Product and Process Oriented Shaping Techniques for Advanced Ceramics at the Example of Ceramic Injection Molding and Extrusion

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Preface

Geometry and quantity play an important role in selecting a suitable shaping method for ceramic components (Fig. 1). Extrusion and injection molding are manufacturing technologies of high productivity and a high degree of automation also for the upstream and downstream process steps. At the same time, these near net shape methods can be used to realize very complex geometries, e.g. such as thin wall thicknesses and smallest holes. Summarized as "Plastic and thermoplastic shaping methods"[1)] extrusion and injection molding combine many general questions: from the selection of suitable binder systems for a homogeneous plasticization and the adjustment of defined rheological properties through the modeling and simulation of shaping processes up to the characterization by non-destructive testing methods. In both technologies high deformation degrees are used in order to mold the ceramic bodies in cavities with complex geometry so that a near net shape production with high precision becomes possible also for very filigree structures. In ceramic injection molding the component's contour is completely formed by the tool cavity; shaping takes place cyclically in the closed tool. In comparison, extrusion is a continuous process through open cavities, where the die geometry forms the cross section of the shaped component (Fig. 2). The binder concept is different: For the injection molding process thermoplastic binders are used to plasticize the ceramic powders. These binders allow one to shape the component at temperatures above their melting point, and also guarantee a reliable ejection at low temperatures. In the case of extrusion, the clay-typical moldable behavior at temperatures near room temperature is adjusted by using water- soluble binders on the basis of cellulose in combination with lubricants. When extruding thermoplastic masses the shaping process is supported by cooling the extrudate after it has left the die. Before removing the organic binders the content of which is lower than in ceramic injection molding an additional drying step is necessary. Binder removal is identical in both methods.

Injection molding and extrusion provide good opportunities for the development of new as well as the further development of existing products as well as their improvement as they allow for a significant increase of the level of integration (e.g. the miniaturization of injection-molded components or by reducing wall thicknesses and channel diameters of extruded honeycombs).

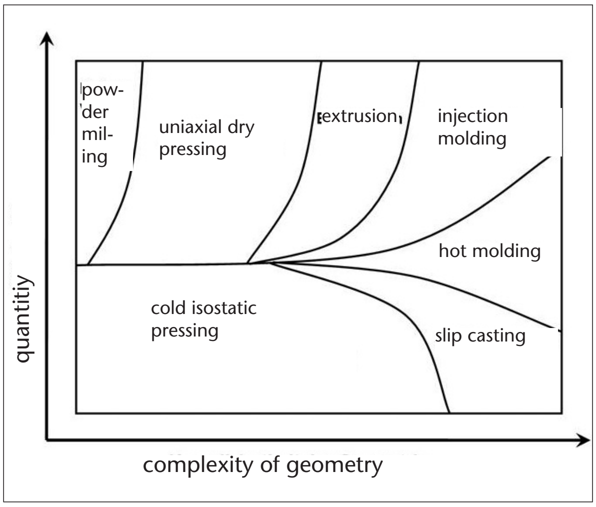


Fig. 1
Selection of shaping method in dependence of geometry and quantity

Many technological solutions successfully realized in practice, thus, prove the high potential of plastic and thermoplastic shaping methods. At the example of two current developments the interaction of specific requirements, material concept,

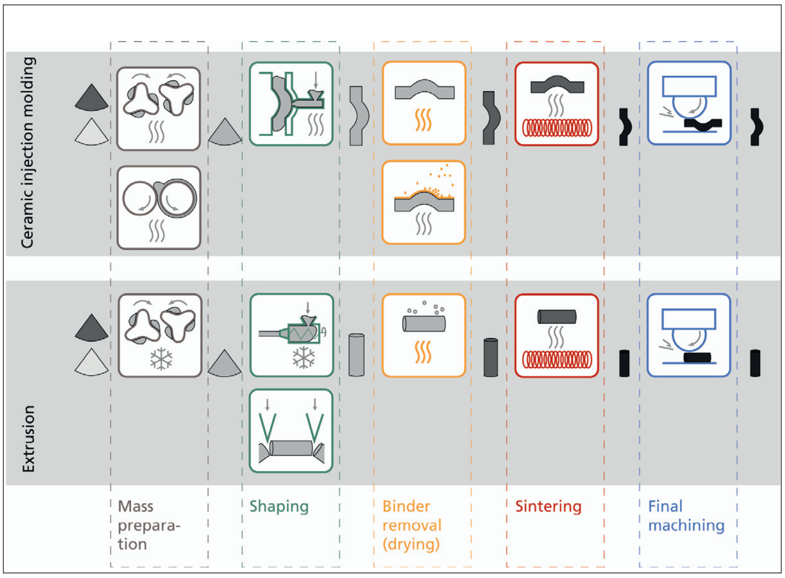
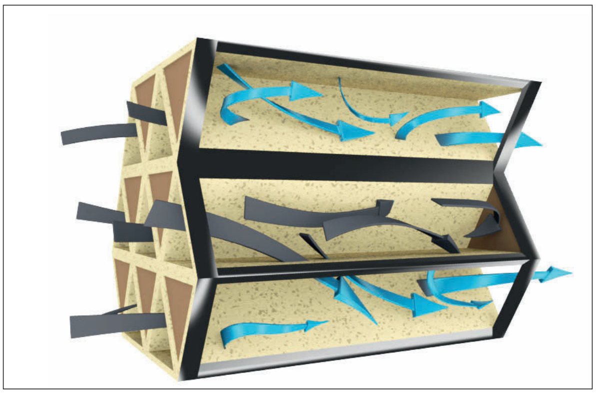


Fig. 2 Schematic of the process steps in ceramic injection molding and extrusion

1) Topic and introductory lecture of the DKG autumn symposium 2009/Erlangen



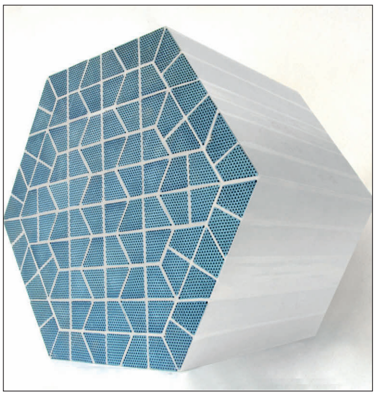


Fig. 3 left
Schematic of filtraton process with three-cornered, reciprocally closed channels

Fig. 4 right
Diesel particule filter (CleanDiesel-Ceramics GmbH) with a segmentation of asymmetric components

product design as well as manufacturing technology is shown.

Highly Efficient Ceramic Diesel Particle Filter of CleanDieselCeramics GmbH[2)]

Whereas diesel particle filters for cars can be produced in high quantities and are standardized the filters for non-road applications are characterized by an extremely high degree of diversification in terms of batch size and geometry. On top of it, the filters have to meet even higher requirements with regard to ruggedness, longevity and efficiency. Therefore, a new filter material of liquid sintered silicon carbide (LPS-SiC) was developed and adapted for use in diesel particle filters in terms of size, distribution and volume of its pores. The raw materials are comparatively inexpensive and can be handled at lower temperatures as well (approx. 400 K lower than the state of the art). They have a top position among the ceramic filter materials regarding separation efficiency (99,5 %), pressure drop and thermomechanical stability.

By a new filter segment design with asymmetric trapezium geometry it is possible to flexibly produce the great variety of filter geometries and sizes. At the same time, the costly hard machining step with diamond cutters can be avoided which usually results in approximately 20 per cent of material loss. Thus, material and energy resources can be carefully used. The channels in the segments are three-cornered (Fig. 3), not square, providing a larger filter surface. This means that, fitted behind the engine, it takes longer for sooty particles to accumulate in the individual channels and to reach the stage where they must be burnt off. The regeneration cycle, thus, can be prolonged and fuel can be saved. Due to this design the filter element is also more resistant against mechanical stress and so more robust.

Following the product concept with the asymmetric segment design, it was then necessary to overcome various technological challenges. So the geometrical and position tolerances required for the canning of the filter elements, which are usually guaranteed by the machining step, already have to be realized in the ceramic shaping process. For this a specifically developed bonding technology is used which can be adjusted to all geometries. The plugging process (more than one hundred cells per segment in a few seconds) also represents a particular challenge.

The diesel particle filter (Fig. 4) has been produced in the new production facilities of CleanDieselCeramics GmbH in Großröhrsdorf near Dresden since 2008. In 2009, the concept was awarded with the Joseph von Fraunhofer prize.

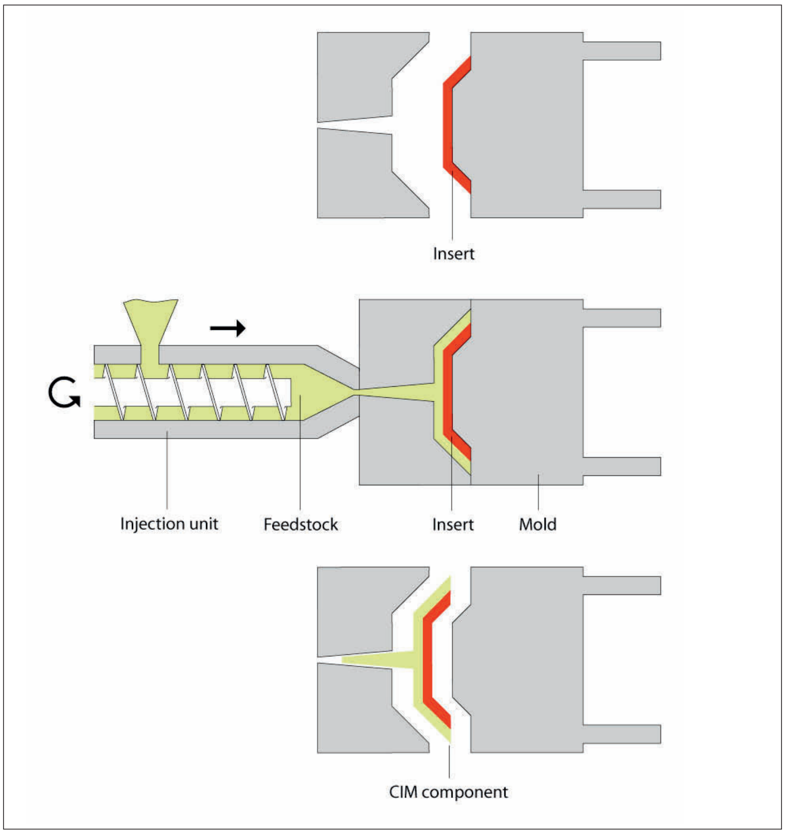


Fig. 5
Schematic process of injected green tapes made of powder materials

Inmold Labeling of Metal-Ceramic Composites[3)]

The development of new material applications are mainly motivated by an improvement of performance as well as a reduction of costs, weight and space. By combining different material properties the functional density may be increased. The combination of powder injection molding and green tape technology offers interesting possibilities for designing multi-component parts. In inmold labeling the main challenges are the compatibility of the used materials and the adjustment of the shrinkage properties during the debinding and sintering process. It is one main advantage of this method that the manufacturing of components with thin functional layers is significantly simplified, and thus, it can be more reliably transferred into mass production as the actual injection molding process

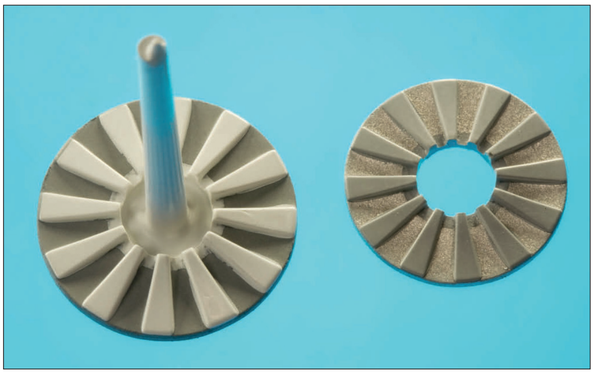


Fig. 6 Prototype, project "GreenTaPIM"[3)] (left after deforming, right sintered part)

remains reduced to one component. The composite is realized by inserting prefabricated green tapes made of a powder material into the cavity, which are then injected with a feedstock made of another material (Fig. 5).

Ceramic or metal green tapes can be produced in different layer thicknesses and stamped by suitable posttreatment processes, i.e. microstructuring, screen printing, lamination and punching. In the injection process the inserted thin-walled tapes may also take on the complex contour given by the cavities. At the same time, extremely thin functional layers made of metal or ceramic materials can be realized as there are no restrictions by limited flow paths as compared to conventional two-component injection molding. In order to compensate stresses caused by different thermal expansion it is also possible to design the green tapes as laminar structure with a continuous transition of the material composition. Such an example is shown in Fig. 6. The punched green tape made of powder steel was inserted into the tool cavities by means of an automated handling system, and then injected with a zirconia feedstock and sintered as composite.

Prospects

First of all ceramic shaping methods must guarantee that the properties expected from the material are reliably transferred to the component and may be well reproduced. As the price is important for the success of a product in the end, the ceramic shaping method must additionally allow for an efficient production of the component in the required geometry and quantity. However, as necessary as these both requirements are – in order to develop new ceramic applications they often cannot compete with other material solutions. The important it is to consider the technical possibilities already in the product development process and to utilize all degrees of freedom given by the specific production processes. Then, ceramic shaping can be much more than a means to an end: an important driver and a solid basis for ceramic innovations in new attractive applications. The realization of new material concepts using innovative plastic and thermoplastic shaping methods can make an important contribution to this process. For this purpose, joint efforts of material development, manufacturing technology and system application are necessary.

2) A joint development of Fraunhofer IKTS and CleanDieselCeramics GmbH, financed with funds of the European Regional Development Fund (ERDF) during the period 2000–2006 and the Free State of Saxony. The project partner, funding organization and project management are gratefully acknowledged.
3) Funded by the Federal Ministry of Economics and Technology (BMWi) within theframework of the InnoNet program (16IN0319). The project partners, funding organization and project management are gratefully acknowledged.