WHITE PAPER
STEEL CONDUIT/FIBERGLASS CONDUIT: HOW DO THEY COMPARE?

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What are the construction differences between rigid steel or PVC-coated rigid steel conduit and fiberglass conduit?

Conduits are raceways of circular cross section designed for the physical protection and routing of electrical conductors or cables and fiberoptics.

Rigid steel and PVC-coated rigid steel conduits are principally made from hollow, carbon steel tubulars with either zinc, organic or a combination of zinc/organic coatings applied for corrosion protection. An interior and exterior coating of zinc or of PVC (organic) coating provide superior corrosion protection for the base steel tube. Rigid steel conduit with a PVC coating over galvanize is used in many corrosive applications to provide increased protection for the base metal. The choice of three rigid steel conduit products is available for application in the specified corrosive environment and all three products are assembled into a conduit system with threaded connections. Superior electrical conductivity makes rigid metal conduit useful for electrical shielding and safe operation.

Fiberglass conduit is made from an epoxy and fiberglass hollow tubular fabricated with high-speed winding equipment and high temperature curing ovens. Since the epoxy and fiberglass do not oxidize like metals, supplemental coatings are not required for corrosion protection. Although fiberglass conduit does not oxidize like metal, it will deteriorate in some application environments such as sulfuric acid, hydrochloric acid and sodium hydroxide depending on the epoxy blend and the corrosive concentration. Fiberglass conduit sections are fabricated with several different end designs that are joined with an epoxy adhesive.

Underwriters Laboratories and the Canadian Standards Association evaluate the performance and list conduit according to the respective metal and fiberglass conduit standards. Since the products are different, the standards and tests required to list fiberglass and metal conduit are significantly different. Listing means that the fiberglass or metal conduit meets the specifications for its respective standard. It is the responsibility of the user or designer to select the appropriate conduit for the specific application. The National Electric Code (NEC) contains references to a number of listed conduit types, but it is not a design manual. This paper provides additional aid to help with the decision.

What differences exist between the physical properties of rigid steel and fiberglass conduit?

A partial listing to compare the physical property differences between rigid steel or PVC-coated rigid steel and fiberglass conduit appear in the table at the top of the next page. With the exception of the corrosion protection coating, the PVC-coated steel conduit and rigid steel conduit have the same physical properties. The values in the table are typical values published by steel and fiberglass conduit manufacturers. Obviously steel and fiberglass are different materials and have significantly different properties. These

differences must be evaluated in light of the conduit system function. One must determine which conduit system provides the best protection for the enclosed wiring or cable system in the application environment and under the application conditions. The corrosives present in the environment; the physical properties required; and the economic factors should be carefully considered.

PROPERTY	PVC COATED or RIGID STEEL	FIBERGLASS
Tensile	330 MPa (Min) 47,863 psi	76 MPa 11,023 psi
Elongation	29%	2%
Hardness, HRB	65	Not Published
Thermal Conductivity	320 BTU/ft^2-hr-^{0}F-in	2.0 BTU/ft^2-hr-^{0}F-in
Electrical Conductivity	200 x 10^{-6} ohms	1.1 x 10^{14} ohms
Impact	350 ft-lbs.	30-140 ft-lbs.
Joint Pull Out Force	18,000 lbs. (US Size 1; Metric 27)	1000 lbs. (Interference Joint)
Corrosion Protection	Excellent	Excellent
Weight (Specific Gravity)	7.8	1.9

What other significant differences exist between steel and fiberglass conduit?

The material and property differences result in unique product performance differences. These technical performance differences must be considered and evaluated to make the best decision for the application. The following information documents some important parameters that should be carefully evaluated:

1. **Connection Differences**

   Fiberglass conduit sections are bonded together with an epoxy resin adhesive system. The qualification tests in the fiberglass conduit standards require joint water tightness and/or joint separation tests depending on the design. The standards require that "Two joints in each trade size are to be assembled as intended." or "according to the manufacturer's installation instructions." The joints are then tested according to the specification.

   Joints bonded for these tests are bonded under ideal conditions in a laboratory where the surfaces are clean, the conduit is new, the cleanliness is controlled, etc. On a job site the conduit may be stored in unclean environments for extended periods before installation commences. Surface cleanliness is extremely important to the formation of acceptable and durable adhesive fiberglass bonds. Experience confirms that joining the threaded ends of rigid steel and PVC-coated rigid steel conduit that have been stored under nearly every condition does not affect the physical integrity of the joint.

The threaded steel conduit joint pullout values are nearly 20 times greater than fiberglass conduit. Not only are the initial pull out values with clean conditions much superior for steel conduit, the deleterious effects of field installation will have less relative effect with steel conduit. Confidence when an epoxy resin adhesive system is used to bond fiberglass conduit under adverse field conditions is an unknown entity.

The adhesive system used to assemble fiberglass conduit is very sensitive to temperature as evidenced by the recommended use of several different adhesives depending on the ambient curing temperatures. Not only must construction personnel select and use the correct adhesive for the curing conditions, but they must also thoroughly clean and apply the adhesive to form a reliable joint. A significant concern exists because a joint failure can be catastrophic.

2. Threaded Connection Interface

The steel conduit threads provide a positive mechanical interface to maintain the connections between conduit sections. The mechanical interface also provides electrical continuity that enables the conductor to be used as a ground path. This electrical conductivity can also be used to confirm that the threads are appropriately engaged. If the connection is loose, the electrical resistance will be high and the loose joint can be detected and identified. Because fiberglass conduit is non-conductive, the integrity of a connection cannot be confirmed by a simple electrical continuity check.

An electrical method to evaluate the integrity of a fiberglass conduit system installation is not possible. A mechanical method to evaluate the integrity of a fiberglass conduit system may be possible, but any recognized method would be time consuming, costly and of questionable reliability. For these reasons a method has not been proposed. If the integrity of a joint is not confirmed, the joint could fail during an unexpected impact or a seismic event regardless of how resistant the base material may be to the same loading.

3. Electrical Shielding

In addition to the physical protection provided by rigid conduit, the steel conduit acts as an electrical shield to prevent spurious signals from interfering with the wiring system protected by the conduit system. The fiberglass conduit system offers no EMI/RFI shielding because it is non-conductive. To provide the same degree of security as the steel conduit, it will be necessary to use more expensive shielded wire and cables. In today's world of increasing security concern about terrorism threats, steel or PVC-coated conduit provides both the best electrical shielding and the best physical protection. Shielding data for metal conduit are available and documented in the GEMI program developed and available through

the Georgia Institute of Technology and the Steel Tube Institute of North America.

4. Conductivity

The conductivity of the steel conduit system provides electrical protection that cannot be duplicated with a fiberglass system. The National Electric Code recognizes rigid steel conduit as an electrical conductor and ground return path; a separate ground wire is required for the fiberglass conduit system. Routinely monitoring the conductivity of the steel conduit system can provide a continuing check on system integrity; the non-conductive fiberglass conduit system affords no such opportunity. This could be very valuable to assess damage after an unexpected impact or a seismic event.

5. Conduit System Aging

Aging of fiberglass or metal conduit systems and the aging failure modes are a concern. It is very difficult to devise a single aging test that will characterize either the fiberglass or metal conduit system in an infinite number of existing applications. Increasing the temperature conditions will accelerate the aging process, but increasing the temperature too much will have unintended consequences and failure modes. Temperature is not the only parameter that can be used to artificially age a conduit system.

Rigid steel and PVC-coated rigid steel conduit systems have a long history of successful performance for extended periods of time in nefarious environments; fiberglass conduit does not have similar historical operating data. With the absence of historical performance data, aging tests for fiberglass conduit systems should include long-term exposure data for the adhesive connections.

6. Installation

Commercial equipment and trained contractor personnel familiar with the bending procedures are readily available for steel conduit. Steel conduit offsets have been successfully implemented for years in an infinite number of installations in numerous applications. Special bending equipment is required to make offsets for fiberglass conduit. Training and special skills are required to make fiberglass conduit field offsets.

7. Failure Modes

The failure modes of fiberglass and steel conduit are significantly different. The primary function of the conduit system is to protect the wire or cable contained therein. A large impact load will dent the steel conduit; under a similar impact load fiberglass conduit will probably fracture. The fracture will expose the internal wiring to the environment. Water and other corrosive elements now have direct access to the fiberglass filaments and water will wick along the individual filaments causing additional damage. If the dented area on coated steel conduit has

penetrated the PVC coating, the galvanize coating on the conduit will continue to offer protection. Touch-up compound can be painted over the damaged area to provide additional protection.

It is much more difficult and risky to attempt to touch-up the fractured area on fiberglass conduit because of the jagged failure. As the touch-up area is exposed to additional weathering and humidity, moisture will penetrate the patch area and wick along the glass fibers leading to a subsequent failure as the epoxy separates from the glass fibers.

8. Re-Making Connections

Re-make capability with an adhesive fiberglass conduit joint is more cumbersome than re-make with a rigid steel or PVC-coated rigid steel conduit threaded coupling. If a section of fiberglass conduit is damaged in service or must be replaced because of changes to the wiring scheme, the fiberglass system must be replaced or sections shortened to make new joints. A damaged steel conduit section with threads can be reused several times without making new joints.

9. Thermal Conductivity

The higher thermal conductivity of steel removes heat more quickly from the enclosed wiring and cable systems. The respective thermal conductivities are shown in the physical properties table appearing on page 2. The lower operating temperature of the wire and cable system will increase the operating life of the wire and cable system.

10. Electrical Fault Conditions

Fiberglass conduit will not melt or weld the wire to the inside of the conduit under fault conditions as can happen with rigid steel or PVC-coated rigid steel conduit. If a fault condition is severe enough to melt or weld wire to the inside of the steel conduit, it must be severe enough to melt or puncture the insulation on the enclosed wire or cable. During such a fault the grounding wire will be compromised and the ground system will require replacement in a fiberglass conduit system.

Fault conditions are equally bad in either conduit system and wire replacement will usually be necessary. Among other considerations it depends on the magnitude of fault current, the duration of the fault and the associated arc damage whether the steel conduit must be replaced when wire welds to the inside of the steel conduit. The same considerations and arc burn will damage and carbonize the surface of fiberglass conduit. In some instances it may be possible to remove the conductors and clean the interior of rigid steel conduit.

11. Weight

Fiberglass conduit is lighter weight than rigid steel or PVC-coated rigid steel conduit. This property offers an advantage when designing the support system; however, the added weight of steel conduit provides significant application benefits including better fulfillment of the primary goal, i.e., protection of wiring from physical damage. As outlined above the steel conduit and the coupling method will protect better against unexpected impact loads. It also provides security benefits that fiberglass conduit cannot provide without additional measures.

12. Corrosion Protection

Corrosion protection is unique to the environment, but a comparison of the published corrosion resistance tables for fiberglass conduit and PVC coated steel conduit show that PVC coated steel conduit has application in several environments not recommended for fiberglass conduit. An example where PVC coated conduit is better than epoxy fiberglass is sulfuric acid dependent on the temperature and concentration. This is a function of the corrosives that appear in the application environment and is unique to the application. Corrosion protection must be evaluated for the specific application.

13. Vibration

Another concern is vibration in the application. Rigid steel conduit joints have been applied for many years under the vibration conditions that could be expected in a specific application such as a bridge. No requirements are specified for vibration testing of fiberglass conduit joining methods.

14. Connection Pullout Strength

As reported in a Fiberglass Conduit catalog, the average pullout strength of a trade size 4 fiberglass conduit joint is 11,270 psi. This is an unusual method to report a pullout value. Tensile test machines measure pullout force in lbs, not psi. In the Fiberglass Conduit catalog the pullout strength is calculated as the average ultimate value times the cross sectional area of the conduit. The calculated cross sectional area of the conduit is 3.34 sq in, i.e. the pullout strength is 3.34 sq. in. x 11, 270 psi = 37,642 pounds.

The anticipated failure mode during the pullout test of either fiberglass or coated/rigid steel conduit will be for the conduit to pull out of the fitting, whatever fitting may be used in the test. For fiberglass conduit the pullout strength will depend on the integrity of the adhesive bond between the conduit section and the fitting (coupling, elbow, tee, whatever). The pullout strength is completely independent of the cross section of the conduit unless the fiberglass conduit fails; the pullout strength is dependent on the adhesive contact surface area. The coated metal conduit

pullout strength will depend on the mechanical interface of the metal threads and the tensile strength of the steel.

The pullout strength of the fiberglass, galvanized rigid steel, PVC-coated rigid steel and PVC-coated rigid steel galvanized conduit is dependent on proper assembly procedures. Joints made by turning threaded conduit into couplings is obviously less complicated than cleaning ends, choosing the correct adhesive and assuring the use of proper application procedures. Delays while waiting for adhesive cure are also a consideration. The threaded steel conduit is much less susceptible to assembly problems as compared to fiberglass adhesive.

Since the fiberglass conduit test unit was probably assembled in a laboratory under pristine conditions, the published test value will be difficult to match during field installation. Using data presented in the Fiberglass Conduit vendor catalog, the measured pullout values for the trade size 4 fiberglass conduit was 37,642 lbs. This is an average value based on three test results. The condition of the fiberglass conduit after the tests is not described. Based on data from a UL Fact-Finding Report, the minimum average pullout strength for trade size 4 rigid steel conduit is 93,250 lbs.

15. Thermal Expansion

The coefficient of thermal expansion (CTE) for fiberglass conduit is 1.5×10^{-5} in/in/^{0} F. The CTE for steel conduit is 0.65×10^{-5} in/in/^{0} F. The PVC coating has absolutely no impact on the CTE for coated steel conduit; the CTE for PVC-Coated and Rigid Steel Conduit are the same. The thermal expansion of rigid steel and PVC-coated rigid steel conduit is less than half the thermal expansion of fiberglass conduit. The difference in CTE means that the distance between expansion joints can be increased significantly with steel conduit. The thermal expansion is independent of the conduit size.

16. Impact Strength

Impact test loads are normally expressed in ft-lbs or in-lbs; the published impact value for trade size 4 fiberglass conduit is 180 lbs. at -40^0 F (-40^0 C). It is unclear from the published data exactly how the impact resistance of fiberglass conduit was determined or the reason it is not expressed in ft-lbs or in-lbs. Trade size 4 rigid steel conduit has a confirmed test impact resistance of 375 ft-lbs. If the published fiberglass value of 180 lbs is actually 180 ft-lbs, then the rigid steel conduit has twice the impact strength of similar size fiberglass conduit.

Another very important question is the condition of the conduit after the impact test. The impact resistance of the trade size 4 coated steel conduit is 375 ft-lbs. A 25 lb. weight was dropped from a height of 15 ft on the metal conduit. The dent on the steel conduit made by the falling weight

reduced the cross sectional area of the steel conduit by 10%, but the conduit was functional and did not fracture. The internal conductors were not damaged from the impact. The failure mode with fiberglass conduit will be much different. The fiberglass will fracture and expose the internal wiring to sharp fragments of fiberglass or epoxy. Under these conditions the internal wiring may be damaged and could be exposed to the existing environmental conditions.

The fact that the impact test was made at -40^0 F (-40^0 C) is not significant. Steel or coated steel conduit will maintain its impact strength at this temperature. At much colder temperatures such as -75^0 F or more, the steel may become brittle. This is not an issue unless the conduit installation is in Antarctica or Arctic regions.

Conclusion

This is not a complete listing of technical points that should be considered when selecting a conduit system. It does present several important differences that should be evaluated in addition to the economics when determining the most appropriate system for the application. Data presented in this white paper were provided from testing performed by a group of producers under the auspices of industry associations and the published literature from fiberglass manufacturers. If you have any additional questions about the information in this document, you may contact a producer of either steel or PVC-coated rigid steel conduit.

Bibliography

References used to prepare the information in this paper include:

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3. ROBROY Industries Product Bulletins & Catalogs for PLASTI-BOND REDH2OT, PERMA-COTE and KORKAP Coated Conduit; information available at www.robroy.com.

4. EPON® Resin Structural Reference Manual; 2001 Resolution Performance Products.