Comparison of Static and Dynamic Strength of Rugged Optical Cables

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1. ABSTRACT

Strong, but thin, optical cables are a key component for many underwater applications such as ROVs, sensing systems and many DoD weapons systems. Strength members used in cable constructions are materials such as extruded Liquid Crystal Polymers (LCP) and aramid yarn.

In many of the applications the cable is used as a communication link between discrete nodes deployed in the open ocean environment where the span can stretch from meters to miles. The cable may need to survive the constant pull and push of changing currents for days or even months. In this situation it is important to understand the dynamic strength but also the static strength of the cables.

2. INTRODUCTION

When a constant static stress is applied to a thermoplastic it undergoes creep which is the increase in strain with time. The rate at which strain increases is proportional to both the applied stress and temperature.

When a plastic material is subjected to a constant load, it deforms continuously (Figure 1). The initial strain is roughly predicted by its stress-strain modulus. The material will continue to deform slowly with time indefinitely or until rupture or yielding causes failure. The primary region is the early stage of loading when the creep rate decreases rapidly with time. Then it reaches a steady state which is called the secondary creep stage followed by a rapid increase (tertiary stage) and fracture. This phenomenon of deformation under load with time is called creep. Of course, this is an idealized curve. Some materials do not have secondary stage, while tertiary creep only occurs at high stresses. All plastics creep to a certain extent. The degree of creep depends on several factors, such as type of plastic, magnitude of load, temperature and time. The standard test method for creep characterization is ASTM D2990. In this test procedure, the dimensional changes that occur over time under a constant static load are measured.

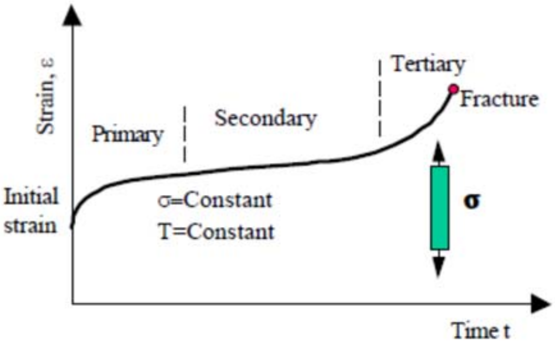

Figure 1. Creep curve for plastics, a constant load is applied. σ is load and T is temperature

If the applied load is released before the creep rupture occurs, an immediate elastic recovery equal to the elastic deformation, followed by a period of slow recovery is observed (Figure 2). The material in most cases does not recover to the original shape and a permanent deformation remains. The magnitude of the permanent deformation depends on length of time, amount of stress applied, and temperature.

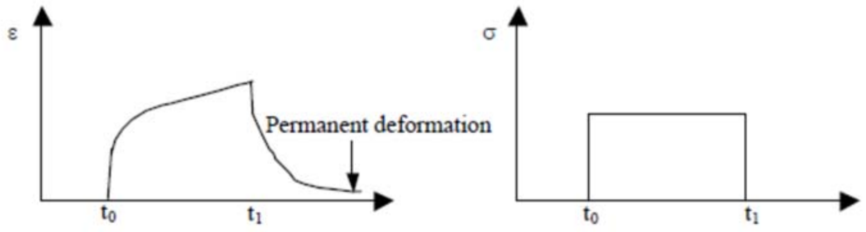

Figure 2. Creep curve with recovery. A constant load, σ, is applied at t_0 and removed at t_1

The creep rupture is basically similar to a creep test with the exception that it is continued until the material fails. Since higher loads are used, creep rates are higher and the material fails in a shorter time. This test is useful in establishing a safe envelope inside which a creep test can be conducted. The basic information obtained from the stress rupture test is the time to failure at a given stress or load. Based on this data, a safe stress can be determined below which it is safe to operate, given the time requirement of the end use application. The construction of the creep rupture envelope is shown in Figure 3. Test is conducted under constant stresses and the points of the onset of tertiary stage are connected to form the creep rupture envelope.

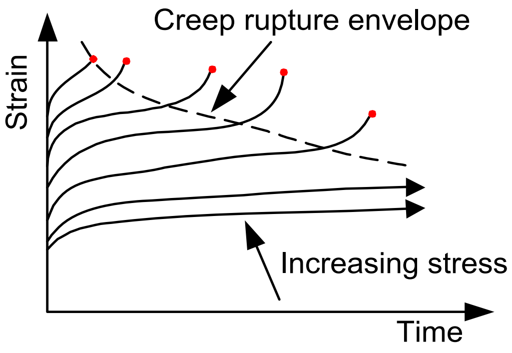

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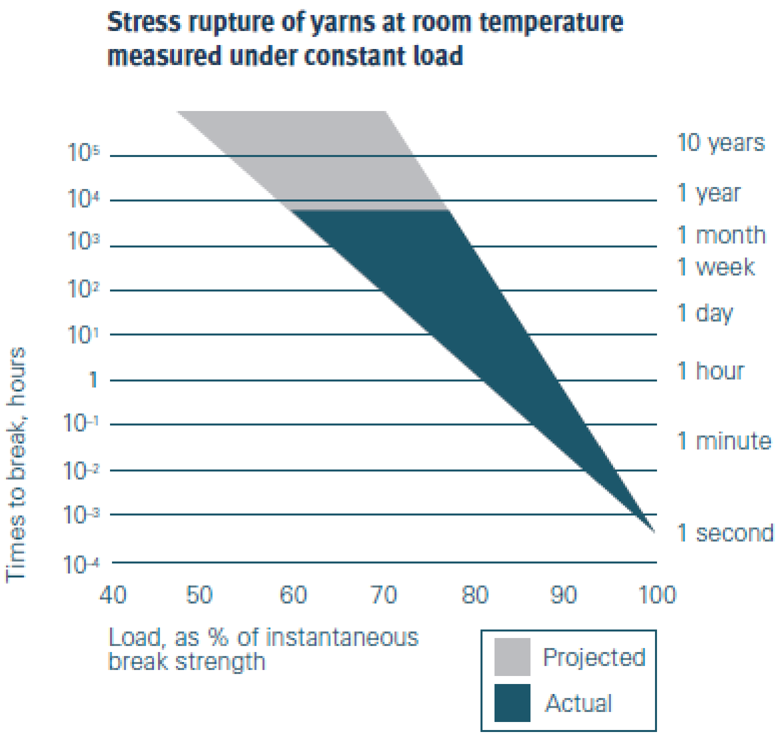
Figure 3. Creep rupture envelope

To survive for a certain period of time the stress must be low enough such that the strain does not increase to the breaking strain over that period of time.

3. CREEP IN ARAMID YARN

Cables for use in many applications such as ROV tethers and tow cables, are often strengthened with aramid braid or served aramid. Other thermoplastic layers are applied to achieve abrasion resistance, low friction or durability, however, the tensile strength comes from the aramid. Ideally one wants a strength member where the static strength retention is as large a percent of the short term strength as possible. In this respect aramids are very good candidates as shown in Figure 4. The horizontal curve shows applied static load as a % of the short term breaking load. For purposes of comparison in this paper we will look at an application that requires 1000 hr survival. From 0 we see that for 1000 hr survival the applied load can be as much as 60% to 80% of the short term strength. This is much more than most thermoplastics which can only sustain 10% to 20% of short term strength for 1000 hr survival.



Stress rupture of yarns at room temperature measured under constant load

Value for the range of Kevlar® fibres lie within the shaded area.
Source from technical report KV-76-50, P.G. Riewald.

Figure 4. Kevlar static strength as a % of short term strength (Ref. 1)

Several emerging underwater applications require cables of long length, often tens of kilometers, to be deployed in continuous lengths. Braiding of aramid strength members is an inherently slow, therefore expensive process. In these applications we explore thermoplastics that can provide high strength and be applied by conventional, high speed, extrusion to generate long lengths limited only by the continuous length of the optical fiber available.

4. CREEP IN LIQUID CRYSTAL POLYMERS (LCP)

LCPs have good resistance to creep as shown in Figure 5 (Ref. 2). In this figure creep is shown as modulus measurement instead of a strain measurement. The difference from Figure 1 is that the fixed stress is divided by the time dependent strain to generate a time dependent modulus. Since strain increases with time while stress is fixed, the modulus is seen to decrease with time. Results are shown for two temperatures - 23°C and 120°C. The maximum exposure time was 1,000 hours. Interestingly, although creep modulus is lower at higher temperature, the slope of the two curves is the same. The stress levels were chosen to be 30% of the short-term failure stress and none of the samples failed in testing over a period of a 1000 hours. No sign of creep rupture was observed at stress levels below 30%.

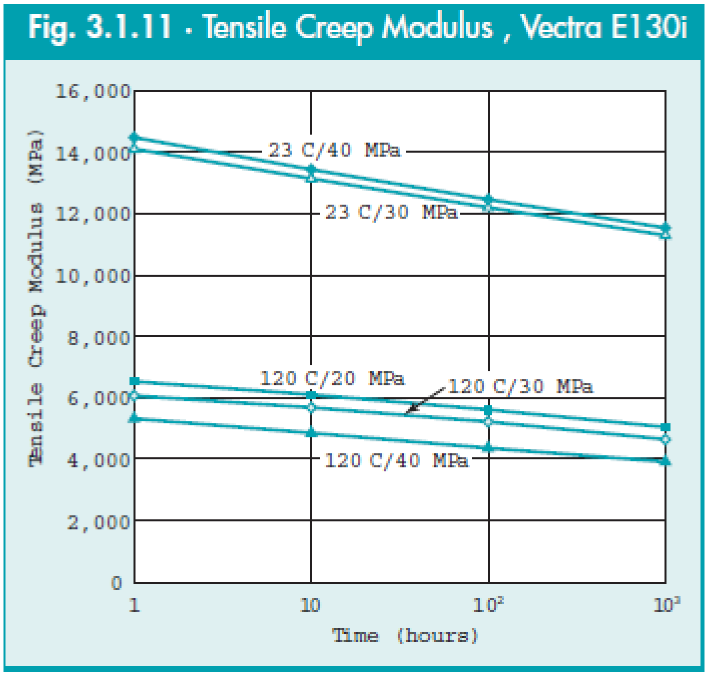


Figure 5. Typical creep modulus in LCP at two different temperatures

We see that at room temperature the tensile modulus has decreased about 16 to 20% over the 1000 hour test. These are measurements on dog-bone molded test samples. With optical cables we are using thin layers of extruded LCP where the aligned material forms a larger fraction of the total volume. What is not known is whether creep in aligned LCP differs from that in molded LCP and if so, by how much.

5. SOME STATIC STRENGTH MEASUREMENTS FOR STFOC™ CABLES

Linden manufactures and sells a line of thin, but strong fiber optic cables, with the acronym STFOC™, that are widely used in underwater ROVs and defense tactical systems. The cables need to be strong to survive long term in turbulent waters or survive the rigors of high speed deployment.

The cables use thermoplastic coatings made of Liquid Crystal Polymers (LCPs) that have specific strength similar to aramid yarn. However, unlike aramid, thermoplastic LCPs can be applied through extrusion to produce long, continuous lengths (> 40 km) of ruggedized, thin optical cable. A typical stress-strain curve for LCP coated cables is shown in Figure 6. Unlike most thermoplastics the curve is almost linear up to fracture.

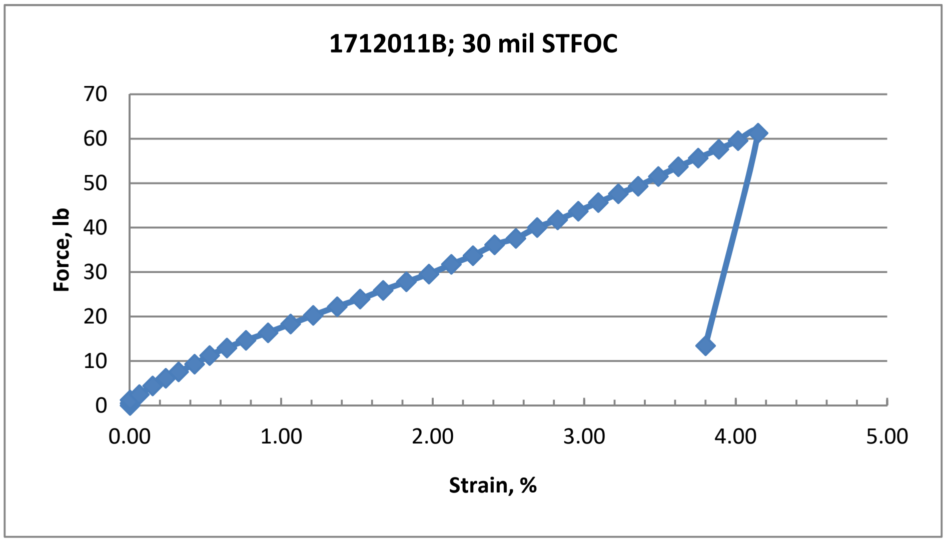


Figure 6. Typical stress vs strain curve for a 30 mil OD STFOC™ cable

Figure 7 shows load vs time to failure for a 30 mil STFOC™ cable. These measurements are time consuming. Whereas accelerated testing may be possible much effort will initially be needed to determine the thermal activation energy. What we are reporting here is initial results which can be updated in the future with more data points.

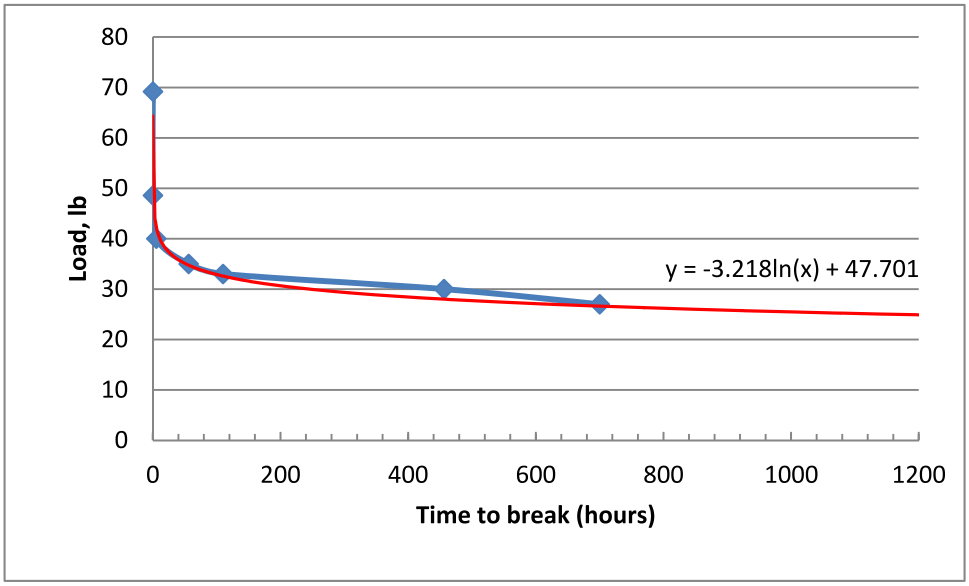


Figure 7. Load vs time to failure for 760µm OD STFOC™ cable

Figure 7 also shows the trendline and equation for the trendline. From this we calculate the maximum load that can be applied for the cable to survive for 1000 hours is about 26 lbs. This is about 37% of the short term strength (70 lb).

For comparison purposes Linden Photonics has also fabricated strengthened optical cables using Kevlar yarn. Some limited data showing load vs time to break for such cables is shown in Figure 8.

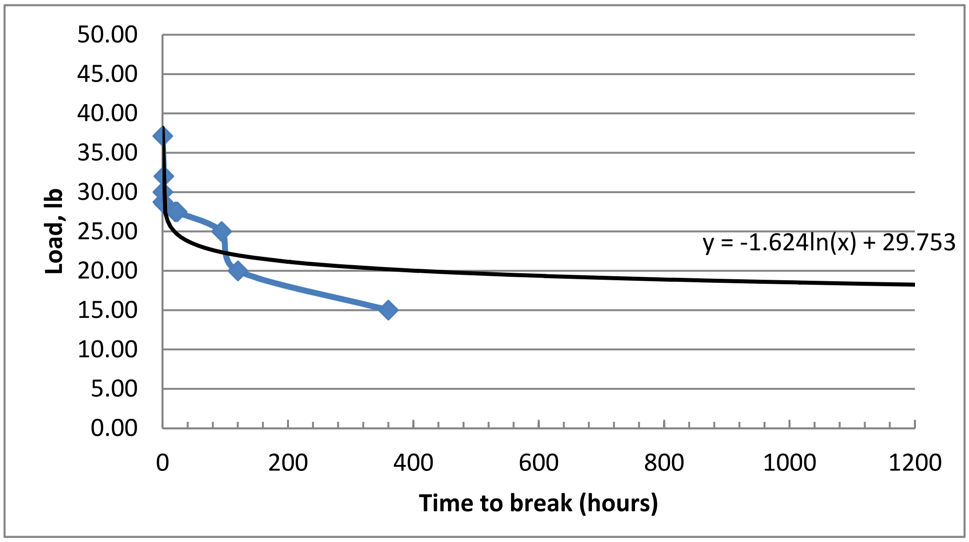


Figure 8. Load vs time to failure for optical cables using aramid yarn strength members

From the trendline in Figure 8 we calculate the maximum load that can be applied for the cable to survive for 1000 hours is about 18.6 lb. This is about 43% of the short term strength (43 lb). This is approximately the same percentage as for extruded LCP – which means ruggedized cables using extrusion methods can exhibit the same static strength retention as cables using aramid yarn.

6. Conclusions

Conventionally ruggedized cables have being fabricated using high strength yarns such as aramid. These yarns allow excellent static strength retention, in theory, as much as 60%. Linden has demonstrated through fabrication of ruggedized cables that these cables, built with aramid yarns, can retain 43% in static strength compared to short term strength. However, it is time consuming and expensive to make ruggedized cables using yarn in long continuous lengths that are required in some applications.

Linden Photonics has, for the first time, developed and fabricated LCP extruded, ruggedized cables that can be manufactured in long, continuous lengths (40 km) that retain close to 40% static strength compared to short term strength.

REFERENCES

Ref. 1: Dupont Kevlar brochure located at
http://www.dupont.com/content/dam/dupont/industries/energy/oil-gas/documents/Kevlar_Oil_Gas_Brochure.pdf

Ref. 2: Vectra brochure loacated at:
http://www.hipolymers.com.ar/pdfs/vectra/diseno/Vectra%20brochure.pdf