From Prototype to Series Production in Technical Ceramics

The use of new materials increases the efficiency and reliability of plants and machinery. For instance, oxide ceramics have frequently proven effective in resolving wear and corrosion problems as well as electrical and thermal insulation problems. Technical ceramics are also making valuable contributions to material efficiency, energy efficiency and lightweight design. These megatrends will influence product development over the next few years.

Fig. 1
Complex shaped ceramic components made from various materials

Why is prototyping essential?

Wear and corrosion are system properties. As knowledge of the characteristics of materials is often not enough, for field applications ceramic prototypes are needed for long-term trials.

Prototypes should have the same material properties in the design environment as in series production. In the case of subtractive prototyping process, this is guaranteed. If after the first successful material trials, test machines are equipped with small series, tool-less scaling up to small series is feasible.

What advantages do oxide ceramic materials have?

Alumina ceramics electrically separate even at high temperatures, are resistant to corrosion, biologically harmless and do not age. The diamond-like hardness makes them wear-resistant and dimensionally stable. The different and easily reproducible microstructures of alumina depend on the alumina content, the fabrication route, the mechanical and thermal after-treatment. Accordingly, defined surface finishes can be obtained for guide elements. From this variety of options, for demanding applications, the optimum material can be selected with subtractive prototyping processes in series of tests.

Zirconia is a typical engineering ceramics material. When zirconia is stabilized with magnesia (Mg-PSZ) or yttria (Y-TZP), a microstructure is formed with high fracture toughness and wear resistance. The dry running properties, the high dimensional stability and the low friction coefficient on metal make zirconia a successful material for plain bearings. The low thermal conduct-

Keywords
subtractive prototyping, oxide ceramics, flexible design

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ivity and the high compressive strength are interesting for the optimization of thermal balance, e.g. in tools. Mg-PSZ (magnesia stabilized zirconia) is cheaper than Y-TZP (yttria stabilized zirconia). Y-TZP has the highest flexural strength of the oxide ceramic materials. If the edge strength of Mg-PSZ is sufficient for the planned application, the substitution of Y-TZP with Mg-PSZ helps save raw material costs.

Oxide ceramic prototypes in 3D design and state of the art

In the prototyping of ceramics and the fabrication of the first test samples, new technologies have set new standards. Geometric variants in 3D design used to be tied to the production of tools and subsequent tool changes with the correspondingly long fabrication times. Ceramic materials shrink during sintering differently and increase the costs of different variants. Today CAD and 5-axis machining centres are available.

For prototyping, compacts with simple geometry are pressed from existing tools and pre-sintered. In pre-sintered state, the ceramic compacts can be machined with carbide tools. Tool changing devices and adapted clamping systems make production flexible and cost-efficient. Then the pre-fired white-machined components are sintered at temperatures between 1600 °C and 1700 °C depending on the material. The material-specific shrinkage of 15 % to 25 % is taken into consideration as allowance in the CAD data.

Fig. 1 shows the wide design freedom based on examples from the field.

What additional degrees of freedom does the ultrasonic process bring?

Sintered semi-finished ceramic are dense and, on account of their high hardness, can no longer be machined with carbide tools. The ultrasonic process is now available as an innovative process to fabricate prototypes in 3D precision for test purposes. The 5-axis cutting machine is upgraded with an ultrasonic machining head. The actuator tools vibrate with around 20 000 Hz in a diamond-oil emulsion and remove small particles from the ceramic surface. The continuous gap between tool and workpiece leads to low process forces and thermal loads, protecting the tool and the workpiece.

Fig. 2 shows the design possibilities. Boreholes to 0,3 mm, 3D contours, pockets, grooves and slits can be machined very reproducible and with very high precision. R_a values of 0,3 µm are achieved all round.

The machining of sintered half-finished components by means of vibration-assisted grinding and drilling gives the designer additional degrees of freedom. In a clamping, different materials can be machined without tools and without consideration of different shrinkages. In a clamping, different designs for test series are realized. Borehole diameters, groove widths, curvature radii can be reworked, modified and optimized.

From prototype to large-scale production

Once the development has been optimized and concluded and the design has been finalized, large-scale production starts. Shaping processes suitable for large-scale production are near-net-shape ceramic injection moulding and dry pressing with subsequent CNC machining. In the design other manufacturing processes, like debinding or pre-firing, sintering and hard machining, e.g. surface grinding, polishing, honing, cylindrical grinding, internal grinding, have to be taken into account.

Subtractive prototyping processes in comparison

As the field examples show, with the subtractive processes for engineering parts made of oxide ceramics, a 3D design with complex geometry can be achieved with high precision and very good surface quality. A part can be cut in a few minutes. The ceramic components are dense and have reproducible series quality with regard to mechanical, electrical and chemical properties. New material development is not necessary. The component size is determined by the size of the compact, the machining space in the 3D machining centre and the downstream sintering and hard machining processes.

With the range of proven materials, microstructures, surface finishes, and geometry, a modular system is available for the developer to optimize the design.

Fig. 2
Selection of design possibilities of ceramic components

Cost-saving potential with 3D technology in technical ceramics

Cost savings, long-term stability, individualization, weight and space savings and multifunctionality are key innovation drivers. Multifunctionality also means developing a component with complex geometry from several components with simple geometry. This save tool costs, production processes, reduces the production time and contributes to material and energy efficiency. It simplifies storage and procurement of replacement parts. Assembly processes are eliminated with their high requirements for the integration of ceramic components in the engineering environment of metal and plastic components. The latest 3D technology with subtractive processes prompts the rethinking of current designs with regard to megatrends. Especially future technologies, such as electromobility and solar technology rely on long-term stable electrical and thermal separation.

In plant and mechanical engineering and in sensor systems, the need for repairs, maintenance costs and service costs are reduced with wear-resistant, corrosion-resistant and aging resistant ceramic components.