CHAPTER FIVE

ORGANIC AND IN- ORGANIC MATERIALS

5.1 ORGANIC MATERIALS

An **organic compound** is one that has carbon as the principal element. Organic compounds are composed of hundreds to thousands of individual molecules. The single molecules in a polymer are called **monomers.**

The long molecules formed by repeating patterns of monomers are called **polymers.**

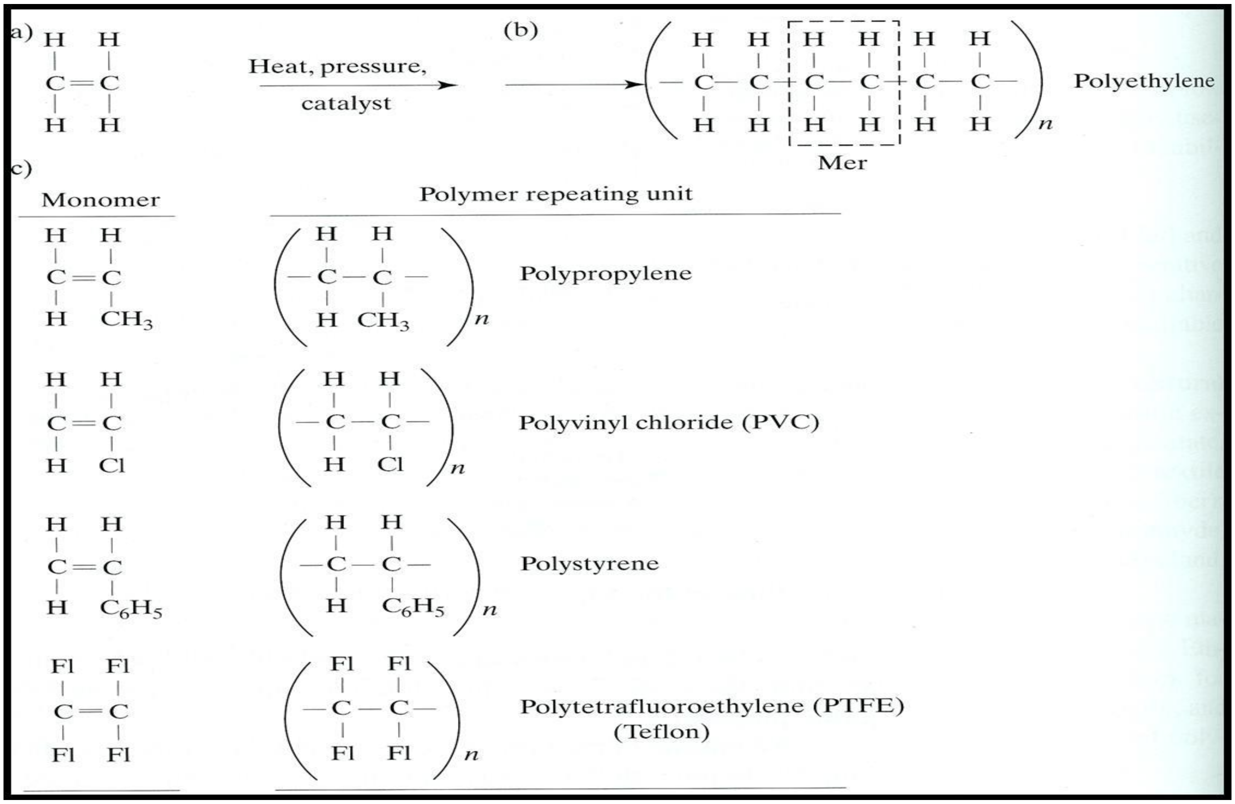


Figure: The structure of polymers

5.1.1 PLASTICS

Plastics, **also known as polymers**, are generally organic compounds based upon **carbon** and **hydrogen.** They are very large molecular structures. Usually they are low density and are not stable at high temperatures.

The word plastics are from the Greek word ***Plastikos***, meaning **"able to be shaped and molded".**

Plastics are moldable organic resins. These are either natural or synthetic, and are processed by forming or molding into shapes. Plastics are important engineering materials for many reasons. They have a wide range of properties, some of which are unattainable from any other materials, and in most cases they are relatively **low in cost.**

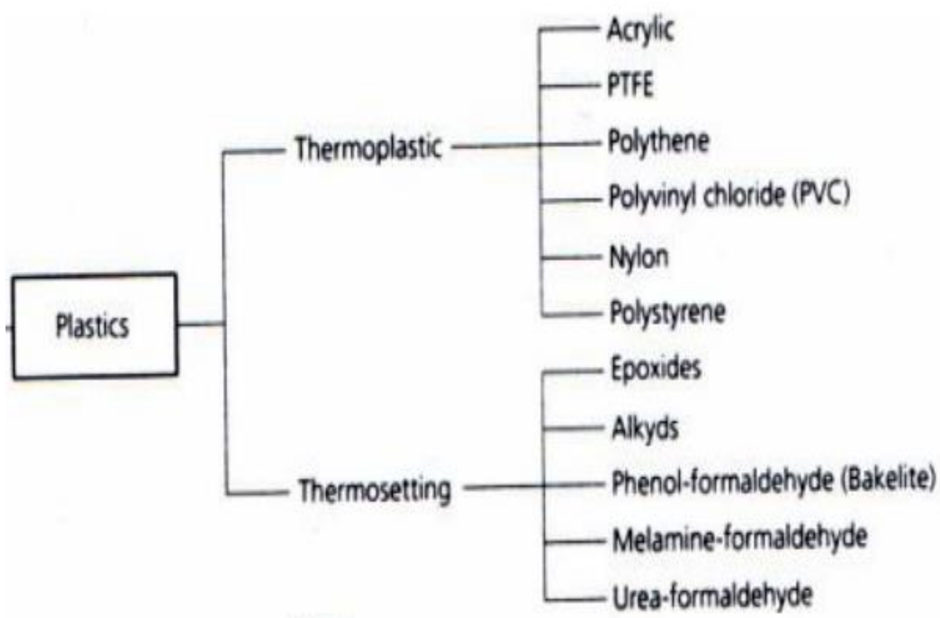
5.1.1.1 PROPERTIES OF PLASTICS

The following is the brief list of properties of plastics: light weight, wide range of colors, low thermal and electrical conductivity, less brittle, good toughness, good resistance to acids, bases and moisture, high dielectric strength (use in electrical insulation), etc.

- Plastic are **easily formed** materials.
- The advantage to the manufacturer is that plastic products can be **mass-produced** and require **less skilled staff**.
- Plastics require little or **no finishing**, painting, polishing etc. Plastic is referred to as a **self-finishing material**. Particular finishes can be achieved at relatively low cost.
- Plastics can be easily printed, decorated or painted.
- Plastics are **corrosion resistant**, and **generally waterproof** although certain types of plastics such as UPVC can become brittle and it is possible for the sun's rays to cause the colour of the plastic to fade. It becomes bleached.
- Plastics are **lighter than metals**, giving **deeper sections** for a given weight, and hence **stronger sections**.

5.1.1.2 CLASSIFICATION OF PLASTICS

Plastics are classified in two groups depending on their mechanical and thermal behavior as **thermoplasts**(thermoplastic polymers) and **thermosets**(thermosetting polymers).



a) Thermoplastics:

These plastics soften when heated and harden when cooled – processes that are totally reversible and may be repeated. Thermoplastics are reversible in phase by heating and cooling. It is Solid phase at room temperature and liquid phase at elevated temperature.

They are linear polymers without any cross-linking in structure where long molecular chains are bonded to each other by secondary bonds and/or inter-wined. They have the property of increasing plasticity with increasing temperature which breaks the secondary bonds between individual chains.

Common thermoplasts are: acrylics, PVC, nylons, polypropylene, polystyrene, polymethyl methacrylate (plastic lenses or Perspex), etc.

b) Thermosets:

These plastics require heat and pressureto mold them into shape. They are **formed into a permanent shape** and cured or 'set' by chemical reactions such as extensivecross-linking. It is ***irreversible in phase by heating and cooling.***

They cannot be re-melted or reformed into another shape but decompose upon being heated to too high a temperature. Thus thermosets cannot be recycled, whereas thermoplasts can be recycled. The term thermoset implies that heat is required to permanently set the plastic. Most thermosets ***composed of long chains that are strongly cross-linked*** (and/or covalently bonded) to one another to form 3-D network structures to form a rigid solid. Thermosets are generally stronger, but more brittlethan thermoplasts.

Thermoset plastics are categorized into phenolic resins, amino resins, polyester resins, silicon resins, epoxy resins, and polyurethanes.

5.1.1.3 CHARACTERISTICS AND TYPICAL APPLICATIONS OF FEW PLASTIC MATERIALS

Advantages of thermosets for engineering design applications includeone or more of the following: high thermal stability, high dimensional stability, high rigidity, light weight, high electrical and thermal insulating properties and resistance to creep and deformation under load.

A) THERMO - PLASTICS

1. Acrylics (poly-methyl-methacrylate)

Characteristics: Outstanding light transmission and resistance to weathering; only fair mechanical properties.

Application: Lenses, transparent aircraft enclosures, drafting equipment, outdoor signs

2. Fluorocarbons (PTFE or TFE)

Characteristics: Chemically inert in almost all environments, excellent electrical properties; low coefficient of friction; may be used to 260^{o}C; relatively weak and poor cold-flow properties.

Application: Anticorrosive seals, chemical pipes and valves, bearings, anti- adhesive coatings, high temperature electronic parts.

3. Polyamides (nylons)

Nylon is hard, tough; self-lubricating has a high melting point and has very good resistance to wear and tear.It has been used to make clothing, bearings and propellers.

Nylon is used in clothes, shoes, jackets, belts, and accessories. It's not surprising a magazine is named after this polymer. Where did nylon get its name?

Nylon was discovered in 1935. The name nylon is derived from two cities where it was discovered namely New York (NY) and London (LON).

Characteristics: Good mechanical strength, abrasion resistance, and toughness; low coefficient of friction; absorbs water and some other liquids.

Application:Bearings, gears, cams, bushings, handles, and jacketing for wires and cables.

Fig: Automotive tire

4. Polypropylene

It is used for bottles, buckets, jugs, containers, toys, even synthetic lumber, and many other things.

Characteristics:Resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light.

Application:Sterilizable bottles, packaging film, TV cabinets, luggage

Low density polyethylene is used to make plastic bags, plastic wrap, and squeeze bottles, plus many other things.

5. Polystyrene

Characteristics: Excellent electrical properties and optical clarity; good thermal and dimensional stability; relatively inexpensive

Application: Wall tile, battery cases, toys, indoor lighting panels, appliance housings.


Figure: application of polystyrene

6. PVC

Polyvinyl chloride (PVC, commonly called "vinyl") incorporates chlorine atoms. The C-Cl bonds in the backbone are hydrophobic and resist oxidation (and burning). PVC is stiff, strong, heat and weather resistant, properties that recommend its use in devices for plumbing, gutters, house siding, enclosures for computers and other electronics gear. PVC can also be softened with chemical processing, and in this form it is now used for shrink-wrap, food packaging, and rain gear.

The rigid type is used to make pipes, guttering and roofing. It is very lightweight and is resistant to acids and alkalis.

The plasticised type is used for suitcases, hosepipes, electrical wiring and floor coverings.

Figure: Application of PVC (Plumbing U-bend)

B) THERMO SETTING POLYMERS

1. Epoxies

Epoxy is used widely in numerous formulations and forms in the aircraft-aerospace industry. It is called "the work horse of modern day composites". This is not only used in aircraft-aerospace demand. It is used in military and commercial applications and is also used in construction. Epoxy-reinforced concrete and glass-reinforced and carbon-reinforced epoxy structures are used in building and bridge structures.

Characteristics: Excellent combination of mechanical properties and corrosion resistance; dimensionally stable; good adhesion; relatively inexpensive; good electrical properties.

Application: Electrical moldings, sinks, adhesives, protective coatings, used with fiberglass laminates.

2. Phenolic

This polymer was developed by man back in the late 19th century. Phenolic was the first truly synthetic polymer and it is often referred to as the "workhorse of thermosetting (T.S.) resins". A heat-cured T.S. resin has overall excellent properties, particularly dimensional stability, elevated temperature, creep resistance and applications requiring heat resistance.

General purpose molding compounds, engineering molding compounds and sheet molding compounds are the primary forms of phenolic. Phenolic is also used in some Honeycomb core (H/C) as the matrix binder. This Phenolic is used in many electrical applications such as breaker boxes, brake lining material and even, recently, combined with various reinforcements in the molding of an engine block-head assembly, called the polimotor. Phenolics may be processed by the various common techniques, including compression, transfer and injection molding.

Characteristics: Excellent thermal stability to over 150ºC; may be compounded with a large number of resins, fillers, etc.; in-expensive.

Application: Motor housing, telephones, auto distributors, electrical fixtures.

Advantages and Disadvantages of thermoset polymers

Advantages

- Well established processing and application history
- Overall, better economics than thermoplastic (T.P.) polymers
- Better high temperature (H/T) properties
- Good wetting and adhesion to reinforcement

Disadvantages

- Resins and composite materials must be refrigerated

- Long process cycles
- Reduced impact –toughness
- Poor recycling capabilities
- More difficult repair ability

5.3.4 Disadvantages of using Plastics

- Low strength
- Low useful temperature range (up to 600 ^oF)
- Less dimensional stability over period of time (creep effect)
- Aging effect, hardens and become brittle over time
- Sensitive to environment, moisture and chemicals
- Poor machinability

5.2 IN - ORGANIC NON- METALLIC MATERIALS

An **in-organic element** is any compound that is not an organic compound. Ceramics are defined as a class of in-organic, non-metallic solids that are subjected to high temperature in manufacture and/or use. The most common ceramics are composed of oxides, carbides, and nitrides. Silicides, borides, phosphides, tellurides, and selenides also are used to produce ceramics.

Ceramic processing generally involves high temperatures, and the resulting materials are heat resistant or refractory.

- Ceramics are **compounds** between **metallic** and **nonmetallic** elements; they are most frequently oxides, nitrides, and carbides
- Traditional ceramics -> clay minerals (i.e., porcelain), as well as cement, and glass
- Common (non-traditional) ceramics -> alumina, silica, silicon carbide, silicon nitride

Ceramics are compounds of **metallic and non-metallic elements**, examples include;

- ✓ **Oxides (alumina** – insulation and abrasives, zirconia – dies for metal extrusion and abrasives).

- ✓ **Carbides** (tungsten-carbide tools).
- ✓ **Nitrides** (cubic boron nitride, 2nd in hardness to diamond).

5.2.1 PROPERTIES OF CERAMICS

- Always composed of more than one element (e.g.,Al2O3, NaCl, SiC, SiO2)
- Generally hard and brittle
- Generally electrical and thermal insulators
- Traditional ceramics – based on clay (china, bricks,tiles, porcelain), glasses.
- Relatively stiff and strong—**stiffness's** and **strengths** are comparable to those of the metals
- Moreresistant to high temperatures and harsh environments than metals and polymers.
- Ceramics may be transparent, translucent, or opaque
- some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior

5.2.2. APPLICATION OF CERAMICS

- The compressive strength is typically ten times the tensile strength. This makes ceramics good structural materials under compression (e.g., bricks in houses, stone blocks in the pyramids).
- Silicate Glasses - non-crystalline silicates (SiO2) containing other oxides (CaO, Na2, K2O, A2O3). Silicate Glasses used for Containers, windows, lenses, fiberglass, etc.
- The compressive strength is typically ten times the tensile strength. In structures, designs must be done for compressive loads.
- The transparency to light of many ceramics Þ optical
- applications (windows, photographic cameras, telescopes, etc)
- Good thermal insulation Þ use in ovens, the exterior tiles of the Shuttle orbiter, etc.
- Good electrical isolation Þ ceramics are used to support conductors in electrical and electronic applications.
- Good chemical inertness Þ applications in reactive environments.

1. **PROPERTIES AND APPLICATIONS OF ALUMINA (AL_2O_3)**

Alumina can be produced in a range of purities with additives designed to enhance properties. A wide variety of ceramic processing methods can be applied including machining or net shape forming to produce a wide variety of sizes and shapes of component. In addition it can be readily joined to metals or other ceramics using metalizing and brazing techniques.

Alumina based ceramics are by far the largest range of advanced ceramics made by Morgan Technical Ceramics. Due to the important combination of properties, we have thoroughly researched the behavior and characteristics of our Alumina products to give you the best possible component.

Typical Alumina characteristics include:

- ✓ Good strength and stiffness
- ✓ Good hardness and wear resistance
- ✓ Good corrosion resistance
- ✓ Good thermal stability
- ✓ Excellent dielectric properties (from DC to GHz frequencies)
- ✓ Low dielectric constant
- ✓ Low loss tangent

Typical Alumina applications include:

- ✓ Laser tubes
- ✓ Electronic substrates
- ✓ Thermocouple tubes
- ✓ Electrical insulators
- ✓ Grinding media
- ✓ Wear components

2. PROPERTIES AND APPLICATIONS OF SILICON CARBIDE (SIC)

Silicon carbide is a hard covalently bonded material predominantly produced by the carbo-thermal reduction of silica (typically using the Acheson process). Depending on the exact reaction conditions the resulting silicon carbide is either a fine powder or a bonded mass that requires crushing and milling to produce a usable feedstock.

The outline properties of Silicon Carbide are that it is a refractory material (high melting point), it has excellent thermal conductivity and low thermal expansion, and consequently it displays good thermal shock resistance. In addition, the high hardness, corrosion resistance and stiffness lead to a wide range of applications where wear and corrosion resistance are primary performance requirements. Silicon carbide possesses interesting electrical properties due to its semiconductor characteristics, the resistance of different compositions varying by as much as seven orders of magnitude.

3. PROPERTIES AND APPLICATIONS OF SI_3N_4

Silicon nitride has better high temperature capabilities than most metals combining retention of high strength and creep resistance with oxidation resistance. In addition, its low thermal expansion coefficient gives good thermal shock resistance compared with most ceramic materials.

Key Properties

Applications exploit the following properties of silicon nitride:

- low density
- high temperature strength
- superior thermal shock resistance
- excellent wear resistance
- good fracture toughness
- mechanical fatigue and creep resistance
- good oxidation resistance

Applications

The material is used currently in niche market applications for example in reciprocating engine components and turbochargers, bearings, metal cutting and shaping tools and hot metal handling.

1. **Reciprocating Engine Components**

The largest market for silicon nitride components is in reciprocating (diesel and spark ignited) engines for combustion components and wear parts. Their development has been a more difficult and complex task than envisaged. Cost factors and the severe technological problems of mass producing complex ceramic components have limited growth, but the material has also met with design conservatism and concerns about the reliability of ceramic components.

Small dense sintered silicon nitride components are used in both automobile and truck engines for applications where stresses and temperatures are relatively low and the consequence of failure is not catastrophic.

2. **Bearings**

The wear resistance, low friction and high stiffness of fully dense silicon nitride improve the performance of high temperature un-lubricated roller and ball bearings. HPSN bearings have shown increased bearing life, better speed capability and greater corrosion resistance compared to conventional higher-density steel and hard metal bearings.

The vast majority of silicon nitride bearings are used in hybrid ball bearings (bearings with ceramic balls and steel races). Applications include machine tool spindles, vacuum pumps and Sterilizable and un-lubricated dental drills.

All ceramic bearings are used in applications where corrosion, electric or magnetic fields prohibit the use of metals. For example in tidal flow meters where seawater attack is a problem or electric field seekers.

3. Industrial Applications

There is a range of general industrial applications where the material properties can be exploited. Reaction bonded silicon nitride (RBSN) is often used in these cases as the operating conditions are less demanding than in the preceding applications.

Applications include:

- Non- automotive wear components are a growing market for silicon nitride. For example, fixtures to position and transfer metal parts during processes such as induction heating and resistance welding exploit the electrical insulation, wear resistance, low thermal conductivity and thermal shock resistance of the material.
- Spouts, nozzles, thermocouple sheaths and melting crucibles for handling molten aluminium, zinc, tin and lead alloys. The increasing requirement for controlled metal purity makes the use of metallic components less desirable.
- Arc welding nozzles are also a steady market for RBSN given the strength, electrical resistance and thermal shock resistance of the material
- Specialized kiln furniture with low thermal mass and high thermal shock resistance for use in firing components such as dental porcelain where repeated thermal cycling is required.

4. PROPERTIES AND APPLICATIONS OF PSZ

Zirconia (ZrO_2) may look like a an excellent engineering ceramic on paper due to its desirable physical properties such as extremely high melting temperature, high strength and fracture toughness. However the phase changes that it undergoes during sintering are deleterious to these properties and hence pure zirconia is not a useful engineering material.

In partially stabilized zirconias, similar additions are made, except, not enough to stabilize all of the material, hence the name “partially stabilized zirconia” or “PSZ”. These materials typically consist of two or more of the phases cubic, tetragonal and monoclinic.

Typical Properties of Partially Stabilized Zirconia

- ✓ Excellent fracture toughness
- ✓ Excellent wear resistance
- ✓ Excellent impact resistance
- ✓ Good resistance to thermal shock
- ✓ Good chemical resistance

- ✓ Good corrosion resistance

Applications of Partially Stabilized Zirconias

Typical application of PSZ materials include:

- ✓ Dies and tooling
- ✓ Knives, scissors and blades
- ✓ Wear resistant components including bearings and linings
- ✓ Pump parts
- ✓ Grinding media

Partially Stabilized Zirconia (PSZ) components are considerably more expansive than alumina and other oxide ceramics. However, PSZ components have unique properties such as extremely high fracture toughness, high thermal expansion, high flexural strength (MOR), and low thermal expansion. With a high fracture toughness and MOR, PSZ components resist crack propagation, are less brittle, and able to hold a sharp edge. The high thermal expansion of PSZ components makes it easier to join metal to steel due to a low thermal conductivity. PSZ components act as thermal insulators. Some typical applications are dental implants, knives, guides, and pump and valve components for abrasive solutions and slurries.

5. PROPERTIES AND APPLICATIONS OF SIALON

Sialons are ceramics based on the elements silicon (Si), aluminium (Al), oxygen (O) and nitrogen (N). They are solid solution of silicon nitride (Si_3N_4) and exist in three basic forms. Each form is iso-structural with one of the two common forms of silicon nitride, beta and alpha and with silicon oxynitride. The relationship between that of sialon and silicon nitride is similar to that between brass and pure copper. The later case, copper atoms are replaced by zinc to give a stronger alloy than the mother metal. In the case of sialon, there is substitution of silicon by aluminium with corresponding atomic replacement of nitrogen by oxygen, to satisfy valency requirements. The resulting 'solution' (sialon) has superior properties to the original pure solvent (silicon nitride).

Sialonceramics are a specialist class of high-temperature refractory materials, with high strength (including at high temperature), good thermal shock resistance and exceptional resistance to wetting or corrosion by molten non-ferrous metals, compared to other refractory materials such as, for example, alumina. A typical use is with handling of molten aluminium. They also are exceptionally corrosion resistant and hence are also used in the chemical industry. Sialons also have high wear resistance, low thermal expansion and good oxidation resistance up to above ~1000 °C.

The general formula is SiAlON.The SiAlONs were developed as a more economic alternative to hot pressed silicon nitride.

SiAlONs have a complex chemistry and should be thought of as a family of alloys with a wide range of properties. They are formed when silicon nitride (Si_3N_4), aluminium oxide (Al_2O_3) and aluminium nitride (AlN) are reacted together. The materials combine over a wide compositional range.

Fully dense polycrystalline bodies can be formed by pressureless sintering if sintering aids such as yttrium oxide are added to the compact. This innovation allows near net complex shaped components made at an economic cost. The most commonly used compositions at present are β-SiAlON and (α + β) SiAlONs, which contain a substantial excess of sintering aids. However, the field is still changing with compositions developing to suit specific applications.

Sialon exploit the following properties:

- ✓ low density,
- ✓ high strength
- ✓ superior thermal shock resistance,
- ✓ moderate wear resistance
- ✓ fracture toughness,
- ✓ mechanical fatigue and creep resistance,
- ✓ Oxidation resistance.

In pressureless sintered materials, the high temperature properties are limited by the glassy phases that form at grain boundaries during sintering. These materials are only suitable to long term use at temperatures of less than 1000°C.

Applications

As with other silicon nitride based ceramics, SiAlONs are used currently in niche market applications for example in:

1. **Cutting Tools**

The hot hardness, fracture toughness and thermal shock resistance of fully dense SiAlON makes it well suited to use in cutting tools. The material is an attractive low cost alternative to hot pressed silicon nitride for machining grey cast iron for automotive applications. The material gives both increased metal removal rate and longer tool life compared with conventional cutting tools.

SiAlONs have also replaced cemented carbide tools when machining nickel based super alloys. These alloys are used for their heat resistance or in aerospace applications and are notoriously difficult to machine.

Pressureless sintered SiAlON can also increase tool life by up to 10 times in comparison with silicon nitride tools when machining these alloys.

2. Wear Components

Wear components exploit the electrical insulation, low thermal conductivity, and wear and thermal shock resistance of the material. Representative wear applications are fixtures for positioning and transferring metal parts during processes such as induction heating or resistance welding (see figure 1). For example, SiAlON has been used to make location pins when resistance welding automotive components. The conventional hardened steel pin with an alumina sleeve lasted 8 hours, whilst the SiAlON pin lasted one year.

Figure: SiAlON wear guides (photo courtesy International Syalons Newcastle Ltd).

3. Metal Forming Tools

SiAlONs have been used in metal wire and tube drawing tools for non-ferrous metals such as copper and aluminium alloys. In general the hardness, low coefficient of friction and lack of adhesion and reaction have given good results. High levels of copper oxide in copper alloys must be avoided however, as it attacks the material and tolerance control is lost.

The end!!!