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Printability of pharmaceutical Fused Deposition Modeling (FDM) feedstock material: Mechanical characterisation of FDM filaments and the FDM 3D printing process

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PURPOSE

3D printing (3DP) of pharmaceutical formulations via commercially available FDM printers facilitates advanced control of the microstructure of the tablet core and therefore drug release properties. For this 3DP process an intermediate feedstock material is manufactured and used in the FDM process.

However, mechanical and rheological properties of pharmaceutically approved polymers are often not suitable for this process. In order to identify suitable filaments for the FDM process, the objective of this study was to perform a mechanical and rheological characterisation of the feedstock material during an FDM process.

OBJECTIVE(S)

To assess the printability of FDM feedstock material by mechanically characterising the filaments and the extrusion during an FDM 3DP process.

METHOD(S)

- Hot-Melt-Extrusion (HME): 5-50 % (w/w) Paracetamol (PCM) in Affinisol 15LV™ were extruded on a 16 mm Hot-Melt-Extruder [1]
- Mechanical characterisation of filaments was performed on a TA-XT Plus Texture Analyser
- Mechanical characterisation of the extrusion process of FDM filaments were recorded on a Texture Analyser TA-XT (Figure 1): ABS (MAXX), PLA (MAXX) and 5-50% w/w PCM-Affinisol 15LV™ filaments
- Complex viscosity was measured on a Haake Mars III rotational rheometer

RESULT(S)

Mechanical testing

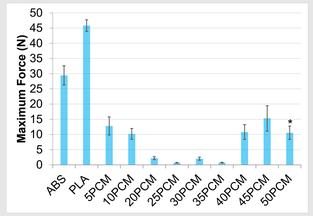

Figure 2: Compression test to determine maximum force on filament during feeding. Maximum force (N) for commercial (ABS, PLA) and in-house produced (5-50% w/w PCM-Affinisol™ 15LV) filaments.

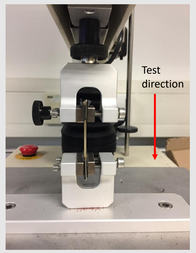

Figure 3: Compression test: Mechanical assessment of filaments using a texture analyser TA-XT equipped with mini grippers.

Maximum force during extrusion – 0.2 mm nozzle diameter

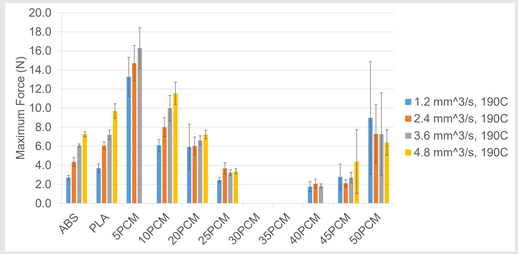

*Figure 4 : Maximum force recorded during extrusion of commercial filaments (ABS @240℃, PLA @190℃) and in-house prepared filaments (5-50% w/w PCM-Affinisol 15LV™@190℃) through an FDM print head [1] equipped with a **0.2mm** round nozzle diameter. Extrusion was performed at volumetric speeds of 1.2 (blue), 2.4 (orange), 3.6 (grey) and 4.8 mm³/s (yellow).*

Maximum force during extrusion – 0.4 mm nozzle diameter

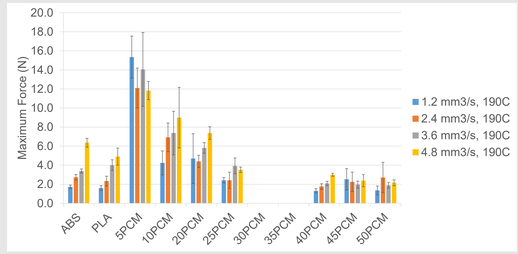

*Figure 5 : Maximum force recorded during extrusion of commercial filaments (ABS @240℃, PLA @190℃) and in-house prepared filaments (5-50% w/w PCM-Affinisol 15LV™@190℃) through an FDM print head [1] equipped with a **0.4mm** round nozzle diameter. Extrusion was performed at volumetric speeds of 1.2 (blue), 2.4 (orange), 3.6 (grey) and 4.8 mm³/s (yellow).*

Summary

	Maximum Force Extrusion, 0.2mm nozzle, 4.8mm^3/s (N)	Maximum Force Extrusion, 0.4mm nozzle, 4.8mm^3/s (N)	Maximum Force Compression test (N)	Complex viscosity (η*, Pas) at 190°C	Printability[1] Yes (Y) No (N)
5PCM	no extrusion	11.8 ± 0.9	12.8 ± 3.0	4142	Y
10PCM	11.5 ± 1.2	9.0 ± 3.2	10.2 ± 1.8	3309	Y
20PCM	7.2 ± 0.5	7.4 ± 0.7	2.2 ± 0.5	1623	Y
25PCM	3.4 ± 0.3	3.5 ± 0.3	0.7 ± 0.1	*not measured*	Y
30PCM	no extrusion	no extrusion	2.0 ± 0.5	1011	N
35PCM	no extrusion	no extrusion	0.7 ± 0.1	*not measured*	N
40PCM	no extrusion	3.0 ± 0.2	10.8 ± 2.4	554.9	N
45PCM	4.4 ± 3.3	2.4 ± 0.6	15.3 ± 4.2	*not measured*	Y
50PCM	6.4 ± 1.3	2.2 ± 0.3	10.6 ± 2.2	249.1	Y

Table 1 : Summary of experimental results.

Maximum force during extrusion – 0.8 mm nozzle diameter

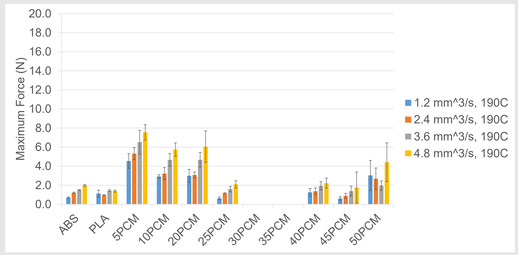

*Figure 6 : Maximum force recorded during extrusion of commercial filaments (ABS @240℃, PLA @190℃) and in-house prepared filaments (5-50% w/w PCM-Affinisol 15LV™@190℃) through an FDM print head [1] equipped with a **0.8mm** round nozzle diameter. Extrusion was performed at volumetric speeds of 1.2 (blue), 2.4 (orange), 3.6 (grey) and 4.8 mm³/s (yellow).*

Maximum force during extrusion – 1.0 mm nozzle diameter

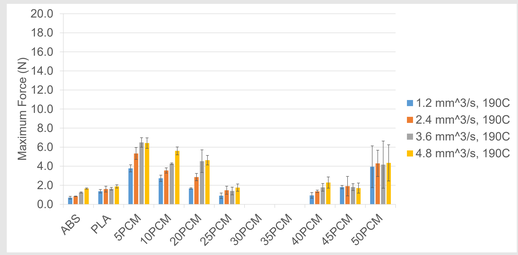

*Figure 7: Maximum force recorded during extrusion of commercial filaments (ABS @240℃, PLA @190℃) and in-house prepared filaments (5-50% w/w PCM-Affinisol 15LV™@190℃) through an FDM print head [1] equipped with a **1.0mm** round nozzle diameter. Extrusion was performed at volumetric speeds of 1.2 (blue), 2.4 (orange), 3.6 (grey) and 4.8 mm³/s (yellow).*

FUNDING / GRANTS / ENCORE / REFERENCE OR OTHER USE

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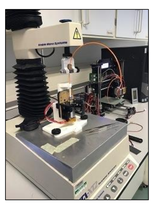
Reference: 1. Prasad E, Islam MT, Goodwin DJ, Megarry AJ, Halbert GW, Florence AJ, Robertson J 2019. Development of a hot-melt extrusion (HME) process to produce drug loaded Affinisol™ 15LV filaments for fused filament fabrication (FFF) 3D printing. Additive Manufacturing 29:100776.

CONCLUSION(S)

Mechanical properties of an FDM process for commercial and in-house prepared pharmaceutically relevant feed stock material were investigated and have shown the material dependant impact of print geometries and print speed on the FDM process; informing future development of pharmaceutically relevant feedstock material.



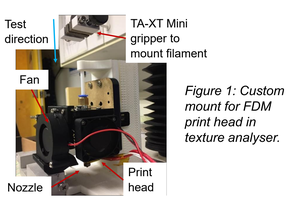


Figure 1: Custom mount for FDM print head in texture analyser.

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