Opportunities in Advanced Technical *Ceramics*

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Above: An F350 armored security vehicle. All photos, except where indicated, are courtesy of Ceradyne, Inc.

Advanced technical ceramics are increasingly the material of choice for applications in a number of diverse markets.

Many ceramic materials classed as traditional ceramics are generally considered to be those made of natural materials, and they are used for applications such as pottery, cookware, tile, and sanitaryware, as well as for more technical products such as electrical insulators and refractory bricks. Other materials can be classed as advanced technical ceramics, which are sometimes called "engineered" or "fine" ceramics. The materials in this class are composed of manmade oxides, like alumina or zirconia, or non-oxides, such as borides, carbides and nitrides. The composition and microstructure of these materials are engineered to obtain unique properties that are generally designed for specific applications or to solve specific problems. Ceramic composites, or mixtures of materials, are common.

Advanced technical ceramics can achieve specifications that cannot be attained by either metals or plastics. Consequently, their unique properties and the resulting benefits make these ceramics the material of choice for applications in a number of diverse markets.

Applications and Markets

Ceramic applications or markets are often grouped by application for a particular type of material. The following applications are grouped by the general market that is being served, and this grouping shows that many applications using different types of ceramics often exist within a market segment. The markets and applications discussed are not inclusive of all ceramic applica-

Ceramic armor, such as this body armor plate, consists of a ceramic hard plate with an aramid or similar composite backing.

tions, but their diversity illustrates the breadth and potential of advanced technical ceramics.

Armor

In the period following the 9/11 terrorist attacks, lightweight ceramic body armor has gained worldwide attention by saving countless numbers of combat soldiers' lives. Ceramic armor is not new, however; it has been used in helicopters since the Vietnam era. Ceramic armor systems are still used in helicopters and other aircraft, as well as other civilian and military vehicle applications, where lightweight operation is key.

Ceramic armor is a composite system consisting of a ceramic "hard plate" with an aramid or similar composite backing. The two materials work together to defeat the projectile. As the bullet hits the ceramic hard plate, the ceramic fractures and absorbs energy from the bullet. The bullet is also deformed and fractured when hitting the ceramic. The remaining low-energy bullet fragments are "caught" by the composite, which deforms but does not fracture.

Armor systems are designed by identifying the threat, type and velocity of the bullet, as well as the required weight of the system. The armor designer then specifies the ceramic and composite materials and the construction of the system. The current systems must have a minimum weight but be capable of stopping the most advanced bullets. Boron carbide is the ceramic of choice because it is the hardest and lightest ceramic material. Silicon carbide or aluminum oxide can be used for applications that call for less demanding threat levels.

Automotive

Ceramic components are used in automotive applications such as spark plug insulators (alumina), oxygen sensors (zirconia), catalyst supports (cordierite) and particulate filters for diesel engines (cordierite and aluminum titanite). Two lesser-known applications are cam rollers for large diesel engines (silicon nitride) and water pump seals (silicon carbide).

Silicon carbide is used as a water pump seal in diesel engines. Photo courtesy of ESK, a Ceradyne company.

Silicon nitride cam rollers are used in the valve train of heavy-duty diesel engines as part of either a rocker arm assembly or a roller lifter assembly, because metal rollers fail by galling and contact fatigue. The stress level of the cam rollers and valve train components has increased dramatically over recent years because of increases in the fuel injection pressure and cylinder operating pressures required to meet emission standards.

Silicon nitride was selected as the material of choice for a number of reasons: its contact fatigue resistance is superior to bearing steels; its coefficient of friction is significantly lower than a corresponding steel-on-steel system; and its weight is 40% that of steel, which reduces the rotating moment of inertial of the rollers. The result has been the elimination of significant warranty problems associated with the valve train, an increase in the cam life and the ability of engines to meet new emissions regulations.

Silicon carbide is used as a water pump seal in light- and heavy-duty diesel engines. Damage to a diesel engine is usually caused by a breakdown of the system, with resultant overheating of the engine and oil system, so the water pump is a critical component. The point where the pump shaft passes through the pump casing is sealed with a mechanical seal that is the pump's critical component.

The seal ring must satisfy a wide range of requirements. It must be resistant to wear and corrosion by the coolant and must be rigid at the high temperatures in the seal assembly. Therefore, the material must have a high modulus and high thermal conductivity to dissipate heat. It has been shown that seal rings made with silicon carbide extend engine service life, allowing engine manufacturers to extend water pump and engine warranties.

Bearings

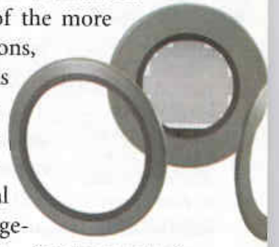
Hybrid bearings containing silicon nitride ceramic rolling elements and steel races have been commercially available since the early 1990s. Bearings are used in a number of niche applications, such as dental drills that must operate at high speeds without lubrication while withstanding high temperatures and the moist atmosphere of steam sterilization. Other applications include turbo molecular vacuum pumps that are used for clean room processing and must run lubrication-free machine tool spindles that are stiffer than conventional bearings, and electric motors in which silicon nitride acts as an electrical insulator.

Silicon nitride is key to the hybrid bearing because of its high compressive strength, superior contact fatigue resistance compared to bearing steels, electrical resistivity and low coefficient of friction vs. bearing steel. These properties allow hybrid bearings to operate with reduced or no lubrication, at higher stress levels or higher speeds, and under conditions that are not favorable to steel bearings (e.g., in electric motors or under magnetic fields). Hybrid bearings can be smaller than steel bearings for the same application, and they operate with reduced audible noise levels.

Hybrid bearings containing silicon nitride ceramic rolling elements and seal races are used in a number of niche applications.

Electronics

Aluminum oxide is the material of choice for most electronic applications, including substrates for electronic packages and electrical insulators. Alumina is an electrical insulator with good dielectric strength, but it also has a relatively poor thermal conductivity. In many of the more advanced applications, aluminum nitride is replacing aluminum oxide because of its high thermal conductivity, which is ideal when thermal management and heat dissipation are required.



Ceramics are used to line semiconductor wafer processing chambers and as tooling to hold the silicon wafers during processing.

A more severe application requiring the extensive use of ceramic material is semiconductor wafer processing. In this application, chlorine and fluorine gases in the form of plasmas are used to create complex electric circuits on silicon wafers. Ceramics, because of their chemical resistivity to corrosive environments, are used to line wafer-processing chambers and as tooling to hold the silicon wafers during processing.

The ceramics used in semiconductor processing applications include quartz, aluminum oxide, silicon carbide, silicon nitride, aluminum nitride and yttrium oxide. These ceramic materials must be specifically formulated to operate in the wafer-processing environment, since corrosive wear and particle generation must be kept to an absolute minimum to produce high wafer yields.