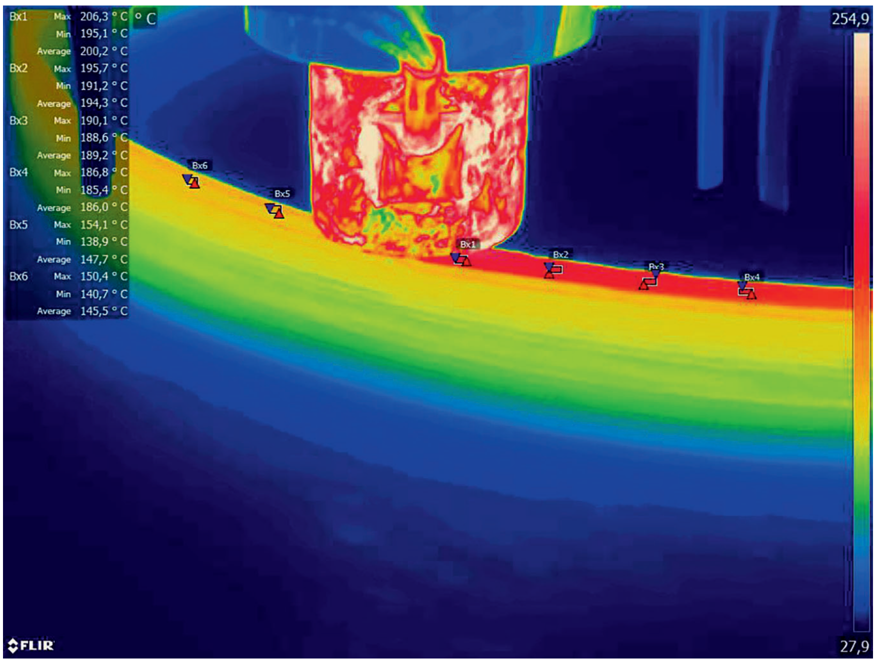
Large but still Economical

An Alternative Approach to Large-Format 3D Printing with Plastic

In a joint project, the Fraunhofer Plastics Technology Center Oberlausitz, working together with the University of Zittau/Görlitz, as well as the industry partners KraussMaffei and Elbe Flugzeugwerke, has enhanced an extruder-based method for additive manufacturing of large-format plastic parts using a flexible melt pipe. Besides a proof of concept, there was also a focus on studies into how the parameters of the experimental set-up influence the output material resulting in the highest possible component quality.



Thermal analysis of the deposited plastic strand in the large-format, extruder-based 3D printing process © Fraunhofer IWU

Many large-format component applications cannot yet be realized using conventional 3D printing technologies. This is because, compared with conventional manufacturing processes, they can often not gain acceptance due to the high machine costs and expensive starting materials. However, commercially available industrial robots in combination with a stationary thermoplastic pellet extrusion system and a flexible pipe system for the thermoplastic melt will make large-format plastic 3D printing competitive in these areas in the future. Current CAD/CAM solutions now allow multiaxial mold parts to also be stably programmed on industrial robots, and thus offer a very high degree of design freedom in the use of this technology.

A major challenge when constructing a large-format 3D printing system consists in reducing the weight on the robot head that has to be moved. Conventional pellet-processing mobile extruder systems have printing-head weights of, in many cases, over 100 kg, which cannot be used on inexpensive industrial robots with low load capacities. One potential solution is provided by the technology described here, which the Fraunhofer IWU, the University of Zittau/Görlitz, KraussMaffei Technologies GmbH and Elbe Flugzeugwerke GmbH, all Germany, have investigated in a joint research project.

Decoupling the Extruder Unit from the 3D Printing Nozzle on the Robot

The system (**Fig. 1**) is constructed from an industrial robot (type: Stäubli RX160; manufacturer: Stäubli Tec Systems GmbH) as well as a stationary single-screw extruder (type: E45PK; manufacturer: Collin Lab & Pilot Solutions GmbH) with coupled melt pipe and a print head specially developed for the project, with exchangeable application nozzles. The melt pipe used was electrically heated, with its own control system; the tested lengths of the melt pipe were 2 to 3 m. This structure solves the above-described weight problem by decoupling the heavy extruder unit from the 3D printing nozzle mounted on the industrial robot.

Since the extruder unit can be located next to the industrial robot, the latter only needs to support and move the lightweight print head. A focus of research consisted in investigating various melt pipe types according to their suitability for 3D printing with thermoplastic standard plastic pellets. For this purpose, various unfilled and reinforced plastics were processed – allowing application rates up to 30 kg/h to be reproducibly achieved.

Thermoplastic materials with high application potential were chosen for the tests. Unreinforced semicrystalline and amorphous thermoplastics (PP, PE, ABS, PC+ABS, PC+ASA), as well as short fiber-reinforced grades (PP, PA), were used. The processing temperature and the screw speed of the extruder were tailored to the processed polymer so that the plastic melt has a sufficient viscosity and was therefore flowable. Special attention was paid to only supplying a modest »

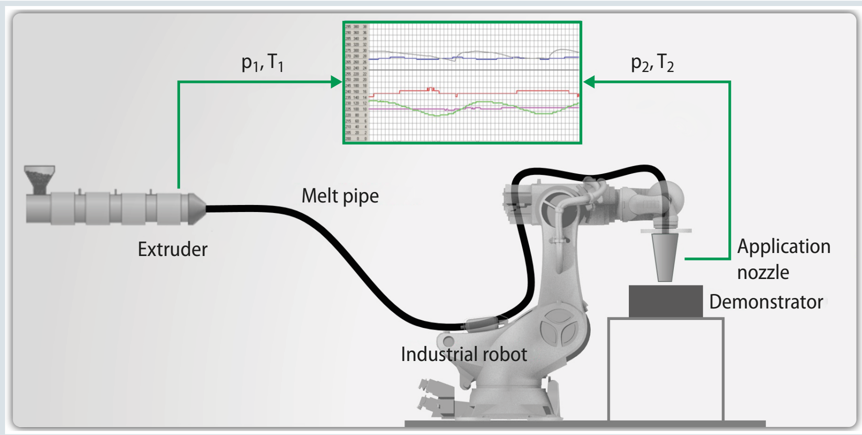


Fig. 1. The extruder is coupled to a flexible melt pipe with the print head fixed on the industrial robot © Fraunhofer IWU

amount of thermal energy, because this has to be dissipated again after the 3D printing process.

Pressure Fluctuations in the Melt Pipe

The goal of the investigations was to characterize different melt pipes according to the melt pressures that are established for different materials. To determine the melt pressure, two pressure sensors were used. One sensor was positioned directly in the nozzle head of the extruder, while another was integrated immediately before the application nozzle, in the print head that was designed for these experiments (**Fig. 2**). The values (pressure) registered by the sensors are recorded by the extruder software, displayed and subsequently evaluated.

Besides the pressure, the associated temperature of the plastic melt was also recorded at the two measurement points. In the case of melt pipes with a small cross-section, very high pressure losses of up to 300 bar between the extruder and application nozzle were measured. The pressure in the print head remains relatively stable, even if the pressure in the extruder was varied by changing the screw speed. In the case of (dynamic) tests, the three-dimensional movement of the robot arm caused a pressure fluctuation of up to 2 bar in the melt pipe.

This behavior was investigated on melt pipes with different internal diameters. With the described construction and suitable polymer types, it is possible to achieve extrusion rates of up to 30 kg/h by varying the discharge rate and screw speed of the extruder (**Fig. 3**).

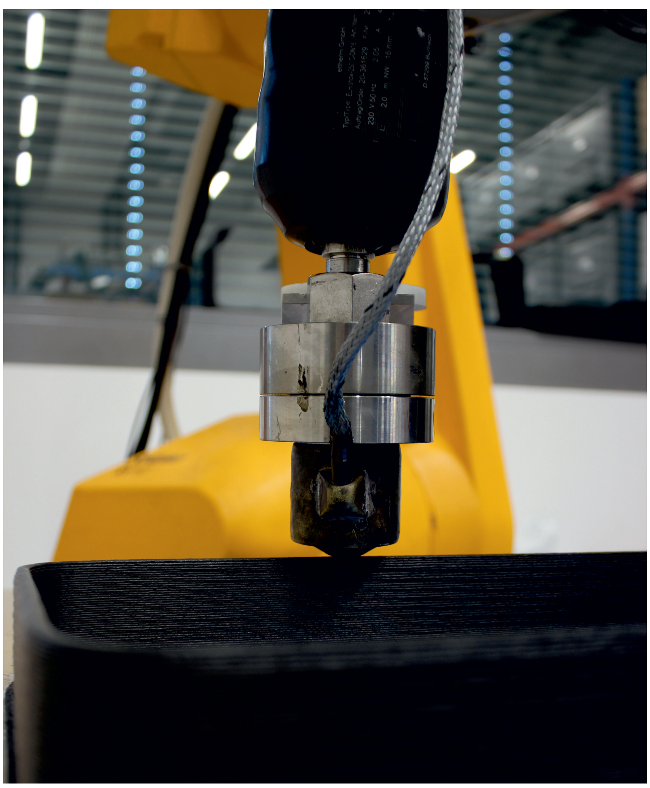


Fig. 2. The innovative print head permits pressure and temperature measurement of the plastic melt © Fraunhofer IWU

Influence of the Material on the Layer Stability

In the first series of experiments, high material shrinkage of the unreinforced material grades was found. To counter this problem, short fiber-reinforced plastics were used in further experiments: polypropylene grades reinforced with, among other things, 6 to 20 % recycled carbon fibers (rCF) or 30 % glass fibers. The first experiments with PP-rCF6 grades showed that the very high flowability and 6 % fiber content are not sufficient for ensuring the stability of the individual layers of an object produced by large-format 3D printing with the chosen parameters, although the melt viscosity was kept at a highest possible level by maintaining the processing temperature low.

Also, the processed low-viscosity PP-rCF20 was not convincing as regards the layer stability that was obtained. Only a higher-viscosity PP-GF30 grade offered a good choice for the 3D printing parameters under investigation. Here it was found that the viscosity of the applied melt strand was high enough to deposit a dimensionally stable layer and to reliably apply the subsequent layer. A test sample with a homogeneous appearance could thus be generated. Using the chosen material, a high accuracy of strand deposition in accordance with the programmed print-head movement could thus be achieved (**Fig. 4**).

In order to improve the dimensional stability of the individual layers – despite the fundamentally low thermal conductivity of polymer materials together with a large cross-section of the plastic strand in large-format 3D printing – an active cooling system was integrated on the print head. The compressed air-based cooling system was operated with different air velocities while maintaining constant extruder settings, in order to evaluate what influence the heat dissipation

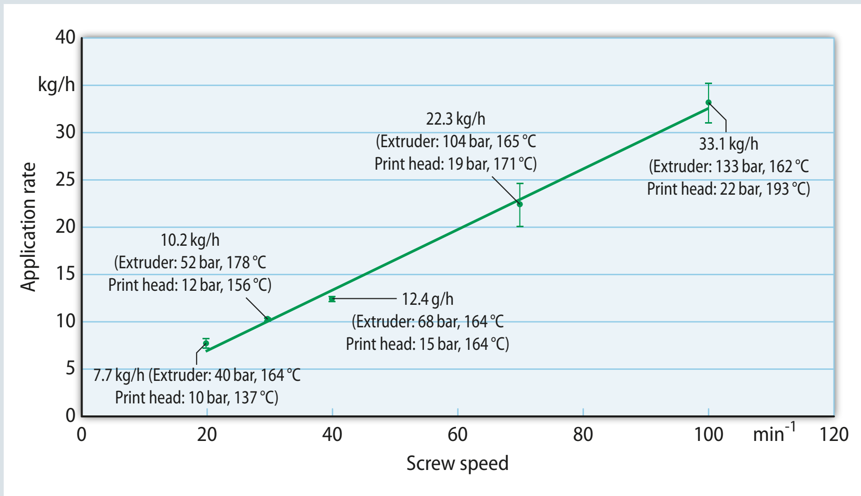


Fig. 3. The application performance of the Collin extruder (melt pipe DN16, printing nozzle 6 mm) has a linear deposition characteristic depending on the speed Source: Fraunhofer IWU; graphic: © Hanser

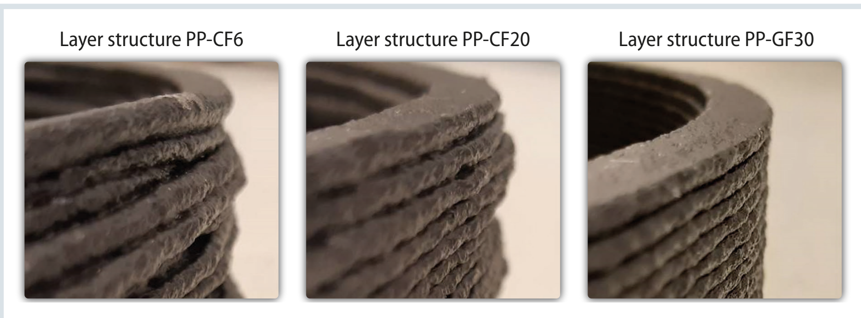


Fig. 4. The fiber length and the fiber content influence the layer stability and thus also the component quality © Fraunhofer IWU

has on the material deposition and the component surface.

Due to the integrated cooling system in the nozzle area, the forming quality of the individual layers on a 3D-printed plastic component can be significantly increased since the generated air current effectively cools down the print region. The thermal effect of the integrated cooling was verified by means of thermographic analysis of the printed component (**Fig. 5**). The results show that, with active cooling, the temperature can be reduced by up to 25 K in the continuous printing process.

Summary

By using inexpensive standard plastic pellets, the printing system presented here, made from standard industrial components, combines low plant investment with high deposition rates. The project partners Fraunhofer IWU, University of Zittau/Görlitz, KraussMaffei and Elbe Flugzeugwerke, can see that this technical approach offers huge potential for economic manufacturing of large-format thermoplastic components. One of the challenges in the further development of the process is to tailor the dimensional stability of the individual layers and the bonding between the layers, in order to produce sturdy, dimensionally stable and low-warpage large structures. ■

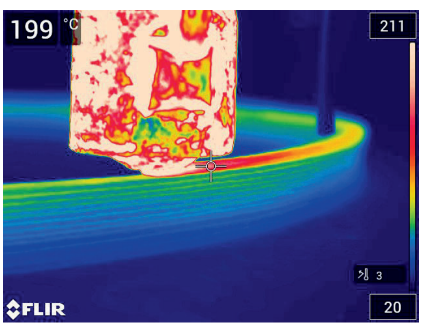


Fig. 5. The residual temperature of the deposited plastic strands fundamentally influences the component strength in the build direction (Z-direction) © Fraunhofer IWU

To-Dos until Series Maturity

The investigated 3D printing technology, while using commercially available, industrial technologies, such as plastics extrusion and robot automation, offers the clear advantage over plastic filaments that inexpensive plastic pellets are used. For scaling up to industrial use, it is necessary to transfer the model-file of the printed object into the machine software (G-Code) of the robot. In addition, a high component quality as well as optimum layer connection requires a temperature-control concept.

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