

Fiber Optic Connectors

Choosing the Best Ferrule Material for Your Network Application

White Paper



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Introduction

Fiber connectors are terminated onto optical cable to provide a separable interface that allows for moves, adds and changes (MACs). This allows for such media to be deployed into enclosures and panels to form structured cabling solutions, or in patch cords to facilitate transceiver connections.

To minimize losses associated with the mated connector interface, it is imperative that connectors provide accurate fiber alignment (core-to-core alignment of the fiber media) and that the ferrule endface be precisely shaped so that optimum physical contact can be maintained between each mated fiber pair. Two common ferrule materials—zirconia ceramic and lower-cost plastic composites—provide comparable performance and achieve compliance with TIA/EIA-568-B.3 requirements (Insertion Loss <0.75dB and Return Loss >20dB). However, the ability of each connector type to maintain physical contact can differ over a variety of structured cabling applications and environmental conditions.

This white paper reviews key ferrule cost and performance factors to help network stakeholders select the best connector for a particular structured cabling application. Selection of a ferrule material should not be based on cost alone, but on a combination of relevant performance factors that include durability of ferrule materials, connector mating frequency, and ability of each material to retain endface geometry and surface finish over time.

Material Properties of Ceramic and Composite Ferrules

Independent, spring-loaded fiber optic contacts (ferrules) have proven themselves in all performance aspects through years of field use. Historically, system designers have specified connector ferrule materials based on the manufacturer's ability to easily process and control the dimensionality of those materials. This focus has widened recently to include the ability of the connector to maintain physical contact between fiber pairs over time and under a variety of applications.

Two types of ferrule materials are commonly used in the manufacture of fiber optic connectors: zirconia ceramics and composite plastic polymers.

Ceramic materials. Ceramic ferrules are well known for having high durability and the highest levels of dimensional control, making them suitable for use in all fiber applications (both singlemode and multimode) specified in TIA/EIA-568-B.1 cabling architecture standards. Zirconia materials exhibit excellent control over grain size (<0.4 microns typical), which enables efficient polishing with greater repeatable geometry and a finer surface finish. Proper fiber alignment in zirconia ceramic ferrules is assured through state-of-the-art precision molding/machining of the ferrule to ensure full physical contact of fiber ends.

Polymer composite materials. High-performance amorphous engineering plastics also are used to produce lower-cost ferrules for specific connector applications within premise cabling plants. These materials have been employed in concert with low expansion coefficient filler agents to create high tolerance and dimensionally stable ferrules. These and other materials have improved to the point that composite ferrules provide an attractive alternative to more costly ceramics, as both solutions exceed TIA/EIA-568-B.3 performance requirements.

High-performance amorphous engineering plastics offer good chemical resistance, high mechanical strength, and high dry-heat capability. These materials also exhibit low, uniform shrinkage and thermal expansion/contraction, so precise tolerances can be molded-in and maintained over a wide variety of service conditions. The addition of filler agent to the base resin increases the rigidity, tensile strength, creep resistance (i.e., stress relaxation over time), dimensional stability, and chemical resistance of the base material.

Molding a product with the requisite filler agent offers a composite material close to that of the fiber itself and ensures controlled rates of expansion and contraction relative to the fiber and thus, the ability to accurately align the fiber and maintain specified tolerances. Also, the high hardness of the composite material improves the uniformity of material removal in the polishing step, reducing problems associated with surface “smearing” historically associated with fiber connectors made from polymer materials.

The Impact of Mating Cycles on Connector Performance

Insertion loss in fiber connectors is strongly affected by the variation in physical characteristics of the fiber connector, specifically the business end of the connector—the ferrule. The product should remain stable and resist mechanical changes that could conceivably infringe upon the original optical performance. In this regard, the dimensionality and bulk material properties of engineered plastic composites are equal to those of traditional ceramic materials, and designers confidently deploy connectors with ferrules fabricated using these cost-reduced materials.

Also, the shape of the physical contact (i.e., the endface geometry) should be near spherical, with a precisely prescribed and controlled radius that is centered on the axis of the fiber. Both ceramic and composite connectors are batch processed on precision fiber connector polishing machines to deliver precise and repeatable connector endface geometry and back reflection that exceed industry specifications. Figure 1 shows typical polishing results for both ceramic and composite material ferrules with multimode fiber.

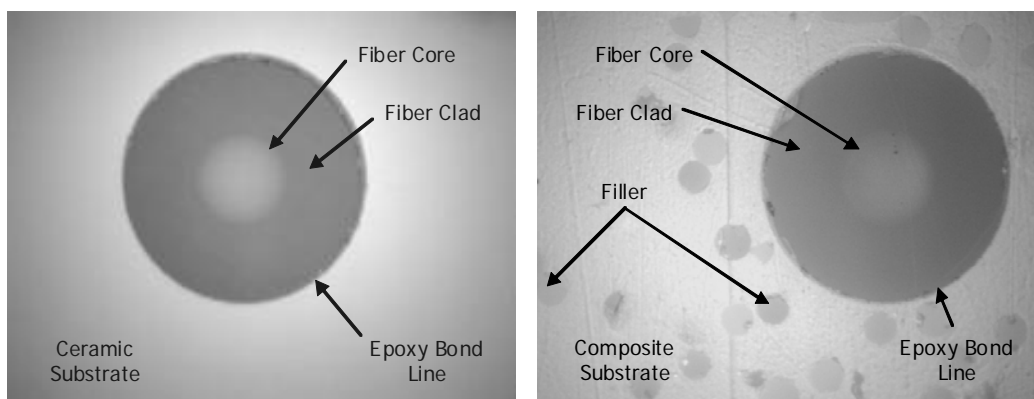


Figure 1. Polished multimode fiber endfaces viewed through a fiber inspection scope. Note lack of obvious surface structure and texture on the ceramic ferrule in comparison to the scratches present on the composite ferrule material due to breakaway of filler components during the rough polishing steps.

Marked and distinct differences are exhibited in the connector endfaces: ceramic materials tend to polish to a near mirror-like finish, whereas composite ferrules yield surfaces that exhibit more minor surface marks and appear more textured than their ceramic ferrule counterparts (as shown in Figure 1). This is because the composite material is loaded with filler agent, and hence particulate from the filler is released into the polishing slurry and affects the fiber and substrate surface quality.

There is no discernable performance difference between composite and ceramic ferrule connectors as a result of connector processing. Minor surface marks on freshly-processed connector endfaces are typically less than 1 micron in width and/or depth, achieving average insertion loss values of 0.3dB and return loss values of ≤ 20 dB when recommended installation instructions are followed.

However, the performance of composite ferrule connectors tends to degrade over time and across many MACs and mating cycles due to the accumulation of endface defects, especially when mated against ceramic ferrules. Figure 2 shows the endface of a composite ferrule connector in which the fiber has moved slightly with respect to the ferrule: the contact region close to the fiber has been flattened and additional pitting in the ferrule surface has occurred.

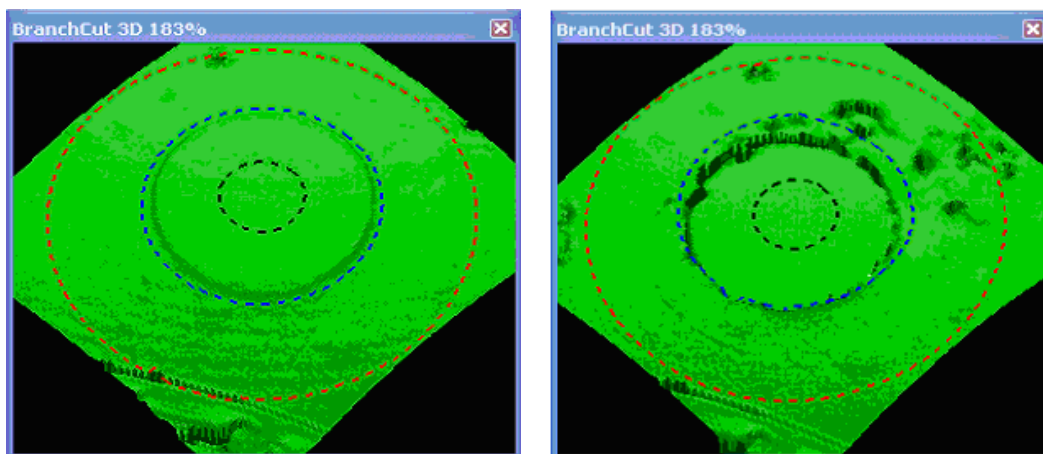


Figure 2. Magnified view of composite ferrule endface before use (left) and after being subject to many moves, add and changes (right). Defects in connector endfaces such as pits, cracks, chips, and deep scratches can result in high insertion loss and low return loss, which in severe enough cases can impact network reliability. The scale of the pits and undercuts at right represent 10s of nanometers.

Matching the Best Connector to the Cabling Application

Physical fiber contact in connector systems is critical to achieving environmental stability and high levels of network performance. The versatility of ceramic connectors to perform well under any structured cabling application has led to an industry perception that ceramic ferrules are intrinsically “better” than composite options. However, with lower-cost plastic composite ferrules available, it makes sense for network stakeholders to specify connectors that both maximize their budget and meet the demands of the application for which they are deployed. This decision requires knowledge of which connector types are a good match, from both a materials and application point of view, as well as the type of alignment sleeve used to guide the connection.

In general, three general principles should be followed to match ferrule materials with a given application:

- In mission critical permanent link and patch cord applications, it is recommended that zirconia ceramic ferrule products be deployed.
- In any dynamic application (such as a patch field) the durability of ceramic solutions is preferred.
- In more static interconnect environments (such as behind walls, at consolidation points, or in telecommunications rooms) composite solutions are a cost-effective and standards compliant choice.

Materials Analysis. Table 1 summarizes the quality characteristics that can differentiate the performance of ceramic and composite ferrules under a variety of cabling applications and environmental conditions. The key characteristics are reliability and durability: to comply with TIA/EIA-455-21A requirements a connector must be able to maintain the optical performance over 500 mate/de-mate events before the insertion loss deteriorates to a prescribed level.

Table 1. Quality Analysis for Ferrule Materials

Quality		Characteristic(s)	Zirconia Ceramic	Composite
Required	Performance	Insertion Loss and Return Loss	Comparable	
	Conformance	TIA/EIA-568-B.3 and IEC/ISO 11801 Compliance	Comparable	
	Reliability	Mechanical Shock, Humidity, Temperature Life	Excellent	Good
	Durability	MACs (repeated mating)	Excellent	Fair
Desired	Serviceability	Troubleshooting Ease, Maintenance	Comparable	
	Features	Installation Time, Tooling	Comparable	
	Aesthetics	Construction, Materials	Comparable	
	Perceived Quality	Application Type, User History	Excellent	Good

Ceramic and composite ferrule designs both offer compliance with standards-based durability requirements. However, the mate and de-mate tests only call for same connector mating and not a random mating condition. A typical “random” mating application would be a cross-connect patch field. In this scenario, a permanent link connector may be mated with many different connectors throughout its service life, so a ceramic ferrule connector solution would be best suited to this type of permanent link application.

Application Analysis. Table 2 is an application-based guide for deploying ceramic and composite ferrules across cabling elements found in the three most typical premise LAN architectures:

- **Hierarchical Star** – fiber backbones from Equipment Room (ER) to remote Telecommunications Rooms (TRs) that house workgroup switching equipment and copper horizontal to user outlets.
- **Fiber to the Enclosure (FTTE, or Zone Cabling)** – fiber backbones from ER to remote enclosures (i.e., “mini-TRs”) and shorter copper horizontal to user outlets.
- **Fiber to the Desk (FTTD, or Centralized Fiber)** – fiber backbones from ER to user workstations (i.e., fiber horizontal); the TR functions as a passive optical interconnect/patch.

Table 2. Application Analysis for Ferrule Materials

Cabling Element	LAN Architecture			Zirconia Ceramic	Composite
	H. Star	FTTE	FTTD		
ER Main Cross-Connect	X	X	X	Recommended	Not Recommended
ER Intermediate Cross-Connect	X	X	X	Recommended	Not Recommended
Cross-Connect Patch Cords	X	X	X	Suitable*	Not Recommended
ER Main Interconnect	X	X	X	Comparable	
TR Interconnect	X			Comparable	
Enclosure Interconnect		X		Comparable	
Consolidation Point			X	Comparable	
MUTOA			X	Comparable	
User Outlet			X	Comparable	
Workstation Patch Cords			X	Suitable*	Not Recommended

*PANDUIT® OPTICAM® Ceramic Ferrule Connectors may be deployed in patching applications, although factory polished patch cords are preferred.

Figure 3 illustrates the best practice application of ceramic and composite ferrule connector types across a typical Fiber to the Desk (FTTD) cabling architecture. Active cross-connect areas in TRs and the main ER experience high levels of MACs, so patch cords and permanent link connectors with ceramic ferrules are the recommended solution. At less active, more “static” cabling areas including the user outlet, MUTOA and consolidation point, a composite ferrule connector may be mated to a ceramic connector for a cost-effective and performance comparable solution.

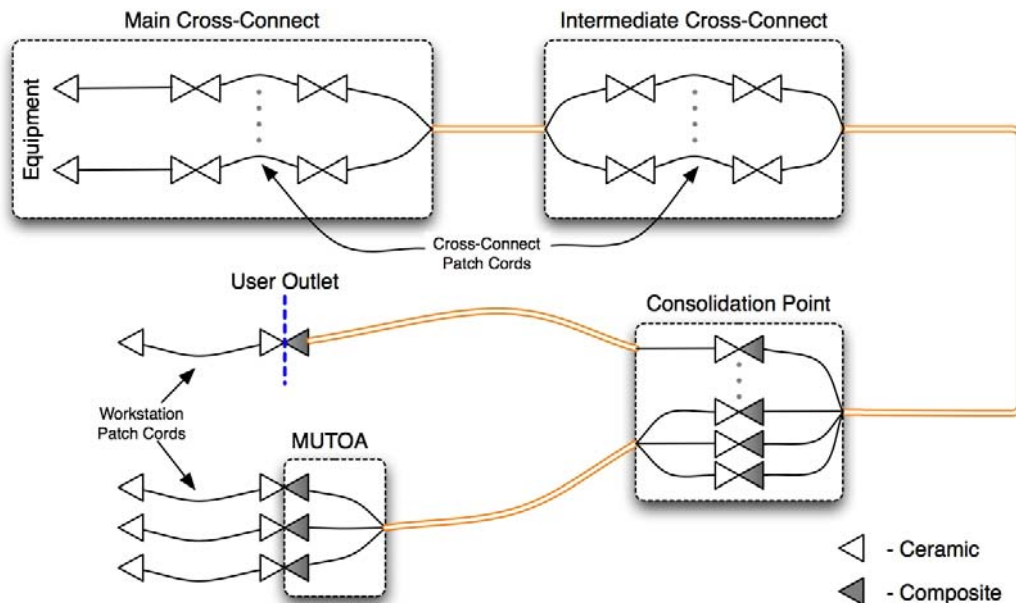


Figure 3. Example FTTD Architecture Showing Recommended Ferrule Materials Across Typical Network Connection Points

Connector Alignment Sleeve Considerations. The selection of connector ferrule material is also influenced by the choice of alignment sleeve material in which the two ferrule endfaces make contact. Alignment sleeves are constructed of either zirconia ceramic or phosphor bronze materials, and should be chosen based on fiber grade, performance, and cost considerations. Table 3 identifies recommended ferrule material mated pair and alignment sleeve material combinations for the fiber grade being deployed.

Table 3. Ferrule Material Mated Pair and Alignment Sleeve Material Combinations

Fiber Grade	Alignment Sleeve Material	Mated Pair Configuration		
		Ceramic to Ceramic	Ceramic to Composite	Composite to Composite
62.5/125µm OM1	Phosphor Bronze	Recommended	Recommended	Suitable**
	Zirconia Ceramic		Suitable	
50/125µm OM2	Phosphor Bronze		Recommended	
	Zirconia Ceramic		Suitable	
50/125µm OM3 (LOF)*	Phosphor Bronze	Suitable	Not recommended	
	Zirconia Ceramic	Recommended		
9/125µm OS1/OS2	Phosphor Bronze	Suitable		
	Zirconia Ceramic	Recommended		

* LOF = Laser Optimized Fiber

** Composite-to-composite mated pair configurations are suitable for **static** standard multimode fiber grade applications (50/125µm and 62.5/125µm) when one connector in the mated pair is a factory-terminated composite connector.

PANDUIT® OPTICAM® Cam-Style Pre-Polished Fiber Optic Connectors

Field polishing of fiber optic connectors requires polishing materials (in the form of consumable items) and a reasonable level of training in assembly and polishing to ensure that endface geometry and finish requirements are met. Advancements in pre-polished connector design enable speedy termination of both ceramic and composite connector types while retaining the desired endface quality and optical requirements to deliver link performance that exceeds TIA/EIA-568-B.3 requirements (Insertion Loss <0.75dB and Return Loss >20dB).

PANDUIT® OPTICAM® Pre-Polished Fiber Optic Connectors are available in both ceramic and composite ferrule variants, offering flexibility in product choice in addition to the benefits of pre-polished connectivity. These quick-terminating cam-style connectors provide fast and consistent fiber optic terminations with yield rates approaching 100%. LC, SC, and ST OPTICAM® Zirconia Ceramic Ferrule Connectors are available for multimode (10GIG™ 50/125µm, 50/125µm, and 62.5/125µm) and singlemode fiber optic termination onto 900µm buffered fiber or 1.6-2.0mm or 3mm jacketed cable.

SC and ST OPTICAM® Composite Ferrule Connectors offer a cost-effective, comparable solution to zirconia ceramic ferrule connectors for multimode 50/125µm and 62.5/125µm fiber types in static structured cabling applications. In addition, OPTICAM® Composite Ferrule Connectors deliver an average insertion loss of 0.3dB to meet minimum performance requirements after a 500 mate/de-mate test with less than 0.2dB change in insertion loss.

Conclusion

Both ceramic and composite ferrule types deliver excellent optical performance when deployed in a suitable environment and application, with average insertion loss values of 0.3dB when recommended installation instructions are followed.

PANDUIT OPTICAM[®] Pre-Polished Singlemode and Multimode Fiber Optic Connectors with zirconia ceramic or composite ferrules are offered to deliver fast and easy terminations, high yield rates, and to meet the standards requirements outlined in TIA/EIA-568-B.3.

- In mission critical permanent link and patch cord applications, it is recommended that zirconia ceramic ferrule connectors be deployed. Ceramic ferrules also are recommended for deployment in dynamic application areas such as patch fields that see a high incidence of MACs.
- In “static” interconnect applications, such as behind walls, at consolidation points, or in telecommunications rooms, the composite ferrule product offers a cost-effective alternative to ceramic ferrules. In these applications, the material used in the *OPTICAM*[®] Composite Ferrule Connector delivers optical performance levels comparable to that of the *OPTICAM*[®] Ceramic Ferrule Connector.

About *PANDUIT*

PANDUIT is a leading, world-class developer and provider of innovative networking and electrical solutions. For more than 50 years, *PANDUIT* has engineered and manufactured end-to-end solutions that assist our customers in the deployment of the latest technologies. Our global expertise and strong industry relationships make *PANDUIT* a valuable and trusted partner dedicated to delivering technology-driven solutions and unmatched service. Through our commitment to innovation, quality and service, *PANDUIT* creates competitive advantages to earn customer preference.

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