Zirconia Fuel System Components

Heavy Vehicle Propulsion System Materials

Transportation

FOR THE 21ST CENTURY

U.S. DEPARTMENT OF ENERGY

ENERGY EFFICIENCY AND RENEWABLE ENERGY PROGRAM

OAK RIDGE NATIONAL LABORATORY

UT-BATTELLE

Background

Under the direction of the U.S. Department of Energy, FreedomCAR and Vehicle Technologies Program, Cummins, Inc., has conducted research and development of zirconia materials for diesel engine fuel system applications.

A mandated change in fuel sulfur levels for diesel fuel in late 1993 resulted in lower lubricity fuel and subsequent increase in scuffing and wear for metal plungers in fuel system injectors.

Research to reduce the scuffing led to evaluation of different ceramic materials including silicon nitride and zirconia. One critical feature in operation of the injector plungers is maintenance of a minimum clearance to prevent fuel leakage. Silicon nitride has a thermal expansion coefficient (CTE) much lower than steel (2.6 ppm/°C vs 12 ppm/°C) and could not maintain the tight clearances over the operating range. Yttria stabilized zirconia had a CTE closer to that of steel (10.5 ppm/°C) but exhibited a phase transformation and loss of strength when exposed to water and organic acids in the operating temperature range. Magnesia stabilized zirconia had an adequate CTE (9 ppm/°C) and showed no strength loss from environmental or temperature factors.

The Technology

Cummins conducted extensive bench test evaluations on zirconia for the CELECT™ timing plunger application. Additional engine and rig tests proved the ability of the zirconia plungers to withstand scuffing and seizing even with water introduced into the fuel.

One significant barrier to timing plunger implementation was the lack of high volume centerless grinding capability to grind the outer diameter of the plungers to sub-micron tolerance levels. Cummins developed this capability and performs the final outer diameter grinding operations.

Following the success of the timing plunger, a zirconia metering plunger was introduced in 1997. This component had an increased level of complexity with a drain hole through the diameter and intersecting a blind hole through the center of the plunger. Sharp metering edges in two locations were also a necessary part of the design. The grinding and handling operations were improved to maintain these edges.

In 1998, Cummins introduced the CAPS™ common rail fuel system for mid-range engines with a zirconia pumping plunger. This was the first system at Cummins to be introduced into production with a ceramic component included in the design and development process. This enabled the plunger design to be modified for ceramic to reduce the total cost.

Zirconia materials with improved strength (790 vs 480 MPa) and increased CTE (9.7 vs 9.0 ppm/°C) improved the robustness for sharp edges and closer matching at the operating conditions. This material was introduced into production in 2001.

Commercialization

The CELECT™ timing plunger was was introduced in 1995, the CELECT™ metering plunger in 1997, the CAPS™ pumping plunger in 1998, and a new, higher strength zirconia for all three applications in 2001.

Success Story

Benefits

- Zirconia components have established themselves in high performance diesel fuel systems.
- The success of zirconia direct replacement of steel components led to zirconia being considered in initial design, thus permitting ceramic manufacturing processes to be included in the optimization.
- Close cooperation among ORNL, Cummins, and ceramic suppliers resulted in improved properties and more successful applications for zirconia.

For more information on how ORNL is helping America remain Competitive in the 21st century, please contact:

D. Ray Johnson
Heavy Vehicle Propulsion Materials Program Manager
Metals and Ceramics Division
Oak Ridge National Laboratory
(865) 576-6832
johnsondr@ornl.gov

November 2002