



## Modeling of Failure for Analysis of Triaxial Braided Carbon Fiber Composites

**Better understanding of triaxial braided composites will lead to improved aerospace and automotive structures.**

*John H. Glenn Research Center, Cleveland, Ohio*

In the development of advanced aircraft-engine fan cases and containment systems, composite materials are beginning to be used due to their low weight and high strength. The design of these structures must include the capability of withstanding impact loads from a released fan blade. Relatively complex triaxially braided fiber architectures have been found to yield the best performance for the fan cases. To properly work with and design these structures, robust analytical tools are required that can be used in the design process.

A new analytical approach models triaxially braided carbon fiber composite materials within the environment of a transient dynamic finite-element code, specifically the commercially available transient dynamic finite-element code LS-DYNA. The geometry of the braided composites is approximated by a series of parallel laminated composites. The composite is modeled by using shell finite elements. The material property data are computed by examining test data from static tests on braided composites, where optical

strain measurement techniques are used to examine the local strain variations within the material. These local strain data from the braided composite tests are used along with a judicious application of composite micromechanics-based methods to compute the stiffness properties of an equivalent unidirectional laminated composite required for the shell elements. The local strain data from the braided composite tests are also applied to back out strength and failure properties of the equivalent unidirectional composite. The properties utilized are geared towards the application of a continuum damage mechanics-based composite constitutive model available within LS-DYNA. The developed model can be applied to conduct impact simulations of structures composed of triaxially braided composites.

The advantage of this technology is that it facilitates the analysis of the deformation and damage response of a triaxially braided polymer matrix composite within the environment of a transient dynamic finite-element code

such as LS-DYNA in a manner which accounts for the local physical mechanisms but is still computationally efficient. This methodology is tightly coupled to experimental tests on the braided composite, which ensures that the material properties have physical significance.

Aerospace or automotive companies interested in using triaxially braided composites in their structures, particularly for impact or crash applications, would find the technology useful. By the development of improved design tools, the amount of very expensive impact testing that will need to be performed can be significantly reduced.

*This work was done by Robert K. Goldberg and Gary D. Roberts of Glenn Research Center and Justin D. Littell and Wieslaw K. Binienda of the University of Akron. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18435-1.*

## Catalyst for Carbon Monoxide Oxidation

**This catalyst forms carbon dioxide in a high-powered, pulsed CO<sub>2</sub> laser.**

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In many applications, it is highly desirable to operate a CO<sub>2</sub> laser in a sealed condition, for in an open system the laser requires a continuous flow of laser gas to remove the dissociation products that occur in the discharge zone of the laser, in order to maintain a stable power output. This adds to the operating cost of the laser, and in airborne or space applications, it also adds to the weight penalty of the laser. In a sealed CO<sub>2</sub> laser, a small amount of CO<sub>2</sub> gas is decomposed in the electrical discharge

zone into corresponding quantities of CO and O<sub>2</sub>. As the laser continues to operate, the concentration of CO<sub>2</sub> decreases, while the concentrations of CO and O<sub>2</sub> correspondingly increase. The increasing concentration of O<sub>2</sub> reduces laser power, because O<sub>2</sub> scavenges electrons in the electrical discharge, thereby causing arcing in the electric discharge and a loss of the energetic electrons required to boost CO<sub>2</sub> molecules to lasing energy levels. As a result, laser power decreases rapidly.

The primary object of this invention is to provide a catalyst that, by composition of matter alone, contains chemisorbed water within and upon its structure. Such bound moisture renders the catalyst highly active and very long-lived, such that only a small quantity of it needs to be used with a CO<sub>2</sub> laser under ambient operating conditions.

This object is achieved by a catalyst that consists essentially of about 1 to 40 percent by weight of one or more platinum group metals (Pt, Pd, Rh, Ir, Ru,

Os, Pt being preferred); about 1 to 90 percent by weight of one or more oxides of reducible metals having multiple valence states (such as Sn, Ti, Mn, Cu, and Ce, with SnO<sub>2</sub> being preferred); and about 1 to 90 percent by weight of a compound that can bind water to its structure (such as silica gel, calcium chloride, magnesium sulfate, hydrated alumina, and magnesium perchlorate, with silica gel being preferred). Especially beneficial results are obtained when platinum is present in the catalyst composition in an amount of about 5 to 25 (especially 7) percent by weight, SnO<sub>2</sub> is present in an amount of about 30 to 40 (especially 40) percent by weight, and silica gel is present in an amount of 45 to 55 (especially 50) percent by weight.

The composition of this catalyst was suggested by preliminary experiments in which a Pt/SnO<sub>2</sub> catalyst was needed

for bound water to enhance its activity. These experimental results suggested that if the water were bound to the surface, this water would enhance and prolong catalyst activity for long time periods. Because the catalyst is to be exposed to a laser gas mixture, and because a CO<sub>2</sub> laser can tolerate only a very small amount of moisture, a hygroscopic support for the catalyst would provide the needed H<sub>2</sub>O into the gas. Silica gel is considered to be superior because of its property to chemisorb water on its surface over a wide range of moisture content.

The catalyst may be produced by first preparing a mixture of a commercially available, high-surface-area silica gel and an oxidizing agent. The second step is accomplished by preparing an aqueous mixture of the tin (IV) oxide coated silica gel and a soluble, chloride-free salt of

at least one platinum group metal. It is beneficial if the coated silica gel is first deaerated by boiling. The platinum group metal salt is adsorbed onto the high surface area and coats the surface. A chloride-free reducing agent is then added to the aqueous mixture whereby the platinum group metal is deposited onto the tin (IV) oxide coated silica gel. After the platinum group metal has been deposited onto the tin (IV) oxide coated silica gel, the solution is evaporated to dryness, whereby the desired catalyst is obtained.

*This work was done by Patricia Davis of Langley Research Center; Kenneth Brown, John Van Norman, and David Brown of Old Dominion University Research Foundation; and Billy Upchurch, David Schryer, and Irvin Miller of Science and Technology Corporation. Further information is contained in a TSP (see page 1). LAR-14155-1*

## Titanium Hydroxide — a Volatile Species at High Temperature

*John H. Glenn Research Center, Cleveland, Ohio*

Titanium hydroxide, TiO(OH)<sub>2</sub> (g), has been identified as the primary reaction product of TiO<sub>2</sub> (s) + H<sub>2</sub>O (g) at high temperatures (1,200–1,400 °C) through the use of the transpiration technique. This technique is a well-established method used to measure equilibrium pressures at 1 atm. Reactive O<sub>2</sub>/H<sub>2</sub>O mixtures of gases flow over the sample, and react to form volatile Ti hydroxides. The collected reaction gas condensate is analyzed to determine the vapor and dissociation pressures. From the amount of condensate and its relation to the partial pressures of the

reactive gases, the identity of the volatile hydroxide can be determined. From the relation of product pressure to temperature, thermodynamic enthalpy and entropy of formation can be calculated.

The reaction of the identified titanium hydroxide is useful to understanding the volatility of titanium-containing materials for high-temperature conditions that contain water vapor (i.e., combustion from hydrocarbon fuels, etc.). The identity of this molecule and thermodynamic data on this molecule contribute to the high-temperature materials database that

would directly impact future selection of refractory oxide materials for use in combustion environments. This will also aid in furthering the understanding of oxide stability with high-temperature water vapor.

*This work was done by QuynhGiao N. Nguyen of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18482-1*

## Selective Functionalization of Carbon Nanotubes: Part II

**Different species are deposited at different distances.**

*Ames Research Center, Moffett Field, California*

An alternative method of low-temperature plasma functionalization of carbon nanotubes provides for the simultaneous attachment of molecular groups of multiple (typically two or three) different species or different mixtures of species to carbon nanotubes at different locations within the same apparatus. This method is based on similar principles, and involves the use of mostly the same basic apparatus, as those of the methods described in “Low-Temperature Plasma Func-

tionization of Carbon Nanotubes” (ARC-14661-1), *NASA Tech Briefs*, Vol. 28, No. 5 (May 2004), page 45.

The figure schematically depicts the basic apparatus used in the aforementioned method, with emphasis on features that distinguish the present alternative method from the other. In this method, one exploits the fact that the composition of the deposition plasma changes as the plasma flows from its source in the precursor chamber toward

the nanotubes in the target chamber. As a result, carbon nanotubes mounted in the target chamber at different flow distances ( $d_1$ ,  $d_2$ ,  $d_3$  . . .) from the precursor chamber become functionalized with different species or different mixtures of species.

In one series of experiments to demonstrate this method, N<sub>2</sub> was used as the precursor gas. After the functionalization process, the carbon nanotubes from three different positions in the