Dyneema and Not Dying: 2020 Update: Section 1.

A) New Mode of Presentation: This will be a living document, as opposed to what I wrote in 2017. I'll keep updating it, adding new sections; else I will procrastinate forever. I've done many, many experiments since 2017, and Dyneema raps are part of my quiver. The current document is just an introduction; ***future*** sections, as separate pdfs, will cover:

What Is Dyneema (or UHMWPE or HMPE or Spectra)?
Historical Use of Dyneema for Raps (Yes it Does Exist) and Caveats
Before You Read More: Where BARE Amsteel Sucks
Never Pair Bare Dyneema with Other Climbing Ropes Inside Rap Device!
A Very Good Use for Amsteel: Light Anchor-Extenders
More on Munters and Carabiners
The Heat Conductivity Advantage (and Disadvantage)
Splices—They Really Can Be Very Strong
Knots, Not-Knots, High-Friction Sleeves, Splices, and Heat Again
Shrinkage and Heat Again! The Problem with Polyester Sheaths
Construction Stretch and Maximum Force; How Static Is Static?
Samthane and Melting
Dyneema "Friction" Knots
Light Throw Bags
Abrasion

B) Background and Introduction: How the Obsession Began

This document summarizes my experiences using bare (uncovered) and polyester-covered Dyneema for short rappels and ascents. It was initially written in 2017, and I've had much, much more experience since then. The bare Dyneema is Amsteel, a brand of Samson ropes.

Initially, I wanted to test thin high-modulus cord for **emergency** raps down a snowfield, using minimal equipment, such as a Munter on a carabiner and hasty harness. However, I was stunned by the number of negative responses I received, all based purely on the low melting point of Dyneema (148 °C (298 °F)) and some odd views on energy transfer. I had done many tests rappelling on bare Dyneema, and I had never found the rope to heat anywhere as much as polyester- or nylon-sheathed ropes.

Before we get into a technical discussion, let's have a visceral example. Here is the place I test 155' rappels on Dyneema:

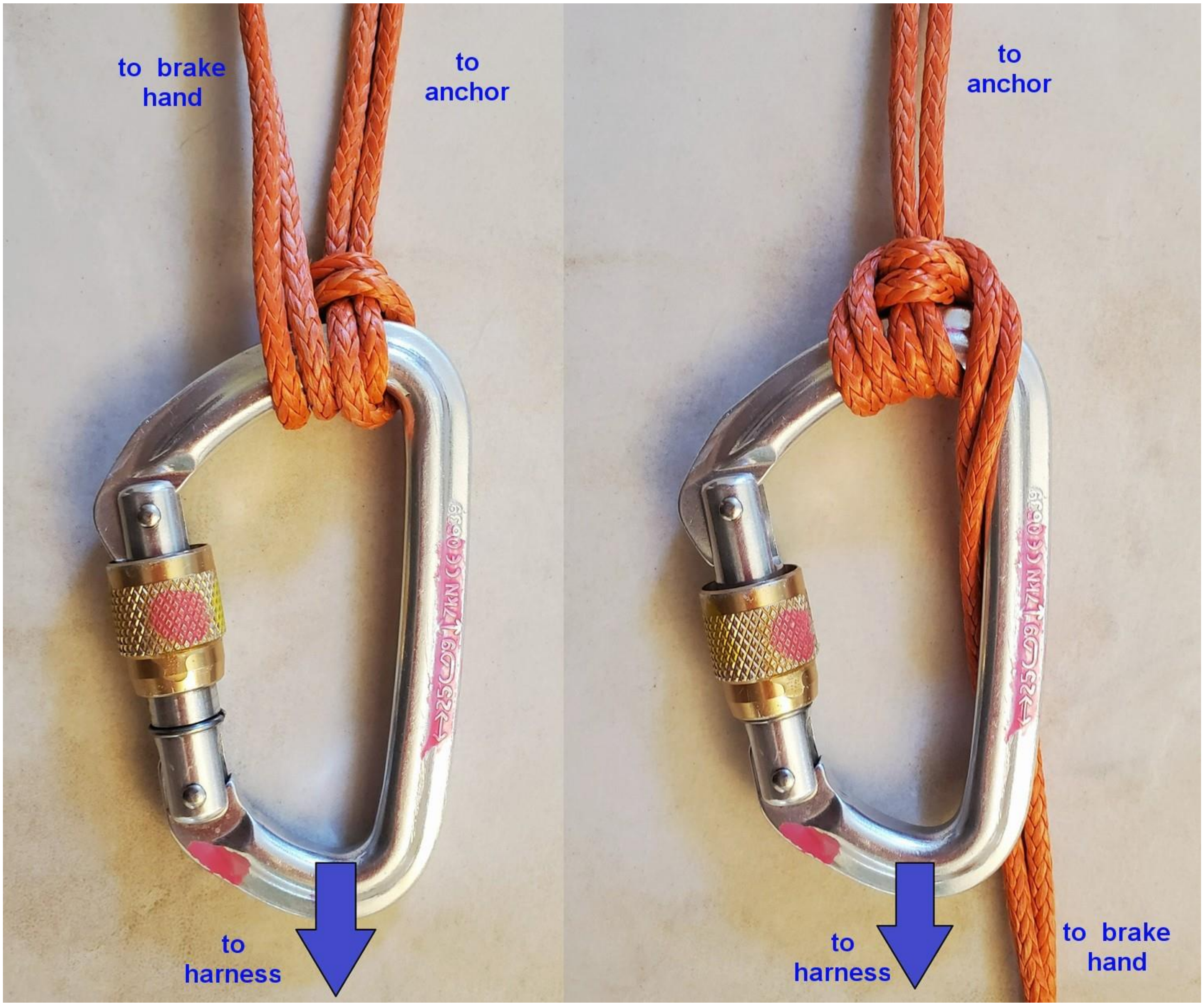
I’ve done this rap both with an 8mm polyester-covered canyoneering rope and a pull line (ATC for braking); and with a 5/32” braided Dyneema “rope” with a 1/8” Dyneema pull line, and a superMunter on a small locking carabiner. The most notable differences were that the pull was much easier with Dyneema, and the descent was slower. I measured the temperature between the Dyneema superMunter and the carabiner at the end of the rap (via thin NIST-traceable thermocouple), and it was about 40 F above the ambient; this temperature probably reflects the carabiner more than the rope. (I generally don't recommend Dyneema raps > 100' "to be safe".)

C) An Immediate Limit

Let's make clear that the major weakness of using Dyneema for rappels is not just the low melting point. Potentially, a bigger problem is that the mass per unit length is likely to be very small compared to a kernmantle nylon or polyester rope, so a small amount of heat can bring about a big temperature change. That assumes you are using Dyneema to cut down on your carried burden, as it is much stronger than nylon or polyester by weight. The very low surface coefficient of friction of Dyneema, and the very high axial thermal conductivity, ***reduce*** the concerns about heating the ***rappel device***; it takes unusual (and purposely destructive) geometries for heat-related failure. A future chapter will attempt discuss the subtleties of heating.

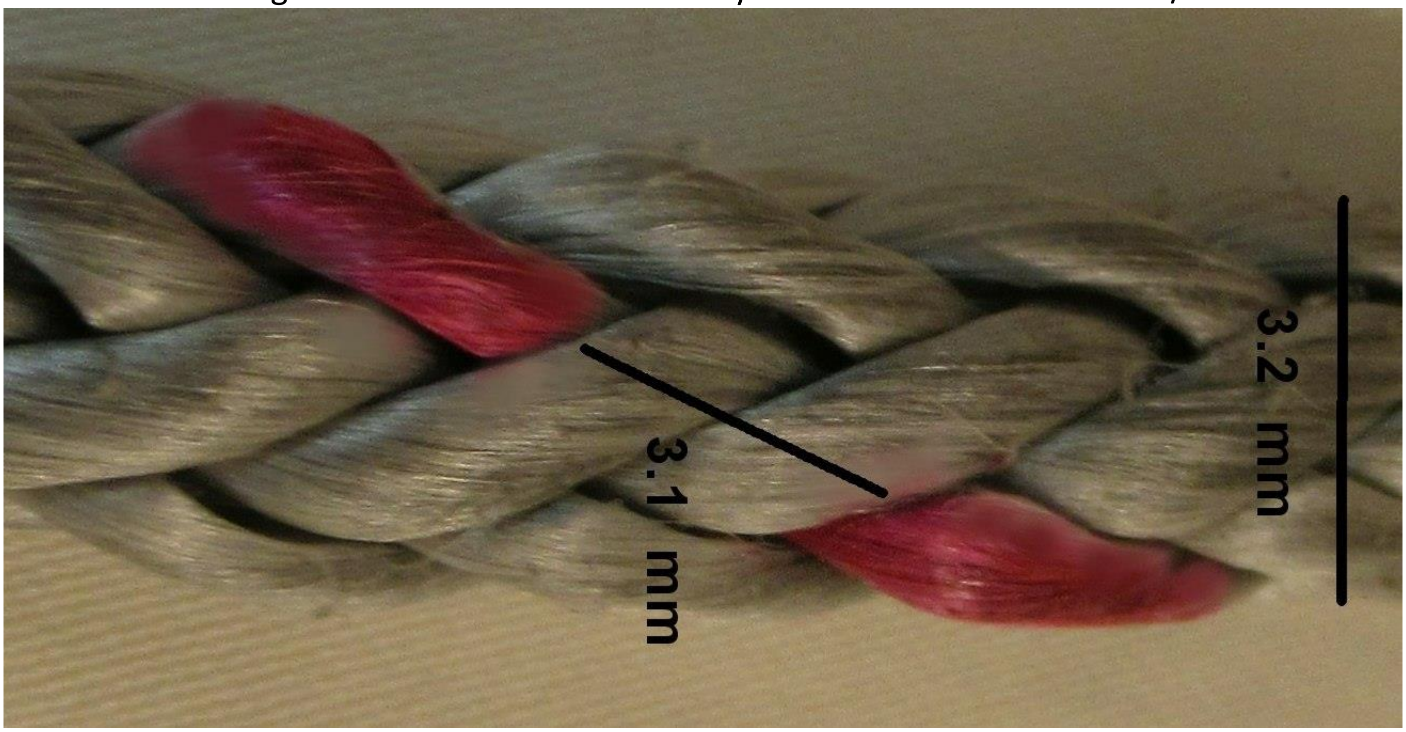
But the reality is this: Every length you descend corresponds to a lowering of potential energy of your body, and that lowering has to be accommodated by adding energy to the rope-rappel-device system (with some energy lost to internal and rotational energy of your body).

I always use a super Munter, single Munter, or single Munter an extra wrap, for rappels on bare Dyneema. ***(Please see Chapter 2 for a discussion of the extra wrap!)*** Here is how a single Munter (left) and superMunter look with 1/8" Amsteel cord (2500 lbs per line):



Consider the heat produced in a Dyneema rap on a carabiner. For the regular Munter, the part of the hitch that contacts metal or crosses cord contains 3 sharp turns and takes up 5.5" (0.14m) on each strand. For the super Munter, the hitch has 4 tight turns and takes up about 7" (0.18m) on each strand (technically, the strands that go to the brake hand may touch more metal, but on the exit side, the tension has diminished ~50x). With my clothes and pack, I mass just 76 kg, so my descent of 0.14m or 0.18m is a potential energy change of 91 or 117 J, which is taken up almost entirely by frictional forces in the hitch. In Dyneema, most of this energy is taken up by the deformation and bending of the rope, which is then manifest as heat. (The surface coefficient of friction, when Dyneema rubs on metal, is only 0.2x to 0.3x that of polyester, nylon, and common aramid sheath fibers.) AND as we will discuss, for braided hollow-core ropes, some of this internal friction heat is almost immediately available for dissipation to the carabiner. For the temperature range between 25 and 50 C, the specific heat of Dyneema is about $2.0\text{x}10^3$ J/(K kg). But 1/8" Dyneema does not have much mass per length, so those 0.14m and 0.18m descents warm the rope, which went through the hitch, by as much as 22.1 and 22.2 C—at least, in our very simple model. Indeed, as Amsteel goes through the biner, it feels surprisingly warm on your guide hand; I've never measured more than 10 C change in the exit rope with a thermocouple, but the mass and heat capacity of the thermocouple is great compared to the Amsteel, so it really measures some weighted average of it and the Amsteel. And, the loss to radiation and convection is not totally trivial.

So here's the thing about braided hollow-core Dyneema. Here as section of 1/8" Amsteel:



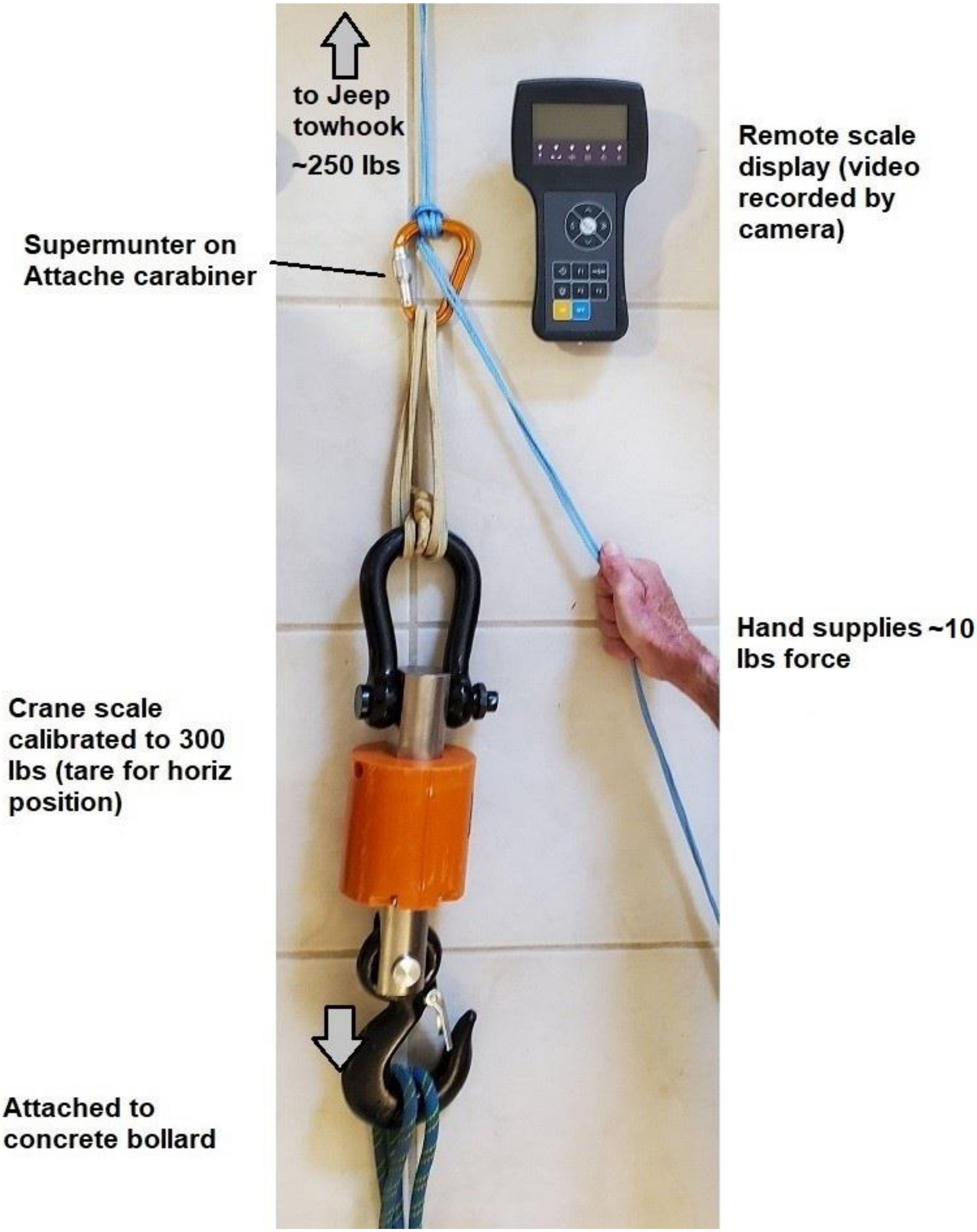
The pink strand shows how heat generated inside the rope is on the outside in about 3.1 mm, and visa versa. The heat diffusion coefficient along the fiber axis, D_a, is $1.10x10^{-5}$ m^2/s. However, the diffusion coefficient transverse to this, D_t, is 1% as great (polyester also has anisotropic diffusion, but the ratio is ~20x smaller). The characteristic distance for heat travel is ~ √(D·t) where t is the time in seconds; thus in 1 s, heat will travel along the fibers to the outside or inside strands (3.3mm), but will travel transverse to the fibers only about 0.33mm. This result is tantalizingly ambiguous; 1 s is generally much longer than rope will stay in the bends of the Munter, but it does mean that a Munter in thin Amsteel has a much better chance of diffusing its bending-derived heat throughout the rope, compared to (say) a kermantle nylon or polyester rope.

In a rap, the biner itself is absorbing heat from surface friction and the easy availability of the Amsteel bending friction, but I have never experienced biner heating of more than about 40 C in real raps, when I've placed a thermocouple directly between the biner and the Amsteel loops of the Munter at the end of the rap. Later we will discuss how me might "better" measure temperature.

D) Wow, that's Scary, Shouldn't You Do Experiments?
I'm glad you asked.

The rap simulation setup is shown below (the test was done in a parking lot, not on my tile floor!). Two tests pulled 80’ of double-strand 1/8” amsteel through a supermunter at ~250-300 lbs, then let the Amsteel in the supermunter sit on the stationary, friction-heated carabiner for several minutes.

The equipment was laid out horizontally, and the force was measured by a calibrated crane scale attached to a large concrete bollard at the base of a light pole. Two strands of 1/8” (2500 lb test) Amsteel braided Dyneema were hitched on an Attache carabiner with a superMunter. The “anchor end” was attached to the towhook of my jeep, which my wife drove forward so the 80’ “rap” was accomplished in 30 s. I gripped the brake end of the rope, and by adjusting the grip of my hand (just a few pounds of tension), kept the reading on the scale to 250 lbs (actually 249.9 +/- 40 lbs). After 80’ (double strand) had pulled through, the ropes tangled, and the force went up to an average of 744 lbs for 3s, giving the superMunter a pulse of high energy input, before we stopped the experiment and lowered the tension. Significantly, the supermunter was kept loaded with >400 lbs force for ~100s; during this time, the carabiner, now heated by friction equivalent to an 80’ free-hanging rap by a 250-lb person, was against the same section of unmoving Amsteel. Contrary to popular belief, the biner did not just slice through the Amsteel. I couldn’t get to measure the temperature between hitch and carabiner for 38 s, when it was 77F above the ambient, or 150 F. I know from tests of carabiner/Munter cooling, it may have been as hot as 170F maximum (tests are discussed in a future section; again, this temperature may be biased more by the carabiner temperature). When I completely released the tension and inspected the Amsteel that had been inside the superMunter, I found the fiber was visibly undamaged. In fact I used the same rope for a rap the next day.



I repeated this test, again pulling 80' of double strand 2500 lb (1/8") Amsteel through a superMunter at 3.2 ft/sec average, using my hand to control the force to an average of 290 +/- 49 lbs. Again I let the supermunter sit tightly on the carabiner, this time for several minutes. When I undid the superMunter, there was no sign of melting, even though in a few spots the blue urethane/dye coating had become slightly gray. The cord could be massaged back to supple, and close examination showed the fibers were not fused or broken (I have purposely brought Amsteel to melting by back-and-forth motion over a carabiner at body weight, and it gets stiff and the fibers fuse before breaking). So this is a pretty ultimate test; at 2x my body weight on the equivalent of an 80’ hanging rap, the “rope” was undamaged by heat when the hot carabiner sat in the stationary superMunter for several minutes.

I actually weigh about 145-148 lbs with my gear, pack and clothes, and use 1/8”, 2500 lb test double Dyneema as a minimum. I recommend a person scale up the diameter by:

SquareRoot[(his weight)/(my weight)]

So a 250 lb person (with gear) would use a rope of about 5/32”, or 4000 lb test.

So actual raps and tests with realistic forces seem to suggest the Amsteel simply won’t get that hot – at least on 80-100’ raps, even 80’ hanging raps, or 155’ raps with some hanging sections. ***For those who have had their hands burned by rap devices, remember: your rope was undoubtedly sheathed in polyester, nylon, or technora,*** which produced much more contact heating from surface friction, and traditional rap devices are designed to maximize the energy dissipated by surface friction. But are we missing some scary mechanism?

Let’s do a harsher check on this scenario: suppose somehow you have heated the carabiner well above what is suggested from our rap simulations, to well above the melting point of Dyneema. Then you stop on ledge the very hot device suddenly rests on the unmoving Dyneema and cuts through it like butter.

Here is a simple test (click on the image below to see the movie). I drilled a thermocouple hole in a half-inch slightly oxidized aluminum tube, then filled the center with aluminum rods and tightly packed aluminum foil, to simulate a fat carabiner. I placed a thermocouple in the bottom of the tube (display in Fahrenheit at top), and heated the tube with a propane torch. Then I dropped a room-temperature loop of Amsteel, weighted by an iron dumbbell, over the very hot aluminum (the test below is the third trial with the same piece of Amsteel). The thermocouple read 466F (241 C) after the Dyneema was weighted on the hot spot. The Amsteel did not melt, even though the temperature was well above the melting point of Dyneema; it took three trials to get even a little bit of scorch.

One sees that it may not be that easy to melt Amsteel, simply by having it come to rest on a hot aluminum “carabiner.” Above about 250 F, the aluminum cools quickly by radiation and convection, and little of the heat really travels into the Dyneema fibers, because that material has a low thermal conductivity transverse to the fibers. In this case, the heat from the contact is probably spread along the length of the fibers, away from the aluminum, because the axial thermal conductivity (parallel to a fibers) is ~100x greater than the transverse conductivity.

So that’s it for today. We’ll try our best to quantify heating effects with a set of experiments in future chapters.

E) Wait, Isn’t There a Better Way to Measure Temperature?

Hold that thought. There are two common ways to measure temperature ranges of more than 50C, which are not extraordinarily expensive: thermocouples and IR cameras. The major disadvantage of thermocouples is that they perturb the temperature you are trying to measure, by virtue of their own thermal mass, and can take a while to reach some sort of equilibrium. The main disadvantage of IR cameras if that they can only see the surface, with some caveats. In addition, the scene will likely contain portions with widely varied emissivity, so there may be substantial errors in the IR-extracted temperatures. Anodized carabiners (almost all aluminum carabiners these days) have much higher emissivity than polished aluminum, but may still be reflective enough to be affected by the temperatures of the surroundings. I try to calibrate IR temperatures with a thermocouple, and the carabiner temperatures tend to be 4-8F higher in IR readers. The action of Amsteel on the carabiner is not necessarily as an insulating blanket – there are actually patented fabrics that cool objects via “blankets” of fibers that are almost identical to Dyneema.

Unfortunately, it’s very hard to focus an IR camera on a constantly-moving rope and wiggling rap device.

I’ve taken both approaches; we’ll discuss the ambiguities in a future section.