**Chapter No 6: FORMING OF CERAMICS**

1. **Introduction, Additives in ceramic forming**

In the forming of ceramics, the use of certain additives, sometimes in concentrations as low as a fraction of a percent by weight, is often vital for controlling the characteristics of the feed material, for achieving the desired shape, and for controlling the packing uniformity of the green body. In methods such as tape casting and injection molding, the selection of suitable additives forms one of the most vital parts of the forming process. The additives are either *organic* or *inorganic* in composition. Organic additives, which can be *synthetic* or *natural* in origin, find greater use in the forming of advanced ceramics because they can be removed almost completely (e.g., by pyrolysis) prior to the sintering step. Therefore the presence of residues that can degrade the microstructure of the final product is largely eliminated. Inorganic additives cannot generally be removed after the forming step and are used in applications, particularly in the traditional ceramics industry, where the residues do not have an adverse effect on the properties of the final product.

The additives serve a variety of specialized functions, which may be divided into four main categories:

(1) solvents,

(2) dispersants (also referred to as deflocculants),

(3) binders,

(4) plasticizers.

1. **Solvents:**

Liquids serve two major functions:

1. Provide fluidity for the powder during forming.

2. Serve as solvents for dissolving the additives to be incorporated into the powder, thereby providing a means for uniformly dispersing the additives throughout the powder.

The selection of a solvent involves basically a choice between water and an organic liquid. Organic solvents generally have higher vapor pressure, lower latent heat of vaporization, lower boiling point, and lower surface tension than water, due in a large part to the strong hydrogen bonding of the water molecules Several common organic solvents also have a lower viscosity than water. The actual choice of a liquid for a given application often involves the consideration of a combination of several properties from the following list:

1. The ability to dissolve other additives,
2. Evaporation rate,
3. Ability to wet the powder,
4. Viscosity,
5. Reactivity towards the powder,
6. Safety,
7. Cost.

Generally, solubility of the solid in the liquid is enhanced if the chemicals have similar functional groups or similar molecular polarity. Water has a relatively high viscosity, and its tendency to form hydrogen bonds with hydroxyl groups on the surfaces of oxide powders can often steepen the effect of particle concentration on the suspension viscosity. The result is often a reduction in the solids content of the suspension for the maximum usable viscosity when compared to the use of an organic solvent. Secondly, the surfaces of many powders can be chemically attacked by water, leading to a change in composition and properties while this doesn’t happens with organic solvents. Despite of these disadvantages water has a distinct advantage over organic solvents when safety, cost, and waste disposal are considered. Two main areas of safety are flammability and toxicity. Many organic liquids used in ceramic forming are toxic and flammable.

1. **Dispersants:**

Dispersants, also referred to as deflocculants, serve to stabilize a slurry against flocculation by increasing the repulsion between the particles. While normally used in very small concentrations (e.g., a fraction of a percent by weight), the dispersant plays a key role in maximizing the particle concentration for some usable viscosity of the slurry. Dispersants cover a wide range of chemical composition. Dispersants are divided into three main classes, based on their chemical structure, as follows:

1. Simple ions and molecules

2. Short chain polymers with a functional head (or end) group, commonly referred to as *surfactants*

3. Low to medium molecular weight polymers

1. **Binders:**

Binders are typically long chain polymers that serve the primary function of providing strength to the green body by forming bridges between the particles. In some forming methods (e.g., injection molding), they also provide plasticity to the feed material to aid the forming process. A large number of organic substances can be utilized as binders, some of which are soluble in water, while others are soluble in organic liquids. Some common *synthetic* binders include the vinyls, acrylics, and the ethylene oxides (glycols). The binder as well as the other additives used to aid the forming of the green body must normally be removed as completely as possible prior to sintering. The concentration of the binder is commonly much greater that of the other additives, so the burnout characteristics is of primary importance in the selection of the binder. If a dispersant is used in the forming process, then the binder should be compatible with it.

1. **Plasticizers:**

Plasticizers are generally organic substances with a lower molecular weight than the binder. The primary function of the plasticizer is to soften the binder in the dry state, thereby increasing the flexibility of the green body, especially utilized in tape casting. For forming processes in which the binder is introduced as a solution, the plasticizer must be soluble in the same liquid used to dissolve the binder. In the dry state, the binder and plasticizer are homogeneously mixed as a single substance. The plasticizer molecules get between the polymer chains of the binder, thereby disrupting the chain alignment and reducing the van der Waals bonding between adjacent chains. This leads to softening of the binder but also reduces the strength.

1. **Grain Growth and Coarsening**

*Grain growth* is the term used to describe the increase in the grain size of a single-phase solid or in the matrix grain size of a solid containing second-phase particles. Grain growth occurs in both dense and porous polycrystalline solids at sufficiently high temperatures. For the conservation of matter, the sum of the individual grain sizes must remain constant; so an increase in the average grain size is accompanied by the disappearance of some grains, usually the smaller ones. In porous solids, both the grains and the pores commonly increase in size while decreasing in number. Because of the considerable interaction between the grains and the pores, microstructural evolution is considerably more complex than for dense solids. Frequently, the term *coarsening* is used to describe the process of grain growth coupled with pore growth.

Grain growth in ceramics is generally divided into two types:

(1) Normal grain growth

(2) Abnormal grain growth, which is sometimes referred to as exaggerated grain growth, discontinuous grain growth