Additive Manufacturing versus CIM, a Business Case

The need for small parts shaped in zirconia or alumina oxide isn't new. Before, many shaping methods such as pressing in combination with machining or Ceramic Injection Moulding were able to serve this market need clearly. However, in the current rapidly evolving market, the requested small parts demand increasingly more complex geometries, shorter lead times and more design freedom. Geometries that challenge todays standard shaping methods create new opportunities for the equally fast emerging Additive Manufacturing technologies. What can this bring for the world of ceramics?

Fig. 1
Example of a small CIM part (courtesy Formatec/NL)

The 3D printing market for ceramics

Small and more complex parts are in demand in various markets. Typical demands today come from parts for surgical instruments, laboratory equipment, fibre ferrules and small sensor components. The market is looking for a higher amount of flexibility during the development cycle, whilst demanding for functional parts to directly apply tests. Secondly the ability to change the design along the development route is a kind of flexibility strongly in favour of R&D teams. For totally new applications or products with an increasing integration of functionality, where ceramics might not even have been applied before, high tech components and machine parts cover the midrange market. Low volume (5–50 per year) complex parts with internal channels such as heat exchangers, mould inserts and fusors profit from increasing production technologies end design freedom.

Keywords
additive manufacturing, ceramic injection moulding

CIM – Ceramic Injection Moulding

Once substantial production series are required, the CIM process is a good production method for shaping small and relative complex components. After design freeze a typical development time of 8 to 12 weeks applies for mould manufacturing and production of zero series for part release. Once qualified the CIM process benefits from the ability to upscale to higher production quantities easily. Typical production volumes for smaller parts range from 1000 to 1 million pieces on an annual basis.

Fig. 1 gives an example of a small CIM part. The part is a glass fibre ferrule featuring 64 octangular shaped holes of each 125 µm positioned on a surface of 2 mm × 2 mm. The demonstrated piece is as injection moulded without any post machining steps. It is important to highlight that developments for injection moulding small CIM parts does continue. A good example are the activities of the EU funded project HiMicro. Using Additive Manufac-

Bart Kooijmans, Michiel de Bruijcker
ADMATEC Europe BV
5066 GJ Moergestel
The Netherlands

info@admatec.nl
www.admatec.nl

turing (AM) to produce monolithic tool inserts with integrated complex internal channels for efficient thermal management and process control, is one of the core objectives of this project. Formatec Ceramics is partner in this project and demonstrates the next step of CIM possibilities.

Additive Manufacturing

First introduced in the mid eighties for modelmaking and prototyping, the layered manufacturing techniques have expanded and evolved rapidly into highly accurate manufacturing technologies. They are no longer making prototypes, but are now also producing fully functional end-products in many materials such as plastics, metals, ceramics and even biomaterials and food. The "staircasing effect" due to rough stacked layers that many remember from the first rapid prototyping machines, has been reduced to smooth surfaces by postmachining or due to building Z layers being reduced to steps in the 20 µm area. With resolutions in X-Y area reaching 15–50 µm, far exceeding Full HD quality, and building speeds and volumes ever increasing, the road is open to manufacturing highly accurate end products.

Using the DLP technology for AM of ceramic parts has an extra useful advantage; the layers are cured in one total projection per layer. So the building speed is not dependant on the amount of products placed in the building area. If a 100 parts fit, they are built equally fast as 1. This is where AM becomes interesting for small series production, eliminating throughput time and costs for tooling. Also the way this AM technology is applied as a job service at Admatec, there is virtually no waist of raw material, where CIM technology needs to fill up hoppers and apply runners that cannot be re-used.

This makes the main benefits of current AM:

1. High accuracy parts (15–50 µm print resolution) without loss of building speed (several hours) or building volume (130 mm × 70 mm × 400 mm [Z])
2. Building speed independent on amount of parts fit on platform (up to 750, see case 1)
3. Complexity of the part is not of influence on the price and can be far more complex than with conventional shaping methods.

Fig. 2–3
Parts of the cases

A case study

For this case study several types of products were evaluated. The cases presented cover a part of a surgical instrument designed to guide a wire and a technical part of a sensor housing. Fig. 2–3 show parts of these cases. Typically iterations in design were performed using resin (micro) SLA models. These only supply answers for geometrical fitting tests, the PU resin does not have the further specs such as the designed ceramic product. With ceramic AM parts, three evaluative steps were executed before a final design was frozen for functional testing. A further 25 parts were printed for this testing purpose. After approval, the design was still open to CIM or AM manufacturing. In Fig. 4, parts of evaluative steps and first AM produced parts for functional testing are shown.

Yearly production quantities were forecasted at 10 000, expected to rise to 25 000 in the years to come. Product life cycle was set at 5 years, however this was based on current models of mould life expectations, it was not driven by innovation nor by marketing desires.

CIM manufacturing would require a 4-cavity mould with one slider, commercially quoted at EUR 18 000 for the required tolerances and a shot guarantee of 150 000 parts. Part price would be 0,45 at MOQ 5000, production capacity due to cycle time and 4-cavities would be 3840 parts per day. That is in case of production without automation for unmanned night production. Typical throughput time for the tool was 8–12 weeks.

AM ceramics is a more expensive process but makes no difference between protoparts, start-up series, first series and de-

Fig. 4
Parts of evaluative steps and first AM produced parts for functional testing

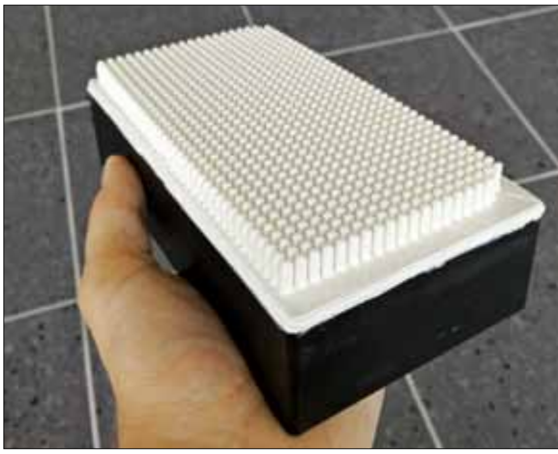

Fig. 5
Every 2 h a batch of 750 parts was produced with AM technology

sign changes along this way. First samples were printed and sintered in the evaluating steps as described above. Costs for these first low volume runs were considerable with single start-up costs at EUR 450 and EUR 34 per part. However these costs were justified because they prevented way more costly setbacks at following TRL levels in the product development cycle. A first zero series was produced within 3 weeks after design freeze including the sintering step. This saves the total costs and time for mould production. Further productions were made building 750 parts per run of 2 h (including machine setup times). This set the production rate at 4 × 750 = 3000 parts per day. For these batch sizes (as of OQ 500) parts were produced against EUR 2,10/piece.

Fig. 5 explains that every 2 h a batch of 750 parts was produced with AM technology.

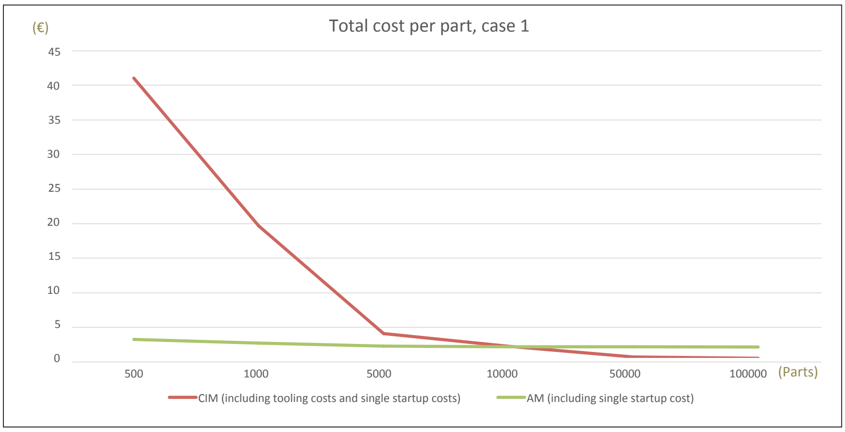

Fig. 6
Relation of costs versus number of parts totally ordered for case 1

Fig. 8
Sensor housing part in need of support structures when building with AM

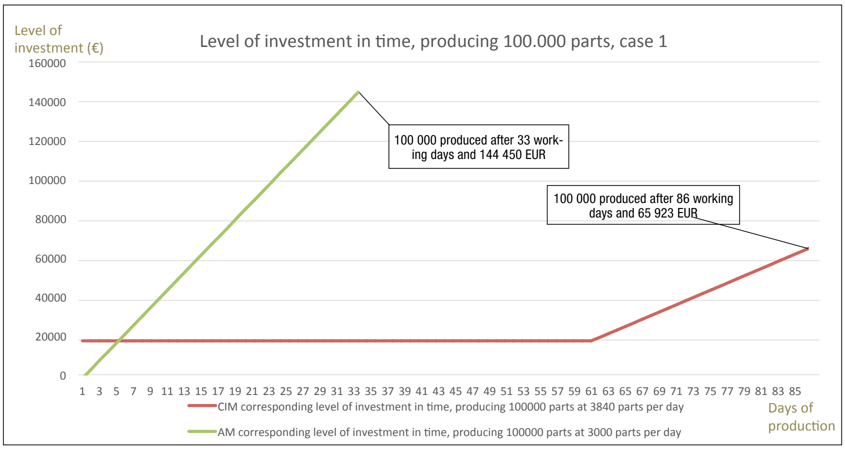

Fig. 7
Level of investment in time while producing a certain total volume for case 1

This put the breakeven point for AM versus CIM in this case at about 20 000 parts. Fig. 6 shows the relation of costs versus number of parts totally ordered.

Fig. 7 shows the level of investment in time while producing a certain total volume. At this stage the consideration would be whether a low cost, flexible and fast start-up and first two years is more important, or that trust in future sales is high enough to invest in a lower part price over the total product lifetime.

For AM the scale benefit is obtained by the ability to produce multiple parts in one run. In this case the geometry was beneficial to AM since many parts could be fitted in one AM production run. For parts where building Z height increases, building time and so costs increase rapidly for AM. Also if size increases in X-Y dimensions and so less parts can be produced per run, the balance shifts rapidly.

For comparison a second case is introduced. This part has a Z-height of 28 mm, needs support structures to be buildable with AM introducing costly manual reworking labour per part. And due to X-Y dimensions only 15 fit in one AM run. Fig. 8 presents a sensor housing part in need of support structures when building with AM. When compared to CIM the same graphs are produced and then it becomes clear that the break-even point for total cost per part is already at 600 parts. This produced volume being reached after 20 working days for AM and 61 working days for CIM due to throughput time for toolmaking. Shorter time to market and level of early investment will need to justify the higher costs per part for AM. It will take AM over 300 days to produce the full batch. This speed can however be divided by the available machines for parallel production, where in CIM this is not needed but also not possible because there is only one tool available. For quantities over 600, CIM rapidly becomes more interest-

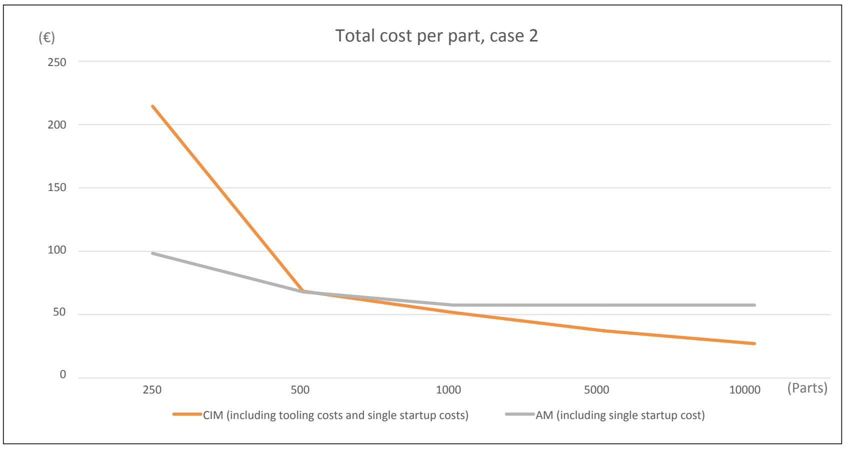

Fig. 9
The figure shows the relation of costs versus number of parts totally ordered for case 2

ing in terms of total costs per product (tooling costs included) and production time.

Fig. 9 shows the relation of costs versus number of parts totally ordered. Fig. 10 presents the level of investment in time while producing a certain total volume.

Conclusion

These new additive technologies are rapidly evolving and will most certainly acquire their place in the production chain within the upcoming 5 years. In the comparison with CIM (and probably also with other green stage producing techniques), they will probably eat away from the lower volume productions (1–10 000) of smaller products (<50 cm^3). The far bigger impact however will be found in the new great production flexibility and design freedom. New integrated products can be made providing new functionality and decreasing technical limitations. These parts can only be made with AM and will in their unique application justify their productions costs. Typical series will be 10–50 against costs up to 2500 EUR/part for high tech machinery or space and medical implants.

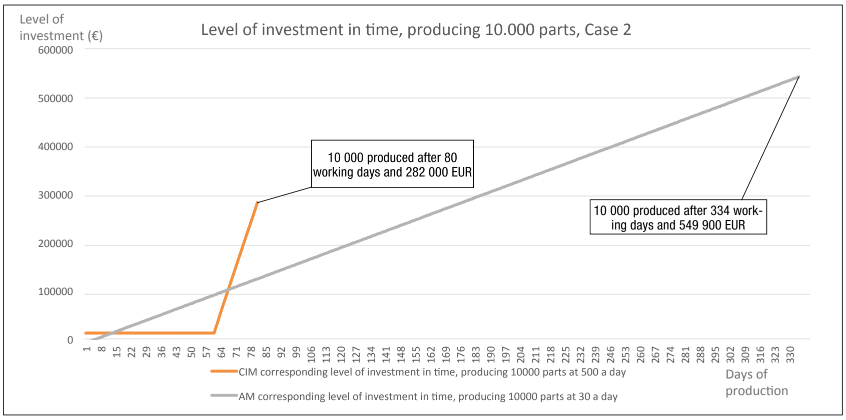

Fig. 10
The figure shows the level of investment in time while producing a certain total volume for case 2