Centrifugal Slip Casting of Components

Centrifugal slip casting is a simple, inexpensive and rapid method to produce reinforced, layered and functionally gradient components.

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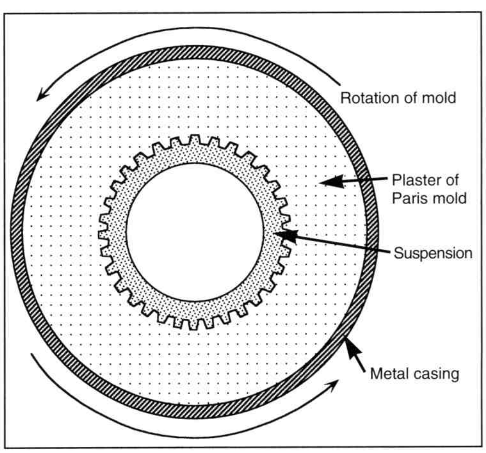
Research in layered and functionally gradient materials has emerged because of the increasing demand for high-performance engineering materials.[1–3] Many techniques have been used to produce layered and functionally gradient components. Common examples include thermal spray processing, powder processing, chemical and physical vapor deposition, high-temperature or combustion synthesis, diffusion treatments, microwave processing and infiltration.[1–20] Of these techniques, powder processing routes offer excellent microstructural control and product quality, and they are capable of producing large components.[20–22]

Centrifugal slip casting is a powder-processing technique combining the effects of slip casting and centrifugation.[22–23] In slip casting, consolidation takes place as fluid is removed by the porous mold. Particles within the slip move with the suspending fluid until reaching the mold wall, at which point they are consolidated. In centrifugation, particles within the slip move through the fluid at a rate dependent upon the gravitational force and particle drag.[22]

By allowing the particles to move through the fluid, possible orientation and hydrodynamic effects can be tailored to achieve the desired component texture and gradation.[22,23] Thus, the combination of the effects of centrifugation and slip casting in centrifugal slip casting allows for microstructure design—phase ratio, layer thickness, phase gradient and morphological or crystallographic orientation—through control of mold shape, rotational velocity, casting radius, powder contents, particle density, particle size, particle-size distribution, suspension viscosity and interparticle surface forces.

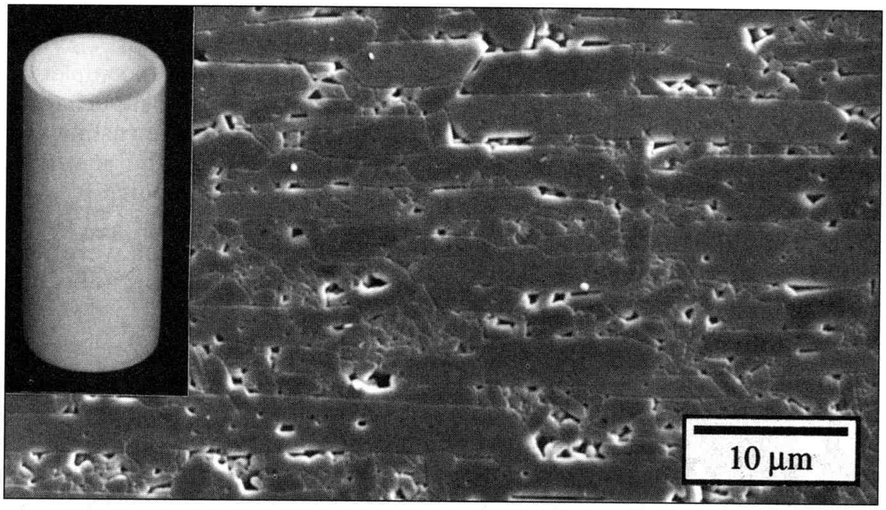
Centrifugal slip casting can be performed in two geometries. A hollow cylindrical mold can be rotated about its axis to produce tubular or other axisymmetric components,[14,23–29] or a mold can be placed at the bottom of a centrifuge bucket and rotated to produce a uniaxial gravitational force acting in the direction of the mold.[20–22,30–33] This process is feasible for producing both small and large components, and it is easily



Cross section of centrifugally slip cast gear and mold.

scaled from prototype to full-scale production, making centrifugal slip casting an attractive process for rapid prototyping of layered or graded components. However, care must be taken in scale-up to control vibration effects[25–27] and maintain constant Reynolds numbers to achieve dynamic similitude.[22]

The potential of centrifugal slip casting for producing practical components with controlled microstructures is demonstrated here. Tube- and gear-shaped components were produced with a homogeneous distribution of reinforcements or multiple layers of continuous-phase gradients.



Microstructure of a centrifugally slip cast tube, with homogeneously distributed Al_2O_3 platelets in an Al_2O_3 matrix.

Processing

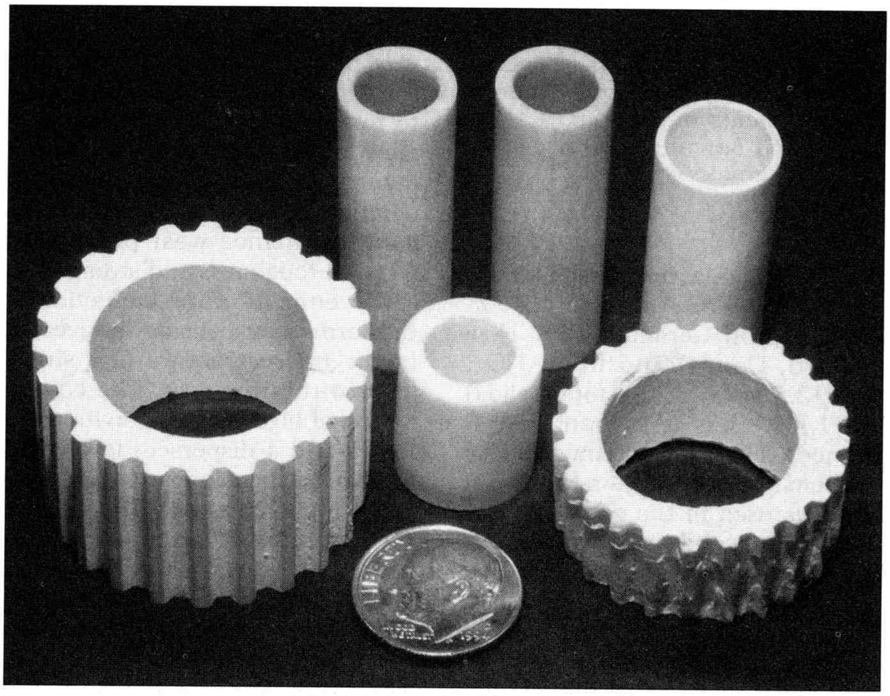
Plaster of Paris molds were prepared for casting both tubes and gears. For tubes, molds were cast by injecting a plaster of Paris slip—10:7 ratio by weight plaster of Paris:deionized water—into a rotating metal casing and allowed to set. The mold was removed, dried and placed in a metal casing with Teflon end caps.[23]

For gears, a positive replica of the desired gear shape was cast with an epoxy. The epoxy positive was placed in a metal casing and coated with an aerosol silicone lubricant. A plaster of Paris slip was poured around the gear. When the plaster of Paris cured, a press was used to remove the epoxy positive, and Plexiglas end caps were glued on the sides of the plaster of Paris mold. For both types of molds, the mold and its metal casing were clamped and centered in a four-jaw chuck of a variable-speed wood lathe.

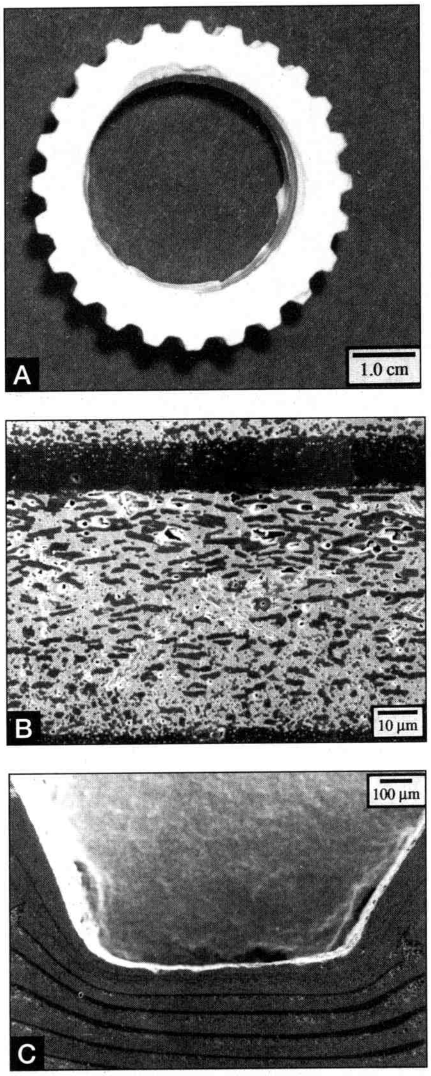
Aqueous suspensions containing 20–33 vol% solids and 8 vol% NH_4PMMA (Darvan C, R. T. Vanderbilt Co., Norwalk, Conn.), at pH 9.5 (using NH_4OH), were dispersed by ultrasonication (Sonicator^R W-380, Heat Systems-Ultrasonics Inc., Farmingdale, N.Y.). The solids contained 10 vol% Al_2O_3-platelets (Atochem, Paris, France) and an Al_2O_3 powder (AKP-15, Sumitomo Chemical, New York). Suspensions were consolidated by injecting multiple additions within rotating plaster of Paris molds.

Accelerations equivalent to ~25*g* and ~65*g* were attained at the outer surface for tube and gear molds, respectively. Once the plaster of Paris molds became saturated, excess supernatant liquid was removed prior to subsequent suspension additions. At the completion of consolidation, all supernatant liquid was removed and the cast parts were dried until they could be removed from the mold. Components were sintered at 1500°C (500°C/h ramp) for 2 h, and specimens were prepared for microstructural observation by scanning electron microscopy (SEM) (Model JSM-35CF, JEOL, Tokyo, Japan).

A dilute (8 vol% solids), dispersed (pH 3 using HNO_3), aqueous suspension was prepared



Centrifuged and centrifugally slip cast components of axisymmetric geometry.



(A) Centrifugally slip cast gear with (B) gradient layers of Al_2O_3 platelet reinforcements in a Ce-ZrO_2/ Al_2O_3 matrix. (C) Layers follow parallel to the outer surfaces of the gear.

containing equal portions of a fractionated Ce-ZrO_2 (see Ref. 12, TZ-12Ce, Tosoh Ceramics Div., New Milford, Conn.) and fine Al_2O_3, and 12.5 vol% (of the total solids) Al_2O_3-platelets (Atochem, Paris, France). The starting powders and suspension preparation were the same as used in the previous centrifugal consolidation procedures, and more detailed accounts are given elsewhere.[20,22]

The suspension was consolidated by consecutively adding 20 separate suspension additions of 2.0 mL and rotating at ~65g at the outer mold surface. Care was taken to maintain the bulk suspension at pH 3 under constant mixing. At the completion of consolidation, the supernatant was poured off and the casting was dried until it could be removed from the mold. Components were sintered at 1600°C (800°C/h ramp) for 2 h, and specimens were prepared for microstructural observation by SEM.

Tube/Gear Produced

Axisymmetric components were produced by centrifugal slip casting. More complex, nonaxisymmetric components also can be produced using a wax positive replica of the desired component that is removed from the plaster of Paris mold by heating—analogous to lost wax casting.

An Al_2O_3 platelet/Al_2O_3 powder tube with uniformly distributed reinforcements was prepared. Despite the large size difference between the Al_2O_3 platelets and particles, segregation was prevented in suspension additions because of a combination of high solids loading and hydrodynamic effects.[22] The platelet reinforcements are highly aligned, primarily because of the centrifugal forces during consolidation.[23,29,33,34]

A gear with gradient layers also was produced. Centrifugal slip casting allows the gradient layers to form parallel to the outer surfaces of the mold. The ability for layers to follow the surface of a complex component should significantly enhance wear properties, fracture toughness and strength.

The consolidation behavior of the ternary suspension is revealed in the microstructure of a single layer within the gear. The combination of high inertial gravitational forces and a dispersed, low solids content suspension promoted segregation because of differential settling rates of suspension components by density and size. The casting rate is anticipated to have a strong effect on segregation in specimens with thick sections. The large Al_2O_3-platelets settle first, followed by the finer, higher-density Ce-ZrO_2 particles and finally the fine Al_2O_3.

Furthermore, upon heat treatment, the location of the large, oriented reinforcements near smaller particles of the same phase allows the reinforcements to grow at the expense of the smaller particles. Thus, the volume fraction of reinforcements increases, and the phase gradient can be modified.[35]

Centrifugal slip casting uniquely produces highly controlled microstructures through control of the mold shape, gravitational forces on particles, constituent particle size, constituent particle-size distribution, constituent density, suspension viscosity and interparticle surface forces. It can be used to combine the texture control and design capability of centrifugation with the shape-forming capabilities possible with slip casting. Centrifugal slip casting may allow sintering shrinkage to be engineered for optimum properties by providing control over phase dispersion and orientation as well as casting density. Centrifugal slip casting can be used for producing metal, ceramic and metal/ceramic components. It is rapid and versatile in comparison to many other techniques currently used to manufacture graded and layered components. ■

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