Additive manufacturing of miniature parts

Technologies for additive manufacturing, such as microstereolithography, are becoming ever more suitable for the production of high-resolution miniature parts. The designs can be complex and production can take place directly. These techniques are easily applicable for product development and can help speed up introduction to the market. TNO Science and Industry and Materials innovation institute M2i in the Netherlands carried out a knowledge transfer project on microstereolithography with pilot companies, the results of which will be presented during a Precision-in-Business day in Eindhoven, the Netherlands, on 18 November.

• *Bart van de Vorst and Henk Buining* •

Microstereolithography is a 3D printing method. The principle is shown in Figure 1, while Figure 2 shows an example of microstereolithography in practice. The technique uses a liquid-based photopolymer as building material. This special resin hardens under the influence of light with a certain wavelength. The resin is located on top of a glass plate, beneath which a projector is positioned that can illuminate the resin. Above the glass plate, a building platform is mounted to a linear Z-stage.

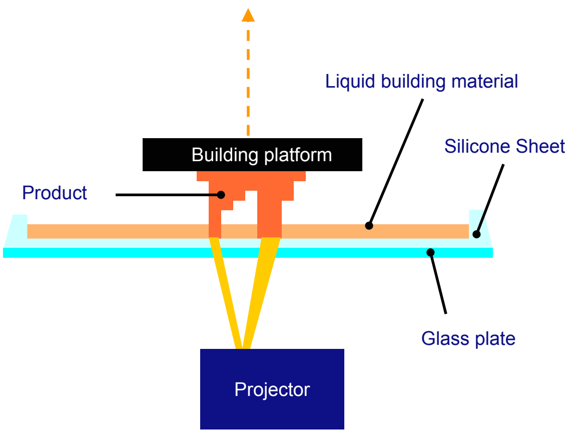

Figure 1. Principle of microstereolithography: the exposure of layers of curable resin with a projector.

In the starting position, the building platform is placed at one layer's distance above the glass plate. The projector illuminates the cross section of the first layer of the product. Curing takes place in the area where the resin is exposed and the first layer of the miniature part is formed on the building platform. Next, the building platform moves up. The first layer is peeled from the glass plate and remains on the building platform. While moving up, new resin flows in between the first layer and the glass plate. Then the following layer can be exposed, producing a new layer on top of the previous layer that was formed on the building platform. This cycle is repeated until the complete product is finished.
Figure 3 shows some examples of miniature parts produced with microstereolithography.

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Figure 2. Building process of a microfluidic chip with internal canals.

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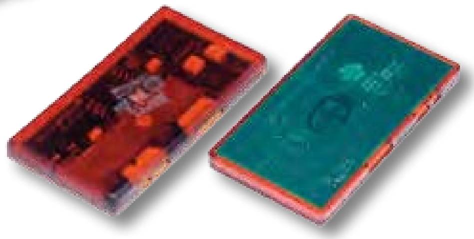

Figure 3. Miniature parts produced with microstereolithography.
(a) Cage for miniature bearing.
(b) Housing of integrated remote sensor.
(c) Functional prototype for micro-injection moulded coil.
(d) Cogwheel for manipulator.

Figure 4. Principle of building a product with volumetric pixels (voxels) in different resolutions.

Using this method, a series of voxel planes are created. They contain individual voxels known as volumetric pixels. The thickness can vary for each single exposure from 10 µm to 100 µm. With high-resolution voxels, smoothly detailed parts can be produced as shown in Figure 4.

Available materials

There is a growing range of photopolymers available for different applications. R5 is a versatile acrylate that produces robust, accurate and functional parts. The chemical resistance is good and the temperature and humidity ranges are broad. There are also resins available that are CE-certified for use in hearing-aid products and that are Class-IIa biocompatible in accordance with ISO 10993. The material mimics traditional engineering plastic ABS, meaning it can be used in many other applications. Some materials have a high wax content, which makes it possible to use the parts for investment casting applications in the jewellery and dental markets.

Support

While the part is being built, the product material is not strong enough to produce a rigid product that can withstand the building forces in advance. The layer being built might bend, particularly when there is an overhang of horizontal features. Therefore, some areas of a product need a lattice

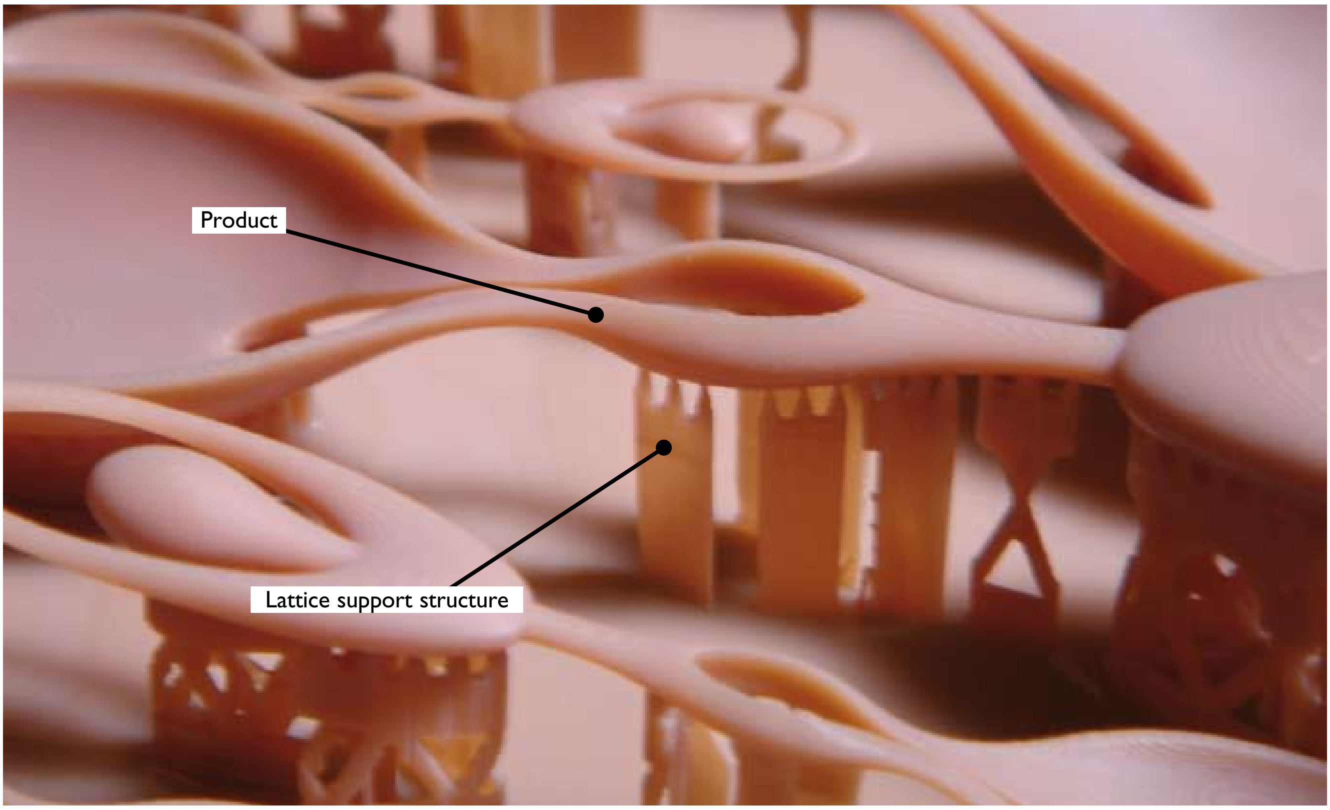

Figure 5. The same principle for stabilising a building structure must be applied to support a workpiece that is built using microstereolithography.

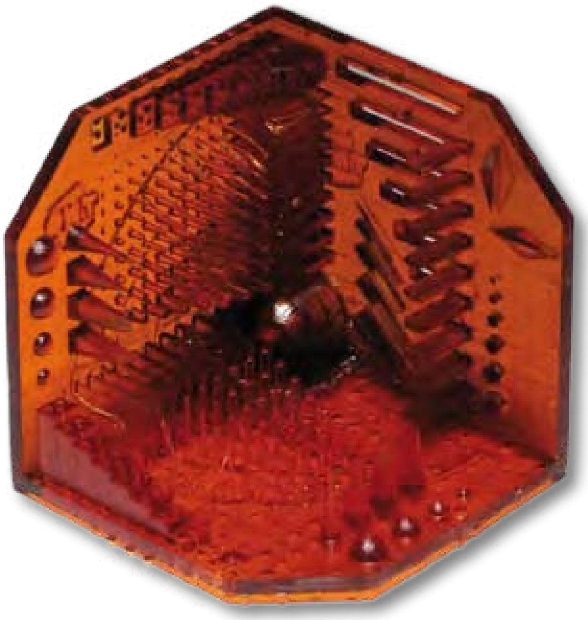

Figure 6. A test workpiece with different product features in different directions, such as small bars and narrow cavities, which highlights process capabilities and can be used to optimise process parameters.

support structure as shown in Figure 5. If possible, however, the use of support structures should be minimised, given that they use material and must be removed manually. Removal is sometimes difficult and could leave marks on the product.

A simple method to minimise support is a clever orientation of the product in the build chamber. The product designer should also bear in mind how support can be avoided. A small slope of 3°, for example, can avoid the need for support under horizontal faces.

Possible features

To explore the possibilities and limitations of microstereolithography, TNO designed a test product as shown in Figure 6. This test product contains different product features such as small holes, small bars and thin plates. The product features are, within a certain range, becoming ever smaller to explore the limits. The features are located in different orientations, exploring the influence of the building direction on the part quality. This test product enables exploration of the effect of the material and process parameters, as well as optimisation of the parameters. For example, while higher illumination intensity gives a stronger product, it causes small holes to be filled with cured resin.

Speeding up the building process

Commercially available equipment for microstereolithography has fixed building cycles and no sensors to control the building process. The movements of the building platform and the start of the illumination follow a pattern with fixed speeds and time frames. The speed is independent of the size of the cross section of the product and must be adjusted to the maximal acceptable

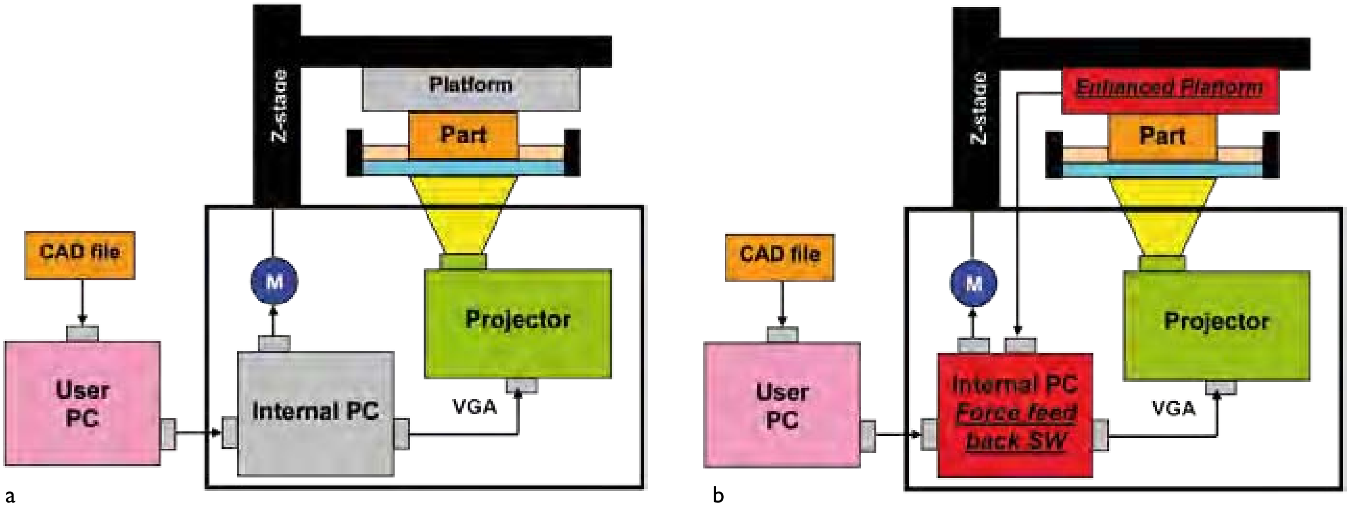

Figure 7. Microstereolithography equipment.
(a) Standard layout with an internal PC directing the building cycle, with standard parameters for all slices of the product.
(b) With tuning kit, having sensors in the advanced building platform and individual process parameters for each layer.

forces in the worst cases. This results in a relatively slow building process of approximately 25 seconds per layer.

TNO Science and Industry has patented an intelligent Force Feedback system in the machine. The controller optimises the movements of the building platform, taking into account process parameters for the specific layer to be built. This results in a safe and fast building process with improved product quality. As shown in the diagram, the controller regulates:

- upward movement of the building platform for a speed-optimised smooth peeling-off of the layer;
- downward movement of the building platform building up a stabilised new layer of resin;
- illumination of the actual layer;
- repetition of the cycle with new parameters optimised for each cross section of the part.

The original equipment as shown in Figure 7a contains a Windows PC with a software suite for the operator to handle the 3D CAD file and to slice the file into bitmaps representing each cross section of the part. The slice file is sent to the internal PC in the machine. For each slice the motor of the z-stage is controlled with standard parameters by the internal PC, while the bitmaps are sent to the projector via the VGA card.

A separate kit for upgrading existing machines has been developed for the implementation of the intelligent control system (see Figure 7b). A modified internal PC calculates the optimised process parameters for each individual layer. The movement of the z-stage is based on real-time force feedback from the sensors in the enhanced building platform.

Higher resolution (factor 10)

Another research project at TNO, which focused on the improvement of product quality by means of a higher resolution of the building process, involved the development of new materials, processes and equipment. Basically, the projector image can be scaled down, while retaining the original high resolution of the DMD (Digital Micromirror Device) chip of, for example, 1280 x 1024 pixels. New optics with higher quality were needed, resulting in an equipment redesign. The projection area was reduced to 3 mm x 4 mm. This results in a projected pixel size of 3 µm; Figure 8 shows an example of a miniature product. To build larger objects, a stepping mode in XY is incorporated.

This equipment processes resin voxels that have a volume one hundred times smaller (see Figure 9). This requires very specific material properties and an accurate illumination cycle.

Lower production costs (factor 10)

A further step towards mass production is to lower production costs. Equipment for microstereolithography is built from components with relatively low prices. In contrast to some other machines for 3D printing, there is no need for a laser with complex mechanics, optics and controllers. Instead, standard technology for computer projectors with no mechanical critical components can be applied. The development of DMD chips used in PC projectors for consumer markets made these projectors cheap and reliable.

Figure 8. Miniature chess castle (height 2.8 mm) containing an internal staircase.

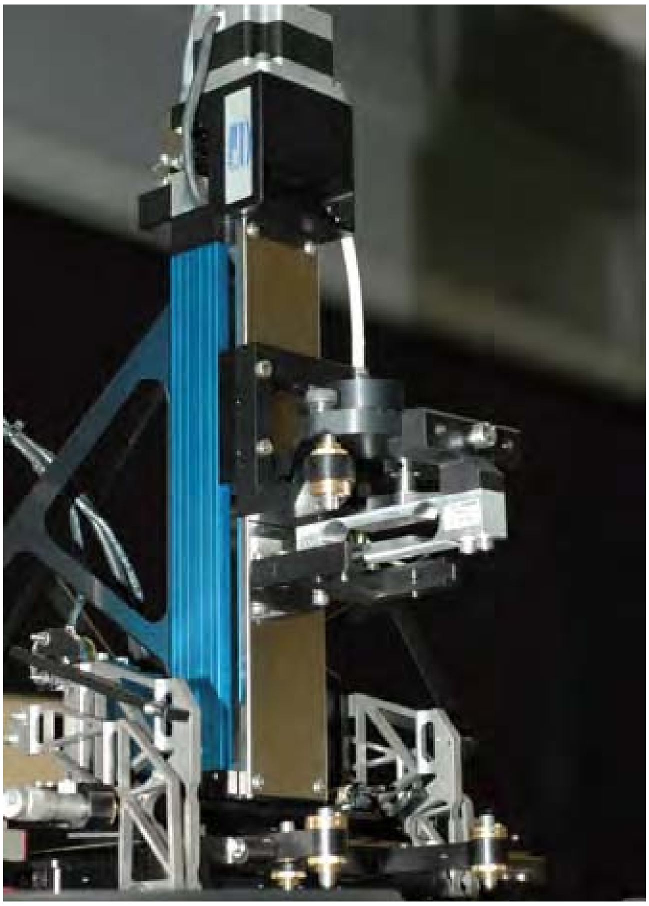

Figure 9. Equipment for highly detailed microstereolithography with voxels of $3 \times 3 \times 10\ \mu m^3$.

Knowledge transfer

With special knowledge transfer projects, TNO and M2i make research results applicable in practice. Pilot cases are worked out to demonstrate the capabilities of the techniques. A recent project focused on the use of microstereolithography. Other projects in progress focus on the use of additive manufacturing for medical applications and on coatings on additive manufacturing parts. Another focal point at TNO and M2i is the development of high-end equipment for micro-milling techniques. In this way, TNO and M2i help to bring innovative techniques to the market.

Acknowledgment

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Precision-in-Business day: microstereolithography

The most important results of the microstereolithography project will be presented on what is known as a PiB-day organised by DSPE in Eindhoven, the Netherlands, on 18 November. See the programme on page 64. Registration by e-mail.

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