Ceramic Injection Moulding: Binder innovations and Additive Manufacturing open up new opportunities

Ceramic Injection Moulding (CIM) is receiving ever more attention as a process for the production of complex shaped components in high volumes and to tight tolerances. As Dr Karin Hajek from Germany's Inmatec Technologies GmbH explains, there have to-date been a number of obstacles to the increased adoption of the technology. The availability of a wider range of binder systems, combined with the opportunities presented by ceramic Additive Manufacturing, may now open the door to a new generation of applications.

Ceramic Injection Moulding is a shaping technology for ceramic parts which offers significant advantages when complex geometries and high part numbers are required. The technology offers the ability to produce complex, three-dimensional designs to a high dimensional accuracy and with a high quality surface finish. Using ceramic powders, parts can be manufactured that meet the highest technical and aesthetic specifications. Narrow tolerances enable the production of complex parts in a single moulding step, so expensive post-processing is rarely needed and the mass production of highly complex ceramic parts is supported thanks to a high degree of process automation.

When looking to the worldwide Powder Injection Moulding (PIM) market, the Metal Injection Moulding (MIM) industry holds the major share, with global growth estimated to be in excess of 12% a year. Broadly speaking, CIM is thought to be around ten years behind MIM in terms of market penetration, but a faster development of the CIM market has been observed. This is supported by positive sales growth for CIM feedstock at Inmatec Technologies GmbH. In 2017, the company experienced its best year ever and the outlook for 2018 is even more promising.

One of the main drivers for the MIM business comes from Asia and is fuelled by the dynamic computing, communication and consumer electronics sector (3C), for which MIM parts are made by the million.

CIM parts are used for structural as well as for functional applications. However, it is the market for coloured zirconia for aesthetical applications that has grown very strongly over

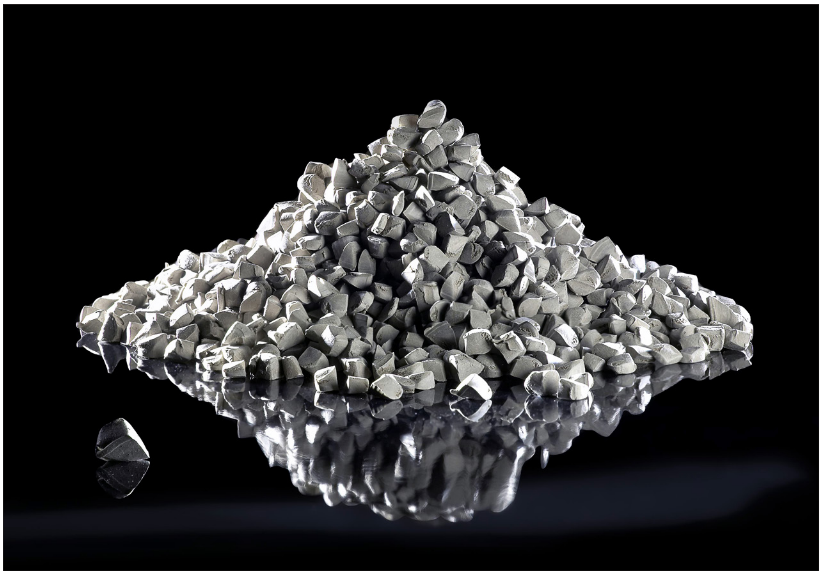

Fig. 1 Feedstock for Ceramic Injection Moulding manufactured by Inmatec Technologies GmbH

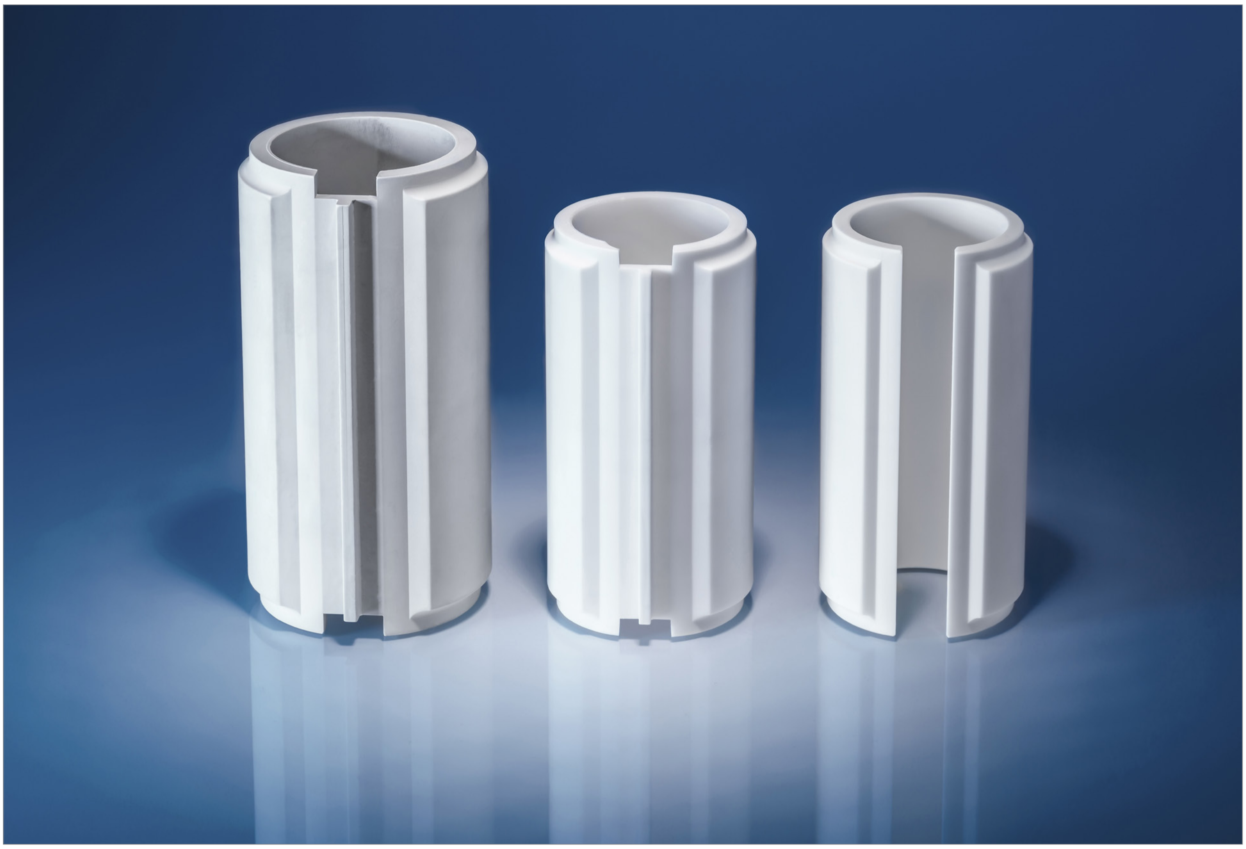

Fig. 2 A CIM thermal insulation tube in the green, sintered and finished states. The tube has been produced with the INMAFEED alumina based feedstock INMAFEED K1008. The dimensions are remarkable: the overall length is 89 mm and the green weight is 335 g (Courtesy Kläger Spritzguss GmbH & Co. KG, Germany)

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The production of translucent CIM parts is also a strong growth area for the industry. The production and processing of feedstock based on ultrapure Al_2O_3 powder for translucent CIM parts is, however, challenging. Parts without any grey tint can be achieved, along with high mechanical strength in the final part, but the entire processing chain must be strictly controlled so that any contamination with metallic particles is prevented. The sintered products must also be free of porosity and the grain size should be smaller than the wavelength of visible light, i.e. 400 nanometres. Substantial efforts have been made at Inmatec to develop this type of feedstock.

In the world of functional ceramics, the demands for more complex multifunctional components has led to the application of CIM parts in a wide range of industries. One example is an innovative glow plug for diesel engines which helps to reduce NOx emissions. These are made from four different ceramic materials, which are co-sintered in one step.

Titanates, with a positive thermal coefficient (PTC), enable the reduction of electrical consumption by 90% in some applications. This enables a longer period of operation for battery powered devices. Here, CIM parts have the added benefit of enabling the production of complex 3D geometries and uniquely thin walls.

These unique advantages of CIM will become even more important in the future, particularly for the automotive industry as it moves towards electrification. The continuously increasing need for electronic parts, coupled with miniaturisation and reduction of powder consumption, is expected to lead to a further accelerated growth in the CIM industry beyond 2020.

What will accelerate CIM's growth?

In order to answer this question, we need to look at the obstacles currently restraining the faster development of CIM parts. At least three related factors can be identified.

Firstly, the CIM parts to be produced now and in the future might have or need:

- Very thin walls combined with long flow distances
- Smaller or larger dimensions than usually considered for CIM parts
- The possibility to allow for green machining
- Green part stability for mass production
- A robust process.

Secondly, the production of all ceramic parts takes time. The production of CIM parts, however, takes even more time because of the long debinding and sintering steps.

Thirdly, for the fast production of high volumes of CIM parts, multi-cavity or multiple moulds are required and the design and the construction of these also takes time. Moreover, a mould is needed at an early stage of the development process in order to evaluate prototype parts. This means that a relatively high investment has to be made with no guarantee of a successful outcome.

In order to address these factors, Inmatec has worked to meet the requirements of the CIM market. The demand for extending the dimensional range of CIM parts, as well as the other requests, have fuelled the R&D activities within our company. Alternative thermoplastic binder-systems have been developed and evaluated and there are now three binder-systems available based on differing thermoplastic base materials. These are available either in combination with the ceramic materials that we offer as 'standard feedstocks' or as custom ceramic feedstocks.

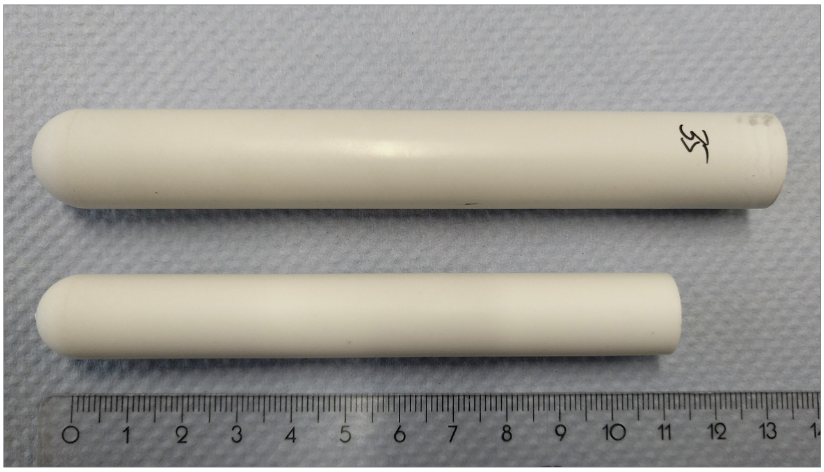

Fig. 3 A CIM tube in green and sintered state made from the feedstock INMAFLOW K2012. The flow distance is more than 130 mm combined with a wall thickness of 2.3 mm (Courtesy Fraunhofer IKTS, Germany)

The three-binder strategy for CIM feedstocks at Inmatec

Depending on the properties of a CIM part, its production volumes and any regional regulations and market needs, a customer can choose one or more ceramic feedstocks based on Inmatec's three different binder systems.

Polyolefin/wax based systems
Inmatec's INMAFEED feedstocks work on the basis of a polyolefin/wax-based binder system. The debinding stage is based on a two-step process, with the first step in water and the second step in a thermal debinding furnace with precise temperature control. This wax-based system has been approved for many years and works without any chemicals or acids. An example part is shown in Fig. 2. The total time needed for debinding parts ranges from 32 to 120 hours, depending on part geometry, wall thickness and the physical properties of the ceramic powder used in the feedstock. Very fine powders, such as zirconia, need the longer debinding times.

Polyamide based systems
The INMAFLOW feedstocks work on the basis of a polyamide-based binder system. These show low viscosity and are perfect for thin walled parts and long flow distances (Fig. 3). Debinding is again a two-step process, with the first step in acetone and the second step via thermal debinding, as with the wax-based feedstocks. Here, the debinding time ranges from 32 to 70 hours.

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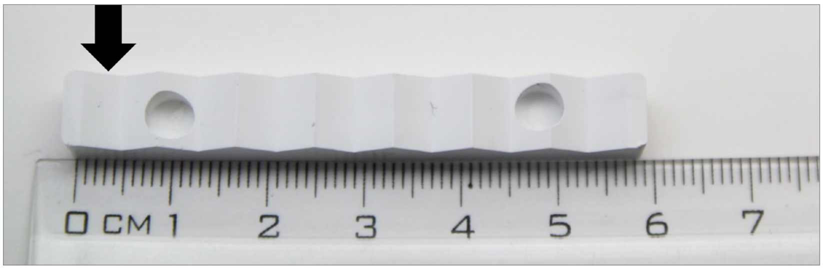

Fig. 4 The test part is a bar with rectangular geometry, a toothed surface and two out-of-line cores. The arrow marks the gate position

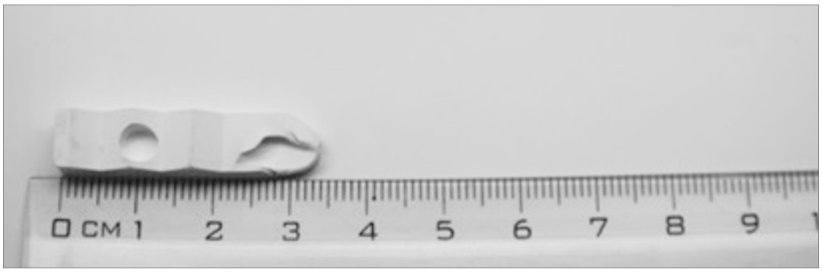

Fig. 5 Typical flow behaviour is observed with the INMAFEED zirconia feedstock. The flow fronts are not completely joined, however this would happen by completely filling the mould

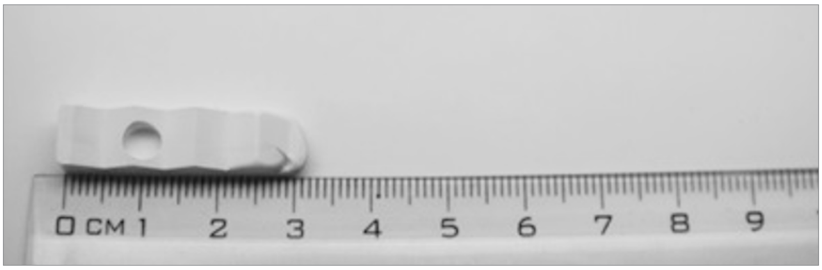

Fig. 6 The flow behaviour which can be observed with the INMAFLOW zirconia feedstock looks similar to that of a plastic material. The flow fronts are almost completely joined

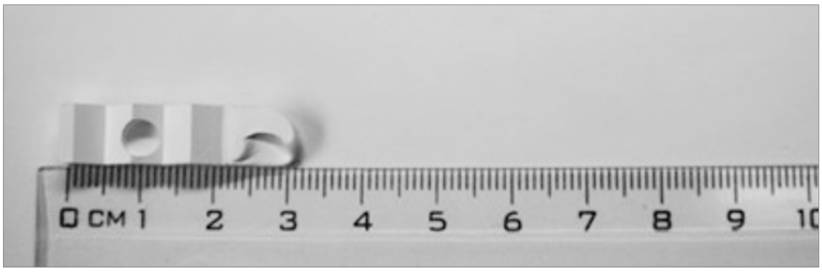

Fig. 7 The typical flow behaviour is observed with the INMAPOM zirconia feedstock. The flow fronts are again not completely joined, this will happen by completely filling the mould

Polyacetal (POM) based systems

Our INMAPOM feedstocks are based on a polyacetal binder (POM), a semi-crystalline thermoplastic material with good processing characteristics, high dimensional stability, high rigidity and good warm strength. Debinding takes place during a single debinding stage in a catalytic debinding oven.

The catalytic debinding process, which is widely used in the PIM industry, can be used as part of a fully automated production process with continuous 24/7 operation. The time needed for debinding ranges from 2 to 24 hours, significantly increasing with greater wall thicknesses.

Process support and application development

All three binder systems can be operated in a semi-automated or fully automated production process and the necessary equipment for efficient debinding of PIM parts is widely available. However, support for optimising the processes can be provided by Inmatec. We are able to perform injection moulding trials and all debinding and sintering processing in our own CIM laboratory.

When it comes to selection of the appropriate binder system, this is ideally based on a part's properties. To demonstrate the differing flow behaviour that the feedstocks exhibit, the flowabilities of the feedstocks have been compared using a unique test mould (Fig. 4) developed by Germany's Expertenkreis Keramikspritzguss (CIM Expert Group), a network of German speaking CIM industry suppliers, researchers and component manufacturers.

It is known that the flow front of a ceramic feedstock behaves differently to that of a thermoplastic material. Plastic materials show a swelling behaviour during injection as well as the willingness to join flow fronts again after splitting. Ceramic feedstocks do not show any swelling behaviour and, once split, the separate flow fronts cool down and are usually difficult to re-unite. In this test mould, the flow front of the injected feedstock is split immediately by the first core. The behaviour of the feedstock flow behind the core is interesting.

The flow behaviour has been observed by means of a short-shot study conducted with all three feedstocks, processed with the same zirconia powder. What can be seen is the differing flow behaviour of each of the three feedstock types (Figs. 5-7). This behaviour should be taken into consideration when deciding on a feedstock for a new application, although other factors such as part size, geometry and number should also be considered.

We are able to support customers along the whole process chain, from part design and feedstock selection to series production. Our injection moulding experts are, in particular, able to support customers during development and optimisation of their injection moulding operations.

Embracing ceramic Additive Manufacturing

Coming back to the original question of what will accelerate the growth of the CIM industry in the immediate future, another processing innovation of great importance is Additive Manufacturing (AM). In general, Additive Manufacturing technologies offer the possibility of the tool-free production of components with complex geometries in a short period of time.

Coming back to the argument of the long time period needed for a CIM component to reach series production, Additive Manufacturing now offers a number of solutions for the ceramics industry, one being Fused Filament Fabrication (FFF), also known as Fused Deposition Modelling (FDM™). This is a manufacturing method in which an endless filament is used as a semi-finished product which is melted and deposited under a heated nozzle.

Ceramic filaments for FFF have been developed by Fraunhofer IKTS, Dresden, and Inmatec (Fig. 8) [1]. With a ceramic filament made from INMAFLOW K2010, ceramic parts have been produced using FFF which shows a dense microstructure after sintering thanks to the highly filled nature of the feedstock (Fig. 9).

The advantage of this shaping process is not only its speed, but also the fact that no mould is needed. The part is directly formed during deposition of the filament made from the ceramic feedstock [2].

INMAFLOW K2010 filament satisfies the requirements of elasticity and printability in standard FFF devices and after printing, the parts are debound in a solvent and processed further in a typical CIM-like way.

Fig. 8 Filament coil made from INMAFLOW 2010 (Courtesy Fraunhofer IKTS, Germany). This was developed as part of a project supported by Germany's Federal Ministry for Economic Affairs and Energy (BMWI) with the "Zentrales Innovationsprogramm Mittelstand" [1]

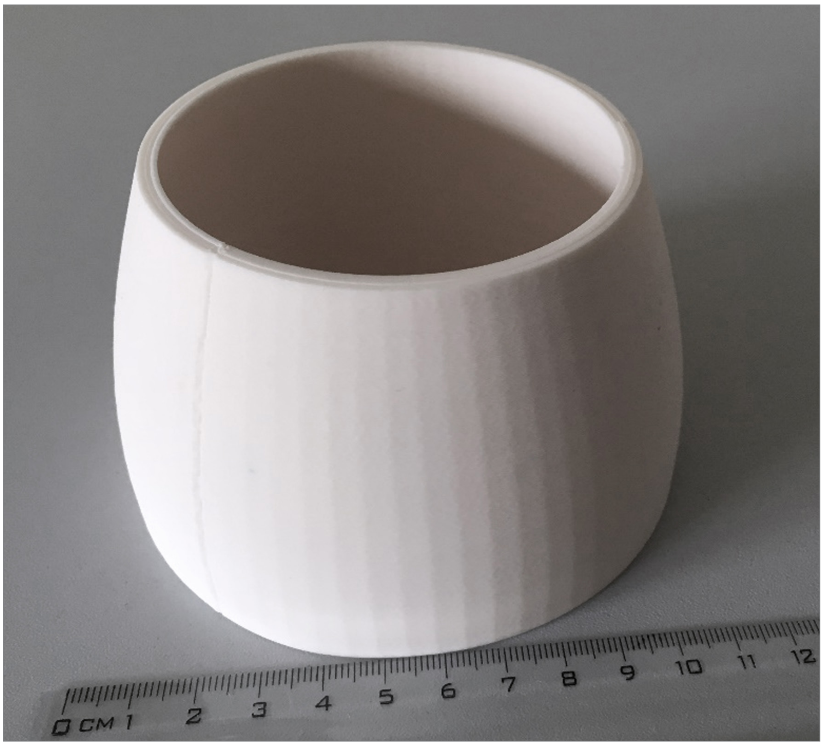

Fig. 9 A sintered Al2O3 laval nozzle made by FFF (Courtesy Fraunhofer IKTS, Germany)

The synergy of CIM and AM

What CIM and ceramic AM have in common is that ceramic parts with complex three-dimensional designs can be produced. By combining the shaping methods, a customer has the possibility to evaluate and test real parts in operation. It is simple and quick to modify parts as often as needed – they can easily be manufactured with the same or altered geometry again by FFF.

Having established the optimal part design using FFF, the next step can be undertaken; the construction of a mould to transfer the production of the part to volume production by CIM. The parts that are produced in high volume by Ceramic Injection Moulding use the same raw material - the ceramic feedstock.

Currently the quality of the FFF part in terms of surface finish and tolerances is still lower than the high dimensional accuracy and high surface quality of CIM parts. In principle, however, the necessary machinery for FFF is already available. Going from three to five axis movement and adding machine heads for subtractive processes, for example machining or drilling, will extend the possibilities and the quality of FFF parts substantially. FFF parts can then be created that meet the highest technical demands and aesthetic standards. Cost reduction and faster component development times are therefore important advantages that AM offers to CIM producers.

Combining AM and CIM for finished products

In the near future, there will be a further connection between AM and CIM. For example, parts could be injection moulded by CIM, followed by an individualisation process by AM. The combination of these technologies would allow the individualisation of production components produced in high volumes.

A piece of ceramic jewellery, for example, could be created with unique details. This flexibility could be taken to the point where the end customer chooses or designs the individual features which are applied to a piece of jewellery. This combination of ceramic shaping technologies could also lead to medical customised products covering a very wide range of applications, from dental parts to surgical tools to other medical devices.

Outlook

Through the ongoing development of binders and feedstocks for advanced ceramic forming applications, Inmatec is well positioned to support its customers in the creation of new applications using CIM and AM technologies. This development is also taking place on a European level through participation in European Research Projects such as CerAMfacturing [3] where, amongst others, the combination of AM and CIM is a main topic.

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[3] European Research Project called CerAMfacturing, Grant Agreement No 678503