Spectrum

PSZ: a formula for saving energy

Components made of PSZ. They're tough, strong, and corrosion-resistant. A piston cap for a diesel engine is on the right; behind it is a cylinder-liner. Other components shown here include extrusion dies and a hip-bone prosthesis.

Instead of having glass-like brittleness, a ceramic developed at the Advanced Materials Laboratory of the CSIRO Division of Materials Science is so tough it can be struck with a hammer without shattering. The material, partially stabilized zirconia (PSZ), is the world's toughest ceramic.

Nilsen Sintered Products is now using PSZ to produce extrusion dies — the orifices through which hot metal ingots are forced under great pressure to form rods and tubes. In this demanding application, the new dies last about four times longer than their predecessors.

The material's toughness, and a range of other highly desirable properties — such as hardness, high strength, high melting point, excellent corrosion resistance, and low friction — make it ideally suited to many other engineering applications.

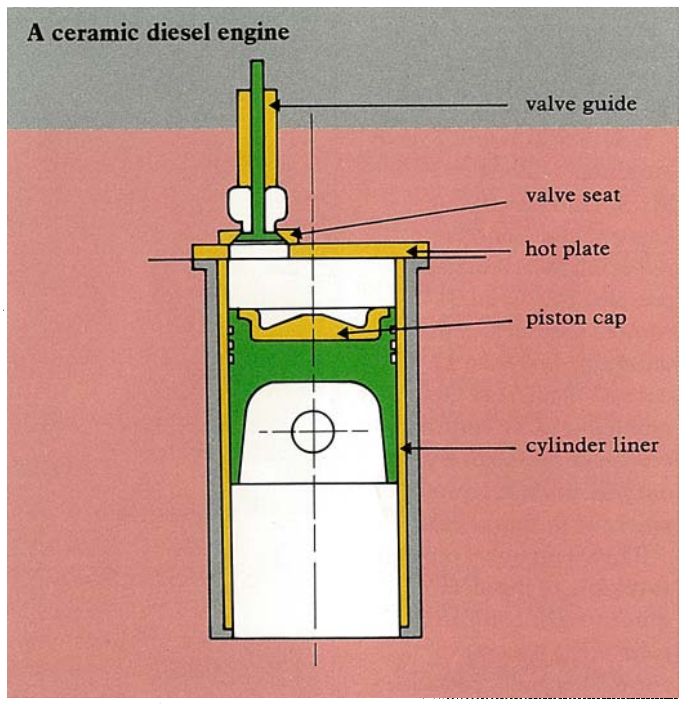
It should be well suited to dry bearing systems, sand-blasting nozzles, and cam followers. The ceramic's compatibility with biological tissues should suit it for implanted prostheses, and diesel engine components made from PSZ are undergoing tests in North America, Europe, and Japan.

This last application has considerable potential. A ceramic diesel engine would operate at a higher temperature and, losing less heat, would be much more fuel-efficient than conventional diesels. Some estimates say a PSZ engine would use up to 50% less fuel.

In conventional diesel engines, much heat has to be removed by conduction to keep the steel cylinder-liners cool enough to prevent seizure, and complicated cooling systems are required. As a ceramic diesel would not be as susceptible to overheating and could operate up to 400°C hotter, it would not need a cooling jacket, radiator, or water pump. Moreover, PSZ has a low value of friction, and it may even be feasible to run a ceramic diesel without any cylinder lubrication!

As a first step towards fully ceramic engines, hybrid steel–ceramic engines, with PSZ piston caps and cylinder-liners, are under test by Ford and Cummins in America.

Because PSZ has a thermal expansion similar to that of steel, it can be used relatively easily in conjunction with steel components. It has a good resistance to thermal shock, making it ideally suited in principle for use in internal combustion engines.



The yellow components (labelled) are made of PSZ. Ceramic diesel engines should run at higher temperatures and more efficiently.

The new ceramic combines the best features of ceramics with some of the properties of a metal, and it achieves this advantage in the same way as steel improves upon the properties of cast iron: through alloying. Indeed, PSZ has been called a ceramic analogue of steel.

Pure zirconia (zirconium oxide) isn't much use as a ceramic. Although it has an extremely high melting point, it is very brittle. As zirconia changes its crystal structure (from 'tetragonal' to 'monoclinic') on cooling through 1200°C, its volume changes by 4%, which causes it to crack and fall to pieces.

Alloying the zirconia with a sufficient amount of magnesia stops the destructive change by converting it into a third ('cubic') crystal structure. This is 'stabilized' zirconia, but the CSIRO researchers — Mr Ron Garvie, Dr Richard Hannink, and the late Dr Terry Pascoe — found that better toughness and shock-resistance result when zirconia is 'partially stabilized', with a mixture of cubic and monoclinic crystal types.

More importantly, they discovered a special way of treating the PSZ material, which gives rise to a powerful, previously unknown, strengthening effect.

Their treatment involves producing, within the cubic-stabilized body of zirconia (at room temperature), fine particles of tetragonal zirconia — the sort that in bulk only exists above 1200°C. These small tetragonal particles, less than 250 atoms across, provide the key to the strength and toughness of the new PSZ.

They act as in-built shock-absorbers. If stress is put on the material, the tetragonal particles at the point of stress absorb energy by turning themselves into the common monoclinic form. Due to this microscopic flip, cracks effectively close up and stress fatigue, common in metals and other ceramics, is markedly reduced. Indeed, within limits, the more it's stressed, the tougher it becomes!

Being uniformly strong, tough, and inert, PSZ seems an ideal material for bone prostheses. It appears less prone to implant failure than the materials presently in use — stainless steel, high-density polyethylene, and alumina.

Orthopaedic surgeons have implanted small experimental samples in animals and have found the material to be biologically compatible. They are now implanting experimental hip prostheses.

Australian beach sands are the source of about 70% of the world's zirconia, but the processing plants are in the United States and Britain. Recently, CSIRO has commissioned a report to examine whether an Australian processing plant would be economically viable.

Ceramic steel? R.C. Garvie, R.H.J. Hannink, and R.T. Pascoe. *Nature*, 1975, **291**, 703–4.
'Research Report 1980–81.' Division of Materials Science. (CSIRO: Melbourne 1982.)