APPLICATION NOTE

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Use of melt pump to produce filaments for additive manufacturing (3D printing)

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Key words
Additive manufacturing, 3D printing, filament production, melt pump, twin-screw compounding, fused filament fabrication, Process 11

Executive summary
3D printing is a form of additive manufacturing technology in which three-dimensional objects are created by depositing successive layers of material until the object has reached the desired shape. 3D printing gives product designers the ability to print parts and assemblies with materials of different mechanical and physical properties using a single manufacturing process. With this technology, solid 3D objects can be created from a digital plan that is created on a computer (i.e.., CAD drawing) or scanned with a 3D scanner. Thus, 3D printing enables the development of a prototype in a fraction of the time and at a lower cost compared to conventional machining.

This application note describes a process for compounding a polymer formulation and producing a filament for 3D printing in a single manufacturing run. This process saves time and labor during end-product development and reduces the thermal stress on the compounded filament by minimizing heat-cool cycles.

From simple filament production ...
While a variety of raw materials can be used in the 3D printing process, including concrete, human cells and metal, polymers are the most common. The "inks" for these 3D printers are polymer filaments with a defined and very constant diameter. Simple single-screw extruders are used to make these filaments from a base polymer. Single-screw extruders have high pressure build-up and constant output, which is important for maintaining a constant filament diameter. A limitation of using single-screw extruders is that they are inefficient at mixing or compounding multiple-component formulations for creating the 3D filament.

If advanced polymer compounds or custom formulations are needed, twin-screw extruders must be used. Twin-screw extruders allow for a much more flexible setup to compound multiple ingredients into a homogeneous blend for creating the filament.

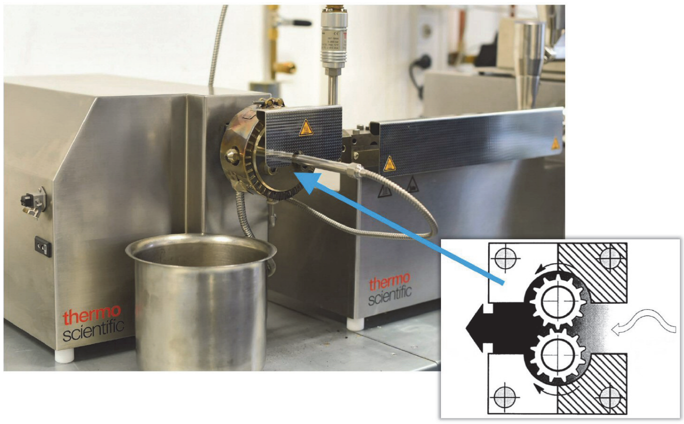

Figure 1: Thermo Scientific™ Process 11 Twin-Screw Extruder with attached Thermo Scientific™ Process 11 Melt Pump.

... to customized compounds
The nature of the twin-screw extrusion process results in a slightly pulsating output, making it difficult to maintain a constant filament diameter. For the use of these filaments in a 3D printer, however, a constant filament diameter is mandatory as it determines the shape quality and stability of the final printed product. Therefore, a constant output of the extruder is necessary to achieve the desired filament specification. The solution to this challenge is the use of a melt pump located between the end of the extruder and the filament-forming nozzle.

As shown in Figure 1 the Thermo Scientific™ Process 11 Melt Pump uses two closely meshing gears that rotate and then separate on the inlet side of the pump. This creates a cavity and a suction that is filled by the melt. The melt is transported by the gears to the outlet side of the pump, where the meshing of the gears displaces the melt. Since the mechanical distances are very small, the melt is effectively prevented from leaking backwards. The rugged construction of the gears and the housing allows the construction of very high pressures (up to 700 bar) and the ability to pump high-viscosity melts.

By controlling the speed of the Process 11 Melt Pump, a very accurate pulsation-free output can be maintained, resulting in a constant diameter filament being extruded.

Materials and Methods

For this study, 3D printing filaments were made using LDPE (Lupolen® 1800H low-density polyethylenen resin; LyondellBasell Industries Holdings, B.V.) with different extrusion setups. The filament production systems used included:

1) Single-screw extruder (Thermo Scientific™ HAAKE™ Rheomex 19/25 OS Extruder)
2) Co-rotating twin-screw extruder (HAAKE Rheomex PTW16/40 Extruder)
3) Co-rotating twin-screw extruder (HAAKE Rheomex PTW16/40 Extruder) with a melt pump.

For all tests the same spooler unit was used to wind the filament. This spooler unit is equipped with a laser-based diameter measurement, which allowed a continuous on-line measurement of the filament diameter.

Figure 2: Process 11 Extruder with attached Process 11 Melt Pump, water bath and filament spooler unit (right to left).

Figure 3 shows the result of the 3D filament diameter measurement over a measuring time of 50 minutes. Clearly it can be seen, that the diameter fluctuations of the filament produced by the twin-screw extruder without a melt pump is significantly higher than the fluctuations of the strand produced by the single-screw extruder, and the one produced by the twin-screw extruder with the attached melt pump. Setpoint for the filament diameter was 1.7 mm.

Figure 4 compares the diameter fluctuations of the filaments produced by the single-screw extruder and the twin-screw extruder with attached melt-pump. The variability with both setups is very low, and both filaments are showing a similar, very high level of quality.

This can also be seen when checking the statistical data from three diameter measurements (Table 1).

Conclusion

Three 3D filament production methods were assessed for consistency of filament diameter; single-screw extruder system, twin-screw extruder system and twin-screw extruder with attached melt pump. The use of the melt pump does significantly reduce the pulsation of the output of a twin-screw extruder, and thus improve the consistency of the diameter of an extruded filament.

Using a Process 11 twin-screw extruder with an attached Process 11 Melt Pump gives the opportunity to transform newly compounded polymer formulations directly into a precise filament that can be used for 3D printers.

Alternative methods of production without melt pumps include a pelletization step of the cooled down compound and use this pellets in a subsequent single-screw extrusion process to manufacture the filament.

Very similar results as presented in this study can be achieved when working with an 11 mm twin-screw extruder with a setup as shown in Figure 2.

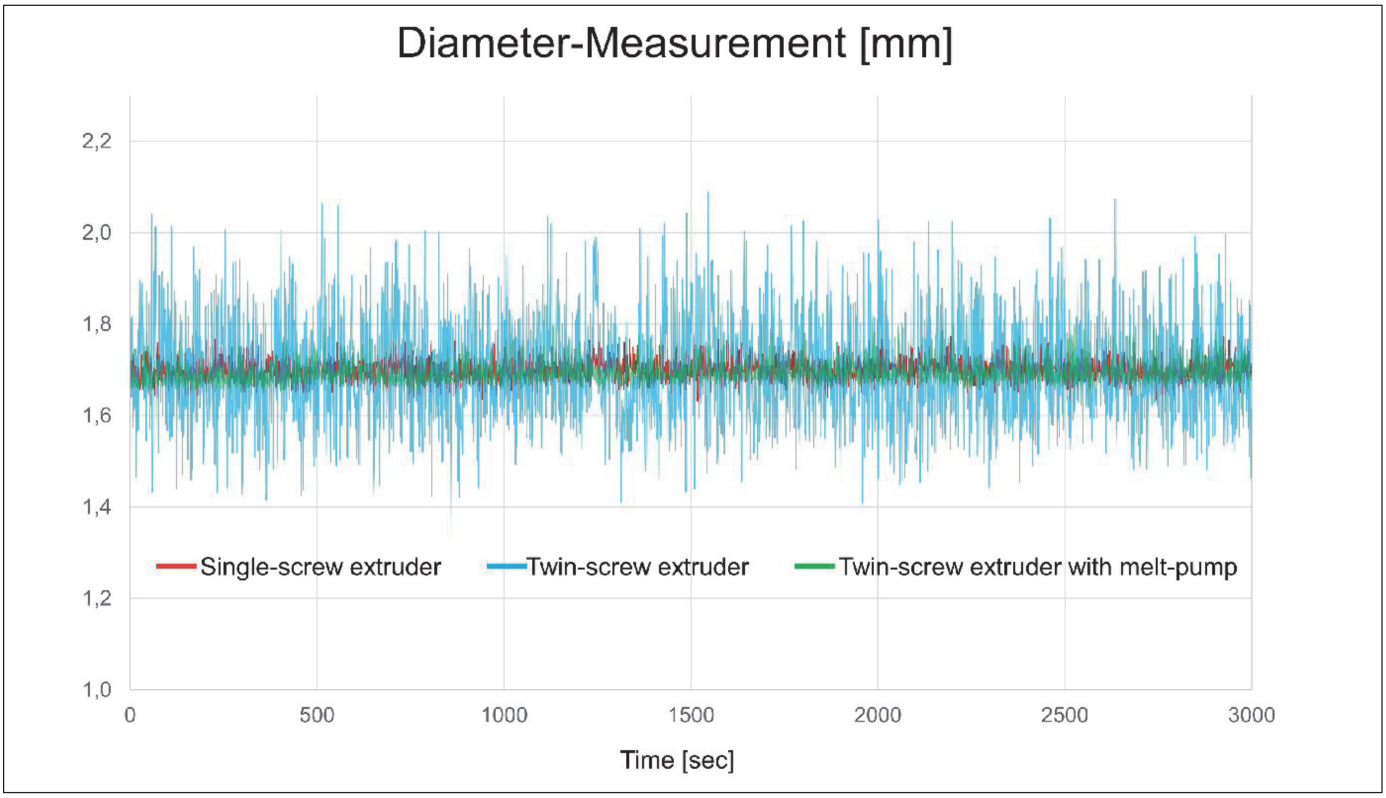

Figure 3: Results of the 3D filament diameter measurement with the single-screw extruder, twin-screw extruder and twin-screw extruder with attached melt pump.

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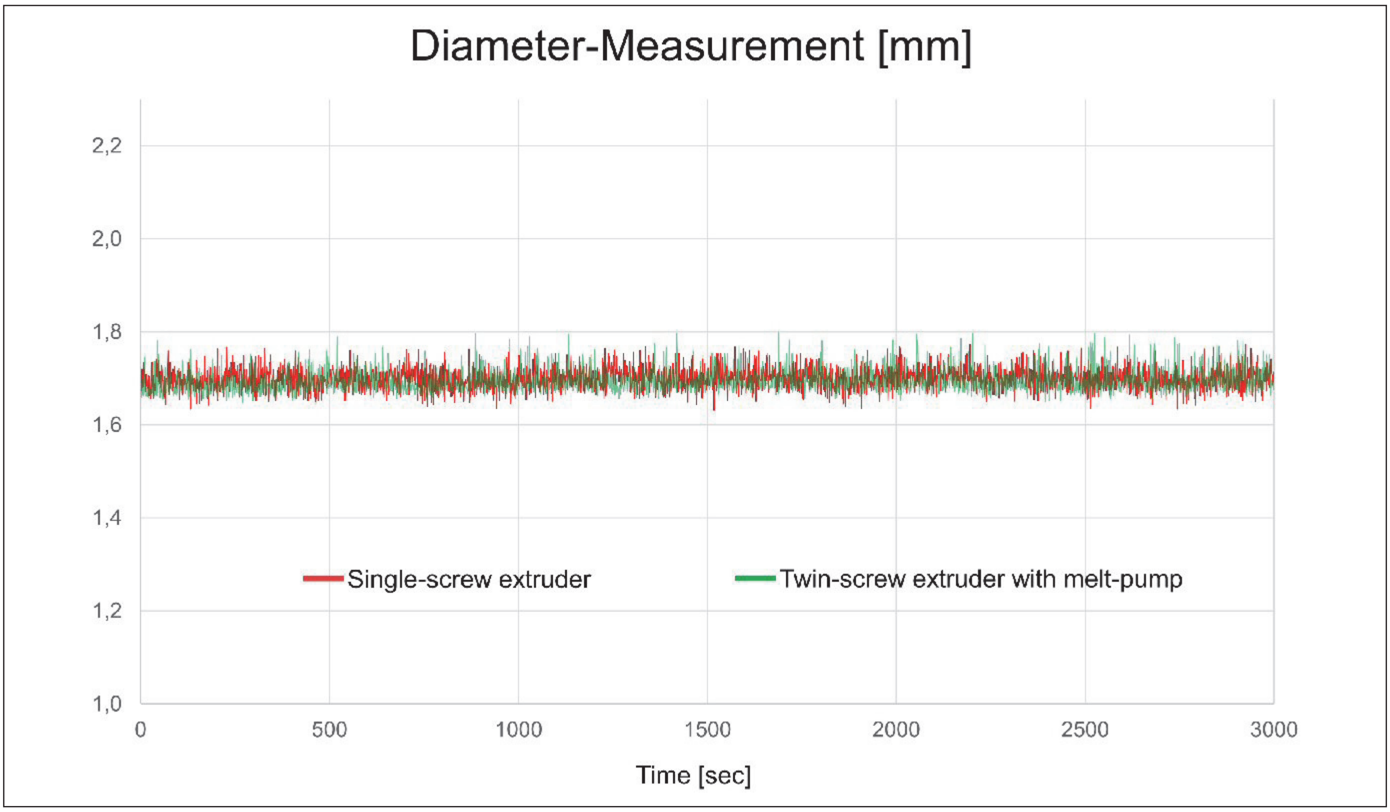

Figure 4: Results of the diameter measurement with single-screw extruder and twin-screw extruder with attached melt pump.

Filament Diameter	Single-screw Extruder	Twin-screw Extruder	Twin-screw Extruder with Melt Pump
Average	1.699 mm	1.699 mm	1.694 mm
Minimum	1.631 mm	1.334 mm	1.648 mm
Maximum	1.773 mm	2.089 mm	1.798 mm
Deviation	0.142 mm	0.755 mm	0.150 mm
Dev. in %	4.2%	22.2%	4.4%
Std. Dev:	0.0227	0.1135	0.0231

Table 1: Statistical results of the diameter measurement with single-screw extruder, twin-screw extruder and twin-screw extruder with attached melt pump.

The above mentioned setup of Process 11 twin-screw extruder with attached Process 11 Melt Pump helps to significantly reduce time and labor in development of such filaments. Also the thermal stress of the material is reduced by eliminating unnecessary heat-cool cycles that occur if compounding and filament production is separated.

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