A SURVEY ON CERAMIC COMPOSITES FOR APPLICATION IN POROUS BEARINGS

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Abstract. *Ultra precision components for optical and mechanical applications are manufactured through special machines with high stiffness and precision of displacement, which assure nanometer tolerance and good superficial roughness. The use of a porous material as the restrictor in aerostatics bearings provides many advantages over conventional restrictors. The correct criterion of material's selection for composites phases is essential to the development and designing of specific applications. Based on mechanics of composites, as well as in dispersion and packing of particles, this present work consists to prepare a review of the main concepts and theory to the development of a ceramic particulate composite to be used as a porous restrictor in aerostatic bearings.*

Keywords: *Porous material, Aerostatic bearing, Ceramic Processing.*

1. Introduction

Each of basic mechanical elements, which assemble an ultra precision machine, contributes for the quality of machining and it must present precision, static and dynamic stiffness and high dimensional stability in order to minimize any and all source of mistake (Rubio, 2000). The aerostatic bearings can provide small variation of temperature, high damping, high operational speeds, no wear and capacity to support radial, axial and combined loadings (Cheng & Rowe, 1995; Rowe, 1991).

The characterization and the manufacturing process have showed to be an important factor to the development of aerostatic bearings, becoming the goal of many researchers in this area. Thus, this paper will bring a bibliographic revision about some relevant concepts to the development of a ceramic particulate composite which meet with the requirements as a porous restrictor.

2. Bibliographic revision

2.1 Aerostatic porous bearings

Unlike contact-roller bearings, air bearings utilize a thin film of pressurized air to provide a "zero-friction" load-bearing interface between surfaces. The two surfaces don't touch. Being noncontact, air bearings avoid the traditional bearing-related problems of friction, wear, particulation, and lubricant handling, and offer distinct advantages in precision positioning and high-speed applications.

Aerostatic bearings utilize a thin film of high-pressure air to support a load. Since air has a very low viscosity, bearings gaps need to be small, on the order of 1-10µm. All operate on the principle of supporting a load on a thin film of high pressure air which flows continuously out of the bearing and into the atmosphere. The common applications of air bearings include profile projection equipment employing air bearing slides, rotary measuring tables and machine tool lead screw measuring heads. Modern developments in both manufacture and measurement are placing greater demands on accuracy and quality, particularly in the area of nanotechnology, (Slocum, 1992).

Besides smoothing stop and starts, air bearings offer less resistance (friction) to steady-state motion. Friction generates heat which, in turn, causes spindles and other components to thermally grow, compromising precision. Air bearings generate much less heat in a given application than rolling-element or plain bearings in most cases. In fact, relative speeds must exceed about 100 ft/sec before air bearings generate any significant heat at normal air gaps. Air bearings excel in applications requiring tight velocity control such as scanning and wafer inspection, because they eliminate force ripples from recirculating ball bearings loading and unloading, (New way, 2004).

Air bearings are typically classed as orifice or porous media types. In orifice bearings the pressurized air arrives at the bearing surface through a small number of precisely sized holes. The concept is similar to the air hockey table amusement game, but with the holes in the puck rather than the table.

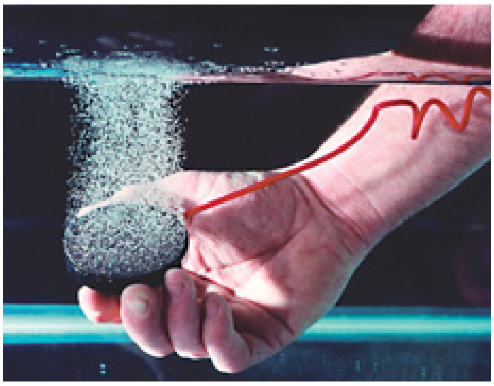

Figure 1. Porous air bearings issue air from millions of submicron pores, (New way, 2004).

Porous-media air bearings are quite different in that the air is supplied through the entire surface of the bearing. Specifically, the bearing surface is laced with microscopic holes and vias through which air flows. These holes are not drilled but are inherent to the bearing material. The porous material controls the airflow in the same way as an orifice bearing that had millions of miniature holes across its surface.

Amongst its many advantages over conventional restrictors are the simplicity of design and manufacture, higher load capacity and stiffness and superior damping characteristics. Even complicated bearing geometries, such as spherical bearings or aerostatics leads crews, can be achieved without difficulties.

Their application in precision engineering has been hampered by the difficulties in predicting the fluid flow characteristics of the porous material, as well as stability problems believed to be related to the void volume between pores at the bearing surface. In particular, experimental study of slip flow within the bearing gap bounded by one porous surface has not been widely reported, especially at small clearances common in ultra precision applications (Kwan, Corbett, 1998).

A common misconception about air bearings is that they lack the stiffness for precision applications. This is simply not true. For example, a 6-in.-diameter air bearing running at 60 psi supporting a 1,000-lb load has a stiffness exceeding 2,000,000 lb/in. Put another way, that's less than 0.0000005 in. deflection per pound of additional force. Stiffness rises nonlinearly with diminishing film thickness and is proportional to pressure and surface area. However, a factor called compensation also controls air-bearing stiffness.

The two most common compensation methods are orifice and porous. Orifice compensation distributes pressurized air across a bearing face through strategically placed, precisely sized orifices and grooves. But scratches across a groove or near orifices may cause more air to escape than orifices can supply, causing a bearing to crash at normal air-supply pressures.

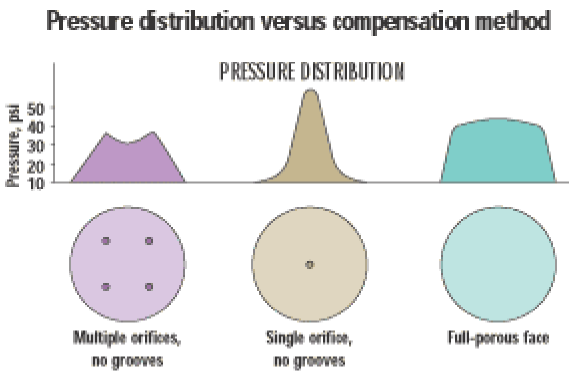

Figure 2. Pressure distribution versus compensation method, (New way, 2004).

Bearings using porous surface compensation, in contrast, issue pressured air from an entire bearing face through millions of micron-sized pores so they are less susceptible to surface scratches. Moreover, where orifice-fed bearings have pressure gradients in the air gap, pressure in porous air bearings remains nearly uniform across an entire surface. Porous bearings also tend to be more stable than orifice-fed types because the porous media damps air flowing into the bearing. Orifice compensation is the most widely used, but porous surface compensation is rapidly emerging as the preferred method.

Despite its many advantages, the availability of porous material with predictable fluid flow characteristics has continued to hamper the widespread application of porous aerostatic bearings. While much of the work immediately after the last review by Kwan and Corbett, concentrated on the dynamic theories of such bearings, the most recent interests have been centered around material development.

2.2 Particulate composites materials

According to Daniel and Ishai (1994), a structural composite is a material system consisting of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of the constituent materials acting independently. One of the phases is usually discontinuous, stiffer, and stronger and is called reinforcement, whereas the less stiff and weaker phase is continuous and is called matrix. Sometimes, because of chemical interactions or other processing effects, an additional phase, called interphase, exists between the reinforcement and the matrix. The properties of a composite material depend on the properties of the constituents, geometry, and distribution of the phases.

The characteristics of particles affect powder flow, viscosity, mechanical, thermal and optical properties. One of the principal difficulties is due to the ability of most fillers to exhibit a variety of particle shapes and sizes depending on the work done is dispersing them. Particle shape is very important in determining the stiffness of a composite, the flow and rheology of a melt or liquid, tensile and impact strength, and the surface smoothness of a component. Shape is determined by the genesis of the filler, by its chemistry, its crystal structure and by the processing it has undergone. The literature abounds with vague terms such as roughly spherical, blocky, irregular, plate, acicular, etc. Size is the one variable that can be controlled for each filler and its importance is felt at all stages of composite production and use. Hence, there is considerable interest in its measurement, especially of particle size distribution rather than single average values, although the latter have the merit of simplicity. It's an easy property to measure accurately using a variety of techniques including sieving, sedimentation, optical scattering and diffraction from particulate suspensions. Each, however, has a different dependence upon particle dimension and varies with particle shape.

Considering a ceramic composite, pressing is a very important fabrication process used to produce products that are of relatively high density and are dimensionally precise. Pressed products vary widely in size, shape, and composition. Pressing should eliminate large pores and produce a product having a uniform density and adequate strength to survive ejection and handling.

2.3 Particle packing

The packing behavior of particles in a matrix phase is a critical factor in the understanding and design of composites, especially when high filled systems are involved. The maximum packing fraction is a particularly useful concept, being the maximum volume fraction of particulate that can be incorporated before a continuous network is formed and voids being to appear in the composite.

The general particle packing theory approach to obtaining high packing fraction powders is to use small particles to fill in the pores in the packed structure obtained from large particles and then to use even smaller particles to fill in the remaining pores and so on.

According to Pandolfelli et al.(2000), particle shape can alter the packing conditions. A simple view of this is presented in Figure 3. Spherical particles provide in an increase of density of material. This occurs due to the friction between the non-spherical surfaces of particles.

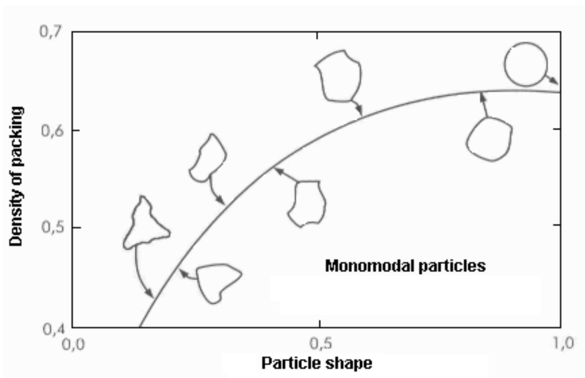

Figure 3. Particle shape versus density of packing

The packing behavior of bimodal mixtures of irregular and spherical particles is similar, although the values of density are different (Figure 4).

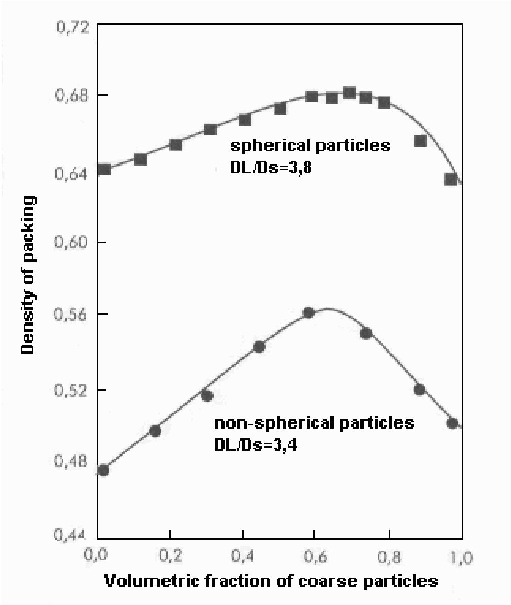

Figure 4. Comparison between spherical and non-spherical particles in function of the density of packing

Particle porosity is another relevant factor to obtain high densities of packing. The particles can be found with internal pore (b), external pore (c) and nonporous (a) (Figure 5). The maximum packing is obtained when using particles with less porosity.

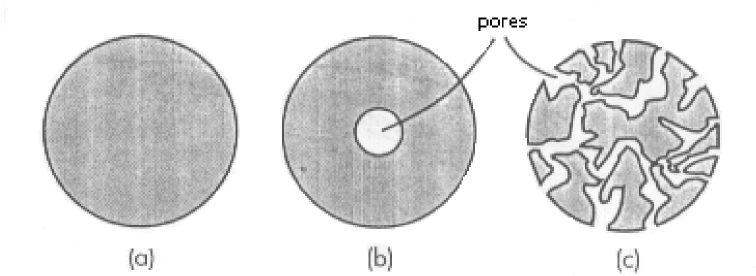

Figure 5. Representation of different pores.

Small particles can hinder to obtain high densities of packing due to present a trend of agglomeration. This effect inhibits the spatial order that provides the high densities of packing.

Practical procedures for producing maximum packing systems were originally worked out by Furnas. It must be borne in mind, however, that other considerations may restrict the particle size range than can be tolerated in a composite.

2.4 Final considerations

According to Kwan and Corbett (1999), the ratio of viscous to inertia permeability coefficients (Φ_v/Φ_i), for the ceramic material used as porous restrictor, may not exceed the critical value of 8 X 10^{-5}m, which the inertia effect becomes negligible. The value of coefficient is believed to be dependent on the porous structure, but independent of the flow velocity or Reynolds number. The material developed in Cranfield University consists in a base substrate of high permeability, sintered from 23µm alumina powder using the free-capsule hot isostatic pressing process. The base substrate acts as a structural support, on which a thin, pre-sintered layer of porous alumina of 0,5µm powders was hot-pressed.

Darcovich et al. (2002) studied the effect of particles size distribution in sintering process of porous ceramics. The particles used were alumina-α varying between 0,1 to 10µm. The sintering process was carried out in a temperature of 1200ºC and period of 240min, obtaining values of volumetric porosity in a range of 46,7% to 67,5%.

García-Márquez et al. (2003), investigated the effects of alumina and silica addition above the mechanical properties of Portland cement. The fabrication parameters were: load pressing of 180MPa, sintering temperature of 1400ºC in a period of 30min. It was verified that the volumetric porosity increases with alumina addition and decreases with silica addition. Considering the same mixture percentage, alumina obtained a volumetric porosity of 35% and silica 15%.

Cheeseman, Asavapisit e Knight (1998) studied the effects of pressing process above the porosity of ceramic composites. Portland cement was used as the matrix phase. The uniaxial pressing pressures were 0, 16 and 32MPa. The loadings were retained for 1 minute, before being released. The volumetric porosity obtained for 16Mpa and 32MPa were 16,7% and 15,5%, respectively.

Based on the experimental results of Cheeseman, Asavapisit e Knight (1998), García-Márquez et al. (2003), Darcovich et al. (2002) and Kwan and Corbett (1999) and the theory and principles explained in this work, it's confirmed that is possible the development of a ceramic particulate composite that presents specific properties to be applied as a porous restrictor in aerostatic bearings, principally the volumetric porosity. This material can achieve a simple manufacturing using in its composition particles of silica embedded in a Portland cement matrix. A uniaxial pressing will be carried out in order to obtain the fitting values of volumetric porosity and mechanical properties. This proposal material will be developed and investigated in different experimental conditions in order to identify the main effects between the studied factors, such as, particle size, particle shape, pressing pressure, water content and composition of material.

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