Ceramic Foundry Cores by 3D Printing

Ceramic cores are essential in the production of turbine blades and nozzle guide vanes (aircraft or gas). The blades attached to a shaft recover the combustion energy of the fuel and air mixture from the compressor and the injectors in the turbine combustion chamber.

Fig. 1
A new generation of foundry cores produced by 3D Printing

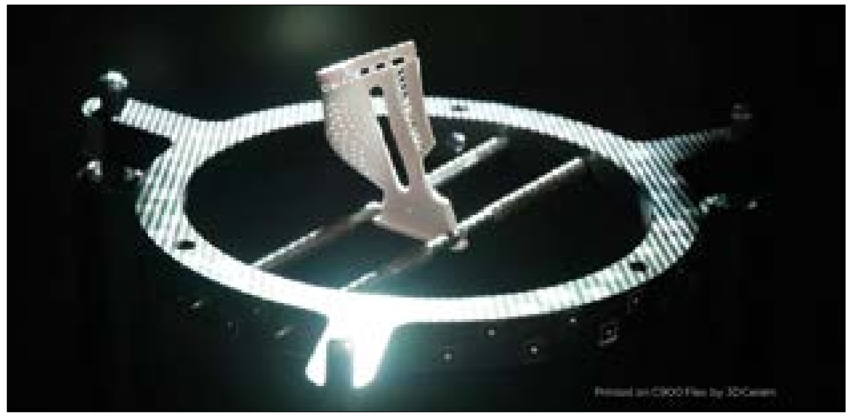

Fig. 2
Foundry core dimension scanning

Introduction

The purpose of the blades is to transmit the energy to the compressor(s), the fan blades or the alternator for land turbines (gas turbines). The temperature to which the blades are exposed is then higher than the melting point of the metal they are made of.

Consequently, the blade, although it is made of a refractory metal alloy to have strong mechanical properties at high temperature, is hollow to house the cooling system channels.

This cooling circuit is the form left by the ceramic core inside the part after it has been removed at the end of the precision foundry process.

The more elaborate the core design is the more efficient the blades are. This helps to reduce fuel consumption and consequently effects greenhouse gas emissions. The need for cores with complex shapes has increased considerably, with customers demanding ever-smaller, more efficient engines at lower costs.

Keywords
3D printing, foundry cores

What impact will 3D ceramic printing have on foundry core production in the future?

Traditionally, cores are made by injection (CIM). The CIM process is a fast process using difficult-to-produce and costly tooling. This process (CIM) is complicated and suitable for strippable shapes. As the designs of the cores become more and more complex (double-skins or even triple-skins), it becomes more and more complicated to make them simply by injection, without having to manufacture them in several parts that are assembled to form the core.

Difficulties can arise at every stage of the production process, particularly when assembling the different parts. As a result, the production success rate of finished parts is very low. In addition, the development of new core forms by CIM is time-consuming and costly, since several moulds must also be developed each time.

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Within U3DC, 3DCERAM and Avignon Ceramic are developing a new 3D printing process for the production of ceramic foundry cores for turbine blades. This new approach enables us to make without moulds and other tools, and to manufacture “complex” cores in one piece. The other advantage is that the rest of the manufacturing stages of a blade remain unchanged compared with CIM.

- Once the core is manufactured by CIM or 3D, it is placed in a mould into which wax is injected.
- The wax cores are assembled in a cluster structure and then coated with several layers of ceramic forming a shell.
- The cores surrounded by wax, itself coated with the shell, are put in a dewaxing furnace, after which only the cores and the shell remain, ready to receive the molten alloy.

Types of moulding processes

There are three types of foundry casting: equiaxed casting, directed solidification casting and single crystal casting. These three methods require specific cores.

- During equiaxed casting. The mould walls are heated to just below the metal solidification temperature. When the molten alloy is cast, it stabilizes very quickly, creating polycrystals in the part. This is the least constraining method for cores. To do this U3DC developed Silicore EQX
- Directed Solidification (DS) casting. Through a controlled cooling process, a microstructure of long crystals adapting to the shape of a blade is created, thus reinforcing the strength at high temperature.
- Single-crystal casting is a technology similar to the DS method. In this process, cooling is perfectly controlled so that a single crystal is created during the cooling phase. Thanks to this process, the single crystal allows us to obtain the best performance. It should be noted that, for DS and SX, the stresses on the cores are much higher than for the EQX. For this, U3DC developed Silicore SX/DS.

In these different types of casting the foundry cores must respect and withstand many constraints:

- Dimensional tolerances
- The mechanical strength necessary for its handling, the injection of the wax and the holding during the casting of the alloy
- The roughness which determines the appearance of the channels inside the blade
- The porosity that will be necessary for the releasing of the core
- Etc…

All these characteristics can be obtained for cores manufactured by 3D printing.

Additive Manufacturing (AM) brings a new dimension compared to the traditional process. In addition to saving time and increasing the overall productivity of the projects, the technological innovations developed within the U3DC partnership, provide several advantages:

- Possibility of increasing the complexity of the cores to reduce the consumption of combustion engines
- Rapidity of new design creation
- Improved responsiveness and productivity
- Ceramics adapted to the different casting processes in order to maintain all properties throughout the production process of a blade.

Fig. 3
C100 CORE, 3D printer dedicated to investment casting

Tab 1
A comparative table of the quantity and time of manufacture for the same core on different machines

	C100 CORE	C1000 FLEXMATIC	C3600 ULTIMATE
No. of parts per platform	18	162	648
Time per part [min]	87	29	17
Production time [h]	26	80	182

Tab. 2
CIM and 3D printing properties comparison

		Avignon Ceramic SX	U3DC Silicore SX
Shaping		CIM	3D printed
Silica/Zircon		80/20	80/20
Porosity		29 %	32 %
MOR 20 °C		12 MPa	5 MPa
Impregnated MOR 20 °C		25 MPa	20 MPa
Surface roughness [µm]		2 µm	3 µm
Thermal expansion	20–1000 °C	< 0,2 %	< 0,2 %
	20–1500 °C	< 0,4 %	< 0,4 %
Cristobalite content	as fired	> 8 %	> 8 %
	after 1530 °C	> 60 %	> 60 %
Trace elements		✓	✓
Leachability		++	+++
Qualified DS/SX foundry		✓	✓

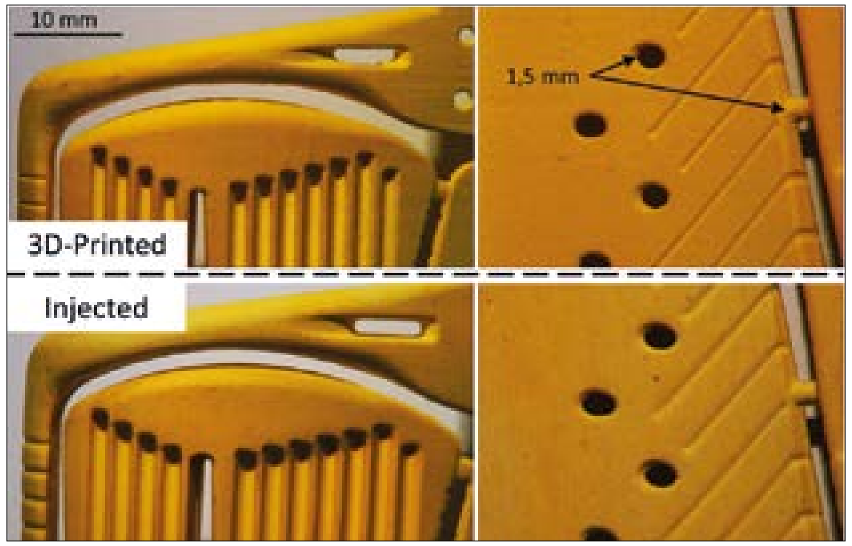

Fig. 4
The illustrations above show the comparison between part made by injection and one made by 3D printing

One of the main advantages of AM is the flexibility enabling us to increase the productivity of complex-shaped cores, thanks to a range of machines with the capacity to cover all requirements:
- C100 CORE to create, develop and qualify
- C1000 FLEXMATIC for production
- C3600 for mass production

- Materials used: Silicore / Eqx / DS and SX
- Core shells produced: 18,65 mm x 4255 mm (l) x 80,72 mm (L) mm, thickness from 0,5–4 mm

3DCERAM Sinto has developed turnkey solutions to enable foundry core manufacturers to benefit from the flexibility and production performance of cores through 3D printing.

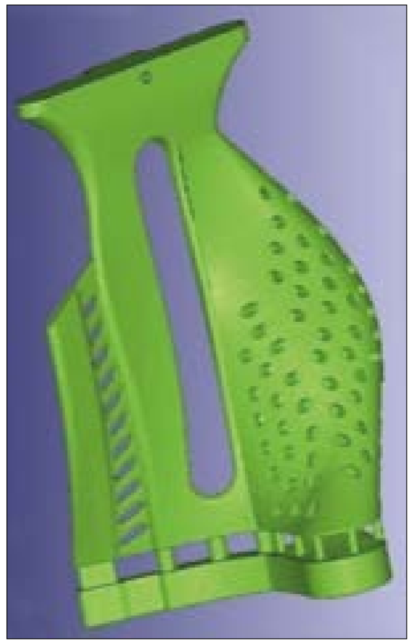

Fig. 5
CAD core file

Fig. 6
Core after printing and firing

Choice of material

The choice of ceramic material used to produce foundry cores is a key part of the 3D printing process. For this, it is important to consider different characteristics:
- The type of alloy used to produce the core.
- The complexity of the core
- No chemical reaction between the core and the metal should happen during casting
- It must be possible to release the ceramic material after the alloy has been cast
- A low CTE and a relatively high mechanical strength
- The casting type: EQX, DS or SX.

Silicore SX has been developed on the same mineral basis used by Avignon Ceramic for its ceramic injection molded cores. This results in similar casting properties between printed and injected ceramic cores (Tab. 2). Thus, the properties of Silicore SX printed ceramic cores make them ideally suited to the severe environment of the single crystal foundry.
However, the mechanical strength of the printed core is lower due to the shaping method. This can be managed by an increased monitoring of the metal casting conditions, especially for parts with relatively thin areas (e.g. use of platinum pins).

Examples of achievements

The illustrations above show the precision the details of 3D printing (without post-processing). It is possible to observe a better reproduction of the diameters of the holes on the printed part compared to the part injected in a mould which already shows some wear after 30 000 parts produced with it. The layering typical of 3D printing is practically imperceptible here due to the specific material/laser combination of the stereolithography technology used. The already relatively low surface roughness can be further improved by finishing the accessible areas.

Dimensional results

The 3DCS printing technology combined with the Silicore SX material allows to reach a very good match between the sintered parts and the dimensional shells of the different cores.
The advantage of 3D printing is that it is possible to quickly perform several manufacturing iterations, to optimise the specific shrinkage due to the geometry and the orientation of each part.

U3DC, a partnership that opens up opportunities

Thanks to the U3DC partnership, the range of mixtures proposed has been expanded to optimize the printing of foundry cores. These formulations have been developed to provide a product quality that is equivalent to traditional methods.
- Silicore Eqx (Equiaxe)
- Silicore SX, high temperature nickel based alloy
- Silicore DS (direct solidification) I

3DMix on demand – a service by 3DCeram

In addition to these materials, 3DCERAM Sinto can also develop customized formulations based on the customer's powder to meet his needs (3DMIX "on-demand" service). Customers can then have the properties of their ceramics, while using Cerambaker 3D printing technology. The process for obtaining a new formulation for cores is as follows:
- Characterization of the customer powder
- Formulation reactivity test after mixing with resins
- Optimization of the formulation and parameters settings of the 3D printer
- Benchmark Part production fired with the thermal cycle supplied by the customer.

This service allows the customer to keep the material he has previously qualified by offering identical properties for the 3D printed cores or other manufacturing processes.

Conclusion

The production of foundry cores by injection was until today a recognized expertise and savoir faire controlled by only a few actors. The use of 3D ceramic printing allows to us optimize the production of cores and to obtain long-term advantages for new actors.
AM brings a new dimension to the industrial process of precision foundry cores, by adding flexibility to the overall principle. It is now possible to quickly create cores with complex monobloc shapes, and to by-pass the assembly stage which is a source of rejects. Furthermore, additive manufacturing enables the preservation of all the ceramic properties that meet the innovation needs of current precision foundry. It is from this point of view that 3D printing serves the priorities of engine manufacturers, the first of which is to reduce the size of engines, their consumption and to improve efficiency. This approach produces very high thermal stresses on the turbine blades. Very com-

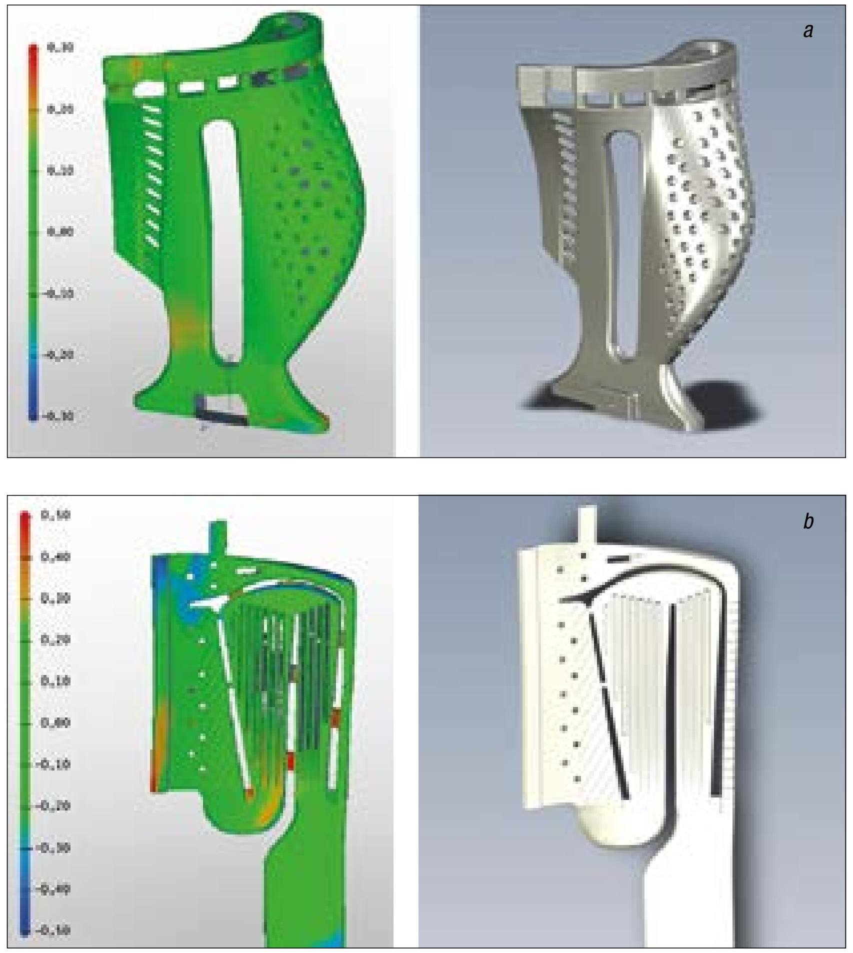

Fig. 7 a and b
The 3DCS printing technology combined with the Silicore SX material allows to reach a very good match between the sintered parts and the cad files. The advantage of 3D printing is that it is possible to quickly perform

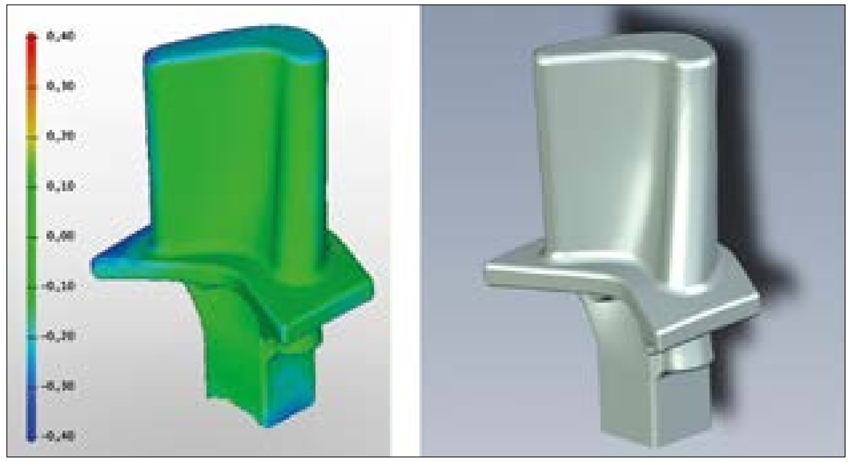

Fig. 8
shell and core can be printed simultenaously

Fig. 9 a and b
the silicore EQX, SX/DS versions developed for investment casting by U3DC

Fig. 10
3D printed ceramic core

plex designs are then, necessary to reduce the temperature with the circulation of the cooling gases.

This interest from aircraft manufacturers is evident from reading Smartech Markets, which projects a promising future for the manufacture of technical ceramic cores by 3D printing. The 3D printing industry for ceramic moulds and foundry cores is expected to represent the largest source of revenue in the decade 2017–2027. This encourages a shift of R&D into the production of technical ceramics. Estimations show an increase in revenues from USD 8 million to USD 1,1 billion.

3DCERAM, an expert in 3D printing, and Avignon Ceramic, a major player in the production of cores, propose to put this radical innovation technology (3D printing) within reach of the foundries with the U3DC partnership. Its ambition is to become an initiator of innovation in the field of precision casting.

Zoom on U3DC, the partnership of Avignon Ceramic and 3DCERAM

3DCERAM Sinto, an OEM recognized for 15 years for its mastery of the stereolithography 3D printing process of technical ceramics and its machines. Avignon Ceramic, a supplier for 30 years of foundry ceramic cores for the largest aero-engines as well as precision foundries;

Two market leaders join forces within U3DC to offer the world of precision foundry proven solutions both in the production of 3D printed ceramic cores and in the provision of turnkey solutions (machines, materials and processes).

The creation of U3DC is the answer to the expectations of the players in the precision foundry, foundrymen and core manufacturers, for a contact capable of offering a turnkey solution. This new service offered by U3DC ranges from the definition of the raw materials, according to the chosen alloy and the casting method, to the production of test cores to validate the process at the foundry.

3DCeram and Avignon Ceramic, with their experience and expertise, will accompany companies who wish to integrate 3D in the various stages of the process, and also to carry out tests with a view to integrate this new printing technology. In this way, the companies aim to meet the challenges of the future for precision foundry.