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Hybrid Glass as Protective Coating for Aerospace Optical Fibers and Cables: Validation Test Results

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UV curable, inorganic – organic coatings called hybrid glassesand representing combination of silica nanoclusters and polymer binder were applied on the optical fibers resulting in thermally stable, chemically resistant protective coatings. This study highlights our efforts to assess the protective properties of hybrid glass coatings for avionic industry. Specifically, we present the results of multiple tests performed on multimode and singlemode optical fiber coated with non-strippable and strippable hybrid glass coatings and inserted into the Liteflight^{TM}-EP semi loose tube cables designed for aerospace.

Keywords Coatings; heat resistance; inorganic-organic hybrids; silica nanoclusters

Introduction

Optical fibers designated to work in adverse environment such as aerospace demand operational performance that exceeds those of existing fibers currently available in the marketplace. These include higher temperature performance, enhanced strength resistance to vibrations, impermeability to water penetration and resistance to sudden temperature shocks. Especially desirable would be non-polymer coating material optical that can provide extremely high strength, reliability and environmental durability combined with small fiber diameter, minimal bend radius and ease of termination.

Currently the coating of choice for aerospace fibers is a polyimide. Polyimide coating is used due to its high thermal stability and resistance to the temperature shocks. High thermal stability of polyimide and its resistance to the thermal shocks is of extreme importance since optical cable is placed close to the aircraft engine where temperature can be occasionally raised to 200°C.

However, polyimide coated fiber is not hermetic and therefore prone to water corrosion. Moreover the polyimide coated fiber has limited resistance to bending and frequently breaks during installation and handling. Since optical cable for aerospace, opposite to telecommunication cable, comprises of only one fiber any fiber break puts the cable out of use. The desired enhanced optical fiber performance could be achieved with the development of novel hybrid protective coatings for silica glass fiber [1,2].

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In our previos studies we have been evaluating a new class of heat resistant coating called hybrid glass made by modified sol-gel process [3,4]. These studies demonstrated the outstanding ability of the hybrid glass material to bond to the optical fiber and protect it from heat, water and chemical corrosion. The studies also proved that hybrid glass provides the optical fiber with better mechanical strength and protection against water corrosion than polyimide coating currently used in aerospace applications. To further demonstrate hybrid glass coatings usefulness for adverse environments we cabled the optical fibers coated with hybrid glass and subsequently subjected the cables to the series of severe tests required by avionics standards.

This paper reports the results of these tests carried on the aerospace optical cables carrying the multimode and singlemode optical fibers that are protected by hybrid glass coating.

Experimental

Hybrid Glass Coatings

The hybrid glass materials were synthesized by copolymerization of organosilanes and silicon alkoxides, in the presence of acidic catalyst in well-controlled, cost effective one-step sol-gel process, which was described elsewhere [1]. The product of this process is a low vicosity liquid comprised of sparcely crosslined silica nanoclusters functionalized with organic groups and able to polymerize by exposure to heat or UV-radiation. Upon adition of stabilizing agents and photoinitiators the hybrid materials were converted into UV curable formulations. The coating formulations were clear, transparent, low viscosity and solvent-free liquids that were stable over period of five months. These formulations were used to coat the optical fibers online during the fiber drawing process.

Fiber Drawing and Cabling

Singlemode and multimode optical fibers coated with hybrid glass were manufactured by Draka Communications (Claremont, NC). The fiber glass diameter was

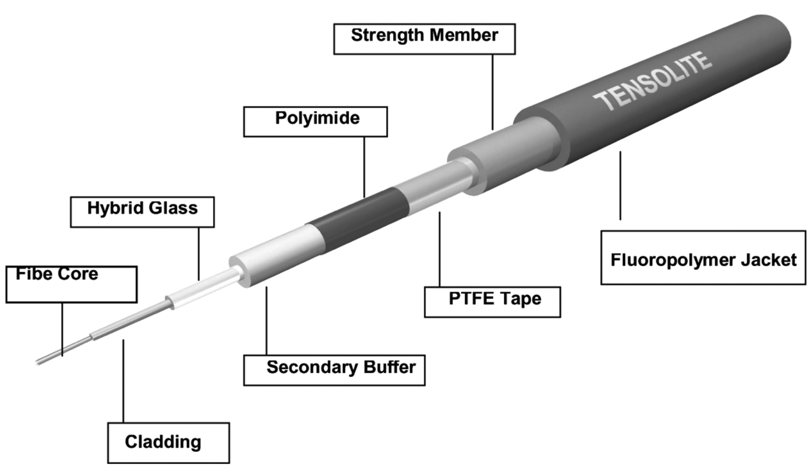

Figure 1. The fiber optic Liteflight cable-design for the aerospace applications.

Table 1. Cable test results for single mode optical fiber, BBXS, with strippable hybrid glass coating in a 1.8 mm cable

Test description	Requirements test	Results
Attenuation TIA/EIA-455-78 Method C	The maximum attenuation shall be: 1.0 dB/km @ 1310 nm 0.7 dB/km @ 1550 nm	Coefficients: a) 1310 nm: .49 dB/km b) 1550 nm: .35 dB/km
Termal Shock TIA/EIA-455-71 Test Condition C 10 Thermal Cycles	The optical cable shall have a min. optical transmittance change of ± 0.25 dB during and after test	Max transmittance ΔdB a) 1310 nm: −0.24 b) 1550 nm: −0.23
Cable Impact TIA/EIA-455-2C 20 Impacts, Force: 4.9 N	There shall be no fiber breakage and shall have a minimum optical transmittance change of ± 0.25 dB after the test is completed	Max transmittance ΔdB a) 1310 nm: −0.03 b) 1550 nm: −0.02
Cable Flexure Endurance TIA/EIA-455-104 Mandrel Radius: .0625" 10,000 Flex Cycles	There shall be no fiber breakage and shall have a minimum optical transmittance change of ± 0.25 dB after the test is completed.	Max transmittance ΔdB: a) 1310 nm: −0.05 b) 1550 nm: −0.02
Cable Bend Radius TIA/EIA-455-71 Mandrel Radius: .375″	The fiber optic cable shall have a minimum optical transmittance change of ± 0.25 dB during and after the test	Max transmittance ΔdB: a) 1310 nm: −0.14 b) 1550 nm: −0.03
Cable Micro-Bending EN3745-504 Mandrel Radii: 5 mm Force: 130 N	The fiber optic cable shall have a minimum optical transmittance change of ± 0.25 dB during and after the test	Max transmittance ΔdB: a) 1310 nm: −0.05 b) 1550 nm: −0.08
Cable Crush Resístanse EN3745-513 Force: 445 N	The fiber optic cable shall have a minimum optical transmittance change of ± 0.25 dB during and after the test	Max transmittance ΔdB: a) 1310 nm: −0.03 b) 1550 nm: −0.04
Cable Kink Resístanse EN3745-509 Loop Diameter: 6.35 mm	The fiber optic cable shall have a minimum optical transmittance change of ± 0.25 dB during and after the test	Max transmittance ΔdB: a) 1310 nm: −0.05 b) 1550 nm: −0.07

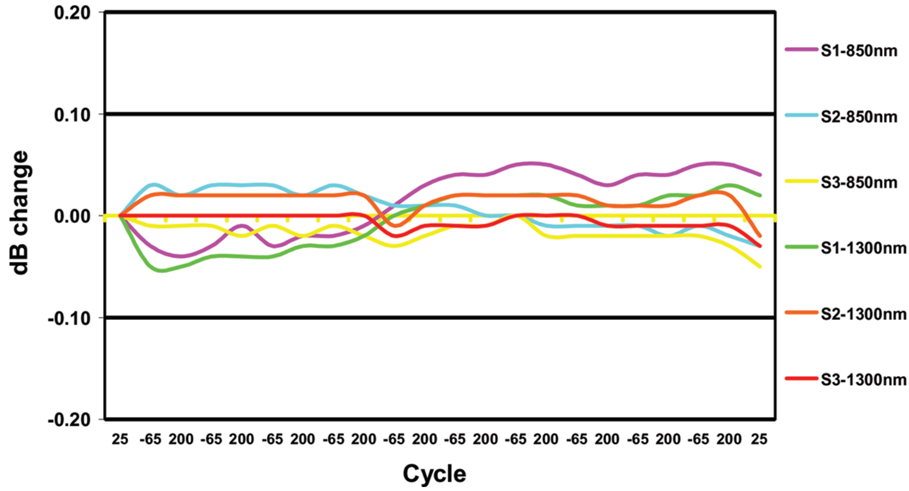

Figure 2. Thermal shock test showing changes in optical power versus ten temperature cycles for three samples of multimode fiber of diameters: 62.5/125/155 with the non strippable coating. Test EIA/TIA-455-71.

held at 125 µm for all samples and the outside coated fiber diameter was kept at 155 µm.

The Carlisle Interconnect Technologies performed the cabling according to the new design of the aerospace cable standard and produced the Liteflight™-EP semi loose fiber optic cable of the outside diameter 1.8 mm. The new cable design, shown in the Figure 1 assures the low smoke low toxicity and light weight cable required for the modern aircraft.

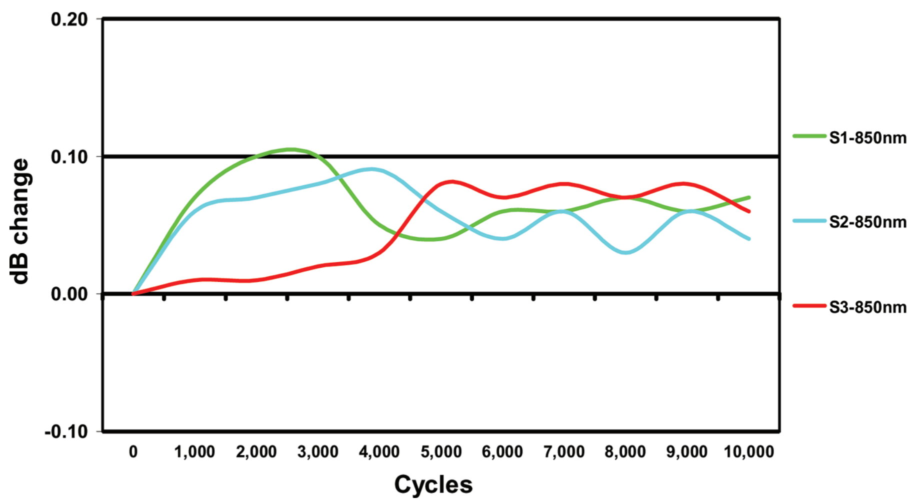

Figure 3. Flexure endurance test showing minimal optical power change during and after 10,000 Flex cycles; 10 N load; 0625″ mandrel radius; test: EIA/TIA-455-104A.

Results and Discussion

The Liteflight^{TM}-EP optical cables bearing singlemode and multimode optical fibers, respectively, were manufactured and tested according to the specifications required for military aircraft. All tests were performed according to the European fiber optic specifications and are also listed in the Table 1. For each tests, the three cable samples, each of 30 meters were used. The results summarizing the performance of the cable with the singlemode optical fiber coated by one layer of strippable hybrid glass are listed in the Table 1. The optical cable bearing multimode optical fiber and coated by one layer of non strippable version of the hybrid glass went through the same tests that produced very similar results. The selected results of those tests are presented in the Figures 2–5.

As evident from the data shown in Table 1 and on Figures 2–5, the optical cables subjected to severe temperature and stress regimes showed no or minimal change in optical power transmitted at 850 nm and 1300 nm or 1550 nm, respectively. The meaningless changes in the optical power during and after those tests indicate on an exceptionally good protection of the glass fiber brought in intimate contact with the hybrid glass. Similar results for both strippable and non strippable coating indicate that the covalent bonding of the hybrid glass to the silica fiber occurring in strippable coating seems to be of a secondary meaning. The primary factor in the fiber protection is the coating resistance to the heat and mechanical stress rather than its ability to covalently bond with the glass fiber.

Protective Coating for Aerospace

The hybrid glass provides the optical fiber with necessary protection for reliable operation in the next generation optical cables for aerospace. A thermally stable,

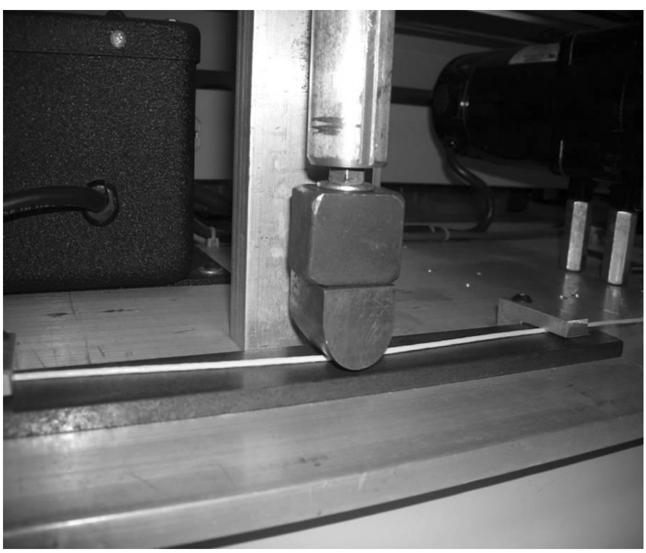

Figure 4. Cable Impact test for the multimode optical fiber. Hammer weight: 5.3 N; Hammer radius: 8 mm and a Drop height: 153 mm. The test showed minimal −0.10 dB changes in optical power after 40 impacts.

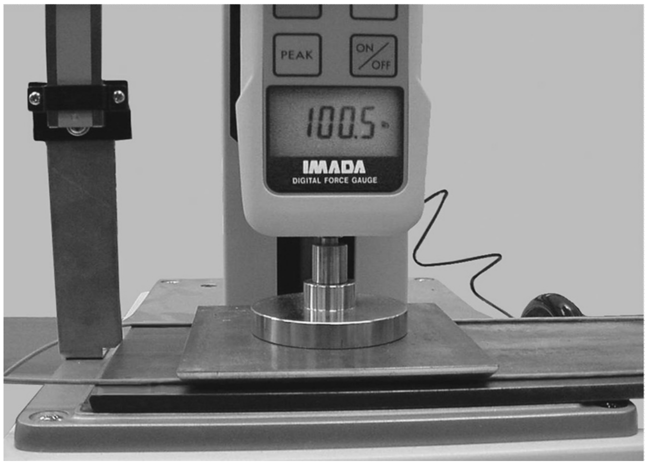

Figure 5. Cable crash test for the cable with multimode 62.5/125 fiber coated with one layer of non strippable hybrid glass showed 0.35 dB change in optical power after the weight of 1000 N was crashing the cable for 15 minutes.

chemically resistant, hybrid glass coating can succesfully replace polyimide coating on fiber used in aerospace cables.

While the most immediate applications of the hybrid coatings being developed are targeted to optical fibers in adverse military environment, all of today's commercial telecom fibers as well as photonic components can potentially be impacted by this technology. More than 99% of all current optical fibers employ UV-cured polymer coatings that make them vulnerable to significant strength reduction and eventual failure in the field. In addition, low cost hermetic packaging technology for electronic and optoelectronic circuity might also benefit from this R&D effort. The immediate use of the hybrid glass would include a diversity of applications such as fiber to home, intelligent infrastracture, environmental monitoring, biomedical imaging and automative sensing.

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