ANOTHER SIDE TO 3D

UV inkjet 3D printing focusses on the digital manufacturing of objects that cannot be produced by other 3D printing techniques or conventional manufacturing methods. Marin Steenackers explores its potential

Marin Steenackers is Project Manager at ChemStream

Over the last decade, 3D printing technologies such as fused deposition modelling (FDM), laser sintering (LS), and stereolithografie (SLA) have been developed for the manufacturing of prototypes (rapid prototyping), as well as finished products (digital additive manufacturing). Objects are usually printed with one single material, leading to the creation of products with one single set of material properties. A relatively young and strongly innovative branch within the 3D printing technology is UV inkjet 3D printing.

APPLICATIONS

Due to features such as high resolution and the possibility of producing multi-material objects, UV inkjet 3D printing technology has a huge growth potential with a focus on digital additive manufacturing. Furthermore, inkjet 3D printing is a highly productive digital additive manufacturing technology, which makes it applicable for industrial mass production. This was demonstrated at Formnext 2019, where German company DP Polar presented its circular AMpolar i2 3D inkjet printer with a $2m^2$ build area, 700-litre build volume and a printed parts output of 10l/h.

"The incorporation of nanodispersions in 3D-printed objects opens up a broad range of new material properties and applications"

By combining different printheads in one single print job, complex objects composed of several interwoven materials with different properties – mechanical (hardness, elasticity, etc.), optical (colour, opacity, refractive index, fluorescent, etc.), electrical (band gap, conductivity, etc.), chemical (hydrophilic/hydrophobic, etc.) and biological activity – can be manufactured. This allows the production of objects for applications in fields such as optics, automotive and bio-medical devices (micro-reactors and lab-on-a-chip).

ChemStream is mainly focusing on applications for which 3D inkjet printing is a unique production process, such as the digital manufacturing of Gradient-index (GRIN) optics or biocompatible multi-material micro-reactors.

Besides the ability to create a desired product, 3D inkjet printing is a versatile and flexible production method for small to medium-size production batches and allows a smooth integration with other production processes. Due to the high resolution of the inkjet 3D printing process, it is currently the only 3D printing technology that allows the production of objects for optical applications with optically smooth surfaces without the need for (usually complex and expensive) post-processing steps such as varnishing and polishing (see **Figure 1**).

HOW DOES IT WORK?

UV inkjet 3D printing uses UV-curable inks which are jetted with high precision (200–2400dpi) as small droplets (3–180-picolitre depending on the printhead technology) onto the substrate (drop-on-demand). The printer consists of one or more printheads, an optional

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Figure 1: Personalised 3D printed ophthalmic lens printed by Luxexcel with ChemStream optical ink.

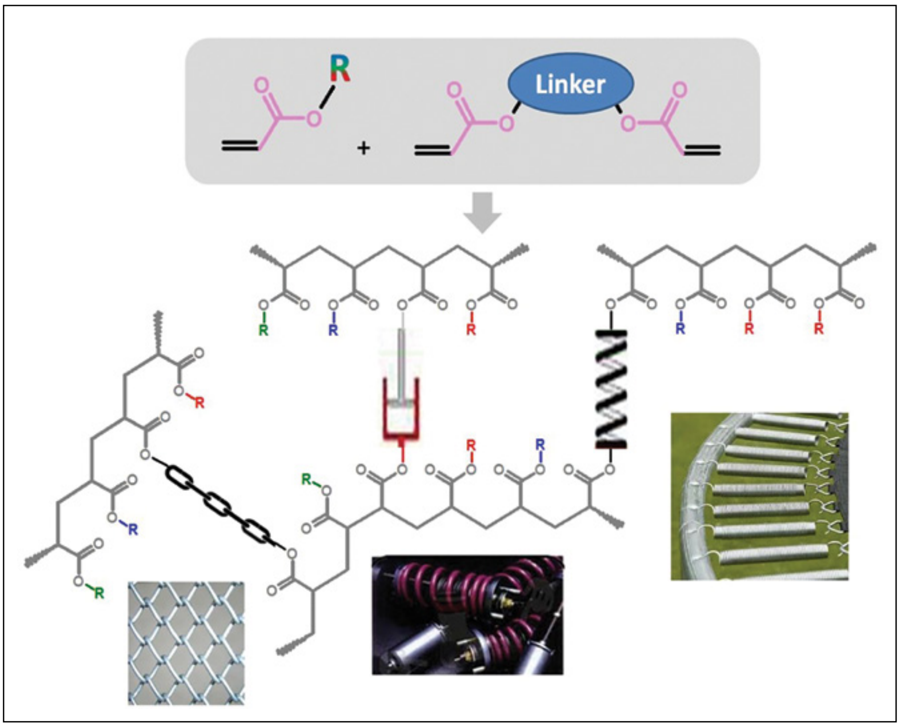

Figure 2: Employing molecular design and an intelligent choice of selected monomers, crosslinkers and oligomers, inkjet inks can be formulated which result in 3D printed objects with a broad range of mechanical properties

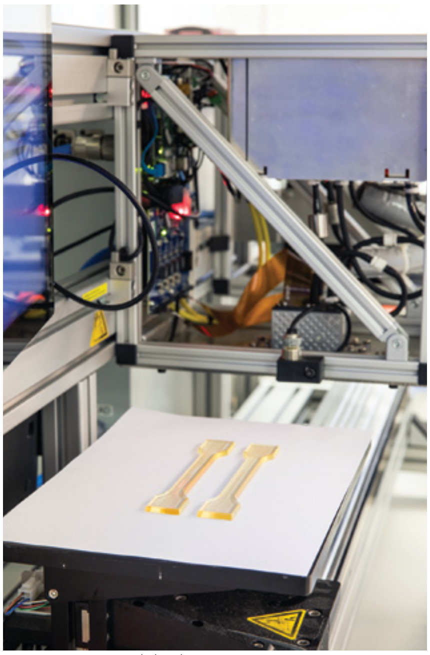

Figure 3: 3D-printed dog bones

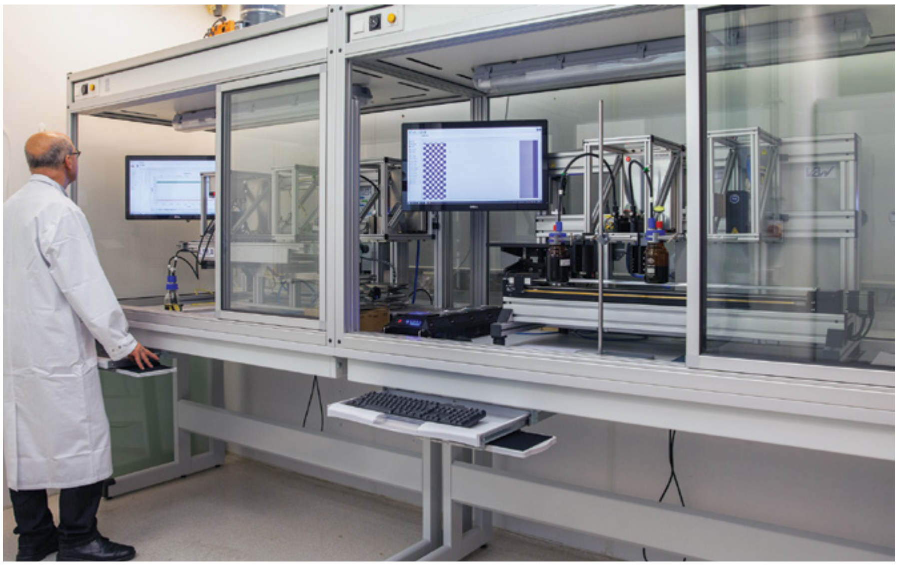

Figure 4: A modular 3D inkjet printing unit from VDW-Consulting. The printer is compatible with a range of industrial printheads such as Xaar, Toshiba-tec, Fuji Dimatix, Ricoh, Konica Minolta and Kyocera

leveller and a UV curing station. After being jetted, the drops can be flattened by a leveller before being cured. Then, the print table lowers down a one-layer thickness before the subsequent ink layer is printed. Similar to conventional graphical 2D inkjet printing (in which a colour image is obtained by jetting different colours simultaneously), inks with different material properties can be 3D-printed simultaneously. In order to increase the productivity for each material, different printheads can be placed in series. The voxel resolution [a voxel represents a single sample, or data point, on a regularly spaced, three-dimensional grid] is determined by different factors such as the drop size, printhead native resolution, multi-pass printing strategies and ink/ink interactions (spreading factor, overprintability, etc.). A lateral resolution of 25x25^2 microns can be obtained in combination with 3-micron resolution (layer thickness) in the Z-direction/axis.

"ChemStream has developed a water-soluble UV-curable inkjet ink that can be removed with tap water"

MECHANICAL PROPERTIES

With molecular design and an intelligent choice of selected monomers, crosslinkers and oligomers, inkjet inks can be formulated to produce 3D-printed objects with a broad range of mechanical properties. Upon UV-curing, the liquid inkjet inks are polymerised to one crosslinked entity. On a molecular scale, a crosslinked and branched polymeric architecture is formed. The mechanical properties of the crosslinked object are mainly determined by the molecular structure of the chemical groups (R) in the monomers as well as by the linker entities of the crosslinkers (see **Figure 2**).

Some linkers are molecular springs which result macroscopically in elastic materials, while other linkers are chemically rigid compounds which result in very hard materials. Some linkers act as molecular 'bumpers' and form materials with a high impact resistance. These diverse chemical building blocks can be formulated to obtain materials with desired properties (e.g. heat deflection temperature, hardness, elongation at break, tensile strength, E-modulus). Mechanical properties are optimised by consecutive iterations based on a Design of Experiment approach. For such an approach, it is essential to be able to evaluate ISO-normed test samples, such as 3D printed dog bones (see **Figure 3**) with a variety of ink formulations in a reasonable time. For such research, ChemStream uses modular R&D 3D printing units from VDW-Consulting that allow rapid ink changes, the use of a wide range of industrial printheads and determination of the print strategy by adapting the printing and curing process parameters (see **Figure 4**).

Figure 5: Preparation of an inkjet grade nanodispersion in a bead mill using tailor-made dispersing agents

EMBEDDED FUNCTIONALITY AND NANODISPERSIONS

Functional inks are obtained by the addition of specific additives. Depending on the application, the additives can be dissolved (e.g. a fluorescent dye) or dispersed (e.g. a pigment). A broad variety of functionalities (such as electrical conductivity, magnetic, high refractive index, high hardness, etc.) can be obtained by the addition of dispersed particles. For inkjet inks, the addition of high loads of such particles is highly demanding because the inks need to have a limited viscosity and must be jetted through micro-channels (nozzles). Low viscous nanodispersions have been used with well-controlled particle sizes and narrow particle size distributions. Such nanodispersions can only be obtained by advanced milling technologies in combination with specific dispersing agents (see **Figure 5**). Besides the use of commercial dispersing agents, dedicated tailor-made dispersing agents can be synthesised to transform a broad variety of solids into high quality inkjet-grade nanodispersions. The incorporation of such nanodispersions in 3D-printed objects opens up a broad range of new material properties and applications. In this perspective, UV inkjet 3D printing focusses on the digital manufacturing of objects that cannot be produced by other 3D printing techniques or conventional manufacturing methods.

"UV inkjet 3D printing opens up possibilities for the material science and digital manufacturing of tomorrow"

SUPPORT INK

In order to print complex geometries, a support ink that can be removed after the print job is required. Different support inks for inkjet 3D printing are commercially available. Most support inks are phase-change inks, in which a solid wax is jetted above its melting temperature or UV-curable inks that can be hydrolysed after curing in an alkaline bath. With both options, it is practically impossible to create very narrow channels since the support ink cannot be removed easily or in such extreme conditions (e.g. alkaline solutions at high temperature) that the object material deteriorates.

ChemStream has developed a water soluble UV-curable inkjet ink which can be removed rapidly in normal tap water. This support ink technology, in combination with advanced printing strategies, forms the basis for the manufacturing of micro-fluidic channels which are mandatory for high end bioreactors, microreactors and microfluidic mixers (see **Figure 6**).

WHAT THE FUTURE BRINGS

The translation of continuously new material requirements into industrially applicable 3D inkjet inks is a fascinating multidisciplinary research field. The realisation of new challenges is not only feasible by the design and synthesis of new molecular ingredients and advanced formulation technology, but also by developing new printing strategies and digital manufacturing processes. In parallel, much can also be gained by further developments of new printheads (higher viscosities, higher temperature, smaller drops, hybrid printheads) and printing robots as well as hybrid manufacturing processes. These developments allow the exploration of new material concepts. Although still in its infancy, UV inkjet 3D printing opens up a broad new variety of possibilities for the material science and digital manufacturing of tomorrow.

Chemstream will be attending INPRINT Münich on 22–24 June. Come and find them at Stand 417, Hall B5. ■

Figure 6: 3D-printed microfluidic channels for high end bioreactors, microreactors and microfluidic mixers

Marin Steenackers is Project Manager at ChemStream

Further information:
ChemStream bv., Edegem, Belgium
tel: +32 3 826 93 29
email: info@chemstream.be
web: www.chemstream.be