FACTORS AFFECTING THE TRIBOLOGICAL PROPERTIES OF ALUMINA

Characteristics of friction and wear of alumina are determined by the combination of its bulk microstructure parameters, surface quality and environmental factors and lubrication conditions.

3.1 Effect of microstructure

- **Grain size**

The main disadvantage of Ceramics as compared to Metals and Polymers is their low fracture toughness.
Toughness is a bulk mechanical property of a material however it correlates with its wear resistance particularly when the wear is a result of abrasive action caused by cracking.
Finer grain structure results in increased toughness and better wear resistance.
Grain size also determines the surface finish quality, which may be achieved by grinding and polishing operations.
Fine grain structure allows to decrease the size of the surface microasperities after the surface finish operation resulting in lower coefficient of friction.

- **Critical flaw size** (the size of a flaw that results in rapid fracture)

Effect of flaw size on the fracture strength of a ceramic material is expressed by the Griffith equation:
$\boldsymbol{\sigma_C = K_{IC} /(Y(\pi a)^{1/2})}$
where:
K_{IC} – stress-intensity factor, measured in MPa*m½;
a – the flaw size;
Y – geometry factor.
According to the equation flaws of lower size result in increased material toughness and higher wear resistance.
Flaw size is generally proportional to the grain size.

- **Homogeneity**

Homogeneous distribution of alumina particles size and pores size, second phase particles (toughening particles) incorporated between the matrix particles, aid phase (binders, etc.) locating at the grains boundaries results in lowering the flaw size and consequently in increase of the fracture strength (according to the Griffith equation).
Higher fracture strength causes higher wear resistance.
Bulk homogeneity of the microstructure allows creating fine and homogeneous surface finish with low content of surface flaws.
High quality surface possess low coefficient of friction.

3.2 Manufacturing processes forming microstructure of alumina ceramics

- **Powder preparation**

Powder characteristics such as particle shape (spherical, irregular), average particle size, size distribution determine the alumina grain size and the amount and size of the pores.

- **Compaction (shape forming)**

The value of the applied pressure, the method of its application (Uniaxial (Die) Pressing, Isostatic Pressing, Injection Molding, Extrusion, Slip Casting, etc.) and the amount of binders and other additives (plasticizers, lubricants, deflocculants, water etc.) determine the pores size and the residual internal stresses.

- **Sintering**

Diffusion proceeding during sintering process causes the pores to diminish or even to close up resulting in densification of the alumina ceramic material.
The bonding and other second phases are distributed between the grains of the main ceramic phase.
The matrix grains may grow during the sintering process. Thus sintering process determines the final alumina grains and pores sizes and the physical and the chemical homogeneity.

3.3 Effect of surface characteristics on tribological properties of alumina ceramics

- **Surface topography**

Friction characteristics (coefficient of friction, wear) are strongly dependent on the type of the lubrication regime (boundary lubrication, mixed lubrication, hydrodynamic lubrication).
The lubrication regime is determined by the ratio of the lubricant film thickness to the surface roughness Ra.

Rough ceramic surface with relatively large microasperities causes direct contact between the rubbing surfaces and results in high coefficient of friction and increased wear.

High surface finish quality allows to improve the tribological characteristics of alumina.

Ceramics are brittle and they wear by fracture mechanism, which is characterized by formation of cracks in the subsurface regions surrounding the wear groove. The volume of the lost material is higher than the volume of the wear track.

Thus wear of brittle ceramics results in roughening the surface. The effect of roughening during friction is lower in toughened ceramics.

- **Surface defects**

Sintering defects, surface machining, impacts during friction, embedded particles introduce surface flaws, which lead to fracture cracking and increase wear.

- **Surface composition and tribochemical reactions**

Ceramic surface may adsorb molecules of the environmental gases and liquids. Such surfaces with modified composition may have different coefficient of friction.
Coefficient of friction of alumina in vacuum is commonly higher than that in air.
Hydration of Alumina ceramics in a humid atmosphere also results in changing their coefficients of friction and wear. Wear of hydrated Alumina ceramics is increased due to chemisorption embrittlement.
Methods of modification of ceramic surfaces:

- **Plasma oxidizing** - a method of surface oxidation by elemental Oxygen supplied to the ceramic surface by plasma.
- **Ion nitriding and carburizing** - a method of introducing nitrogen (nitriding) or carbon (carburizing) atoms into the ceramic surface by means of plasma (glow-discharge).
- **Ion implantation** - a method of introducing a material into a ceramic surface by electrostatically accelerated ions.
- **Laser densification** - a method of heating the ceramic surface layer by a laser beam resulting in closing the pores between the ceramic powder particles.
- **Electron beam densification** - a method of heating the ceramic surface layer by an electron beam resulting in closing the pores between the ceramic powder particles.
- **Chemical etching** - cleaning the ceramic surface by acids.
- **Sputter etching** - bombarding the ceramic surface by accelerated plasma ions, which vaporize the surface molecules.

3.4 Effect of lubrication

Lubricants decrease coefficient of friction and reduce wear of the rubbing parts.
Lubricants remove the heat generated by friction. This function is particularly important for ceramics since they have lower thermal conductivity and usually produce more heat due to relatively high coefficient of friction.
Lubricants remove wear debris from the rubbing surfaces.
Lubricants also protect the ceramic surface from the environment.

- **Liquid lubricants**

Liquid hydrocarbon lubricants are commonly used for relatively low temperatures (up to 392ºF/200ºC). Silicone oils may be used up to 570ºF (300ºC).

- **Solid lubricants**

Solid lubricants may be used for lubricating alumina ceramics in various forms: suspensions in liquid lubricants, dry powders, Dispersions in gases, coatings.
Requirements to solid lubricants properties: good adhesion to the ceramic surface, low shear strength in the sliding direction and high compression strength in the direction of the load (perpendicular to the sliding direction).
Substances used as solid lubricants: graphite, molybdenum disulfide, boron nitride, Polytetrafluoroethylene (PTFE), calcium fluoride-barium fluoride eutectic.
Maximum work temperature some of the solid lubricants is low (PTFE: 392ºF/200ºC). Other lubricants may withstand up to 1508ºF/820ºC (calcium fluoride-barium fluoride eutectic).

- **Gaseous lubricants**

Vapors of some organic substances may serve as lubricants for alumina. The vaporized molecules of such lubricant reach the ceramic surface react with it and form on its surface a film possessing low coefficient of friction.

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