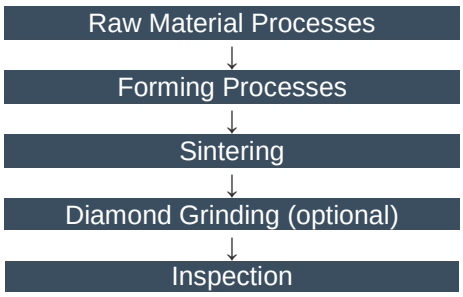
Manufacturing Advanced Ceramics

The process steps in the manufacturing of advanced ceramics such as silicon nitride and sialon, alumina, zirconia and silicon carbide are summarised in the flow diagram below:



Each of these stages in the manufacturing process (with the exception of the inspection step) influences the properties of the final product.

Raw Material Processes

The raw materials for manufacturing advanced ceramics come in powder form. The powders used by International Syalons are of the highest quality, both in terms of purity and particle size, which are usually sub-micron.

Prior to forming, the appropriate blend of raw materials are mixed together to form the stock material used for the forming processes. At International Syalons this is usually one of 3 types: a spray dried powder, an aqueous slip or a dough feedstock.

Spray Dried Powder

Spray drying is a method of producing a free flowing, uniform, granulated powder which is the ideal feedstock for a variety of pressing processes such as uniaxial pressing and wet and dry-bag isostatic pressing. The raw material blend is firstly milled in a ball mill in a solvent, such as water, using ceramic balls. At this stage up to 5% of organic binder can be added to the slurry feedstock prior to spray drying. The binder, which can include a lubricant and pressing aids, helps give the material good green strength in the subsequent pressing stage. The slurry and additives is spray dried by atomizing it in a hot air stream.

Aqueous Slip

Aqueous slip is prepared by milling together the raw material blend in a ball mill in water along with an organic dispersant to produce a fluid, highly concentrated slurry, which is used for slip and pressure casting to produce a high green density part.

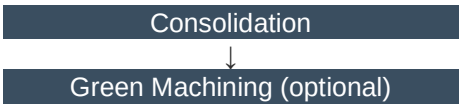
Ceramic Dough Feedstock

Ceramic dough feedstock is prepared by mixing the ceramic raw material blend with a solvent (usually water) and a blend of organic binder and plasticizer to produce a clay-like plastic body that is deformable under pressure, for example by extrusion.

The quality of these raw material feedstocks becomes critical in the next stage of manufacture – the forming process. The better the feedstock, the better the green density achieved during consolidation and consequently the lower the sintering shrinkage in the sintering stage.

Forming Processes

The forming process involves a consolidation stage and an optional machining stage, as shown in the flow diagram below:



Consolidation aims to produce a near net shape part with sufficient strength for subsequent handling (and green machining where required). Consolidation techniques used by International Syalons include uniaxial pressing, isostatic pressing, slip casting and extrusion.

Consolidation Methods

Uniaxial Pressing

Uniaxial or die pressing is a medium to high volume consolidation method for parts ranging from the simple (for example discs or plates) to relatively complex (for example parts with holes or recesses). The process involves the uniaxial compaction of a spray dried powder in a rigid (usually tool steel) die.

Components made by uniaxial pressing do not usually have any subsequent green machining and where possible are made to as-sintered tolerances.

Isostatic Pressing

Isostatic pressing is a small to medium volume consolidation technique of which there are 2 variations: wet-bag pressing and dry-bag pressing. In both cases a spray dried is contained in a flexible (usually rubber or polyurethane) bag which is subjected to an isostatic pressure.

Wet-bag pressing is primarily for simple stock shapes such as rods which are subsequently green machined to the required shape whereas dry-bag pressing can produce more complex shapes such as nozzles which are generally not green machined.

ADVANCED CERAMIC SOLUTIONS

Slip Casting

Slip casting, also known as drain casting, is a small to medium volume consolidation method for generally simple shapes such as tubes and crucibles but also for more complex shapes such as ladles.

Slip casting uses a highly fluid, concentrated aqueous based slip which is poured into a porous mould (usually made from plaster). The water is drawn from the slip into the plaster by capillary action which leaves the consolidated powder mix deposited on the inside of the mould. Over time the thickness of the cast increases. When the required thickness is achieved the remaining slip is drained from the mould.

A variation on slip casting is pressing casting. In this case a pressure is applied to the slip in the mould which allows thicker walled or solid parts to be cast.

Extrusion

Extrusion is a medium to high volume consolidation technique for producing simple shapes such as small diameter tubes. The dough feedstock deforms under pressure and the binders in the mix help retain the extruded form as it dries.

Green Machining

Green machining is the machining of an unfired 'green' or raw body. This needs to be done when the consolidation method used cannot produce the required shape. For example, the best way to make a part like a weld location pin is to green machine an isostatically pressed rod.

At international Syalons we use standard and CNC lathes and milling machines. Depending on the part, as much of the machining as possible is done in the green state. Not only is green machining quick, it is also cheaper than diamond grinding and the dust from the machining process can be collected and recycled.

Sintering

Sintering is the process during which the consolidated green ceramic part is fired to give a dense, advanced technical ceramic. Just before or during this stage any organic binder additives need to be removed. This is best done in an air atmosphere.

During sintering the ceramic is heated to below its melting point. At high temperatures the fine ceramic powders undergo several changes from particle rearrangement to grain growth and finally pore elimination. For ceramics such as alumina or zirconia this process is called solid-state sintering and involves material transport by diffusion.

Ceramics such as silicon nitride and silicon carbide are more difficult to densify and often use sintering mechanism called liquid-phase sintering. In this case a small volume of additives in the mix form a liquid at sintering temperatures in which the primary particles (for example silicon nitride) firstly rearrange due to capillary forces, giving better packing. Then at the points of contact between particles some of the solid particles begin to dissolve in the liquid and are re-precipitated at the neck areas between the particles. Eventually the pores are eliminated and the ceramic reaches full density. Sintering takes place in a different atmosphere depending on the material being sintered. For example silicon nitrides are sintered in a nitrogen atmosphere.

During sintering advanced ceramics typically shrink approximately 20-25%. It is vitally important to obtain good, uniform green density during the forming stage to have a controlled, uniform shrinkage.

Diamond Grinding

Diamond grinding is a machining process which is carried out on a sintered part that needs to be tightly tolerance, needs an improved surface finish or to remove surface flaws and as such is an optional process.

Final machining processes include grinding, cutting, honing and lapping and polishing. Each of these processes requires diamond tooling due to the high hardness of dense advanced ceramics. The rate of material removal is very slow as care must be taken not to cause surface damage. These are therefore relatively expensive processes and so best efforts are always made to minimize the need to diamond grind, for example by working to 'as-sintered' tolerances whenever possible.

Inspection

Inspection is the final stage of the ceramic manufacturing process and generally involves a visual inspection of the part and dimensional inspection to a drawing. Visual inspection involves looking for cracks or flaws in the part and to ensure the part is clean. Dimensional inspection can be done using a variety of equipment such as Vernier calipers, micrometers, coordinate measuring machine (CMM), shadow graph etc.

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