The Effects of a Sharp Edge and an Oxyfuel Cutting Process upon Flexible, Torsionally Balanced Structures of Dissimilar Fiber Types

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PART #1 - Sharp Edge Testing

The intent of this testing was to evaluate the comparative performance of different small diameter (7.5-8 mm) ropes that have the potential to be subjected to a sharp edge during use. Small ropes are commonly being used in “edge kits” such as the AZTEK for a variety of applications where a single rope is used for life support.

This test method simulates a loaded rope sliding horizontally across a sharp edge. The fixture used allows for the following components to be varied depending on the specific test needs:

1. Test Mass
2. Rate of travel
3. Test Mass Offset Distance
4. Edge Type

DETAILS - CONFIGURATION

Initially this testing was aimed at finding the line where some ropes failed and others did not. After some thought it was determined that it would be more useful to conduct each test in a manner where failure was ensured. This allowed for a better statistical comparison of test results.

Calibration tests were done to find the appropriate test mass, speed dampening mass, and offset distance so as to provide good results. The following variables were selected for the initial group of tests:

1. 82.5 mm offset (the distance the mass is pulled away from the initial release point. This offset creates the horizontal force sliding the rope sample across the sharp edge).
2. Test Mass = 125 kg.
3. 4.5 kg speed dampening mass (this mass is a counterweight that opposes the horizontal travel of the rope along the edge. Without the dampening mass there is an impulse that is introduced during the initial sample release that imparts a dynamic that creates less consistent results).
4. The edge utilized is custom made by the Benchmade Company (Portland, OR) made from heat treated M4 steel with a 45 degree chamfer along the cutting surface.

The data acquisition system used was a LabJack U3 HV module with an Omega LC101-2.5k S-beam load cell. Data was acquired at 500 Hz due to the dynamic nature of each event.

Initially peak force was going to be the main test result. After some experimentation a method was created to determine horizontal travel accurately. A ≈6 mm wide line made from an oil-based, silicone polymer was applied parallel to the cutting edge approximately 2-4 mm back from the chamfer. As the rope travelled along the edge it would wipe the polymer from the edge indicating the point furthest travelled. Each test result included peak force and displacement.

5 tests of each rope were initially conducted to see if the data acquired was statistically significant and warranted further testing.

To describe rope type the following convention was used and referred to as the Type Code:

Sheath #1/Sheath #2(if any)/Core #1

N/N = Nylon Sheath/Nylon Core
P/N = Polyester Sheath/Nylon Core
P/D/N = Polyester & Dyneema Sheath/Nylon Core

Abbreviations
N: Nylon
P: Polyester
T: Technora
D: Dyneema

The following 7.5 to 8 mm ropes were tested:

Model	**Manufacturer**	**Sheath**	**Core**	**Type Code**
CanyonPrime	Sterling	Polyester	Polyester	P/P
Escape Pro	Bluewater	Technora/Polyester	Nylon	T/P/N
Escape Webbing	CMC	Technora Web	None	T/Web
FireTech 2	Sterling	Technora	Technora	T/T
Hybrid Escape	Bluewater	Technora	Nylon	T/N
Oplux/CanyonLux	Sterling	Technora/Polyester	Dyneema	T/P/D
PER	Sterling	Nylon	Nylon	N/N
Pro Series Escape	CMC	Technora	Technora	T/T
SafeTech	Sterling	Technora	Nylon	T/N

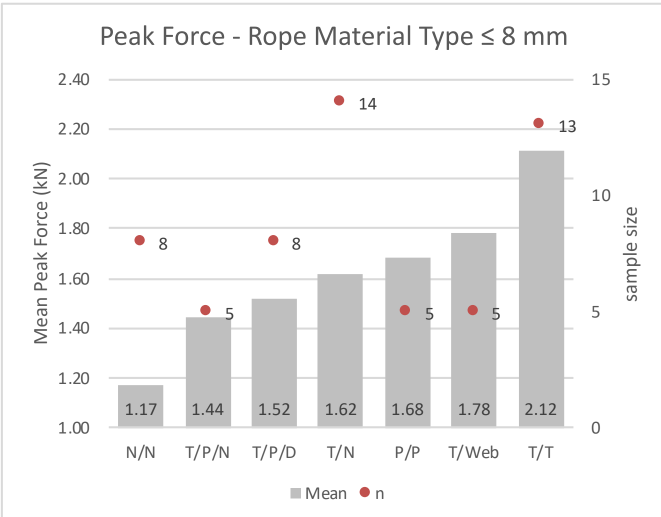
Additionally a series of tests were conducted on ropes >8 mm. This was to see where "failure" might occur as it relates to diameter, rope construction, or another variable.

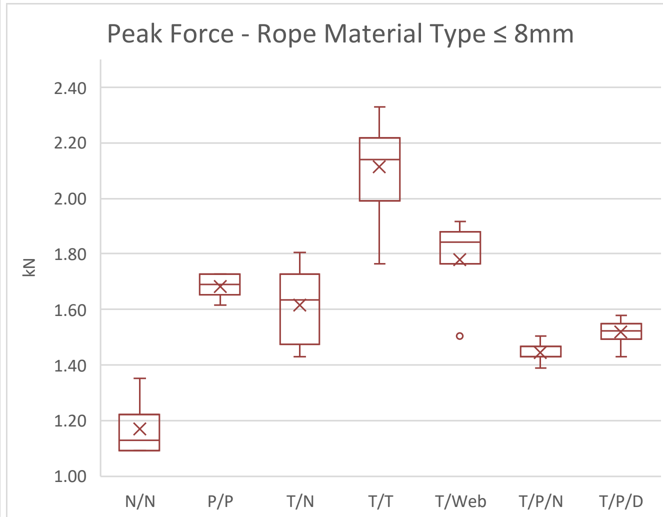
Test Results

The results are grouped in 2 categories, Force and Distance. All ropes tested showed p values well below (≤3.3E-04) a significance level of 5% when compared to N/N . N/N was used as the basis for comparison in all results where applicable since it is the most common style of rope used in various edge kits.

FORCE

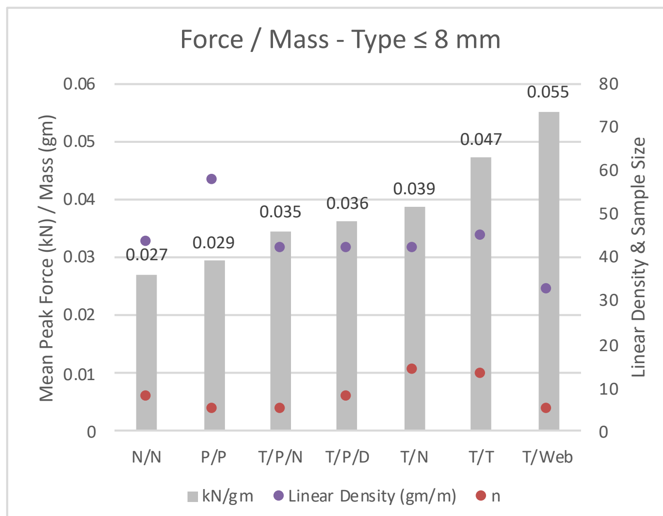
Results as follows:





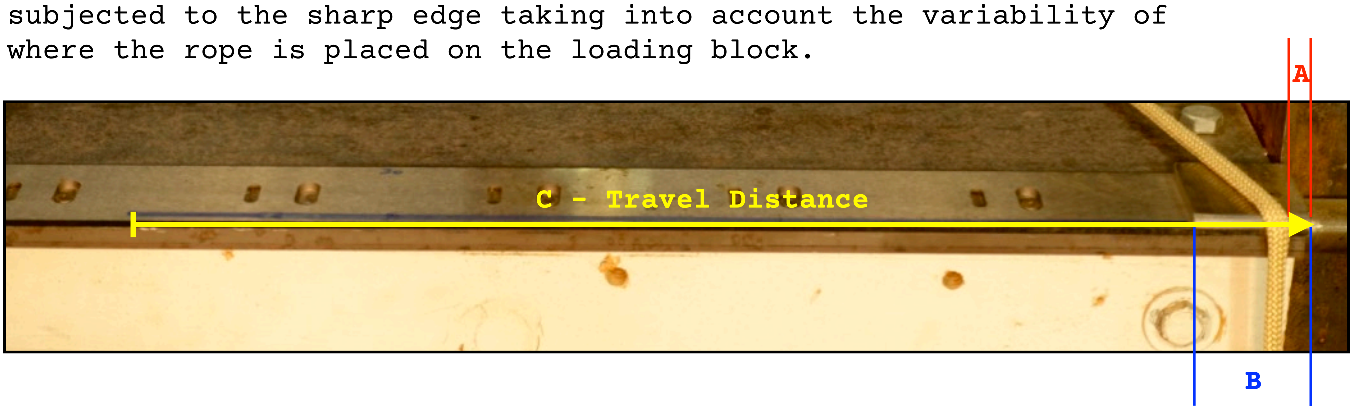
Linear density (mass per unit length) of the ropes was also compared to the peak force in order to see if there was a correlation between mass of the rope and maximum force to failure.

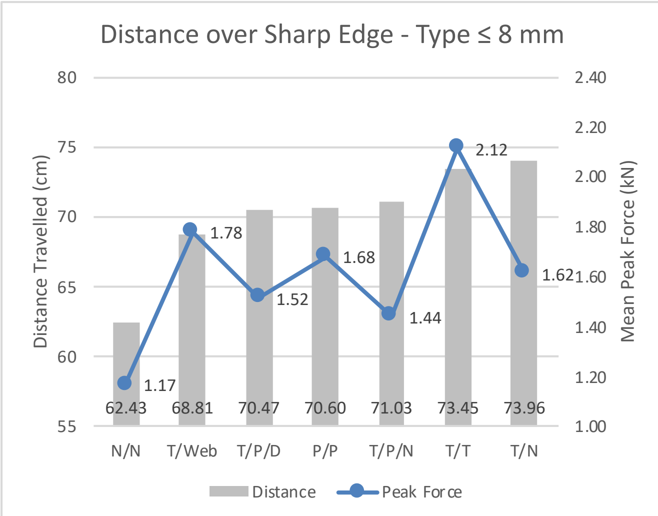
The data suggests that mass is not the only factor that contributes to a higher peak force. T/Web and P/P have densities and forces that do not follow the pattern exhibited by the other rope material types.

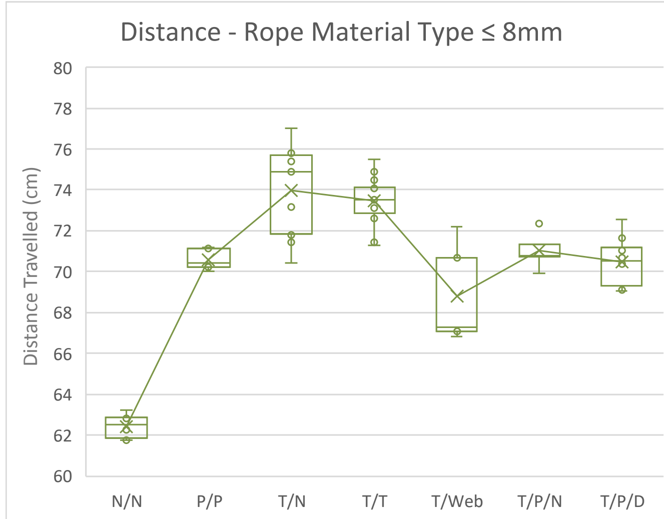


DISTANCE

In order to be consistent when comparing the distance travelled along the sharp edge, an initial distance was measured (measurement A). This was subtracted from the loading block (measurement B). Once the test was complete, measurement C was made to the nearest mm. This produced a distance subjected to the sharp edge taking into account the variability of where the rope is placed on the loading block.







ROPES > 8 MM

This testing focused on measuring 3 factors:

1. Failure (Yes/No)
2. Residual Strength (RS)
3. Functionality (This is somewhat subjective as it is dependent on the intended application. If more than 50% of the sheath was intact and if I felt the rope would travel through a descent control device it was deemed functional. There is room for more investigation into what constitutes a functional rope).

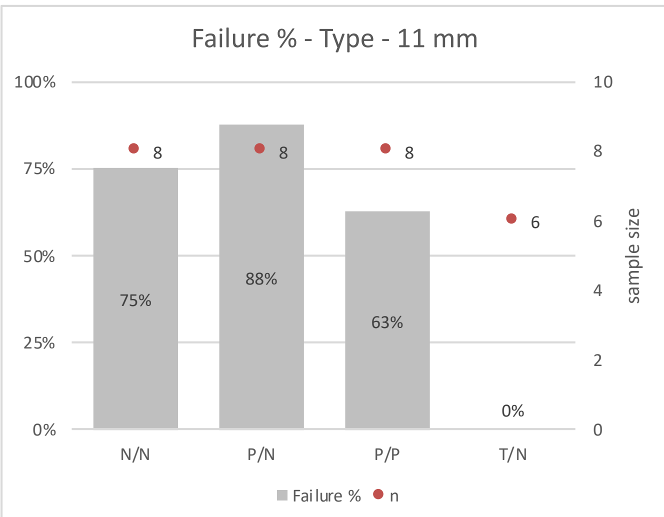
The ropes were subjected to the same test conditions as those for the previous ≤8 mm testing. The following ropes were tested:

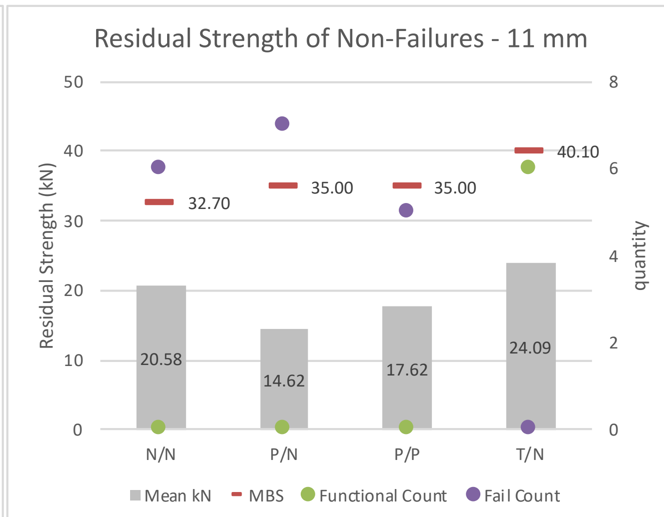
Model	Manufacturer	Short Name	Sheath	Core	D (mm)	Type Code
EZ Bend	PMI	ez11	Nylon	Nylon	11	N/N
HTP	Sterling	htp125	Polyester	Polyester	12.5	P/P
KMIII	New England	km3	Polyester	Nylon	11	P/N
Static-Pro Lifeline	CMC	cmcpp	Polyester	Polyester	11	P/P
Tactical Response	Sterling	tacresp	Technora	Nylon	9.5	T/N
Tech11	Sterling	tech11	Technora	Nylon	11	T/N
WorkPro	Sterling	wp125	Polyester	Nylon	12.5	P/N

Residual Strength Testing

Samples that did not fail during the sharp edge test were pulled to failure in a hydraulic tensile tester. Samples were terminated with double overhand noose knots tied around a 1" pin. Tests of ropes ≤11 mm failed at the damaged portion of the rope. When testing 12.5 mm rope the rope would fail near the entrance of the knot or inside the knot. This occurred at >30 kN. Since the rope samples were 132 cm it was not possible to utilize a standard 4" bollard. Additional work needs to be done in order to determine an accurate way of measuring residual strength in ropes >11 mm that are slightly damaged. For this reason the data below only pertains to 11 mm.

Results as follows:

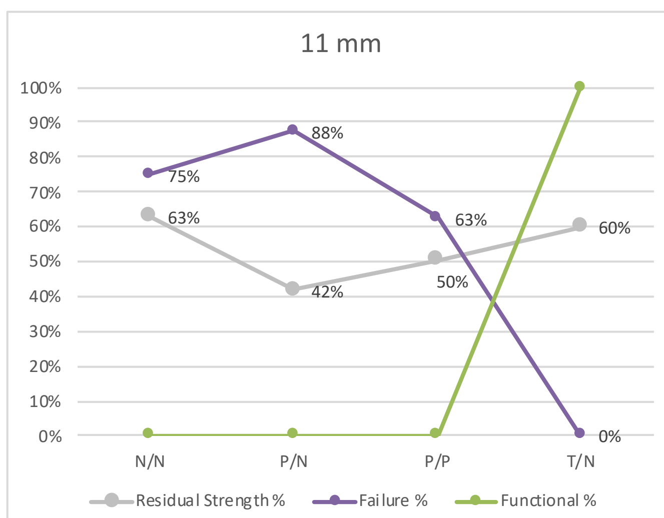




Failure % shows a similar performance between ropes other than T/N which exhibits no failures.

Residual strength (RS) values are based on those that did not fail regardless of functionality. It should also be noted that for all ropes other than T/N the RS is based on data with a small sample size.

Rope Type	n
N/N	2
P/N	1
P/P	3
T/N	6



>8 mm Samples

Typical damage from test method:

PART #2 - Cutting Torch Testing

This testing was aimed at simulating the accidental contact of a cutting torch over a loaded rope by a technician while working on rope. Using a cutting torch at height is an operation that US&R teams and Rope Access Technicians utilize during incidents and on job sites around the world.

Currently, 100% Nylon rope (N/N) is used exclusively by FEMA US&R teams. This test is to evaluate whether further testing is warranted as to whether use of heat resistant ropes would be beneficial during these operations. The rope access industry currently uses ropes of varying materials including those using heat resistant fibers.

DETAILS - CONFIGURATION

A Victor Firepower Heavy Duty oxyacetylene torch was used for all tests with a Victor 2-3-101 tip. Operating pressures were acetylene: 5 psi and oxygen: 30 psi. Tests were conducted with the cutting oxygen activated. During each group of tests the torch was left running and no adjustments were made.

A test fixture was built to ensure the rope would be held in the same position relative to the torch head for each test. A stop was positioned to allow the torch to travel to a repeatable location along a track where the flame would then contact the rope.

3/8” chain grab hooks were used to hold the test samples. Test samples were prepared by tying an overhand blocking knot in each end. An additional stabilizing line was installed to ensure the rope sample stayed in the proper location.

A 300 lb (≈136 kg) test mass was used.

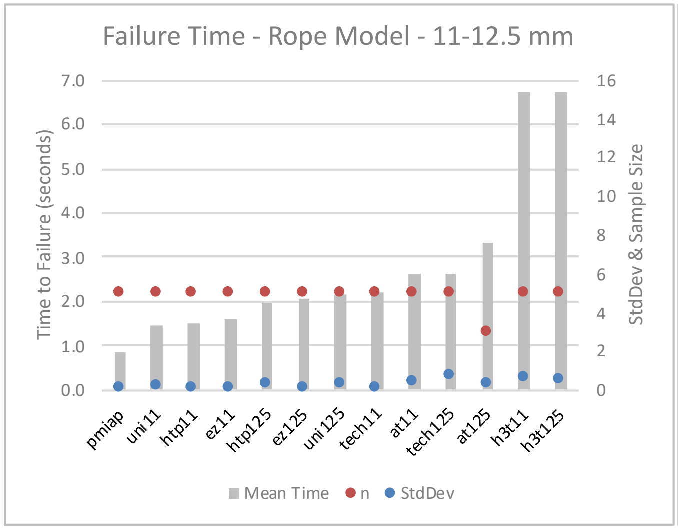
Once a sample was placed in the fixture, the torch was brought to the stop with the cutting oxygen activated. The torch was held there until failure. In order to record time elapsed video was recorded at 60 frames/second. This video was analyzed later to determine the elapsed time with an accuracy of 1/60 of a second.

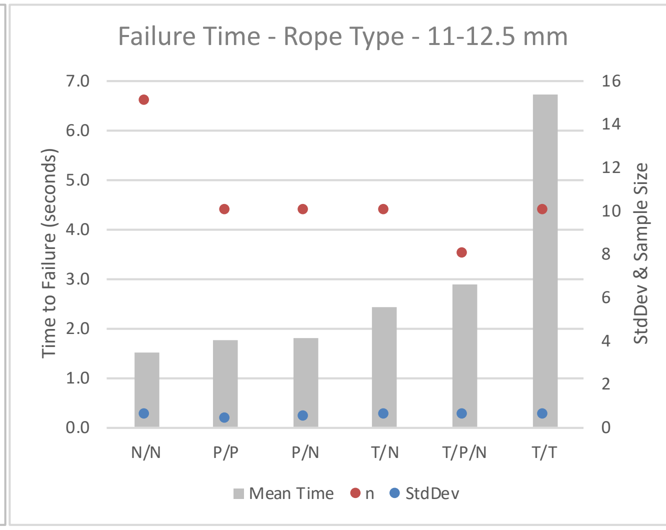
The following ropes were tested:

Model	**Manufacturer**	**Short Name**	**Sheath**	**Core**	**D (mm)**	**Type Code**
Access Pro	PMI	pmiap	Nylon	Nylon	11	N/N
ArmorTech	Bluewater	at11/ at125	Technora/ Polyester	Nylon	11/12.5	T/P/N
Extreme Pro	PMI	uni11/ uni125	Polyester	Nylon	11/12.5	P/N
EZ Bend	PMI	ez11/ ez125	Nylon	Nylon	11/12.5	N/N
H3Tech11 & H3Tech12.5	Sterling	h3t11/ h3t125	Technora	Technora	11/12.5	T/T
HTP	Sterling	htp11/ htp125	Polyester	Polyester	11/12.5	P/P
Tech11 & Tech12.5	Sterling	tech11/ tech125	Technora	Nylon	11/12.5	T/N

Test Results

5 samples of each rope were tested[1]. 1 sample of each rope was placed in groups of 13 ropes. These 5 groups were then tested in order.





Rope Model	Type Code	Time	StdDev	n
pmiap	N/N	0.87	0.047	5
uni11	P/N	1.46	0.190	5
htp11	P/P	1.49	0.111	5
ez11	N/N	1.58	0.096	5
htp125	P/P	1.99	0.350	5
ez125	N/N	2.05	0.059	5
uni125	P/N	2.15	0.262	5
tech11	T/N	2.23	0.138	5
at11	T/P/N	2.62	0.393	5
tech125	T/N	2.63	0.718	5
at125	T/P/N	3.33	0.344	3
h3t11	T/T	6.71	0.607	5
h3t125	T/T	6.72	0.557	5

Type Code	Time	StdDev	n
N/N	1.50	0.505	15
P/P	1.74	0.359	10
P/N	1.81	0.424	10
T/N	2.43	0.532	10
T/P/N	2.89	0.507	8
T/T	6.72	0.549	10

The data shows that 11-12.5 mm ropes made from a T/T construction will outperform other types when subjected to these test conditions. There is also evidence to support that ropes with a Technora sheath will outperform those with Nylon or Polyester sheaths.

More testing is warranted before a conclusion can be drawn from this data as to the cut resistance of a rope when subjected to a cutting torch.

More to come…

[1] ArmorTech 12.5 was tested only 3 times due to a limited supply of the rope.