Applications of Advanced Ceramics and Ceramic Matrix Composites: A Perspective

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Abstract: *Advanced ceramics have the properties of high hardness, hardness retention at high temperature, corrosion resistance and good wear resistance. Reinforcements by fibers, whiskers or particles of materials like C,SiC and TiC give them the added advantage of high toughness. These materials can be used where there is a requirement to maintain hardness at elevated temperatures and in the situations involving high abrasion. This paper provides a perspective of various applications of ceramics and ceramic matrix composites. The role of these materials is expected to enhance substantially in future with advent of more sophisticated technologies in different spheres of engineering industry.*

Keywords—*ceramics, ceramic matrix composites, applications, corrosion resistance, wear resistance*

I. INTRODUCTION

Ceramics are inorganic non-metal solids with bonding between atoms of ionic and covalent nature. Advanced ceramics, also called engineering ceramics, are crystalline and are highly engineered i.e. grain size, shape phase distributions are closely controlled.

Advanced ceramics include oxides, carbides, borides, silicates and glass ceramics. Advanced ceramics have the properties of high strength and hardness, retention of hardness at elevated temperatures, good corrosion and wear resistance and enhanced chemical stability. These are used for components subjected to abrasion and high temperatures in their applications. The only undesirable property of advanced ceramics is their low toughness which renders them vulnerable under tensile and cyclic loads. Composites are made by providing reinforcements in the matrix in the form of long fibers, whiskers or small particles of materials like Carbon (C), Silicon Carbide (SiC) and Titanium Carbide (TiC). The composites can be of polymer matrix – Polymer Matrix composite (PMC), metal matrix (MMC) and Ceramic matrix (CMC). The added property of good toughness in composites in addition to the enhanced properties of ceramics make them useful in various high technology applications. Ceramics and ceramic matrix composites are used in advanced technology automobiles, aeronautics, rocket propulsion, turbine components, high temperature nozzle extensions and small thrust burners in space vehicles. These materials hold promise for future applications in more advanced technologies in space, aeronautics and engineering industries.

II. APPLICATIONS

A. *Aerospace*

Ceramics and Ceramic matrix composite (CMC) materials, due to their qualities of low specific weight and ability to withstanding high temperatures, thus reducing cooling requirements, are very useful in aerospace industry. Fig. 1 shows applications of CMC in structural and non-structural parts of aero-engines [1].

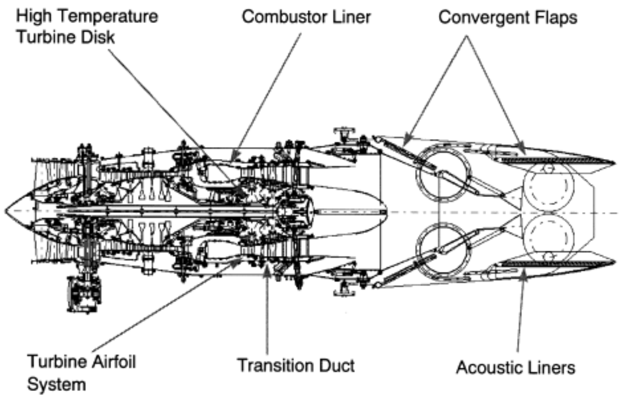

Fig. 1 : Applications of CMC in Aero-Engines (1)

3-D woven SiC polymer fibers in SiC matrix are used in nozzle flaps. Porous Al_2O_3 with up to 10% SiC whiskers are used for acoustic liners to reduce the noise level in exhaust nozzles. Other CMC materials used in aero-engine components are frame folders, transition ducts, heat seals and fasteners [1].

Jet vanes are used to divert the direction of thrust in solid fuel rockets of missiles. They are subjected to very high thermo-mechanical stresses. C/C-SiC composites coated with a ceramic surface protection such as CVD-SiC (CVD : Chemical Vapor Deposition) are used in advanced jet vanes [2].

The nose cap of X-38 planned for a new crew return vehicle for International space station (ISS) is regarded as the current stage of material development for thermal protection systems (TPS) of space-crafts. It is made of C/C-SiC composite made from fabric prepregs using autoclave technique [2]. Prepegs are made by reinforcing fabric which has been pre-impregnated with resin system.

Other items for which the ceramics and ceramic matrix composites are used are combustors, seals, turbine engine components, thermal protection systems and fuel systems and valves [3].

It was found that [4] C/SiC can withstand high wall temperature of about 2300 K and thermal gradients for highest heat flux measured with restricted shock separation. Nozzle extensions made of C/SiC are used in liquid propellant rocket engines. Use of C/SiC enhanced the application potential of Ceramic Matrix Composites (CMC) in combustion chambers for small thrusters. [4].

B. *Automobile*

Advanced ceramics are used in various automobile components such as silicon nitride fuel injector links, high pressure pumping plungers, fuel pump roller, check ball and priming plunger and zirconia injector metering in diesel engines [5]. Some of the applications of advanced ceramics are shown in Fig. 2.

Ceramic composite brakes were introduced in luxury cars in 2001. The trend is likely to continue with more and more applications with decreasing manufacturing costs [5].

Porsche company uses internally ventilated brakes in their different car models. This type of brake gives a

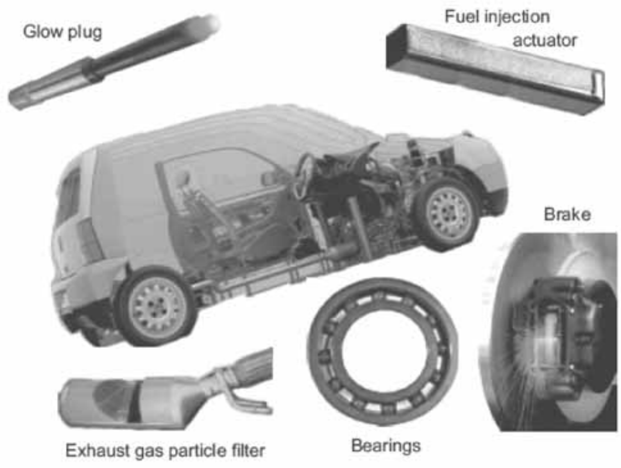

Fig. 2: Examples of Advanced Ceramic Components for Automobiles (5)

weight saving of up to 50% compared to conventional brake systems [2]. Porsche also offers a dual disc clutch. This clutch plate is made of Titanium with a lining of C/C-SiC and it can transmit a maximum torque of more than 1000 Nm [2].

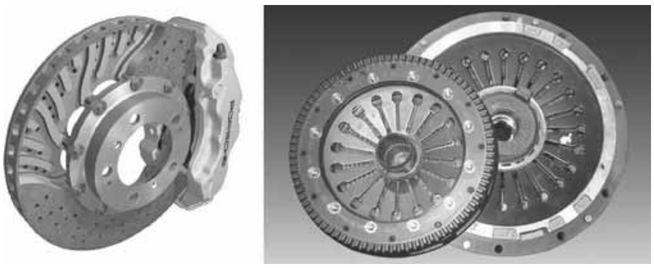

Fig. 3 : Porsche Ceramic Composite Brakes (left) and Porsche Ceramic Clutch (Right) (2)

Aluminum Nitride (AlN) based ceramics are used as fire-proof and chemically inert material, in high temperature applications and as spare parts in engines. Al_2O_3, SiC and ZrO_2 ceramics, being hard and thermally stable material, are used in high temperature technology applications for engine parts. [6].

Discs of car brakes, exploiting the properties of good wear resistance, good conduction and high strength, are made by Alcan Aluminum Limited from A359 aluminum alloy reinforced with 20% volume of SiC particles [7]. See fig. 4.

Other products are Top ring groove for piston for diesel engine (Toyota), Piston head of diesel engine (Izumi Industries), Piston Head of outboard engine (Suzuki), Bore surface of cylinder block (Honda) and

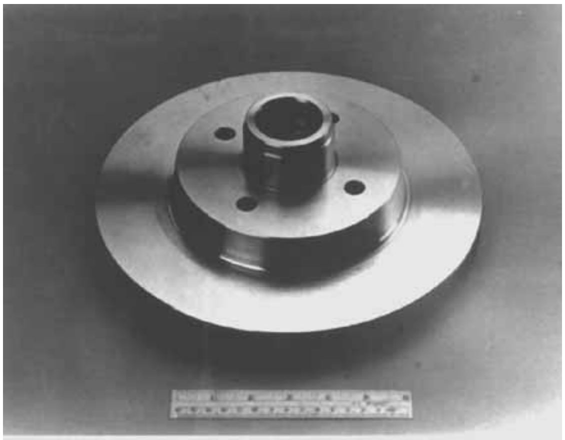

Fig. 4 : An Alcan brake disc of A359 Al alloy reinforced with 20 vol% of SiC particles (7)

Connecting rod (Honda), catalytic converters, fuel injection components and water pump seals. [3].

C. *Heat Exchangers*

The properties of ceramics which make them useful for heat exchangers are their ability to withstand extremely high operating temperatures, their excellent anticorrosive properties and economy in their use. Sintered SiC is used as heat plates in heat exchangers [8]. See fig. 5.

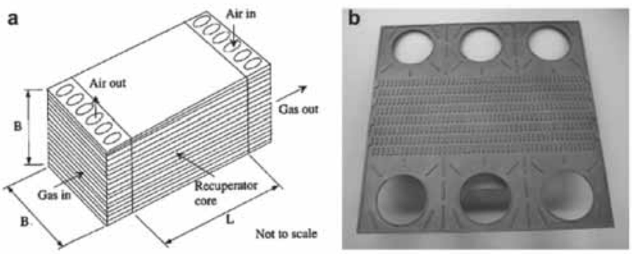

Fig. 5 : (a) Heat Exchanger Body and (b) A Sintered SiC gas plate (8)

Other uses of ceramics are heat sinks of SiC and heat pipe recuperators used to preheat combustion air with exhaust gases [8].

D. *Electronics*

Ceramics and ceramic matrix composites are also being used in electronics. Al_2O_3 and MgO ceramics are used as isolators in electronics. Stealite [$Mg_3Si_4O_{10}(OH)_2$] is used as high density ceramic and in high temperature technology. Aluminum Nitride is used in electronic circuits due to its properties of high thermal conductivity and electrical resistance [6]

TiO_2 based ceramics like Aluminium titanate (Al_2TiO_5) and pure SiO_2 with traces of Cr, Fe, Ni and Fe are used in electronics and optics. Y_2O_3 (Oxide of Yttrium) ceramics have high density. Additions of Th and Zr influence the porosity and density of Y_2O_3. These are also used in electronics [6].

E. *Gas Turbines*

Ceramic matrix composite (CMC) material was used in Japan in their automotive gas turbine project which was started in 1990 and successfully completed in 1997. Five components consisting of turbine rotor, back plate, orifice liner, extension liner and inner scroll support were developed as components of a CGT (Ceramic Gas Turbine) engine. The CMC (Composite Matrix Ceramic) materials were developed for this purpose [9]. The parts and materials used are shown in the Fig. 6 and Fig. 7.

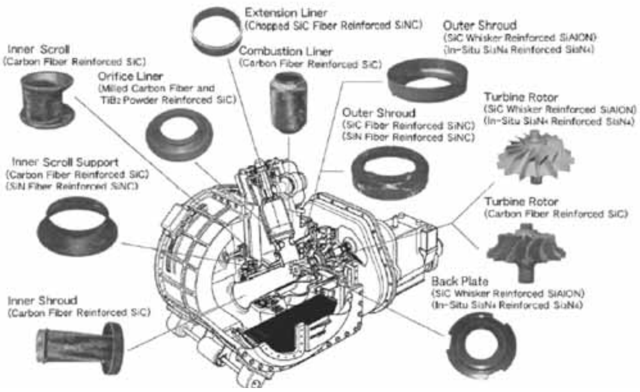

Fig. 6: Major CMC components for CGT (9)

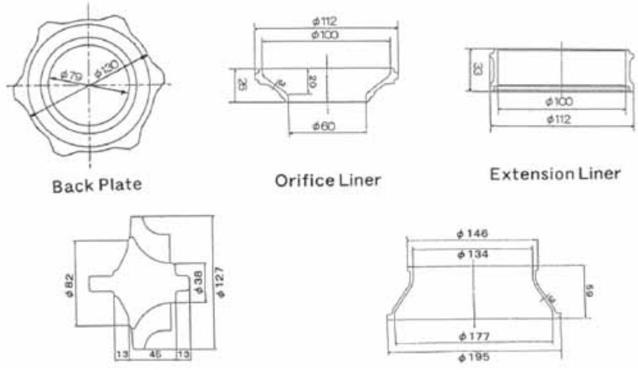

Fig. 7: Shapes of the CMC Components (9)

F. *Medical equipment*

Ceramics are used in medical devices like bone fillers, scaffolds for tissue engineering, dental transplants, total hip replacements and femoral heads (highest part of the thigh bone). Alumina (Al_2O_3) was patented in 1965 for hip joints [10]. We can define bioceramics as ceramic materials suitable for introduction into living tissue especially as part of a medical device. Bioceramics can be further categorized as bioinerts and bioactive. Bioinerts e.g. Alumina and Zirconia do not have direct bone-material interface and a soft tissue interlayer is always there between the bone and the implant. These are normally not used as bone fillers [10]. Bioactive materials have direct interface between the bone and the material. These materials provide favorable surfaces for bone adhesion and bone ingrowth [10] .

Ceramic materials are used in dentistry as these do not suffer corrosion and/or galvanic coupling like metals. Yttria-stabilised Zirconia (Y-TPZ) has been used widely in dental applications. [10]

Major application of ceramics in orthopedics is in total knee and hip replacement. Alumina (Al_2O_3) and Yttria-stabilised Zirconia (Y-TZP) have been used as structural ceramics in orthopedics. Si_3N_4 are under clinical trial for total hip arthroplasty [10].

Nano-structured calcium phosphate, processed using spark plasma sintering are used as bone substitutes. As an alternative to this, 4555 Bioglass (45 wt% SiO, 24.5 wt% CaO, 24.5 wt% Na_2O, 6 wt% P_2O_5) can be used. Bioglass is also used successfully as middle ear and dental transplant [10]. These nanostructured materials and alumina-zirconia composites can be used to develop new implant designs for (i) hip resurfacing implants requiring less invasive surgery and (ii) unicondyler knee component specially designed for minimally invasive surgery.

G. *Miscellaneous*

ZrO_2 ceramics are used as oxygen probe due to the fact that its electrical conductivity is influenced by the partial pressure of oxygen in the surrounding atmosphere [6].

BeO is used as substrate for integrated circuits and as moderator in nuclear reactors. CdO/Ag cermet (composite of ceramic and metal) is used in electrotechnics. Ferrites (MO-Fe_2O_3 with M = Mn, Ni, Zn, Co, Fe and Mg) are used as magnetoceramics.ThO_2 is used as electrical insulator and also as nuclear fuel. [6].

Other uses of advanced ceramics are laser diode and LED in optical industry, flow control valves in oil industry, artificial teeth, bones, joints and heart valves in biochemical industry, nuclear fuel cladding, moderating materials and reactor lining in nuclear industry, multilayer capacitors, resistance heating elements in electrical industry and Filters, Fuel cells (solid oxides), bearings in electric power generation [11].

III. CONCLUSION

Advanced ceramics and ceramic matrix composites are being more and more used in advanced technology products. Their usage in automobile fuel pumps, injectors and braking systems have been seen to be increasing. The extraordinary properties of these materials to withstand high temperatures have ensured their exploitation in rocket and missile propulsion systems and space vehicles. These materials have been found to be very useful in advanced braking systems due to their frictional properties. With the technological advancements taking place at a fast pace, the applications of ceramic matrix composites are expected to exhibit an exponential growth. The industries in the world in general and in India in particular have to be prepared for technological advancements in manufacturing and machining of these materials.

Composite materials used in electronic and computer industries and laser engineering applications can work efficiently at high temperatures and display higher efficiencies compared to conventional materials.

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