COMPOSITE TIE RODS FOR HEAVY-DUTY TRUCK APPLICATIONS

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Abstract

A joint effort between Delphi Corporation, Hendrickson International, and Oak Ridge National Laboratory has led to the development of carbon fiber reinforced polymeric tie rod for use in heavy-duty truck suspension systems. The composite tie rod tube assembly is 65% lighter than current metal tubes with equivalent or improved performance. This paper will summarize the design and test methodology, which have led to successful implementation of this product for heavy truck applications.

Background

In response to a Request for Proposal from UT-Battelle, Oak Ridge National Laboratory in February 2001, a submission from Delphi Corporation led to the award of a subcontract for the development of Advanced Composite Structural Chassis components. Objectives of this project are to:

- Develop an economical manufacturing procedure utilizing continuous and/or long, oriented chopped fibers for structural chassis components for class 7&8 trucks.
- Reduce mass of components by 60%.
- Commercialize and produce the components in substantial volumes.

Sponsored by the U.S. Department of Energy, the duration of the subcontract is three years with an estimated cost of $2.5M. This project is a 50/50 cost share between ORNL and industry. In this project, Delphi Corporation, the world's largest automotive Tier 1 supplier, partnered with Hendrickson International, an industry leading Tier 1 supplier to the truck and trailer industry.

The first component to become commercialized as a result of this research is a tie rod tube assembly for a passive-steer, auxiliary lift axle system shown in Figure 1. The tube assembly consists of a continuous carbon fiber reinforced polymeric composite tube with metal inserts at each end. In a period of 14 months, from June 2001 through August 2002, samples of several designs were tested and low volume production begun. A photo of both steel and composite tie rod assemblies are shown in Figure 2. Complete design and process validation tests were conducted including durability (tension/compression), buckling and three-point bending.

Design and Testing Criteria

The two most challenging technical requirements encountered in this development are the durability of the insert-to-tube interface and buckling performance. To achieve the buckling strength, the tube outside diameter is an important consideration. Current commercial vehicle tie rods are created from tubular steel; typically 6.35 mm (0.25 in) wall thickness with outside diameters of 38.1 mm (1.5 in) or 41.3 mm (1.75 in). These sizes are convenient for an all steel design since the ID can be simply tapped to a standard thread size to accept the ball joint.

However, to meet buckling requirements, a composite construction with lower tensile modulus (standard modulus carbon employed based on current cost levels) than steel requires an increased diameter to allow the increase in sectional properties to offset the lower stiffness. The maximum allowable diameter is dictated by the geometry of the suspension system. Too large of diameter will reduce wheel cut, as the tie rod will either hit the axle or wheel hub.

Durability

In most of the designs considered, metal inserts/fittings were utilized at each end of the tube. The purpose of these inserts are to 1) reduce the inside diameter down to the required thread size of the ball joint, and 2) provide a robust surface and material for the interface and tension loads of a locking nut. Locking nuts replace clamp sets on the composite tube assembly (see Figure 2). For all durability testing of the tube-to-insert interface, 305 mm (12 in) length samples were employed. With the exception of some very early work, all durability testing was conducted at ORNL on an MTS machine shown in Figure 2. The test consisted of sinusoidal tension-compression waveform at 4hz with load set at approximately 33% of ultimate field test recorded data.

Buckling

Requirements for buckling can vary significantly based on vehicle application due to both load and overall length. In the applications investigated, the intent of the composite tube design was to have equivalent buckling strength as the current steel tube. Buckling tests were also conducted at ORNL on the same MTS machine used for durability. Figure 4 shows a typical buckling load test on the current production composite tie rods.

Three-Point Bending Test

Although there are no specific bending load requirements, these tests were conducted as “due care.” The tube could be subjected to a center load by backing into a stationary object or perhaps during maintenance as a technician pushes or pulls on the tube for leverage. In these cases, a possible failure mode of the composite tube was identified as an axial fracture initiated at the insert due to insufficient hoop strength. Delphi Composite Lab personnel conducted this testing at University of Utah. Figure 5 illustrates three point bending test data for current production steel, current production composite, and a hybrid metal/composite tie rod tube assembly.

Environmental Conditioning

In the final product development phases, all samples used in design and process validation testing were subject to accelerated weathering / environmental conditioning prior to testing. This consisted of a heat soak followed by thermal cycle, humidity and salt fog spray.

Product Design Concepts

A large number of product/process design combinations were evaluated in both terms of build/test and cost. Figure 6 contains a chart of many of these combinations. Standard modulus unidirectional carbon fiber (230 GPa – 33 Mpsi) was utilized for reinforcement in all designs. Where required, glass was used in many of the designs to isolate the metal inserts from the carbon fiber to resist galvanic reactions.

Much of the early development work involved variations of epoxy prepreg roll wrapping over a sub-assembly of a pultruded or extruded tube with inserts at each end. This concept provided a finished part with a minimum amount of processing steps and would require virtually no tooling. See Figure 7 for a photo of various end insert concepts. While ultimate tensile tests of these designs were favorable, the initial cost models were not.

Simple mandrel/table roll-wrapped tubes, threaded in a secondary operation and fitted with wire thread inserts were the first to consistently meet all design validation test requirements and were then field-tested over-the-road. With this design, the ID was fixed to that required for the wire thread inserts. However, due to this geometric constraint and the need to meet buckling requirements, the tube wall became quite thick resulting in an unacceptably high composite mass and cost.

At this point, a study of the suspension geometry was conducted to determine the maximum allowable diameter of the tie rod tube. With the OD now held at its maximum, wall thickness and mass is minimized. With this design direction, the ID of the composite tube is threaded to mate with machined metal inserts. These inserts act as adapters or bushings to bring the composite tube ID down to that required for the ball joint threads. A structural adhesive is utilized at the tube-to-insert interface. This design has passed all design and process validation tests and is in production today. The mass of this tube is 2.36 kg (5.2 lb), a 67% mass savings over the steel tube at 7.27 kg (16.0 lb).

Other processes/designs investigated include pultrusion and hybrid (metal/composite tube) options. Early pultruded tubes were sized for the wire thread inserts. The thick wall sections (8.75mm (0.34 in.)) made processing difficult and samples exhibited micro cracking through the wall. Durability test results were very poor. However, the pultrusion process is being reinvestigated with the larger OD, thinner walls, and metal adapter inserts. For high volume applications, pultrusion should be a cost effective production process.

Samples of metal/composite hybrid tubes were also produced and tested. Metal inserts at each end were fastened with various methods (laser weld, roll crimp, etc.) to a thin-walled steel "liner." The liner with inserts was then wrapped with the minimum amount composite material for reinforcement to meet buckling requirements. Samples have tested well and have a mass of 3.4 kg (7.5 lb). Although not as light as the all-composite tube, this design still represents a 53% mass savings over the current steel tube. The initiative behind this design was to replace a significant amount of the expensive composite material with lower cost steel and develop a mass vs. cost curve. However, piece price and assembly cost of the liner was higher than anticipated.

Next Steps

Composite tie rod tube assemblies have been produced which meet and/or exceed the performance of the steel tubes currently common in the commercial vehicle industry today. Although the composite tie rod tube has been implemented in relatively low volume applications, current costs prohibit it from reaching widespread use. The primary cost factor is the cost of carbon fiber.

Several alternative designs are under consideration, which show promise for reduced cost, which will allow penetration into higher volume applications. Shape and sizing optimization CAE software tools have been utilized to design the optimum tube shape and wall thickness along its length. Results of this optimization indicate that the composite material costs can be reduced by up to 30%. Finally, new metal end inserts have been designed which offer over 50% cost savings from current.

Acknowledgements

This paper and the work described herein are a compilation of efforts by many persons. The author wishes to specifically acknowledge guidance and assistance provided by Jeff Zawacki, Hendrickson Components Group, Mike Gottschalk, Hendrickson Auxiliary Axle, Don Erdman, ORNL and Rick Battiste, ORNL, Larry Stanley, Delphi Composites Lab, and James Grutta, Delphi Composites Lab.

Figures

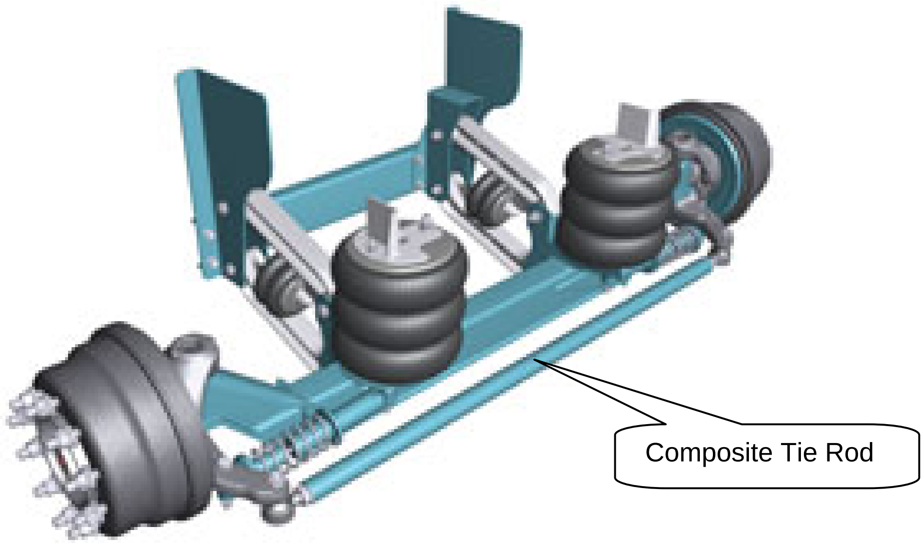

Figure 1: Composite Tie Rod in Hendrickson International's COMPOSILITE-2™ Steerable Lift Axle Application (Courtesy of Hendrickson International)

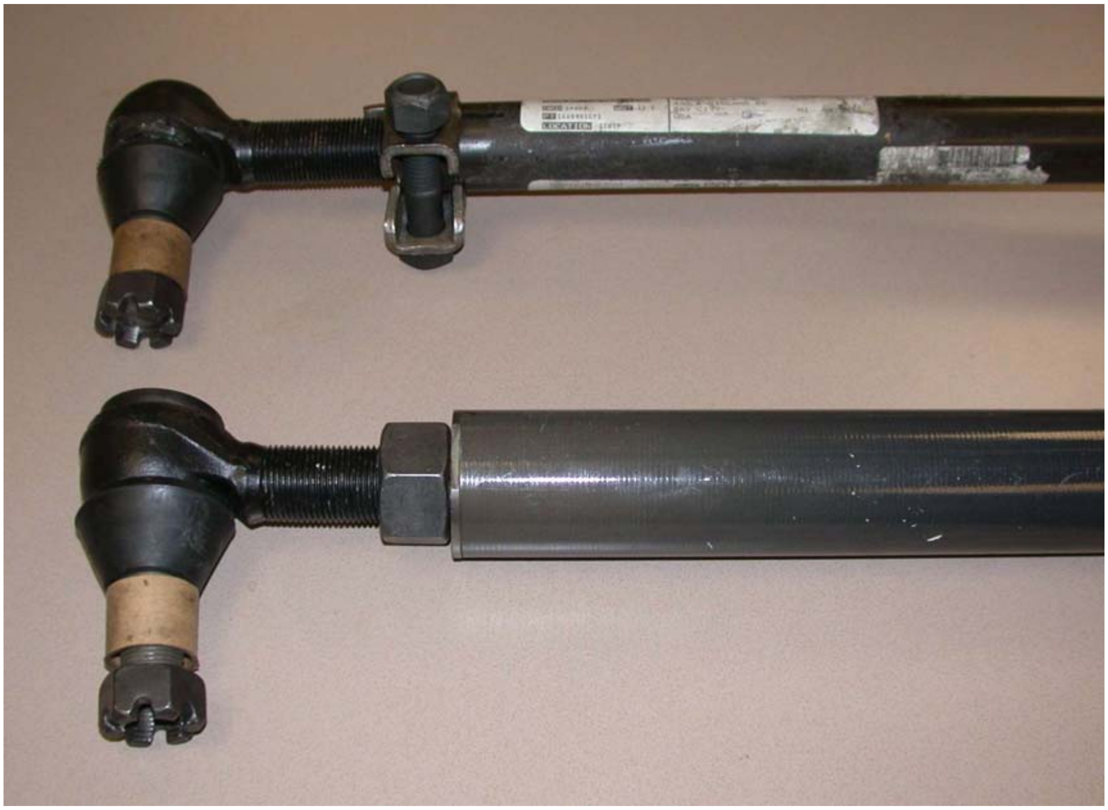

Figure 2. Photo of current production steel and composite tie rods.

Figure 3. Durability testing of end inserts – ORNL MTS machine. This MTS machine also used for ultimate buckling load test. (Courtesy of ORNL)

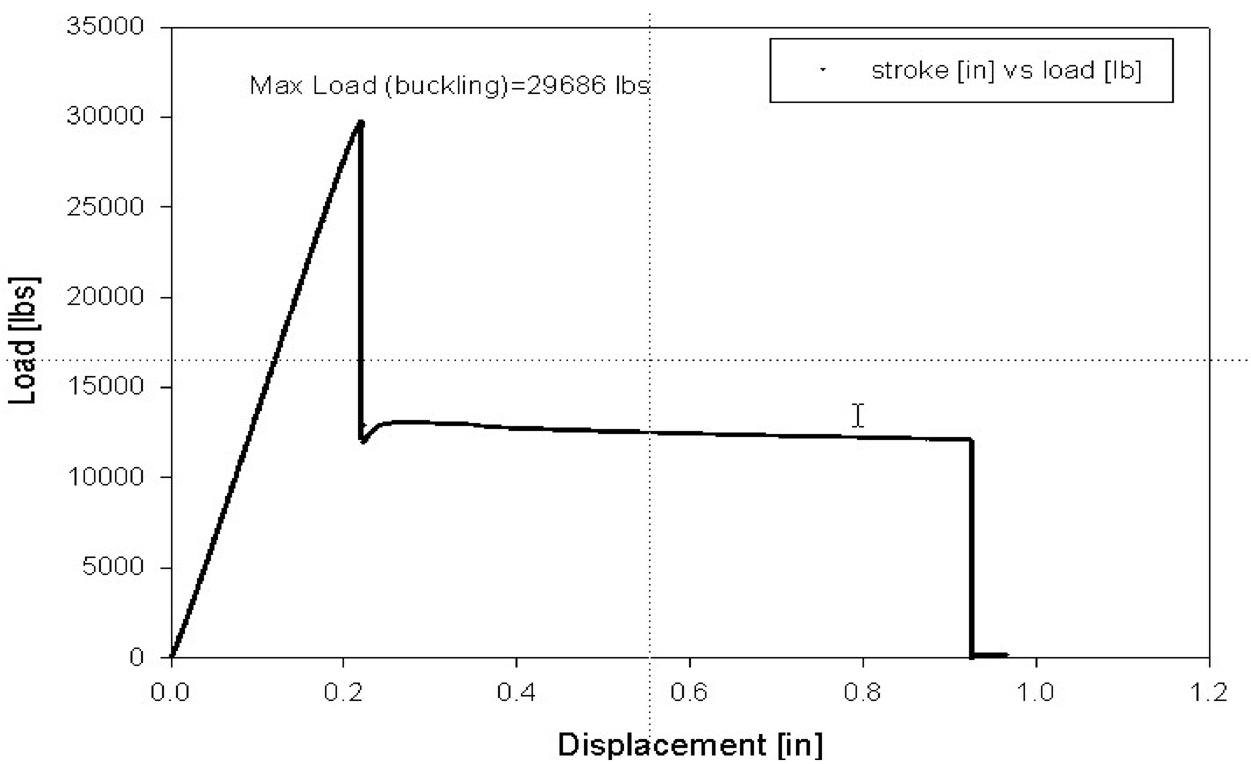

Figure 4. Typical buckling test of current production composite tie rod tube assembly.

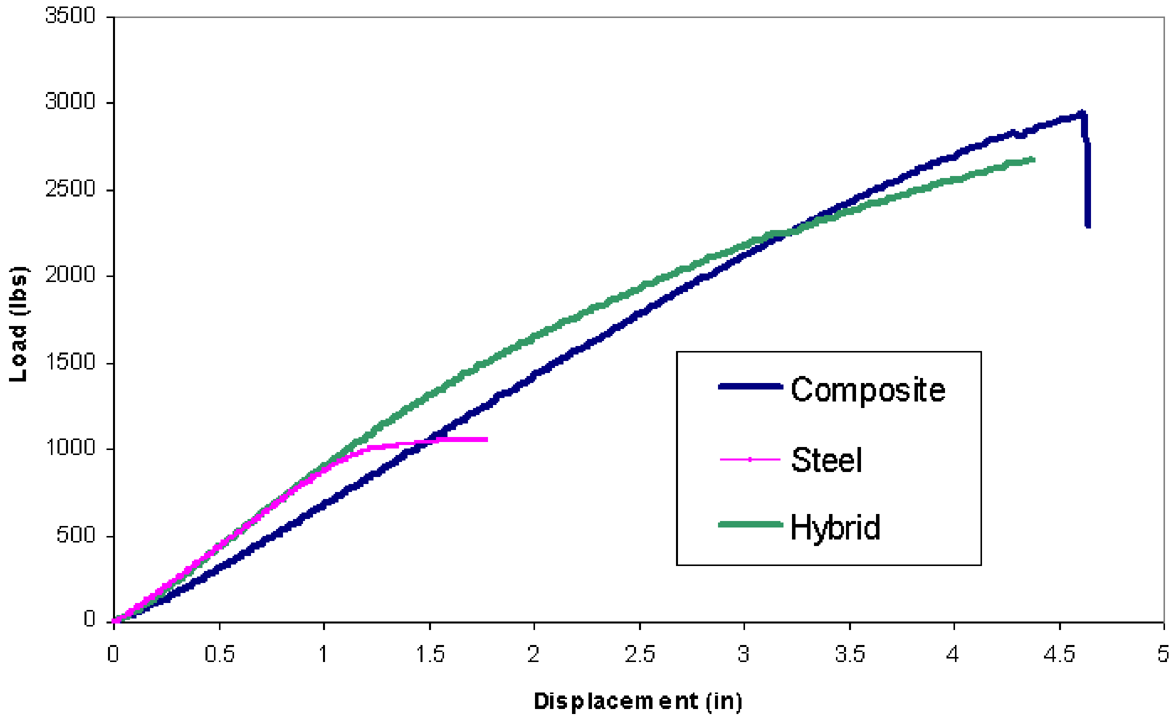

Figure 5. Typical 3-point bending test results. The steel tube yields at approx. 1000 lbs. The composite and hybrid (metal liner over-wrapped with glass and carbon fiber prepreg) did not yield or fail. At approximately 4.6 inches of travel the test fixture buckled.

Composite Process	Machined Threads	Threads Molded-In	Inserts Molded-In	Wire Thread Inserts	Machined Inserts	Hybrid-Comp. Over Metal Liner	Constant Wall Thickness	Variable Wall Thickness	ID / OD Both Variable	Comment
Roll Wrap Over Mandrel	T	T		T	T		T	P		Current Production
Roll Wrap Over Tubing			T	T	T	T	T	P	P	
Pultrusion	T	P		T	T	P	P		P	Testing
Filament Winding	P	P			P	P	P	P		Not Cost Effective
Legend	T	Samples built and TESTED of various combinations								
	P	POSSIBLE design combination. Design complete, cost model being investigated before build/test.								

Figure 6: Chart illustrating various process / design feature combinations.

Figure 7. Various end inserts and tube ends tested during development. Note the step in the tubes indicating the presence of an inner tube used instead of tooling / mandrel during roll wrap and consolidation.