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EFFECT OF HUMIDITY ON 3D-PRINTED SPECIMENS FROM WOOD-PLA FILAMENTS

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ABSTRACT

Filaments from a mixture of wood powder and polylactic acid (PLA) polymer were made and used for 3D printing. Different wood ratios were used: 10 %, 20 %, 30 %, 40 %, and 50 %. Specimens were 3D-printed with fused deposition modelling (FDM) printer and conditioned in climates with different levels of relative moisture (RH): 33 %, 65 %, and 87 %. Moisture content (MC), dimensional swelling, and bending properties of printed specimens were measured after conditioning. The results showed that specimens made from filaments with higher wood content had higher moisture content, larger dimensional swelling, and lower modulus of elasticity (MOE).

KEYWORDS: Wood-PLA filaments, 3D printing, moisture content, dimensional swelling.

INTRODUCTION

Great emphasis has been put on development of 3D printing materials in the last decade including the use of biodegradable, natural or recycled materials like wood, wooden fibres, cellulose, and lignin (Wimmer et al. 2015). Wood residue is an interesting, reasonably cheap material, which could be processed and used in/as 3D printing material. Its use would increase added value to wood, since wood residues are nowadays commonly used for heating purposes, with a low added value.

Wood particles can be included in several techniques for 3D printing, including fused deposition modelling (FDM); injection powder printing or liquid/paste deposition modelling (Tao et al. 2017, Henke and Treml 2013, Kariz et al. 2018). Wood and polymer mixtures have already been used for wood plastic composites (WPC). Depending on the wood particle properties, aspect ratio, size distribution, and compatibility with the thermoplastic wood in polymer composites can serve just as filler or as reinforcement (Kim and Pal 2010).

Including the wood particles in wood polymer composites also brings its negative properties to composites: wood's hygroscopic nature, swelling and shrinking with moisture changes, and proneness to fungal attack. With correct area of use, additives and processing these wood negative properties are less pronounced as in solid wood. The moisture caused dimensional changes can also be used for producing smart materials with moisture induced shape changes (Le Duigou and Castro 2017).

The aim of this preliminary study was to evaluate the behaviour of the 3D-printed parts from wood PLA filaments with different wood ratios in different levels of humidity and is a part of the larger ongoing research on use of wood in 3D printing.

MATERIALS AND METHODS

Filaments with wood particles were prepared by milling beech wood (*Fagus sylvatica* L.) in a laboratory mill (Retsch ZM 200). The wood particles were then sieved, and only particles that went through the mesh with an opening of 0.237 mm were used. Six different filaments were prepared with different wood content: 0 % (control specimens), 10 %, 20 %, 30 %, 40 %, and 50 % wood content by weight. Two commercial filaments without wood particles: Z-ABS filament (Zortrax S.A., Poland) and PLA PrimaValue filament (3D Prima, Sweden) were also used for comparison.

The dried wood particles and PLA granules (Ingeo™ 2003D, NatureWorks, NE) were first compounded in twin screw compounder and pelletized. A Noztek-pro single-screw filament extruder (Noztek, UK) was used to produce 1.75-mm thick filament from prepared pellets. Test specimens were printed using a Zortrax M200 3D printer (Zortrax, Poland) with 0.4 mm nozzle, printing layer thickness of 0.19 mm, a heated bed, printing speed 30 $mm \cdot s^{-1}$ and printing temperatures of 275°C (for ABS) and of 230°C for PLA (Fig. 1).

The model (80 × 12 × 4 mm) was printed from three solid layers on the bottom, top, and sides, but the inside was a mesh structure (solid infill setting: square size 1.25 mm and line thickness 0.4 mm). Four specimens were printed for each combination of climate and wood content, in total 96 specimens.

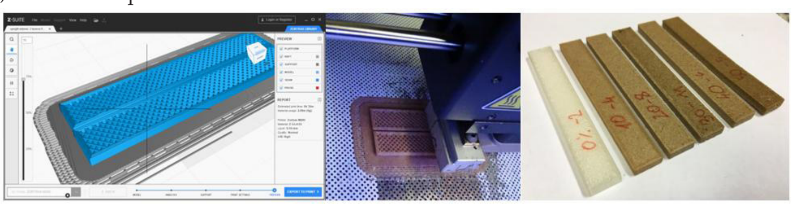

Fig. 1: Two samples prepared for 3d printing in Z-Suite software with mesh structure inside (left), 3d printing the infill mesh structure (middle), 3d printed samples with different wood ratio (right).

After printing the specimens were dried in a laboratory oven for 24h at 80°C to remove any remaining moisture, measured ,and weighed, and then conditioned in different climates: dry (T=20°C, RH 33 %), standard (T=20°C, RH 65 %), humid (T=20°C, RH 87 %) in climate chambers with regulated temperature and relative moisture content. The mass and dimensions were measured after 2, 5, 9, 16 days. The bending properties were tested on Zwick-Roel Z005 universal testing machine after conditioning. Three point bending test was used with position controlled loading 10 $mm \cdot min^{-1}$ until fracture or 50% force drop occurred.

RESULTS AND DISCUSSION

The filaments with wood addition had smaller diameters (Tab. 1). All filaments (with different wood/polymer ratio) were produced under the same conditions (extruder speed and temperature), so the deviation of the diameter was due to increasing viscosity of wood-PLA mixtures with higher wood content and thus higher extrusion forces needed, which changes similar as in wpc production with wood polymer composite formulation, for example wood/polymer ratio, wood particles aspect ratio and additives (Niska and Sain 2008).

Tab. 1: Diameters of the filaments from different filaments, moisture content after conditioning and MOE for 3D-printed specimens after conditioning in different climates.

		Dry climate (T 20°C, RH 33 %)		Standard climate (T 20°C, RH 65 %)		Humid climate (T 20°C, RH 87%)	
	Filament diameter (mm)	Moisture content (%)	MOE ($N \cdot mm^{-2}$) *	Moisture content (%)	MOE ($N \cdot mm^{-2}$) *	Moisture content (%)	MOE ($N \cdot mm^{-2}$) *
ABS	1.73	0.4	1313 (70)	0.4	1383 (51)	1.1	1343 (50)
PLA	1.72	0.3	1568 (146)	1.3	1563 (71)	0.8	1477 (38)
Wood PLA 0%	1.61	0.5	1393 (17)	0.6	1442 (39)	1.0	1483 (109)
Wood PLA 10%	1.45	0.9	844 (97)	1.4	768 (75)	2.3	791 (165)
Wood PLA 20%	1.44	0.7	809 (238)	1.4	846 (245)	3.1	542 (255)
Wood PLA 30%	1.47	1.6	771 (36)	2.3	735 (106)	4.0	681 (131)
Wood PLA 40%	1.48	0.8	790 (78)	2.2	798 (75)	3.6	623 (50)
Wood PLA 50%	1.51	1.3	350 (407)	3.0	475 (339)	5.2	469 (155)

*Standard deviation in brackets

The 3D-printing program was the same for all filaments and was prepared for filaments with 1.75 mm diameter. So the models printed with filaments with wood addition (thinner filament) were made with less material and that influenced the mechanical properties of printed parts. For example, specimens made from filaments with 50% wood were printed with 23 % less material (comparing cross section of the filaments with smaller diameter).

Wooden particles in filaments caused clustering and clogging and uneven flow through the nozzle, which cause drougher, more porous, and non-solid/fused structures, which reduced mechanical properties (Kariz et al. 2018).

The moisture content (MC) of the specimens depended on the RH of climate and wood content. Wood is a hygroscopic material that absorbs/desorbs moisture from surroundings and thus swells/ shrinks. Consequently, filaments with wood addition are also hygroscopic and change their dimensions with changing climate (Kaboorani 2017).

The specimens from commercial ABS and PLA had the lowest MC (for example 1% MC at 87% RH), but the MC of specimens with wood was higher and was increasing with increasing wood content (5.2 % for specimens with 50% wood particles in 86 % RH). The MC of specimens reached equilibrium after 5-9 days conditioning. The MC was still low, compared to solid beech wood in the same conditions (MC for beech in 33% RH is 7%, in 65% RH is 12%, and in 87% RH is 20 %) and was not proportional to wood content compared to solid wood, since polymer encapsulate/surround the wood particles and diminish its hygroscopicity.

The 3D-printed specimens swelled in all directions, with the highest value in the length direction. The specimens with higher wood content (Fig. 2) showed the highest expansion (0.3% for specimens with 50% wood content in 87% RH) and the highest expansion was in the most humid climate. This correlates with the moisture content of these specimens (Tab. 1).

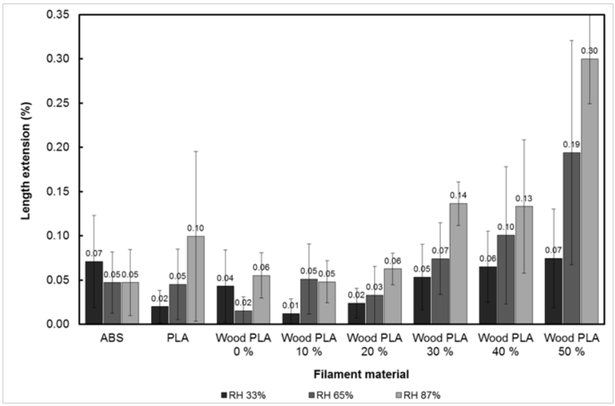

Fig. 2: Length extension of 3D-printed specimens after conditioning from dry to selected climate (RH 33, 65, 87 %).

Bending properties

The modulus of elasticity (MOE) of specimens with wood particles was lower in comparison to specimens without wood (0% wood) or commercial filaments and was decreasing with wood content. A mere 10 % of additional wood to the PLA polymer reduced the MOE of 3D-printed specimens for almost 47% (standard climate).

Several reasons for lower bending properties are proposed: less material due to smaller filament diameter (Tab. 1), wood particles act only as afiller due to small dimensions/aspect ratio, insufficiently fused layers, not fully encapsulated wood particles with polymer, and non-homogenous printing due to nozzle clogging. Similar factors have an effect on mechanical properties as in WPC (Migneault et al. 2014, Wilczyñski et al. 2011).

CONCLUSIONS

The research has shown that the addition of wood powder in the 3D printing PLA material affects the properties of the printed parts. Mechanical properties were lower due to wood acting as filler in the structure and less homogenous printed material due to clogging of the printer nozzle, variations in diameter of produced wood-PLA filament (less material in printed specimens) and insufficiently fused layers. The bending properties reduced with wood content, but the differences among climates were not significant.

The moisture content of the specimens was increasing with the wood content in all climates. The specimens with higher wood content also showed higher length extension/swelling due to moisture absorption. This negative characteristic can be beneficial for forming 4D-printing materials to design products that change in response to climate (Le Duigou 2017) this is the goal of our further research.

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