



A Furukawa Company

CARBON COATED OPTICAL FIBERS

Carbon Coating



Dual coating system protects better!

- OFS has perfected over several years, the application of carbon as a primary coating on optical fibers
- Carbon is always used in combination with a secondary coating for a dual coating system that protects fiber better than acrylate, silicone or polyimide alone

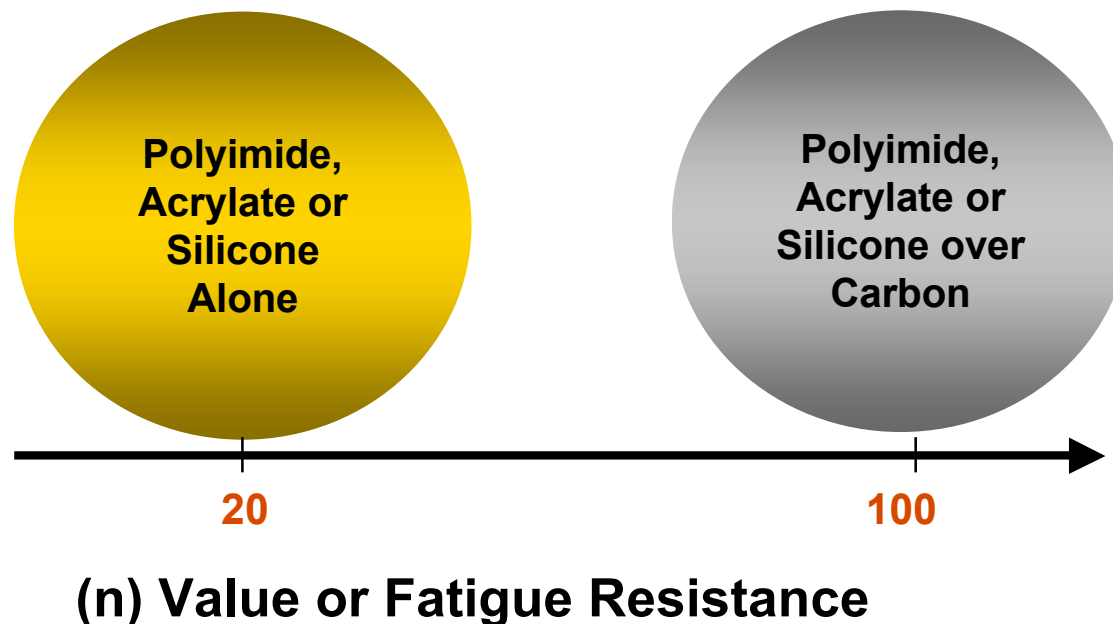
OFS GeoFibers with carbon/polyimide coatings are routinely deployed in the harsh environments seen by downhole optical sensors

OFS FlightGuide® military cables utilize carbon as the primary coating and extend the lifetime of optical cables in aircraft such as F-16, F-22 and F-35(JSF)

Carbon: Increased N-Value

Carbon extends fiber lifetime by hermetically sealing glass

- Carbon is applied during fiber draw and bonds directly to the glass (only 300Å to 400Å thick)
- Carbon hermetically seals the fiber to prevent exposure to moisture
- Carbon used as a primary coating dramatically increases the n-value (fatigue resistance) of the fiber from 20 to > 100



Optical Fiber Strength and Reliability

What is n-value?

- Optical fiber is made of silica glass with tensile strength stronger than steel
- The breaking strength is due to flaw severity along fiber length
- Strength degrades through time due to fatigue resulting from crack growth
- Crack growth is accelerated by moisture
- The n-value is a measure of a fiber's resistance to fatigue (typically 20 for acrylate, silicone or polyimide coated fibers)
- The fiber lifetime can be estimated once n-value is calculated

Hermetic Coating

- This is the Power Law for time to failure (fiber lifetime)

$$t_f = (\sigma_p / \sigma_a)^n$$

where: t_f = Time to failure (seconds)

σ_p = Proofstress

σ_a = Application stress

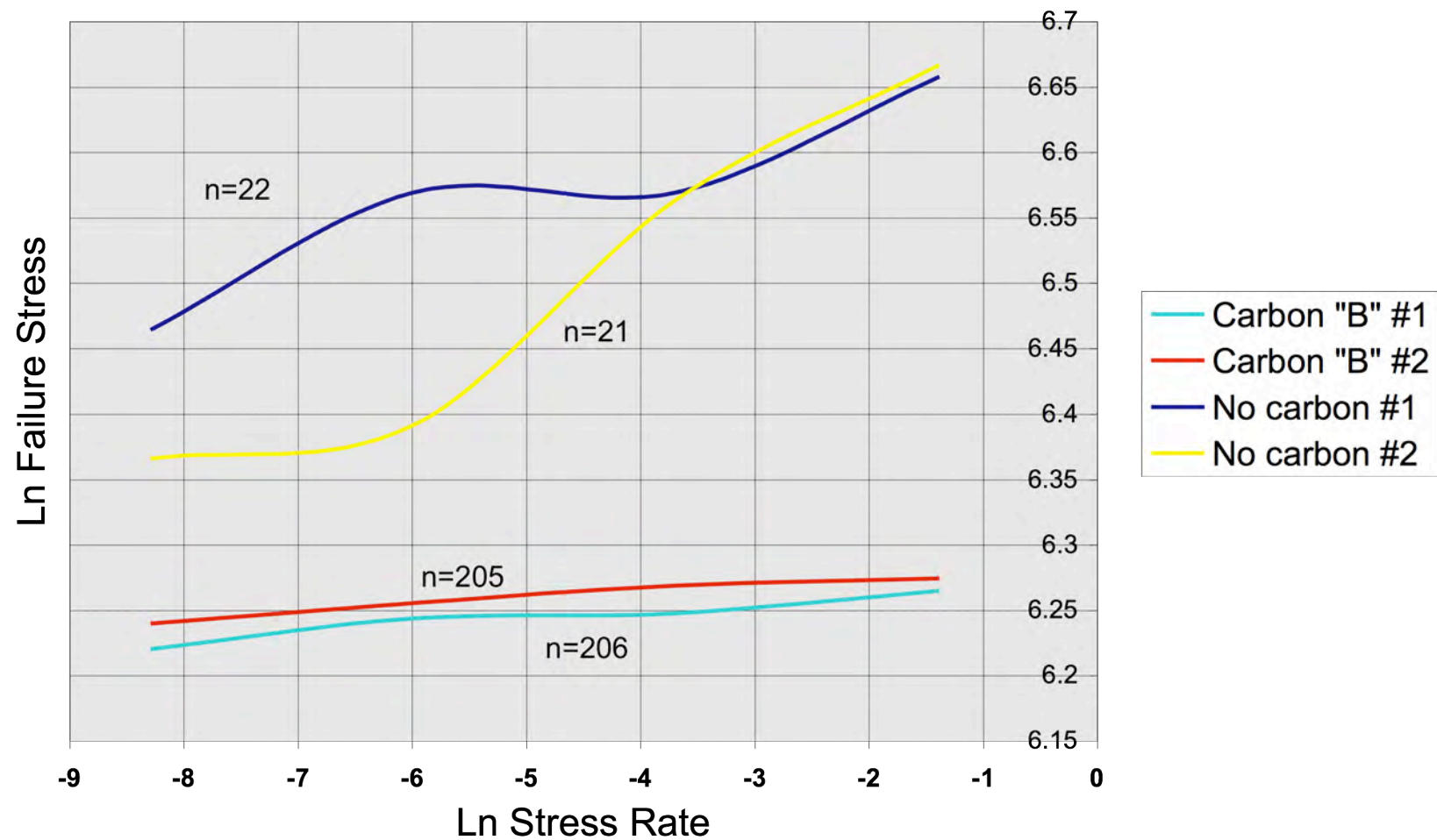
n = Fatigue resistance

- Hermetic fiber can withstand a higher application stress (tensile or bending) than a non-hermetic fiber.
- Standard fibers: operate at 20% proofstress level
- Hermetic fibers: can operate at 80% proofstress level

USE OF CARBON EXTENDS FIBER LIFETIME

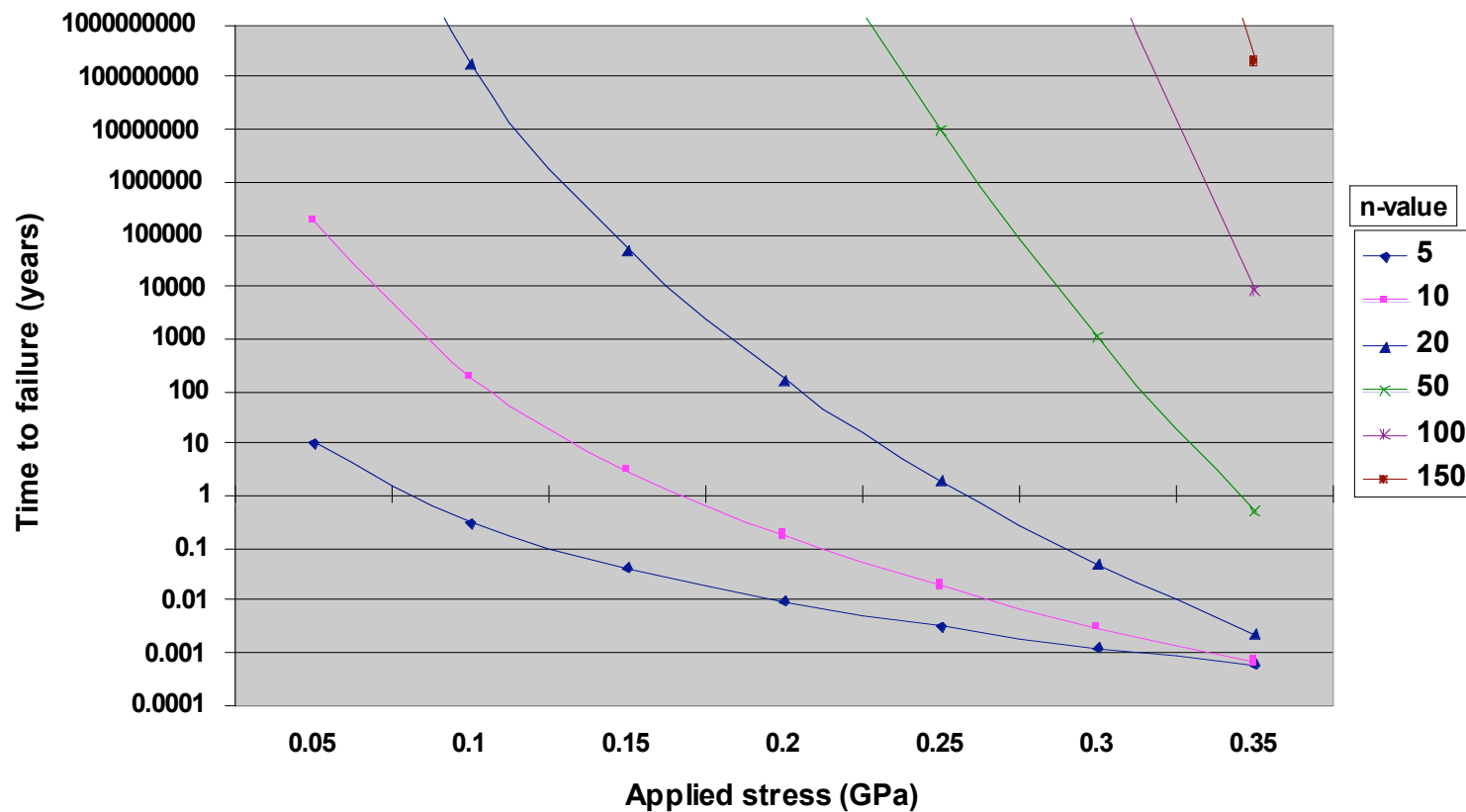
Dynamic Fatigue Plot: carbon vs non-carbon fiber

Per FOTP-28



Predicted Time to Failure vs Fatigue Factor and Applied Stress

Initial proof test level of 100kpsi / 0.7 Gpa



Carbon – Barrier to Hydrogen Ingression

- Hydrogen Ingression is a diffusion of hydrogen molecules, generated through corrosion of metals or released from water or polymers, into the core of the optical fiber causing increased optical attenuation
- The rate of diffusion speeds up as the temp rises
- Carbon layer offers protection from H₂ ingress up to 130°C

What Coating Should You Use Over Carbon?

Carbon always requires a secondary coating. The choice depends on your required temperature range and other environmental factors

Coating Type	Temp Range	Strippability	Typical OD on 125 μm cladding	Other
Dual acrylate	-40 to +85°C	Easy – mechanical strip	250 μm	Most common coating used
Single acrylate	-40 to +85°C	Adheres better than dual – mechanical strip	200 μm	Small form factor
Silicone acrylate	-45 to +125°C	Easy - mechanical	250 μm	Silicone cushions fiber
Polyimide	-65 to +300°C	Chemical strip	155 μm	Abrasion and chemical resistant

When Should You Consider Carbon for Your Application?

- The increased fatigue resistance and protection from H₂ ingress that carbon offers can be beneficial in many applications
- Carbon can be applied to any sm fiber and mm fibers with cladding diameters up to 200 μm
- When to consider carbon for an application:
 - Application stress is higher than 20 kpsi
 - Fiber is exposed to water vapor
 - Fiber is exposed to higher temperatures than 85°C
 - A long fiber lifetime is required
 - Rough deployment conditions may abrade the outer coating
 - Hydrogen outgassing may cause a rise in attenuation

Summary

- Carbon hermetically seals the glass surface of optical fibers at all temperatures at which fibers can operate
- Carbon has the added advantage of protecting against H₂ ingress up to 130°C
- Carbon increases the fatigue resistance of the fiber by eliminating the slow crack growth which is caused by moisture
- The fiber is then able to operate for an increased lifetime or at a higher stress level than a fiber coated with acrylate, polyimide or silicone alone
- There are many applications that will benefit from the addition of carbon as a primary coating