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Additive manufacturing using renewable materials: concept of upcycling peach kernels for use in Binder Jetting and FFF

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Abstract
Additive Manufacturing (AM) processes enable new designs and part functionalities by a new way of using various materials. In the wake of climate change, we decided to investigate how AM technologies could be used to produce parts out of bio-based residual/waste material, providing an upcycling strategy for those materials and making use of their individual properties at the same time. Binder Jetting (BJ) and Fused Filament Fabrication (FFF) technologies (also known as Fused Deposition Modelling) are specifically interesting in this perspective, as various materials can be used as a filler in combination with biodegradable thermoplastics used as a binder. In this work we introduce the concept of manufacturing parts out of residual peach kernels grinded into powder in combination with polyvinyl alcohol (PVA). Parts manufactured from such materials have a decomposition rate measured in hours when exposed to water, making them ideal for applications such as unique single use packaging or short-lifetime products. The aim of research is to determine the feasibility of using these materials in BJ and FFF. For filaments used in FFF, various amounts of peach powder concentration in PVA were investigated with the aim to determine concentration effects on the properties of the test part and to determine the maximum amount of filler that still enables manufacturing of quality products. For BJ, different filler-binder concentrations were investigated in order to produce a stable part. Geometrical stability, density, pressure stability and decomposition rate in water were measured on test specimens. It was found out that these materials could be used in BJ and FFF to produce biodegradable products and support a circular economy paradigm.

Additive Manufacturing, Binder Jetting (BJ), Fused Filament Fabrication (FFF), circular economy, renewable materials, single use packaging

1. Introduction

A lot of research has been conducted on producing biodegradable and biocompatible materials to be used in additive manufacturing manly in FFF and BJ technologies.

PLA is usually used as base material for producing filaments for FFF technology to which different amounts of various filler material is added in order to obtain either new mechanical or visual properties, or to increase the sustainability aspect, etc. [1], [2]. The main motivation of our investigation is to use the residual bio-based materials such as peach kernel as filler material in FFF and the base material in BJ. In food processing, the peach kernels are disposed after being removed from the fruit.

In BJ technology, the percentage of base/filler material is far greater (more than 80%) than with FFF technology (less than 40%), but the mechanical properties of manufactured parts are far inferior.

While PLA is indeed biodegradable and biocompatible it may still take quite a long time for it to degrade, from 6 months to two years [3], which is still an insignificant amount of time compared to decomposition rate of the ordinary plastics, but could be considered as long in applications such as single use packaging and other short-lifetime products.

As an alternative to PLA, PVA can be used with both technologies. Compared to PLA, PVA has shorter decomposition times and is biodegradable as well as biocompatible. On the other hand, it offers lower mechanical properties and is more difficult to handle. The latter facts are probably the main reasons why it is usually not considered as a building material for FFF technology but is mainly used as a support material. In BJ technology however, PVA is more often used as a binder material since it can be dissolved by using water based binders.

In this work we examine the performance of comminuted peach kernels as a building material in abovementioned additive technologies.

2. Methodology

Before being used in either technology the peach kernels had to be comminuted into a powder form. Our aim was to produce a particle fraction below 180 µm. Before comminution the soft inner kernels were removed. Before the shells were grinded into powder form, they had to be dried extensively.

Geometrical stability, density, pressure stability and decomposition rate in water were measured on cuboid shaped test specimens of 10 mm x 10 mm x 5 mm in dimensions. After the first set of optimal parameters was determined for each technology, it was used to manufacture three specimens which were then tested as presented below. Pressure stability was determined qualitatively and only on green part test specimens manufactured with BJ technology.

3. FFF Technology

Our first aim was to determine the maximum amount of peach kernel filler in combination with PVA which would produce the

filament suitable for additive manufacturing. Powder mixtures with various percentages of peach kernel powder were used to produce a 1.75 mm filament using a 450 Composer extruder (3D EVO, NL). Materials were both in powder form and were dried for 12 hours at the temperatures up to 80 °C before they were mixed and filament was created. We were able to produce filament with maximum of 40% of peach kernel powder. However filaments containing more than 20% of peach kernel powder were very brittle and broke inside the extruder of the printer.
Test specimens were therefore manufactured using the filament with 20% peach kernel powder and 80% PVA. The test specimens were manufactured using Creality Ender 3 (CHN) 3D printer. The printing parameters were chosen based on those recommended for pure PVA (Table 1). Material extrusion was performed in a similar way as pure PVA and needed to be dried in order to successfully manufacture the test specimens. The mixture of peach kernel powder and PVA proved to be very sensitive to temperature. Namely, temperature of 200°C seem to be the optimum, at 190°C the extrusion was poor (under extrusion) while at 210°C the materials showed signs of burning. The manufactured parts are shown in Figure 1 and results are presented in Table 2. The geometric stability, i.e. the measured dimensions of the manufactured parts deviated from nominal values in x and y direction by less than 0.18 mm and 0.03 mm respectively, while in z-direction the maximum deviation was below 0.13 mm. The parts showed no signs of delamination, even when small force was applied by hand. It took about 14 hours for the test specimen to completely dissolve in a glass of water.

Table 1. FFF manufacturing parameters

nozzle diameter	0.8	mm
layer height	0.2	mm
print velocity	40	mm/s
print temperature	200	°C
bed temperature	45	°C
infill density	100	%

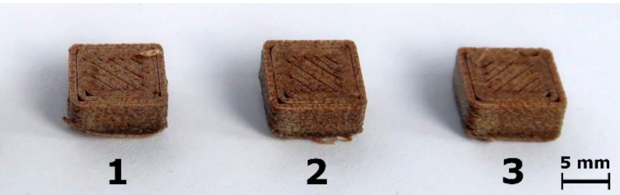

Figure 1. Cuboid test specimens manufactured with FFF technology using the filament produced out of 20% peach kernel and 80% PVA powder mixture.

Table 2. Results of FFF. Nominal dimensions are 10x10x5 mm

Specimen	x [mm]	y [mm]	z [mm]	mass [g]	density [kg/m^3]
1	9.82	9.92	4.87	0.37	779.7
2	9.84	9.99	4.98	0.38	766.3
3	9.84	9.97	4.99	0.38	772.2

4. BJ technology

Test specimens were manufactured on a Zcorp ZP350 (US) binder jetting 3D printer. Water was used as a binder liquid. Test specimens were manufactured using a 15% PVA and 85% peach kernel powder. The powder mixture was dried for 12 hours before it was used. Different layer heights (0.08 mm, 0.1 mm, 0.15 mm and 0.2 mm) and saturation levels (97%, 100%, 150% and 200%) were tested, while the spreading and rolling speeds were kept constant.
Better dimensional stability was observed at layer heights above 0.1 mm. Spreading of the powder was best at layers heights above 0.15 mm, but the dimensional stability in z axis was better at 0.1 mm layer height. Saturation levels didn’t have much effect in the tested parameter sets. Final test specimens were manufactured at layer height 0.1 mm and 97% saturation level. The results of these specimens are presented in Table 3 and in Figure 2. Some shrinkage in x and y axis was observed, while dimensions achieved in z-axis were slightly bigger than nominal. Compared to the FFF manufactured parts the green parts manufactured with BJ technology have 40% less mass. Parts are firm to the touch and somewhat flexible which could be useful for shock absorption if used for packaging. Decomposition time of a test specimen inside a glass of water was around 60 s.

Table 3. BJ results

specimen	x [mm]	y [mm]	z [mm]	mass [g]	density [kg/m^3]
1	9.51	9.52	5.33	0.25	517.6
2	9.70	9.67	5.19	0.24	493.5
3	9.65	9.63	5.25	0.24	492.2

Figure 2. Cuboid test specimens manufactured with BJ technology using 85% peach kernel and 15% PVA powder mixture.

5. Conclusions

Peach kernels can be used as a material for additive manufacturing in both BJ and FFF technologies. Material is more temperature sensitive and prone to burning which should be considered when using FFF technology.

Parts manufactured with BJ technology are sturdy enough to be handled and are slightly flexible when loaded.

Manufacturing parts using the combination of PVA and peach kernel powder is therefore feasible and offers an advantage of being rapidly dissolved in the water. This material could be used to produce biodegradable products and may contribute to a circular economy paradigm.

Further work is needed to improve the methods of powder preparation, which has proved to be challenging. The material properties should be further investigated, using standard test methods to provide the quantitative data. We are currently working on compressive testing after which we will determine the next suitable test method. In addition, the optimal parameters for manufacturing with both technologies need to be determined.

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