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Study of Fine Ceramics Materials : A Review

Introduction :

Fine Ceramics (also known as "advanced ceramics") are used to make components that require high levels of performance and reliability, such as advanced semiconductor packages and automotive engine parts. In fact, Fine Ceramics support the latest technologies in diverse applications throughout modern society. Do you know the history of Fine Ceramics? They share common origins with the conventional ceramics that we use every day, like tableware, vases, pottery and other household items.
The history of ceramics begins with earthenware. Thousands of years ago, humans learned how to make earthenware vessels by kneading, forming and firing clay. Prior to this discovery, the only other man-made items were stone tools made by chipping rocks. In this sense, earthenware could be called "the root of all industrial products." After the Stone Age, countless advancements were made over the millennia before Fine Ceramics appeared as we know them today.

The Era of Electro Ceramics

The 20th century brought the advent of electronics, with the start of radio and television broadcasts and the invention of the transistor. This era was facilitated by ceramics from the beginning, when large vacuum tubes of the early 20th century relied on ceramic materials. Within wireless equipment, only ceramics possessed the properties necessary to provide high signal output even over high frequency ranges. Ceramics could not be replaced with other materials.

Ceramics have benefited from significant advances in material composition as well. In addition to natural raw materials, artficially synthesized raw materials are now commonplace. *Metallization* and other technologies to permit stronger ceramic-to-metal bonding were developed. During this period, ceramics rapidly grew closer to today's Fine Ceramics.

Semiconductors, the core component of the electronics era, have also been supported by ceramics. Transistors and integrated circuits (ICs) were developed in U.S. laboratories shortly after the Second World War. However, because they were extremely sensitive to external moisture and strong light, these early transistors and ICs were not immediately available for practical use. Fortunately, ceramic packages were able to shut out external moisture and light while maintaining the electrical performance of transistors and ICs. It is no exaggeration to say that the semiconductor revolution was launched in these packages.

In addition, ceramics have helped to reduce the size of capacitors and inductors in electronics. Since the middle of the 20th century, ceramics have undergone a continual evolution, and now possess excellent dieletric and magnetic properties. As a result, electronic components were miniaturized and made highly functional. Ceramics thus made a significant contribution to the downsizing of electronic equipment. If capacitors had not been made of ceramics, the portable electronic devices we depend on every day, such as pocket-sized mobile phones and laptop computers, would never have appeared. In fact, a modern mobile phone uses more than 200 ceramic capacitors. Fine Ceramics were born in this era as highly precise industrial materials made through tightly controlled processes from refined or synthetic raw powders, thus differentiating them from all conventionally fired products.

Fine Ceramics as the New Material "Standard-Bearer"

Fine Ceramics can be made to posses a wide variety of unique characteristics through variations in raw materials, synthesizing methods and production processes. Consequently, they have become the standard for new materials in countless fields of advanced technology. Because of their light weight, rigidity, physical stability and chemical resistance, large ceramic components several meters in size are now used in equipment for manufacturing semiconductors and liquid crystal displays. In addition, their high reliability and successful integration with metals allows them to be used in a growing range of automotive components.

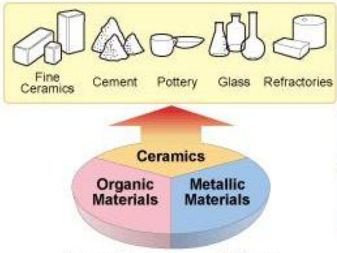
With their dielectric and piezoelectric properties, Fine Ceramics serve as base materials for many essential electronic components, including compact, highly efficient capacitors, filters, and resonators. They perform key roles in various other industries as well. For example, their chemical inertness is very useful in the heavy chemical industry, while their abrasion resistance is valued in textile manufacturing. Beyond industrial applications, Fine Ceramics are increasingly used in the everyday goods we depend on, such as knives, pens, jewellery, decorative items and even medical and dental implants — all of which make use of the unique material characteristics of Fine Ceramics.

What are Fine ceramics ?

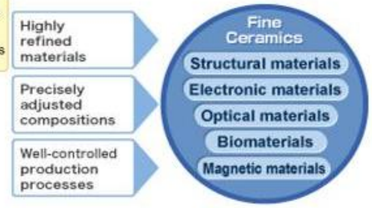
The English word *ceramics* is derived from the Greek word *keramos*, which means "burned clay." The term originally referred to china almost exclusively. Nowadays, however, we often refer to non-metallic, inorganic substances such as refractories, glass and cements as ceramics. For this reason, ceramics are now regarded as "non-metallic, inorganic substances that are manufactured through a process of moulding or shaping and exposure to high temperatures."

Among ceramics, porcelains are used in electronics and other high-tech industries, so they must meet highly precise specifications and demanding performance requirements. Today, they are called Fine Ceramics (also known as "advanced ceramics")*to distinguish them from conventional ceramics made from natural materials, such as clay and silica rock. Fine Ceramics are carefully engineered materials in which the chemical composition has been precisely adjusted using refined or synthesized raw powder, with a well-controlled method of forming and sintering.

Also, according to ISO** 20507 ("Fine ceramics - Vocabulary") and JIS*** R 1600, Fine Ceramics are "produced with precisely controlled chemical compositions, micro structures, configurations and production processes to fulfil intended functions and which are composed mainly of non-metallic, inorganic substances."



Ceramics are one of three major industrial materials



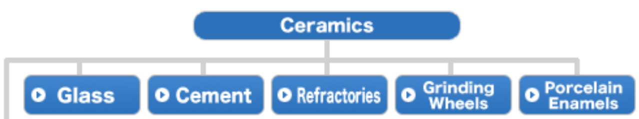
Basic Concept of Fine Ceramics

The Pioneer of "Fine Ceramics (also known as "advanced ceramics")"

The term "Fine Ceramics" came into common use in the 1970s. Kyocera Corporation, founded as Kyoto Ceramic Co., Ltd., has primarily manufactured ceramics for the electronics industry since its inception in 1959. Founder Dr. Kazuo Inamori has maintained that "unlike conventional ceramics, Fine Ceramics possess high added-value in industrial applications. Their value should not be assessed by volume and they must be'fine' physically and structurally." He was therefore the first person to use the term "Fine Ceramics" in the contemporary sense.

Ceramics Vs. Fine Ceramics :

- Ceramic materials exhibit hardness, excellent heat and corrosion resistance, and electrical insulation properties. Typical examples include china, firebricks, cements and glass.
- In addition to these properties, Fine Ceramics (also known as "advanced ceramics") have many advanced mechanical, electrical, electronic, magnetic, optical, chemical and biochemical characteristics. Today, Fine Ceramics have many roles in fields such as semiconductors, automobiles, telecommunications, industrial machinery and healthcare.
- The physical differences between ceramics and Fine Ceramics mainly arise from their raw materials and manufacturing processes. Ceramics are manufactured by mixing, shaping and firing natural minerals including pottery stones, feldspar and clay. In contrast, Fine Ceramics are manufactured using highly purified natural raw materials, artificial raw materials synthesized through chemical processes and other non-naturally occurring compounds. Through a series of precisely controlled, complex processes such as forming, machining, firing and grinding, these compounded raw materials turn into high-value-added products with excellent dimensional accuracy and functional characteristics



Details of Fine ceramics :

Engineered materials with chemical compositions that are precisely adjusted using refined or synthesized raw powders and well-controlled methods of forming, sintering and processing. With higher levels of functionality compared to conventional ceramics, they are widely used in fields such as semiconductors, automobiles and industrial machinery. Fine Ceramics are also called new ceramics or advanced ceramics.

Raw Materials	Chemical Formulae		
Barium Titanate	$BaTiO_3$	Oxide materials	Functional materials
Lead Zirconate Titanate	$Pb(Zr,Ti)O_3$		
Ferrite	$M^{2+}O \cdot Fe_2O_3$		
Alumina	Al_2O_3		Structural materials
Forsterite	$2MgO \cdot SiO_2$		
Zirconia	ZrO_2		
Zircon	$ZrO_2 \cdot SiO_2$		
Mullite	$3Al_2O_3 \cdot 2IO_2$		
Steatite	$MgO \cdot SiO_2$		
Cordierite	$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$		
Aluminum Nitride	AIN	Non-oxide materials	Functional materials
Silicon Nitride	Si_3N_4		Structural materials
Silicon Carbide	SiC		

Types and uses of fine Ceramics :

Barium Titanate

$BaTiO_3$

Barium titanate is used for capacitors due to its high dielectric constant and superiority in storing electricity. Additives can drastically change its dielectric properties.

Lead Zirconate Titanate

$Pb(Zr,Ti)O_3$

A piezoelectric material vibrates when electrical signals are applied, and also converts vibration into electrical signals.Lead zirconate titanate offers strong piezoelectric properties for electronic component applications, such as resonators, buzzers and filters.

Ferrite

$M^{2+}O \cdot Fe_2O_3$

This magnetic ceramic exhibits high permeability, electrical resistance and abrasion resistance. It is widely used in magnetic heads and magnetic cores for high frequency electronics.

Alumina

Al_2O_3

Alumina epitomizes Fine Ceramics and is the most widely utilized. It offers superior mechanical strength, electrical insulation, high frequency retention, thermal conductivity, heat resistance and corrosion resistance. Sapphire is a single-crystal form of alumina.

Forsterite

$2MgO \cdot SiO_2$

Characterized by low microwave loss, superior high temperature insulating properties and a smooth surface, fosterite is suitable for use in electron tubes and circuit boards.

In addition, its high coefficient of thermal expansion is close to that of metals and glass, allowing forsterite to be joined or bonded to these materials reliably.

Zirconia

ZrO_2

Zirconia is the strongest and toughest material among Fine Ceramics. It is used to create special blades for high-performance scissors and knives, once considered impossible applications.

Single-crystal zirconia is also used in decorative applications and jewellery due to its high refractive index, which produces a diamond-like brilliance.

Zircon

$ZrO_2 \cdot SiO_2$

With a low coefficient of thermal expansion and superior thermal shock resistance, this material is used for heat-resistant components, wire-wound resistive bobbins and electron tube components.

Mullite

$3Al_2O_3 \cdot 2iO_2$

Mullite offers heat resistance, thermal shock resistance and excellent resistance to the structural fatigue mechanism known as "creep." It also displays a coefficient of thermal expansion similar to silicon semiconductor chips, making it useful in semiconductor package applications.

Steatite

$MgO \cdot SiO_2$

This material offers electrical and mechanical properties superior to conventional porcelains, and excellent machinability.

Cordierite

$2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$

Low thermal expansion gives cordierite superior thermal shock resistance. Due to its porous properties, it is used for honeycomb carriers as well as refractories for electric heaters and industrial chemical equipment materials.

Aluminum Nitride

AlN

With excellent thermal conductivity, aluminum nitride is used in applications that require heat dissipation, such as semiconductor packages.

Silicon Nitride

Si_3N_4

Among Fine Ceramics, this lightweight, corrossion resistant material offers the highest level of toughness and thermal shock resistance at high temperatures, making it ideal for use in engine components

Silicon Carbide

SiC

This artificial compound is synthesized from silica sand and carbon. It provides the best combination of heat resistance, light weight and corrosion resistance, and maintains its strength at high temperatures (1,500oC / 2,732oF).

Properties of some common ceramics are indicated in the table below:

TABLE NO-1

Material	Specific Gravity	Coefficient of Linear Expansion *(106 ppm/oC)*	Maximum Safe Operating Temperature *(oC)*	Thermal Conductivity *(10-3 cal/cm2/ cm/sec/oC)*	Tensile Strength *(psi)*	Compressive Strength *(psi)**	Flexural Strength *(psi)*	Modulus of Elasticity *(106 psi)*
Porcelain	2.2-2.4	5.0-6.5	400	4-5	1500-2500	25000-50000	3500-6000	7-10
Alumina Porcelain	3.1-3.9	5.5-8.1	1350-1500	7-50	8000-30000	8000-25000	20000-45000	15-52
High-Voltage Porcelain	2.3-25.5	5.0-6.8	1000	2-5	3000-8000	25000-50000	9000-15000	7-14
Zirconia Porcelain	3.5-3.8	3.5-5.5	1000-1200	10-15	10000-15000	80000-150000	20000-35000	20-30
Lithia Porcelain	2.3-4	1	1000			60000	8000	
Cordierite Refractory	1.6-2.1	2.5-3.0	1250	3-4	1000-3500	20000-45000	1500-7000	2-5
Alumina Silicate Refractory	2.2-2.4	5.0-7.0	1300-1700	4-5	700-3000	13000-60000	1500-6000	2-5
Magnesium Silicate	2.3-2.8	11.5	1200	3-5	2500	20000-30000	7000-9000	4-5
Steatite	2.5-2.7	8.6-10.5	1000-1100	5-6	8000-10000	65000-130000	16000-24000	13-15
Forsterite	2.7-2.9	11	1000-1100	5-10	8000-10000	60000-100000	18000-20000	13-15
Titania/Titanate Ceramics	3.5-5.5	7-10		8-10	4000-10000	40000-120000	10000-22000	0.3-0.5

**1 psi (lb/in2) = 6,894.8 Pa (N/m2)*

Conclusion:

From Table-1 we can select the ceramics materials as per our requirement and need of our application

- Porcelain is a ceramic material made by heating selected and refined materials often including clay in the form of kaolinite to high temperatures.
- Cordierite is a crystalline magnesium aluminosilicate
- Steatite, also known as soapstone or soaprock, is a metamorphic rock, a talc-schist.It is largely composed of the mineral talc and is rich in magnesium.
- Forsterite (Mg_2SiO_4)is the magnesium rich end-member of the olivine solid-solution series.

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