"Development of High Pressure High Temperature (HPHT) Optical Contacts and Feedthroughs for use in Subsea and Downhole Systems"

Fiber optic physical contacts (PC) are extensively used in land based and topside offshore communication systems. A majority of these systems utilize epoxies to secure the fiber in the ferrule. This method has been proven over time to be very reliable and cost effective for utilizing fiber optics in traditional terrestrial environments. As technologies are adapted for new offshore, subsea and downhole uses many of these technologies can be directly utilized. This epoxy process has been adapted for capturing the fiber in the optic ferrule as well as in maintaining pressure barriers in many subsea systems. The extended use of the epoxy technology has been verified through some additional qualification and accelerated life testing, specific to the new applications. As the push for reliability increases and the demand for higher temperature and high pressure well completions are desired, these more extreme operating conditions come too close to or exceed the capability of epoxies. Consideration of existing epoxy technologies might not particularly suit the desired HPHT application and new advancements are needed to have a viable solution.
This paper will present AMETEK's experience in developing Fiber Optic Contacts and Optical Penetrators without the use of epoxies for securing the fiber in environments in excess of 15K PSI and 200 deg C. A review of the current concerns of the use of epoxies and how they have been overcome in AMETEK's development program will be discussed in detail.

Types of fiber optic mechanical terminations: 1. Adhesives (Epoxy) 2. Solder/Brazing – Not within the scope of this paper Compression 3. Glass Sealing

<u>Adhesives/Epoxy Methods for Termination Fibers</u>

Using adhesives or epoxy to create the bond and seal of the fiber optic element to its metal housing is a very valid and viable method of providing a reliable seal and mechanical hold on the fiber with temperatures at or below 125deg C.

The epoxy when curing shrinks to the fiber creating a mechanical hold putting a slight compression on the fiber.

When terminating a fiber with epoxy it is critical to control the cleanliness, limit air voids and control the epoxy expansion. These three factors are the most common reasons for a broken fiber in a ferrule or penetrator.

When curing epoxy it is very process and product dependent to ensure the correct shrinkage rates and proper outgassing.

There is one significant consideration to make when selecting an Epoxy for higher temperatures. This being the Epoxy Tg or Glass Transition which will relate to its mechanical strength.

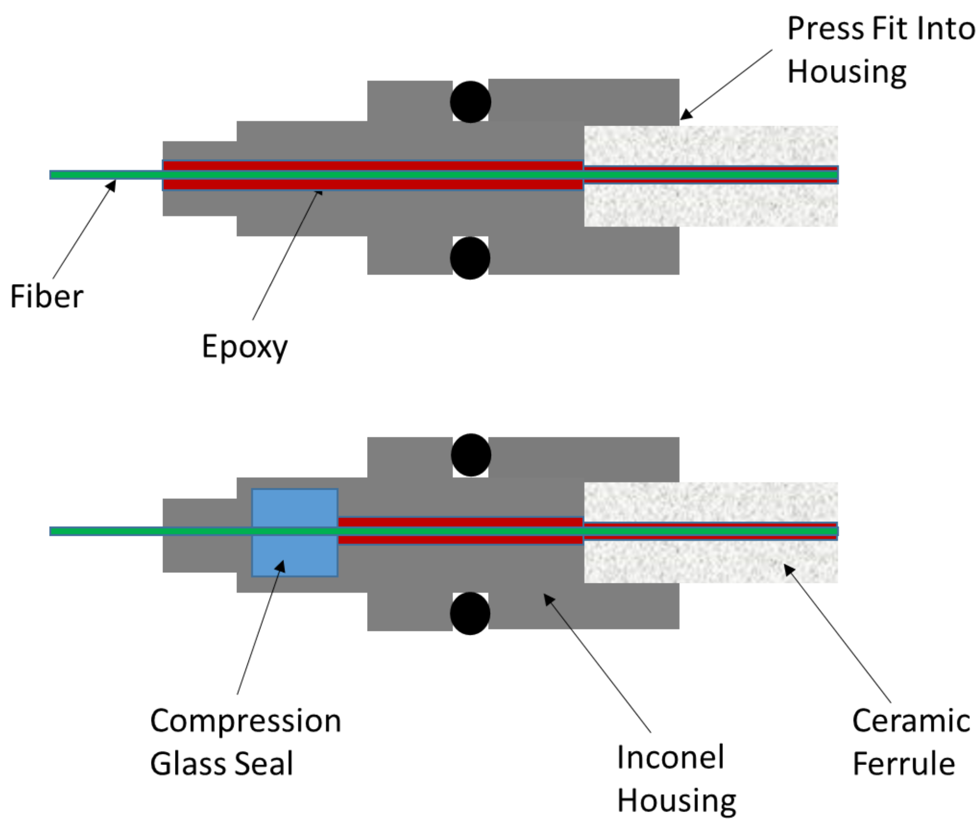
The Tg temperature is the point at which the epoxy transforms from hard and glassy to soft and rubbery.

Epoxies designed for higher strength at higher temperatures have a Tg of 142 deg C, while typical epoxies have a Tg of 90deg C to 120deg C.

Ensuring the stability of the fiber in its package either in an optical ferrule or feedthrough penetrator are critical to its long-term performance optically and mechanically.

The Tg will affect the ability of the epoxy to work in differential pressure and hold the fiber in place at high temperatures over time.

Movement of the fiber in the optical ferrule or its holder will affect the optical performance in respect to Insertion Loss and or Back Reflection due to offset, spacing, bending or physical breakage of the glass fiber (commonly referred to as "pistoning").



Glass Sealing Method

Our problem was how to increase the strength of the fiber terminations at Temperatures above 125deg C.
We felt we had the necessary elements to develop and prove out a Glass Sealing method to a fiber termination and fiber optic feedthrough (FOFT) penetrator for high temperatures, with our experience with glass sealing techniques for electrical connectors and feedthroughs.

Our developments and testing with glass seals having an Glass Transition or Tg of 520 deg C. giving adequate safety margins for current HPHT applications.

Glass as an Engineering Material:

STRENGTH
As an engineering material, glass is unique. Two of the most significant properties that make it so, are (1) the mechanical strength, and (2) viscosity. Glass is a brittle material but one that is truly elastic with no plastic deformation to failure. The intrinsic strength of glass is extremely high and certain experiments have substantiated that glass may be stressed in the order of 3,000,000 PSI before failure. However, it is difficult to achieve, in current practice, more than a small fraction of these strengths. Measurements of the strength of glass are not true measurements of the strength, but the weakness of the surface. It is the condition of the surface that limits our utilization of this high strength material. The surface irregularities create stress risers, and, as a result, surface stress variations, and by the virtue of the lack of plasticity, these stresses are not relieved by plastic deformation and will generate a catastrophic type of failure by virtue of a crack. In other words, it is extremely notch sensitive.
VISCOSITY
Actually, at room temperature, glass is a viscous material. At this temperature, however, the viscosity is so high that for all practical purposes, it is considered a solid. The fantastic reduction in viscosity between 500°C and room temperature is significant; however, the difference between 500°C and 1500°C will be approximately 1,000,000,000,000 times as great. It should be pointed out that glasses do not have true melting points. They simply become less viscous at elevated temperatures, and the viscosity reduction is approximately exponential with temperature.
THERMAL ENDURANCE
One other notable property of glass is its relatively high thermal endurance. The thermal endurance is enhanced when under compressive stress.
ELASTICITY
For all ordinary purposes, it can be assumed that glass is perfectly elastic up to the point of fracture. The Young's modulus of elasticity varies from 6,000,000 to 17,000,000 PSI depending on the composition, but most commercial glasses have values between 9,000,000 and 12,000,000 PSI.
GLASS IN COMPRESSION
Glass has a very high capacity to withstand compression stresses. By virtue of inducing and maintaining only compression stresses in the glass, the glass member can be loaded in many ways; as long as the imposed loading does not exceed the compressive preload, the glass will withstand the applied preload without a stress reversal and not generate tensile stresses where its notch sensitivity would limit its usefulness.

“Compression Type” Hermetic Glass Seals

Housing material and fiber optic material thermal expansion rate much higher than that of the glass.

Upon solidification of the seal during the manufacturing process, the housing will contract around the glass

Applying a desirable compression stress on the glass bead

The strength of the glass-to-metal seal is reinforced mechanically as well as chemically.

Conclusion:

Glass sealing of fiber optics is a viable technological advance to increase the pressure and temperature of fiber optic connectors and feedthrough penetrators given the higher Glass Transition Tg temperatures. More deployment history and testing is still required, however initial results are proving its advantage over existing epoxy technologies.

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