all appeared to be of reasonable quality.

Each test specimen was looped through 3/8 inch steel bars that were bent into a U (see Figure 2(b)). The steel bars were then clamped in the tensile tester using hydraulic wedge grip chucks. The testing apparatus had a six inch stroke and every specimen broke in the stroke of the machine with the exception of one. For each test the force applied to the webbing and the movement of the bottom anchor of the apparatus was recorded for the duration of the test.

The control group of the test was composed of 30 specimens of dry unused webbing that was cut from the spool the day of the testing. These specimens were tested sequentially over the period of one day. For the wet-pull test group we used 20 specimen that were prepared in the same manner as the control group. We filled buckets with normal tap water and placed the specimens in the buckets the saturate with water. The specimens were then allowed to saturate for 30 minutes before being removed from the water. Upon removal from the water, we promptly tested each specimen.



(1) (2) (3) (4) (5)

FIGURE 3: Video frames from frozen webbing load test: (1) Halfway through the 6in stroke ($\approx$ 2500 lbs), (2) Just before fracture, (3) Water ice on webbing surface begins to be ejected, (4) Water ice is discharged during breakage event, (5) Webbing debris on U-bar

The other three simulated exposure conditions were performed over a one week (7 day) period in which each specimen was subjected to a daily cycle of exposure. In the case of the wet-dry cycle the webbing was soaked for five minutes at approximately 8:00am every day. After the soak we hung each piece of webbing on a dowel and allowed it to hang dry for a period of 24 hours at the end of which we re-soaked the webbing and the cycle was restarted. We tested this webbing the morning of the eighth day of the testing period. Before the testing began we soaked the webbing following the defined process and then tested it while it was still wet.

For the cases of the wet-freeze and the dry-freeze cycles we treated them in a vary similar fashion. A small chest freezer was used to subject the specimen to freezing temperatures from 5:00pm to 8:00am every night. In the case of the dry-freeze cycle we removed the webbing from the freezer every morning and allowed it to thaw in a dry location for the nine hour time span from 8:00am to 5:00pm. We then placed the webbing back in freezer for the time span from 5:00pm to 8:00am. In the case of the wet-freeze cycle the webbing was treated in the exact same manner as the webbing for the dry-freeze cycle, with the exception that we soaked the webbing for five minutes and briefly allowed it to hang dry until it stopped dripping before we placed it into the freezer. For both of these test cases we tested the specimen as we pulled them directly from the freezer such that they were still frozen when tested. This would often result in ice ejected from the sample as shown in the five images capture through video recording in Figure 3.

With regard to the webbing retrieved from the canyons, it was tested in the same way as all the other samples. We descended Cassidy Arch and Wife 5 canyons and removed and replaced the majority of the webbing that we found. We were careful to remove the webbing without cutting it in order to maximize the length of webbing available for testing. In the same manner as before we cut each length of webbing into three foot segments and tied them in a loop with a water knot. We then tested the strength of this webbing following the exact same procedure that was followed with the control group. A summary of the various treatments of webbing loops is presented in Table 1.

TABLE 1: Summary of Experimental Treatments

Treatment	Description*
Control	New webbing, tested in dry condition
Dry-Freeze Cycle	New webbing, frozen over night, thawed daily for 7 days, tested frozen on 8th day
Wet-Freeze Cycle	New webbing, submersed in water before freezing over night, thawed during the day, repeated daily for 7 days, tested frozen on 8th day
Wet-Dry Cycle	New webbing, soaked for 5 minutes before drying daily for 7 days, tested in wet condition on 8th day
Wet	New webbing, submersed in water for 30 minutes, tested in wet condition
Collected	Used webbing, collected from Cassidy Arch and Wife 5 Canyons, tested dry

*All water knots of specimens were tied with tails 3.5 inches long

EXPERIMENTAL RESULTS

Table 2 shows the descriptive statistics for the compiled testing results for the six conditions of tested webbing: Control, Dry-Freeze Cycle, Wet-Freeze Cycle, Wet-Dry Cycle, Wet, and the webbing collected from the canyons.

Following the collection of the raw data as seen in Figure 4 we used a simple Python script to determine the maximum force applied to the webbing sample for each test. This script then compiled all of the maximum values for a treatment into a single file for ease in determining the descriptive statistics for the sample set. To determine the descriptive statistics and the statistical relevance of the different treatments we used the JMP statistical package. We calculated the p-values presented in

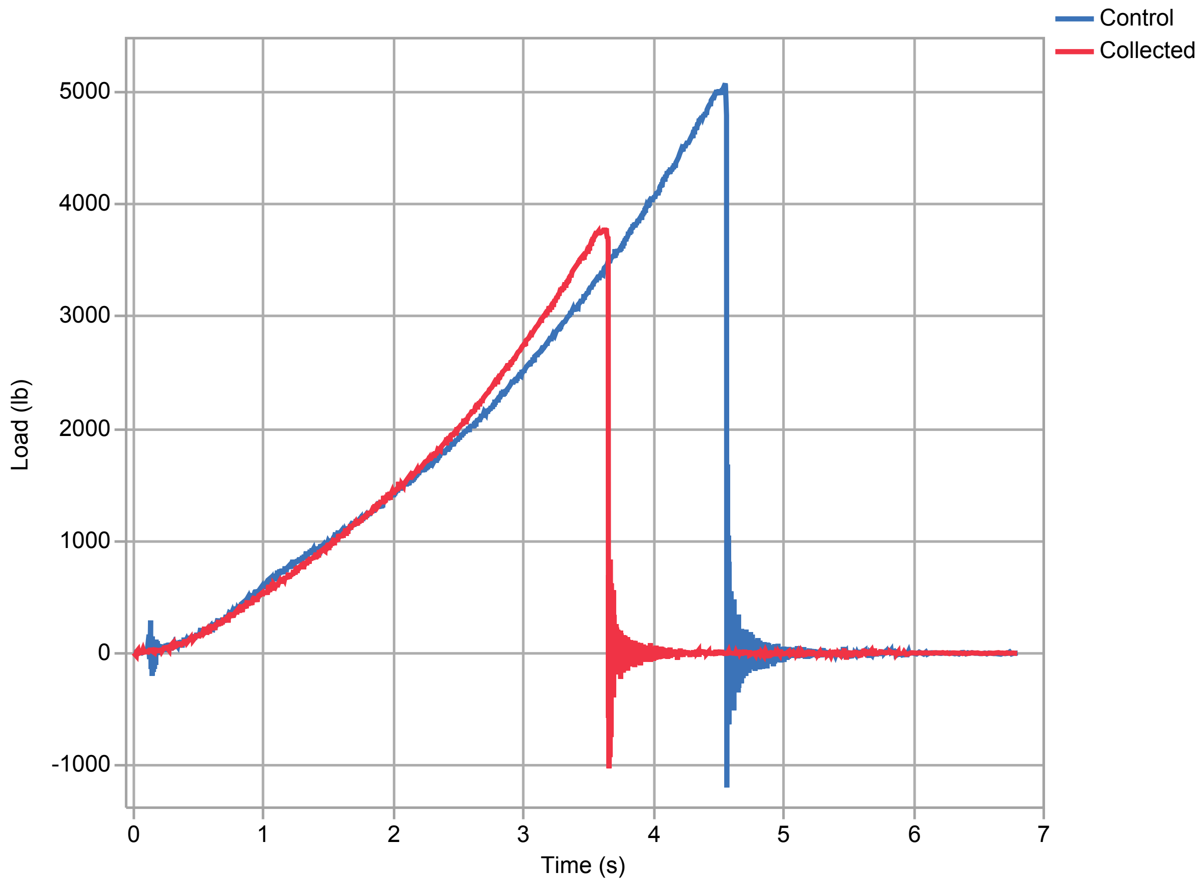


FIGURE 4: Example of two output profiles of load data from the tensile experiments (Control sample in blue and Collected sample in red)

Table 3 using Tukey's HSD test. This allowed us to determine the probability that there is a statistical difference between the control group and a given treatment. For statistical significance we considered a p-value $\leq$0.05 to be statistically significant.

The control group had a mean strength of 22.33 kN with a standard deviation of 1.26 kN. All of the other sample groups showed some decrease in the average strength of the webbing. The collected webbing showed a particularly significant decrease in mean strength of 6.2 kN.

Table 3 shows the percent decrease in strength when compared to the control group. Table 3 also shows the probability that the null hypothesis (the environmental condition had no effect on the strength of the webbing) is true. As seen in the table of the controlled conditions the wet webbing showed the largest decrease in strength at 7.33%. As expected, the collected webbing showed a drastic decrease in strength of 27.77%. This is observed in Figure 5 which shows the distribution of the breaking strengths for each group of webbing in the test. The p-values shown in Table 3 indicate that the wet-freeze cycle, the wet-dry cycle, and the wet cycle all have a statistically significant effect on the strength of the webbing. The webbing that was collected from the canyons was also statistically weaker than the control group. The only group that did not have a statistically significant difference in strength from the control group was the dry freeze cycle.

Figure 5 shows the box plots for the distributions of strength for the various testing conditions. The plot shows that there was a major drop in strength for the webbing that was collected from the canyons. It also shows that, while there was a statistically significant drop in strength for some of the groups, the absolute drop is only a minor amount.

TABLE 2: Compiled Testing Results

	Control	Dry Freeze Cycle	Wet Freeze Cycle	Wet Dry Cycle	Wet Pull	Collected
Mean (kN)	22.33	21.90	21.26	21.06	20.69	16.13
Std. Dev. (kN)	1.26	1.13	1.16	1.05	1.11	1.79
Min (kN)	19.36	19.61	18.22	19.29	18.68	12.71
Max (kN)	24.94	23.74	22.80	22.76	22.64	18.77
Range (kN)	5.58	4.12	4.59	3.48	3.97	6.06
Num. Samples	30	20	20	20	20	20

TABLE 3: Comparisons of test groups with the control group

	Dry Freeze Cycle	Wet Freeze Cycle	Wet Dry Cycle	Wet Pull	Collected
% loss in strength	1.90%	4.76%	5.69%	7.33%	27.77%
P-Value	0.8575	0.05	0.0095	0.0003	$<$0.0001

Through these experiments, we observed that, with the exception of five individual specimens, the webbing almost always failed at the anchor. The five samples that did not fail at the anchor failed at the water knot. We also observed one specimen of webbing that did not fail within the six inch stroke of the tensile testing machine, which was a member of the Wet treatment group. During this specific test we observed excessive slippage in the knot of the specimen. We re-rigged the sample in the tensile testing machine and re-ran the test. The specimen behaved in a manner consistent with the rest of the test group and we included it in the compiled results. We speculate in rigging this particular sample that the water knot became slightly less tight and allowed the water to reduce the friction sufficiently to cause slippage or that the initial knot was not tied as tightly as the other knots. However, we do not believe that this slippage event reduced the strength of the specimen when it was retested as evidenced by the results and load profile.

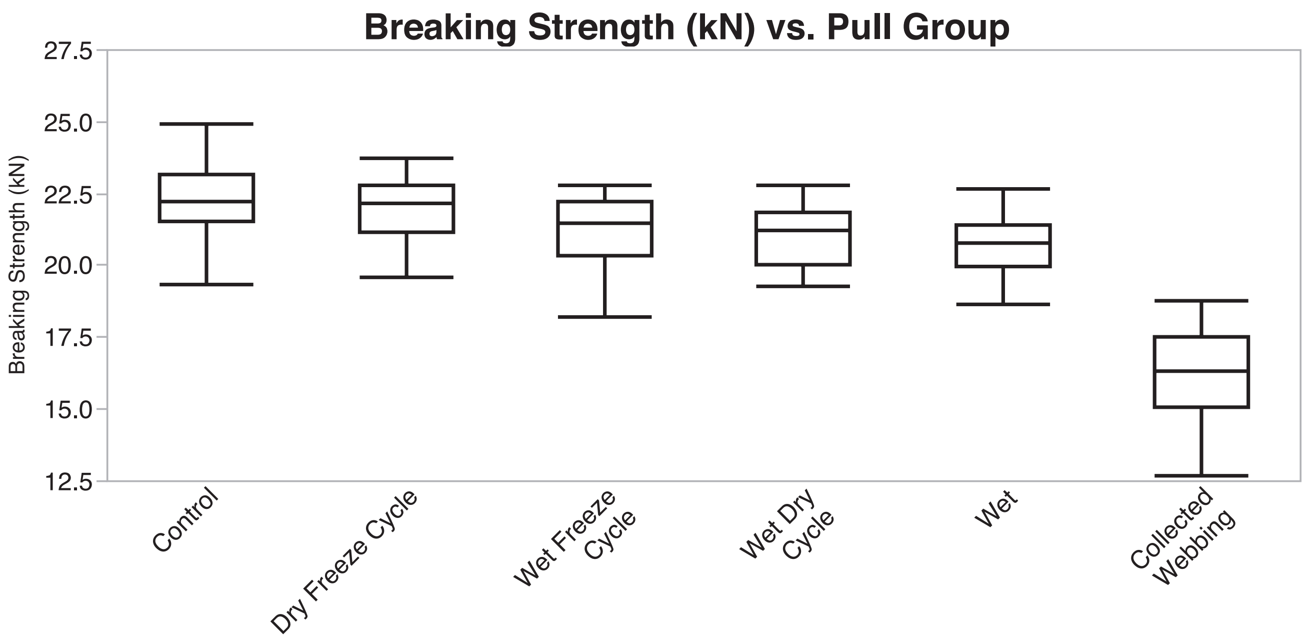


FIGURE 5: Box plots of webbing strength under various exposure conditions.

FURTHER WORK

Further work in the area could consist of performing more extensive testing of the exposure conditions over longer periods of cycles. Webbing found in canyons may be weeks or months old and as such it is unlikely that our testing time of one week was sufficient to fully understand how these environmental conditions might effect webbing strength. Another potential area of research would be to examine the relationship between time of exposure to water and decrease in webbing strength. In these experiments, samples would be exposed to a different number of wet, dry, or freeze cycles and provide insight into how long webbing should be left in canyons with confidence.

The collected webbing also served to illustrate that our testing conditions did not fully recreate the exposure that webbing experiences in a canyon conditions. We did not account for environmental factors such as sand, abrasion, and UV exposure. We would like to further investigate how these factors impact the strength of webbing.

CONCLUSION

Our experiments demonstrate that webbing exposed to water experiences a statistically significant decrease in its ultimate breaking strength while the effects of freezing are negligible in the time period of one week. We also see that webbing which has seen actual environmental use, e.g., the webbing taken from Cassidy Arch Canyon, has a strength reduction of roughly four times that of the harshest simulated condition from the laboratory experiments. This highlights how other environmental factors such as UV exposure, abrasion, and dirt likely have a more profound effect on strength reduction than water and freezing temperatures.

Despite the fact that water has a statistically significant effect on the strength of webbing it makes no difference in real world applications. The loss in strength between our control group and the wet webbing (the treatment that exhibited the largest loss in strength) was only 7.33%. Considering that the webbing used is rated to 17.7 kN and the strength of an anchor is increased from that number when common anchoring techniques are used, there is more than sufficient strength in a webbing anchor even when it is wet. This supports and confirms the findings presented by Evans and Truebe [1].

We can conclude from the results of our testing that tubular nylon webbing used in wet conditions will experience a small reduction in strength. This reduction is of little or no consequence to the men and women who rely on webbing for their safety so long as the manufacturer's instructions and safe anchoring techniques are followed. Our findings also highlight the need for further research in order to determine and quantify the effects that other environmental factors such as UV light, abrasion, and dirt have on webbing strength.

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