USE OF WOOD IN 3D PRINTING TECHNOLOGY – case studies

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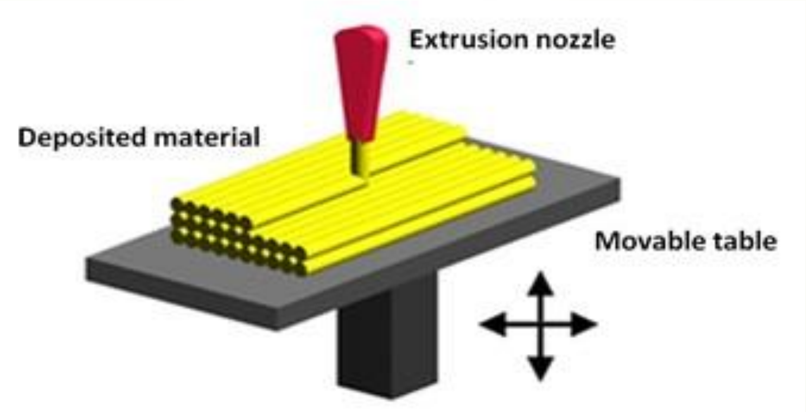
Introduction

3D printing technology has shown extraordinary growth over the past few years. It enables users to create real objects based on a virtual computer model and thus opens up an almost unimaginable number of possibilities.

3D printing is classified as an additive manufacturing process, where the material is added in layers, allowing users to create a real product directly from a 3D computer model. In this way, users can create complex shapes that are not otherwise possible by forming and moulding.



Material extrusion additive manufacturing process (Petrie 2018)

Advantages of Wood for the 3D printer filaments

The wood flour has significant advantages as compared to the thermoplastics are considerably cheaper than thermoplastics (200 USD per ton while 1 ton of PLA is 1200 to 2000 USD). Filaments produced from wood flour compounded with polyethylene or polypropylene are used to make a variety of commercial products because they are less expensive and provide unique mechanical properties when compared to neat resins.

Wood polymer compound

Filament extruder

Filament for 3D printer

As the wood flour is incorporated in the thermoplastics the price of material for 3D printers can be decreased, which considerably increase the use of 3D printer in near future. In addition, the consumers will prefer the environmentally friendly materials for their 3D materials. Cellulose is non-allergic, tolerating high temperatures, and is an excellent electric insulator material, which can be processed with many 3D-printing methods.

As replacements for conventional synthetic fibers like aramid and glass fibers, lignocellulosic fillers are increasingly used for reinforcement in thermoplastics due to their low density, good thermal insulation and mechanical properties, reduced tool wear, unlimited availability, low price, and problem-free disposal.

Additive Manufacturing: Is It a New Era for Furniture Production ?

M. Aydin. Journal of Mechanics Engineering and Automation 5 (2015) 338-347.

Connectors are essential to assembly fixed or moving parts of furniture. Additive Manufacturing (AM) gives an opportunity to print personalized or downloaded connectors to fix furniture at home. Also their dimensions can be altered to fit personalized furniture components. But, essential parts such as surface table need to be ship

The complex connectors can be easily printed by desktop 3D printers and this allows the possibility to assembly preordered components such as simple wood with connector you printed.AM lets users to manufacture consumer products in a few steps even if they have complex geometries. However, using the conventional manufacturing processes to fulfill these issues could be impossible in some cases. AM manufacturing is relatively slower than serial production. This is the one of the main issue that is needed to be developed.

AM lets users to manufacture consumer products in a few steps even if they have complex geometries. When customization comes into prominence, AM provides design flexibility and so each piece of furniture could be printed distinctly. Also open-source of designs allows users to develop any of projects together such as “the puzzle chair”.

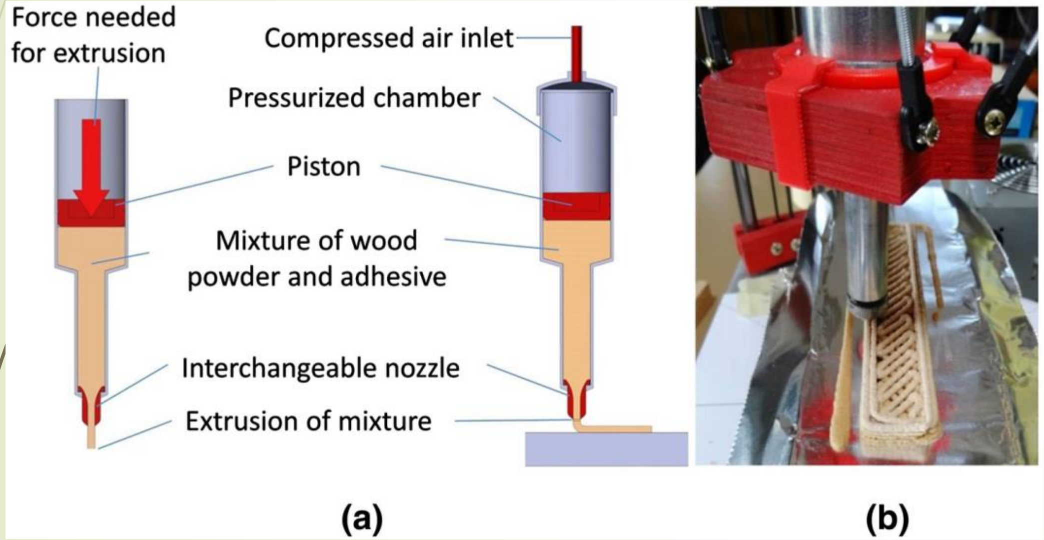
AM can be assumed as the future of modern manufacturing system and localization of the manufacturing. It can be said that furniture manufacturing by AM is relatively new. Non-industrial use of the AM in furniture production can be stated as one of the latest innovative development. And, it is clear that design phase of processes is more important than the others. So, it can be said that craftsmanship and other traditional activities would be affected negatively in the future by its potential if everything starts and ends between designer and printer.

Weight is one of the main parameters of the AM due to used material density. 3D models are generally designed in lattice, mesh or similar forms to reduce weight. 3D printed sofa “Sofa so good” is a good example for this matter as seen in Fig. 12. Its dimensions are 150 × 75 × 55 cm3 and can hold up to 100 kgs while it weighs only 2.5 kgs. It is strong due to its complex mesh design that was inspired by and mimicked of spiderweb and silkworms cocoons.

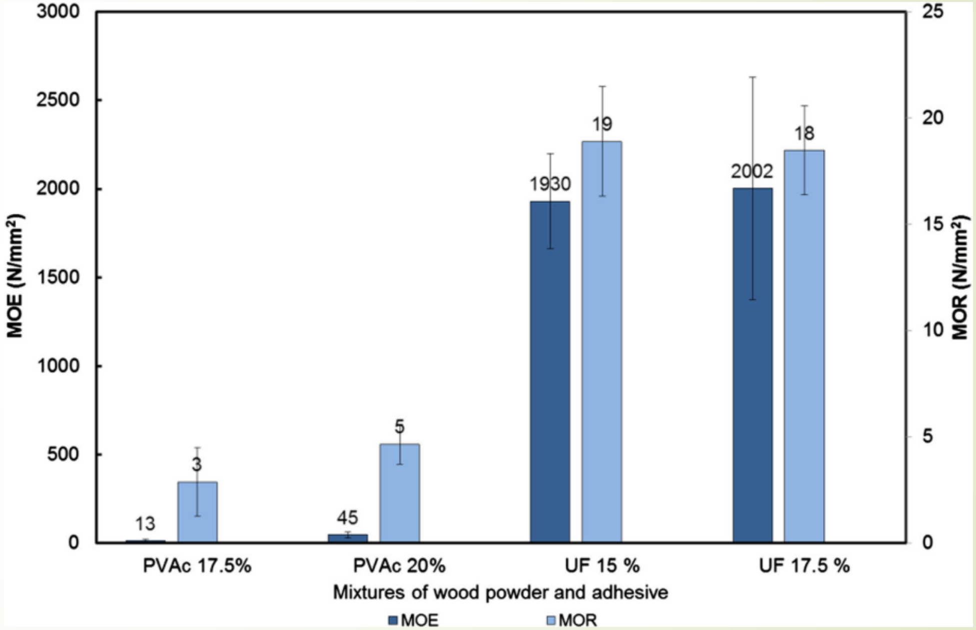
Use of wood powder and adhesive as a mixture for 3D printing

M. Kariž, M. Šernek, M.K. Kuzman, *European journal of wood and wood products*,, 2016, vol. 74, no. 1, str. 123-126.

- Paste extrusion, mixture of fine wood powder and commercial PVAc and UF adhesive
- DIY delta 3D printer
- MOE of 3D printed parts depended on used adhesive and wood/adhesive ratio



a) Test setup for measuring the extrusion force by means of a universal testing machine (left) and the test set-up for 3D printing with a pressurized chamber (right), b) 3D printing with a mixture of wood powder and adhesive

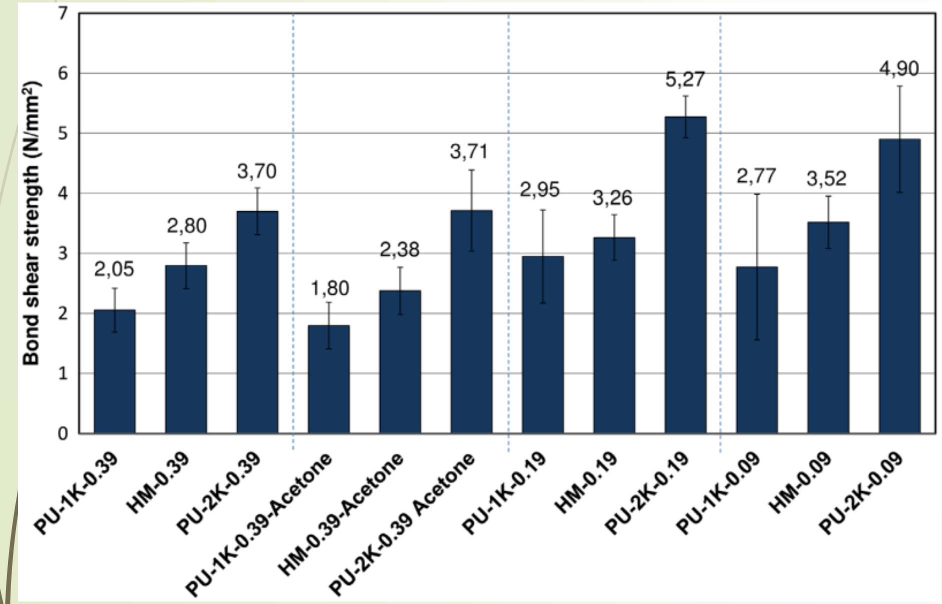


Average bending strength (MOR) and modulus of elasticity (MOE) for the 3D printed blocks made from different mixtures of wood powder and adhesive (n = 5)

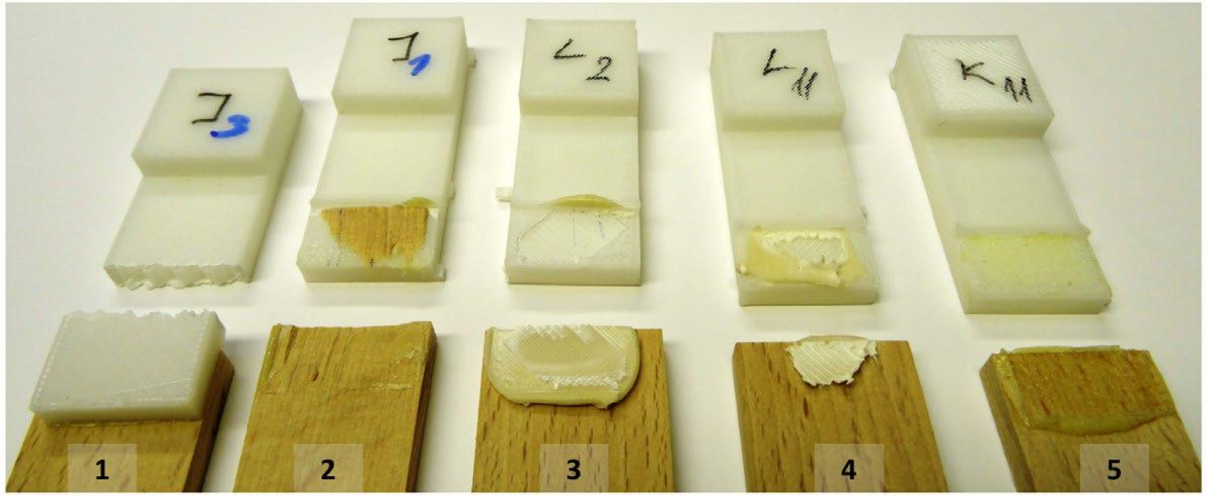
Adhesive bonding of 3D-printed ABS parts and wood

M. Kariž, M.K. Kuzman, M. Šernek, *Journal of adhesion science and technology*, 2017;31:1683-1690.

- 3D printed parts from ABS plastic bonded to wood with different adhesives (1k PU, Hot melt adhesive, 2k PU) and surface treatment (acetone vapours)
- Shear strength of adhesive joints
- Highest strength – joints with 2-component PU adhesive



Average tensile bond shear strength for different printing parameters and adhesives.

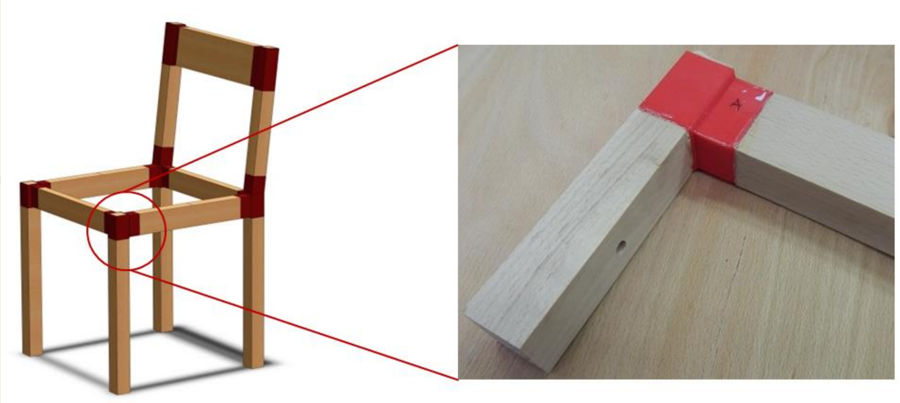


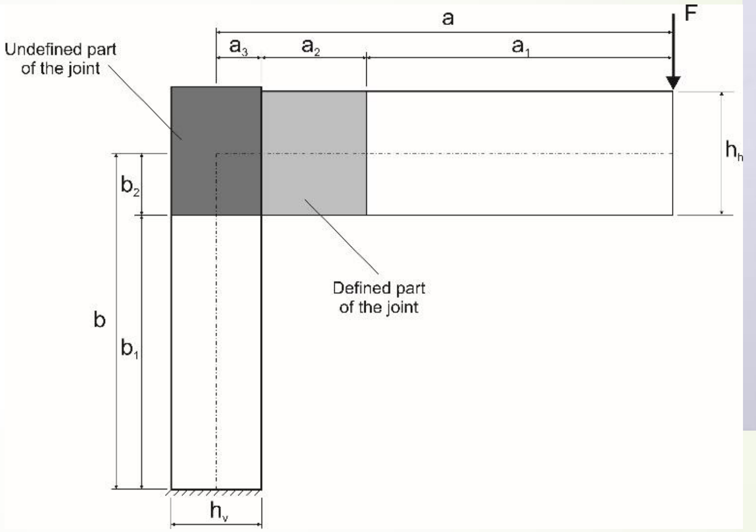
Different types of specimen failure. (1) Tensile failure, (2) wood failure, (3) 3D printed part failure, adhesive adhesion failure, and (5) adhesive cohesion failure.

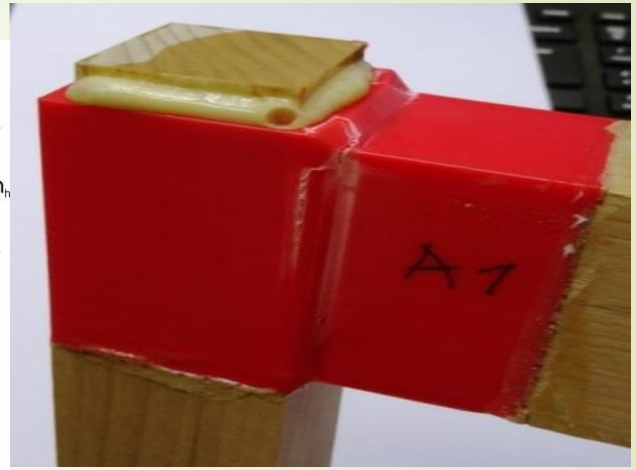
Mechanical properties of 3D-printed connectors for chair's mortise and tenon joints

M. Kariz, S. Vratuša, Hajdarević, M.K. Kuzman

- 3D printed connectors (ABS) for chair joints
- Comparison of mathematical models, real tests







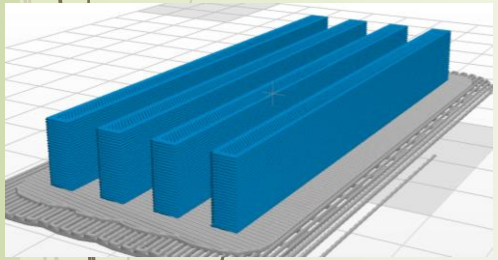
Typical failures for the 3D printed connector

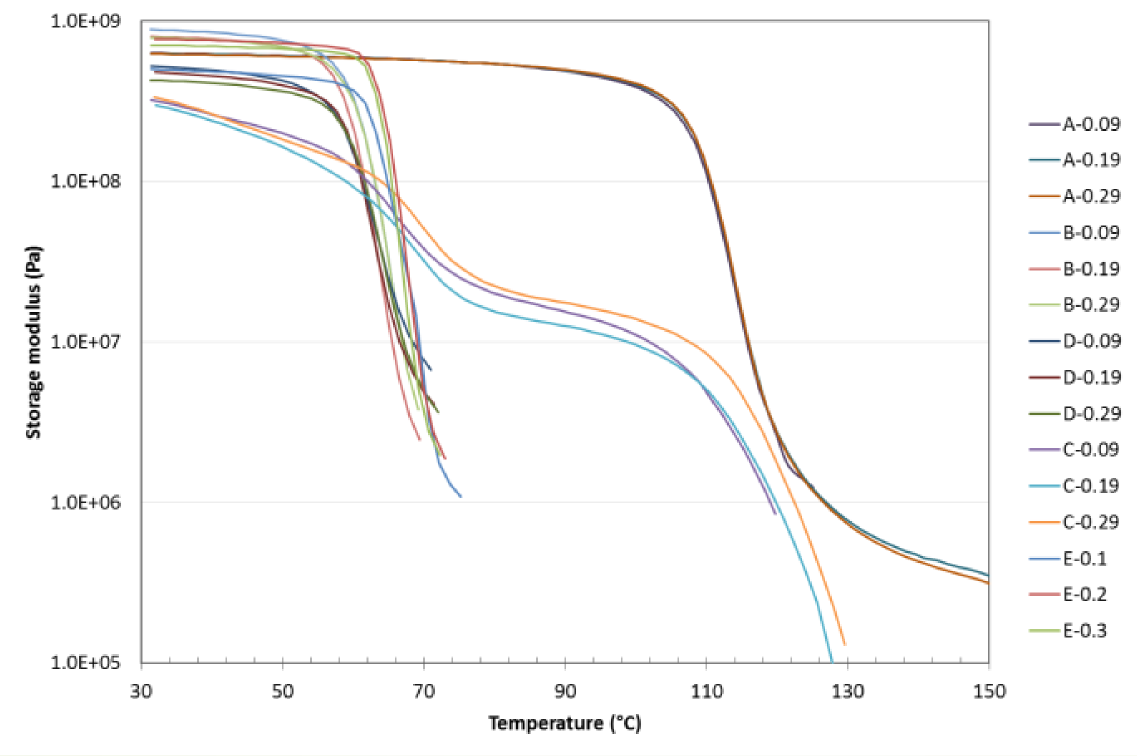
$$dL = \frac{F}{3}\left(\frac{{a_1}^3}{E_{a_1}I_{a_1}} + \frac{(a_1+a_2)^3-{a_1}^3}{E_{a_2}I_{a_2}} + \frac{a^3-(a_1+a_2)^3}{E_{a_3}I_{a_3}} + \frac{3a^2b_2}{E_{b_2}I_{b_2}} + \frac{3a^2b_1}{E_{b_1}I_{b_1}}\right).$$

Rheological properties of selected 3D printing materials with different printing layer thickness

Manja Kitek Kuzman, Nadir Ayrilmis, Milan Šernek, M. Kariž

- Five different printing materials (ABS, PLA, copolyesters, mixtures with different wood content) and three printing layer thicknesses (0.09, 0.19, 0.29 mm)
- Rheological properties of 3D printed samples, Temperature effects





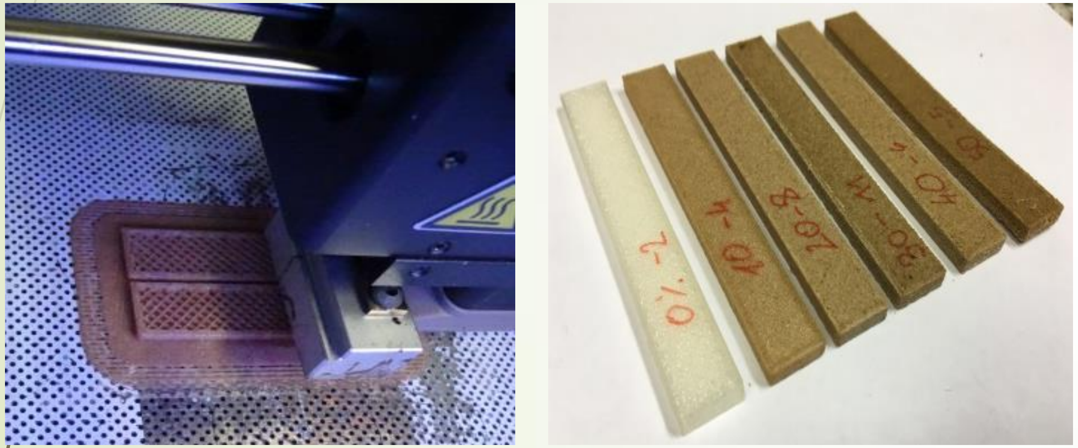
Storage modulus of different materials during heating

Filament	Marking	Printing layer thickness (mm)	Max storage modulus (GPa)	Storage modulus compared to thinnest printing layer (%)	LVR limit (5% drop) (%)
A	A-0.09	0.09	0.6449	100%	0.7909
	A-0.19	0.19	0.6443	100%	0.7907
	A-0.29	0.29	0.6390	99%	0.7900
B	B-0.09	0.09	0.9214	100%	0.4987
	B-0.19	0.19	0.8443	92%	0.6279
	B-0.29	0.29	0.8259	90%	0.6274
D	D-0.09	0.09	0.5617	100%	0.4991
	D-0.19	0.19	0.5151	92%	0.7911
	D-0.29	0.29	0.4605	82%	0.6281
E	E-0.1	0.1	0.5937	100%	0.3149
	E-0.2	0.2	0.8116	137%	0.6278
	E-0.3	0.3	0.7666	129%	0.3965
C	C-0.09	0.09	0.3367	100%	0.9958*
	C-0.19	0.19	0.3060	91%	0.9959*
	C-0.29	0.29	0.3492	104%	0.9959*

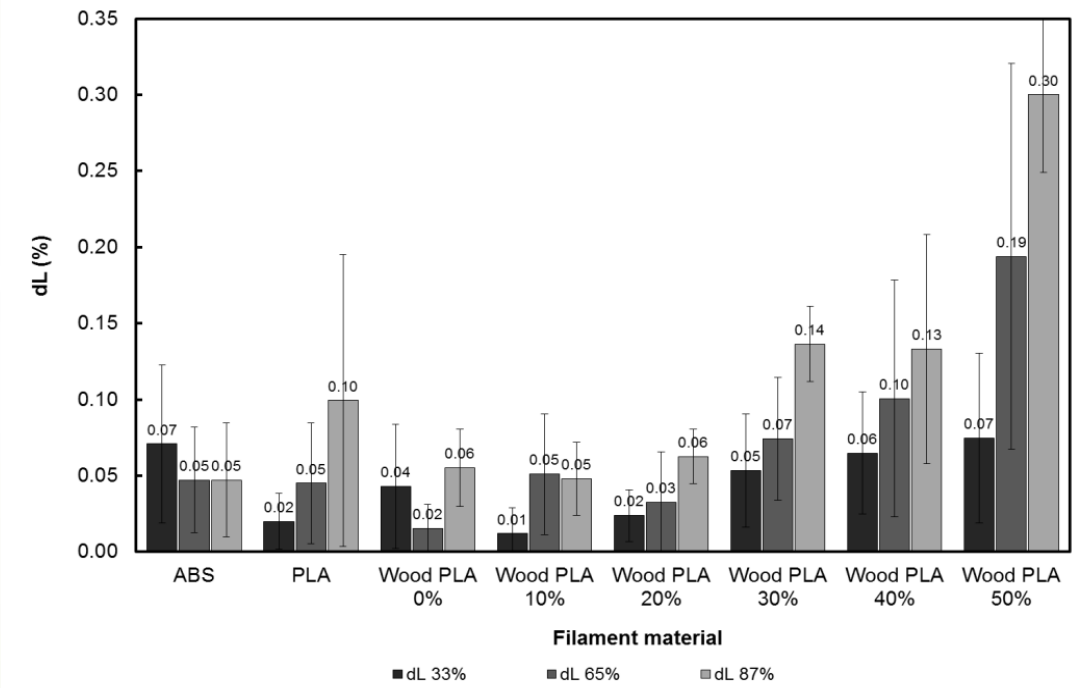
Effect of humidity on 3D-printed specimens from wood-PLA filaments

M. Kariž, M. Šernek, Manja Kitek Kuzman

- FDM 3d printed samples, PLA/wood 0-50% content
- Different moisture climates (dry 33% RH, standard 65% RH, wet 87% RH)
- Dimension changes and moisture changes



3D printed samples with different wood ratio (right)

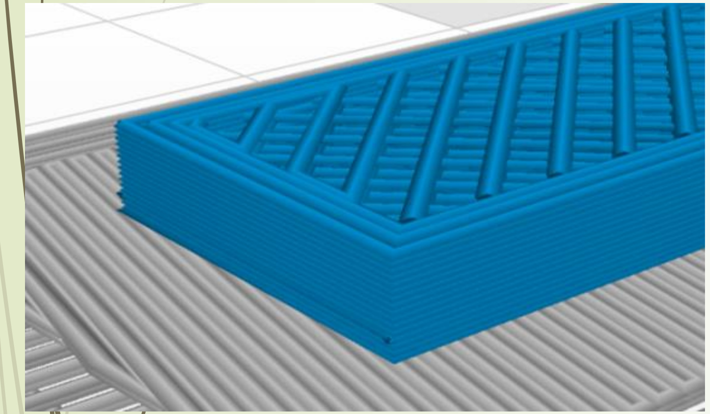


Length extension of 3D-printed specimens after conditioning from dry to selected climate (RH 33, 65, 87 %)

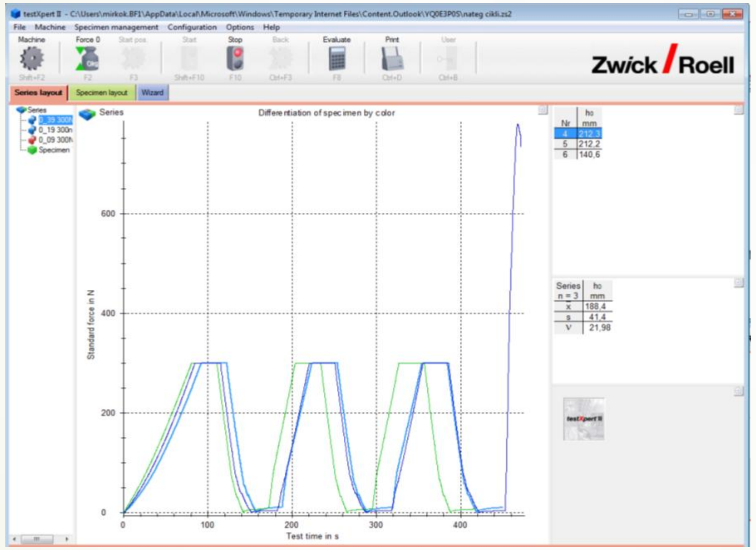
Analysis of the viscoelastic properties of polymeric materials used for 3d printing

M. Obućina, J. Ibrulj, E. Džaferović, A. Čekić, M. K. Kuzman, M. Šernek, M. Kariž

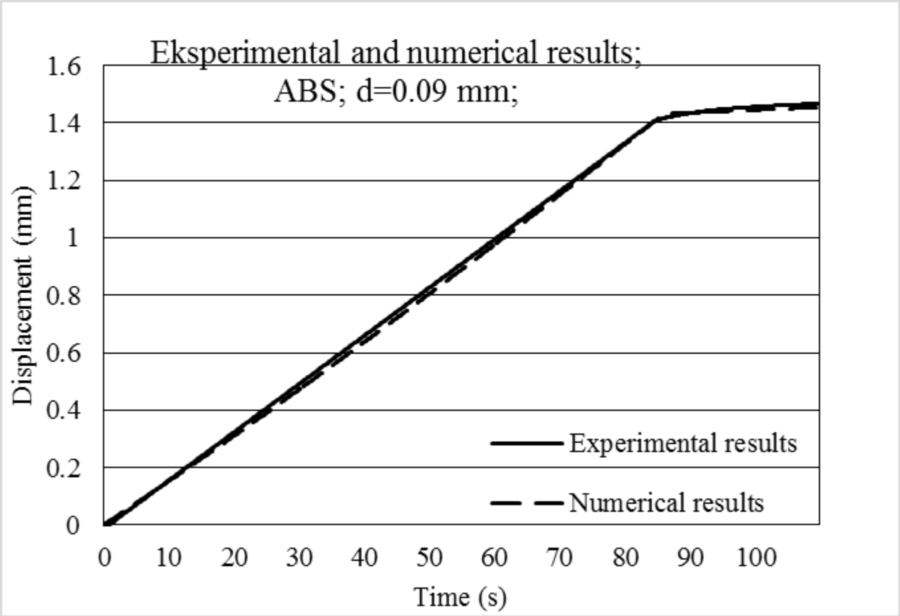
- Viscoelastic properties of polymeric materials obtained by 3D printing from ABS plastic
- Finite volume method



Mesh structure inside 3D printed sample



Tensile tests on Zwick Roel Z005 universal testing machine -TestXpert software for controlling tensile tests.

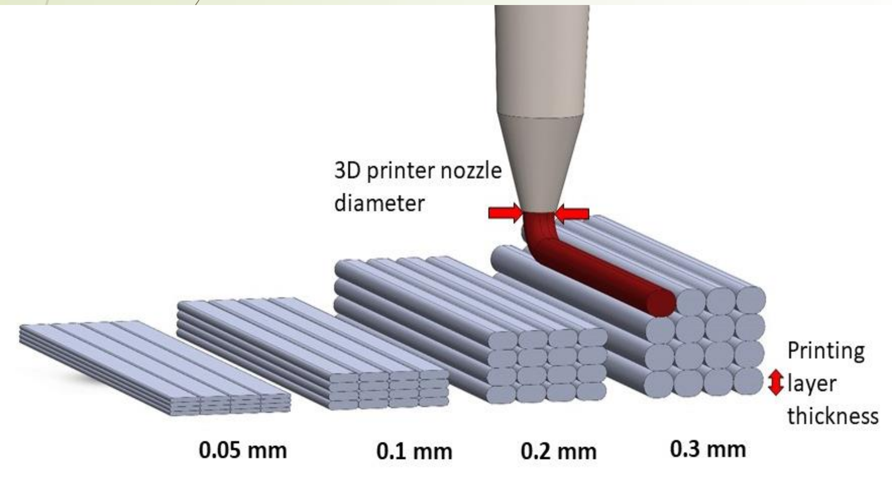


Numerical and experimental results for sample made of ABS printed with layer thickness 0.09mm. t_o=85 s.

Effect of printing layer thickness on water absorption and mechanical properties of 3D printed wood/PLA composite materials

N. Ayrilmis, M. Kariž, M.K. Kuzman

- Effect of printing layer thickness on technological properties of 3D printed materials
- Wood flour/PLA filament
- The water absorption of the specimens (28-days immersion in water)
- Tensile and flexural properties



Schematic representation of printed sample geometry.

Water absorption and mechanical properties of 3D printed wood/PLA composite samples.

3D printed wood/PLA sample code	Printing layer thickness (mm)	Density (g/cm^3)	Water absorption (28-days) (%)	Bending properties		Tensile properties	
				Bending strength (MPa)	Bending modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)
A	0.05	1.008 (0.010)	0.19 (0.03) a	128.3 (4.0) a	4887 (145) a	35.5 (1.5) a	3642 (122) a
B	0.1	0.993 (0.011)	0.22 (0.05) a	121.7 (4.2) b	4350 (125) b	33.9 (1.2) b	3410 (141) b
C	0.2	0.980 (0.009)	0.64 (0.04) b	113.6 (3.8) c	4125 (137) c	28.7 (1.4) c	3115 (133) c
D	0.3	0.975 (0.08)	0.72 (0.06) c	84.3 (2.8) d	3580 (103) d	20.5 (0.7) d	2567 (92) d

Conclusions

Manufacturing furniture parts with low volumes or complex geometries, obtaining low-density parts, eliminating raw material waste are common reasons for using 3D printing technology in the furniture industry.

Furniture manufacturers can prefer 3D printing for being able to use cheaper raw materials or to ensure certain physical properties by using different raw materials together. As a result, 3D printing may provide opportunity for the manufacturers to obtain cost advantages, process, and product improvements. In addition to purposes like testing, design, prototyping, and production of certain parts and some special assembly tools, the furniture industry has tried to utilize 3D printing to manufacture furniture elements.

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