The consolidation behaviour of thermoplastics during 3D-Printing under high ambient pressures

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Abstract

To attain high strength qualities for 3D printed items similar to injection-molded specimens, an experimental setup was built up using a 3D printer incorporated into a customized Autoclave. A maximum temperature of 185 ° C and 135 bar of pressure may both be maintained in the autoclave. Atmospheres of compressed air at 0 bar, 5 bar, 10 bar, 15 bar, and 20 bar as well as nitrogen at 5 bar was used for PLA 3D printing in the autoclave.

The effects of pressure and temperature on 3D-printed samples were examined, and tensile, flexural, and Charpy tests were performed on printed specimens as well as on specimens that had been injection molded. It could be demonstrated that autoclave preheating before printing and autoclave pressure during printing greatly enhance layer consolidation. Increased yield strength, Young's modulus, and impact strength are produced as a result of closer contact between the layer surfaces caused by the pressure within the autoclave. Most experiments produced better results when the autoclave pressure was 15 bar.

Materials & Methods

In this research work, pure PLA (Polylactic Acid) filament of high quality and PLA granules from Herz GmbH, Germany was used

Figure 1 PLA 3D-Printer filament & PLA Injection molding granules

In this research, an Ender-3 as shown in Fig.2, V2 model FDM 3D-Printer from Creality-2020 was used. The maximum possible dimensions are 220 × 220 × 250 mm (L × B × H), and the total weight of the machine is 7.8kgs. General specifications like Maximum bed temperature, maximum extruder temperature, and maximum printing Speed are 100° C, 250° C, and 180 mm/sec, respectively.

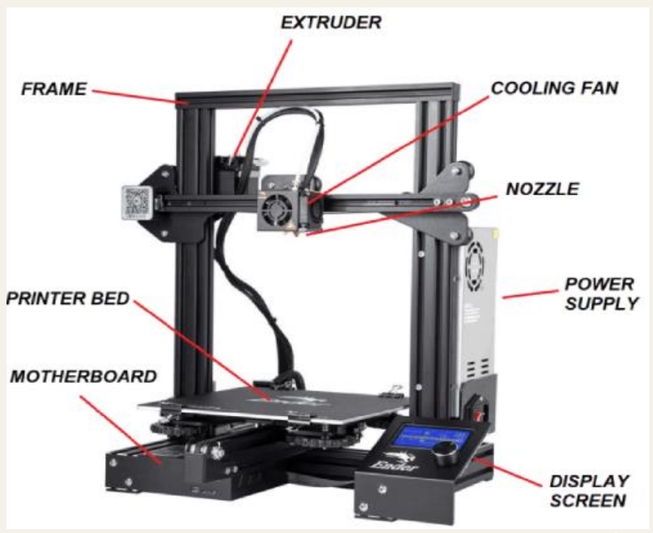


Figure 2 Creality Ender 3 V2 FDM 3D-Printer

In the autoclave, the testing specimens were printed at 0 bar, 5 bar, 10 bar, 15 bar, and 20 bar of additional pressure in a 5 bar nitrogen atmosphere. For each test, 5 samples were printed in an autoclave in two distinct printing patterns (longitudinal and transverse to the printing direction as shown in Fig. 3& 4).

Experimental setup

Figure 3 3D-Printer setup in Autoclave

A customized autoclave chamber from Haage Anagram GmbH, Germany, which had been specially designed to support polymer-processing methods, was used in this research. This autoclave maintains a maximum of 135 bar and 185° C and weighs about 1300 kg (including a front lid with a weight of 300 kg).

Experimental setup

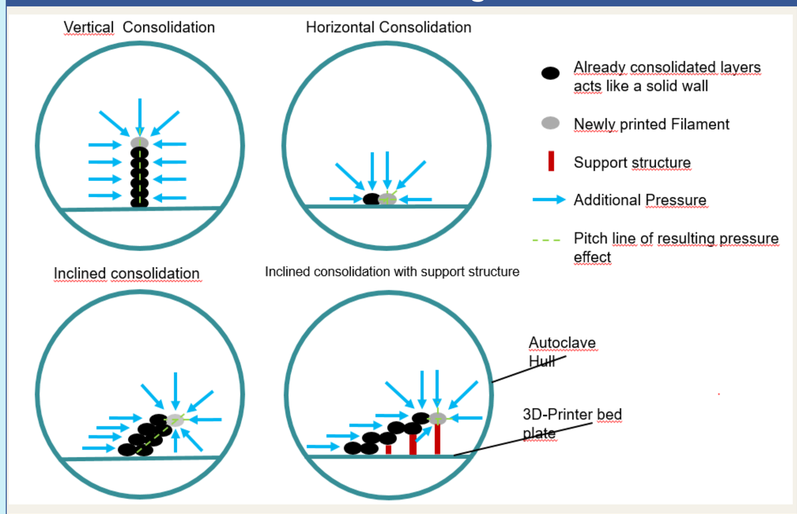
Figure 4 Longitudinal printing pattern

Figure 5 Transverse printing pattern

Tests on samples

- The tensile strength, stiffness, and elongation properties were measured according to DIN ISO 527, using a tensile testing machine from Zwick (Proline-Z005) along with Zwick´s Test Expert software. The strain measurement was done optically with the Video extensions system also from Zwick.
- Charpy impact test DIN ISO 179 was carried out with a Ray-Ran pendulum with an impact energy of 4 joules and an impact velocity of 2.9 m/sec.

Effect of autoclave pressure on filaments while 3D Printing



Test results

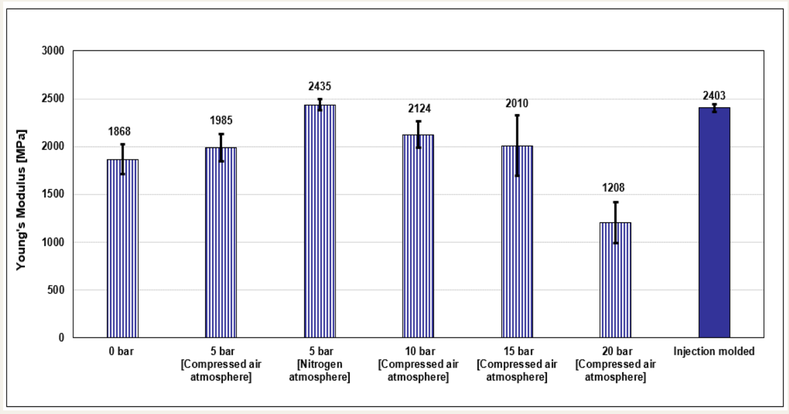


Figure 6: Young´s modulus comparison of samples printed in the longitudinal direction in different pressure conditions with injection molded sample.

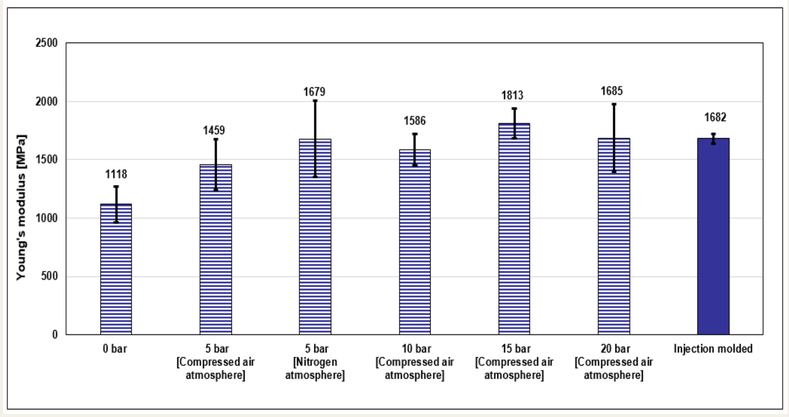


Figure 7: Young´s modulus comparison of samples printed in the transverse direction in different pressure conditions with injection molded sample.

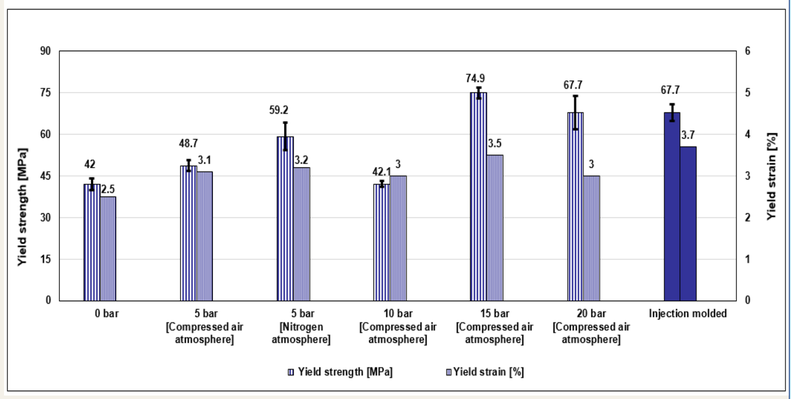


Figure 8: Yield strength comparison of samples printed in the longitudinal direction in different pressure conditions with injection molded sample.

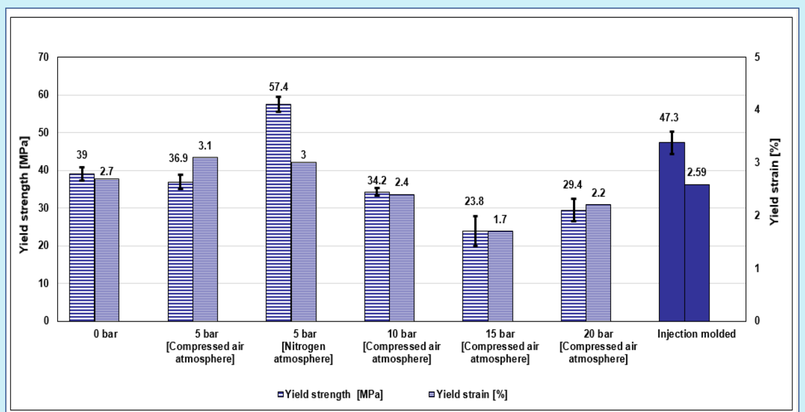


Figure 9: Yield strength comparison of samples printed in the transverse direction in different pressure conditions with injection molded sample.

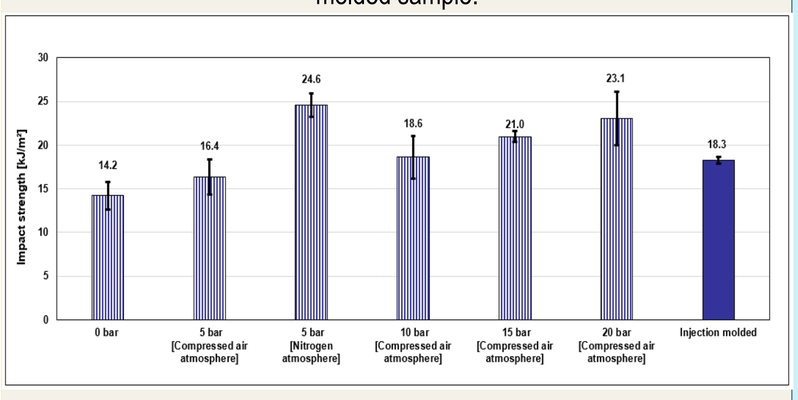


Figure 10: Impact strength comparison of samples printed in the longitudinal direction in different pressure conditions with injection molded sample.

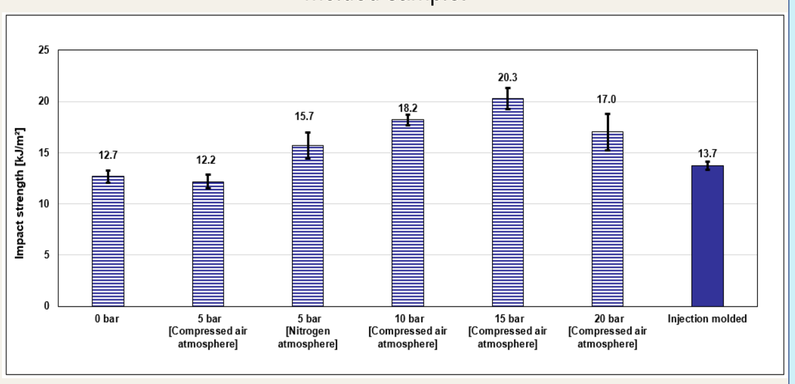
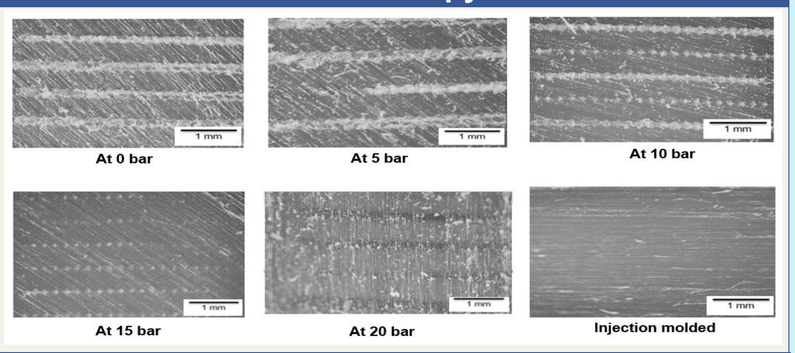


Figure 11: Impact strength comparison of samples printed in the transverse direction in different pressure conditions with injection molded sample.

Microscopy



Conclusion

The autoclave is used for this research to print PLA specimens in two different orientations, longitudinal and transverse, under different pressure conditions.

In order to compare the results of the testing, injection molding was also performed using the same PLA material. The study comes to the conclusion that specimens printed in 3D in the longitudinal direction at autoclave pressure and temperature have superior qualities than specimens produced in a transverse manner.

The cause may be improved consolidation, which leads to more secondary bondings and an increase in shear strength between layers. Another explanation may be a sharp decline in voids. Higher values for the recrystallization temperature, glass transition temperature, melting temperature, and density are obtained for 3D printed objects when autoclave pressure and temperature are used.

Acknowledgements

The author would like to thank Hochschule Kaiserslautern for funding the project, ICCM 2023 Conference, and providing laboratory equipment and its facilities at the University of Applied Sciences Kaiserslautern, Germany & IKW.

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