EFFECT OF FUSED FILAMENT FABRICATION PROCESSING PARAMETERS ON THE MECHANICAL PROPERTIES OF PLA COMPONENTS

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ABSTRACT

This paper studies the influence of Fused Filament Fabrication processing parameters upon mechanical properties and microstructural features of processed PLA parts. The effect of extrusion temperature and raster angle were tested upon two PLA filaments of different trademarks, DoWire and BQ, using a commercial fused deposition extruder. The filling density, layer thickness and velocity were kept constant at 60 %, 0.2 mm and 40 mm/s, respectively.

Results allowed to determine fused filament fabrication parameters resulting in increased mechanical performance of manufactured parts. Mechanical performance is higher when material is stored under controlled atmosphere before use, and when material deposition direction is aligned with applied load. Increasing the extrusion temperature also increases performance, by increasing deformation ability of PLA molecules. Obtained results contribute to accumulation of a property database and provide design guidance to the procurement of additive manufacturing products with enhanced mechanical strength.

Keywords: Additive Manufacturing; PLA; Raster Angle; Extrusion Temperature.

INTRODUCTION

Additive manufacturing (AM) is a most promising area in the manufacturing of components [1,2]. Among AM technologies, Fused Filament Fabrication (FFF) is one of the most popular [1,2], with uses ranging from desktop hobbyist-grade manufacturing to the production of rapid prototypes for functional testing [2]. In FFF a continuous filament of thermoplastic material is fed through an extruder head, where it is heated, molten and forced out, to be deposited on the growing workpiece. Poly(lactic acid), a biodegradable aliphatic polyester, is on its turn an extensively used raw material in FFF processing [2]. This process/material combination brings about significant advantages including low cost, low setup time, needlessness of moulds, tools and cooling systems, minimal material wastage, and ease of material change [2]. FFF is a complex process with a large number of parameters that influence processed material quality and properties, and in as much determine quality and performance of the resulting extruded parts. Such parameters include build orientation, layer thickness, raster angle, raster width, air gap, infill density and pattern, and feed rate [2]. Although they are expected to have substantial effect on the quality and performance of FFF parts, these parameters are mostly empirically chosen, and references on mechanical properties of parts processed by low cost extruders are scarce. Also, to the best of the authors' knowledge, their effect upon poly(lactic acid) plastics with different additives, chain size, and crystallinity hasn't been reported. Since mechanical properties are crucial for performance, it is essential to examine the influence of FFF processing parameters on resulting material properties and on produced parts mechanical behaviour.

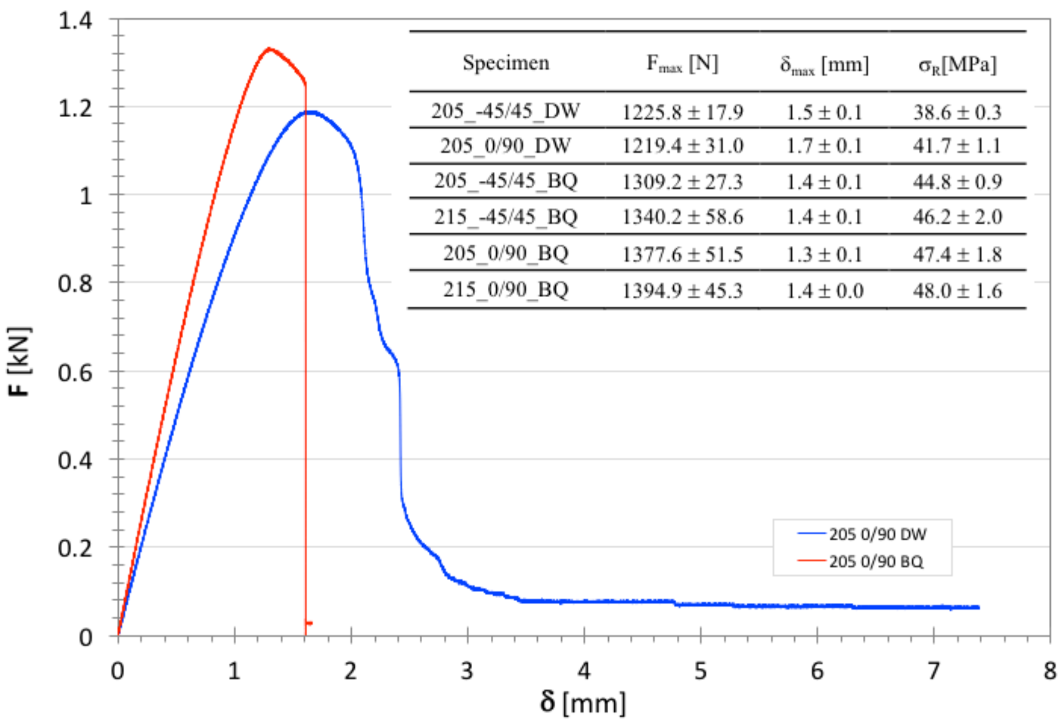
RESULTS AND DISCUSSION

PLA specimens were produced using Type IV dimensions from ASTM D638-14 [3] specification, using a *Tevo Tarantula - Prusa i3* extruder. Table 1 shows specimens' nomenclature. *DW* and *BQ* refer to filament trademark; the numerals designate extrusion temperature and lay-up, *i.e.,* 205º C or 215 ºC, and [0/90] or [45/-45] lay-up.

Table 1. PLA specimens processing parameters.

Specimen	Temperature [ºC]	Lay-up	Filament
205_0/90_BQ	205	[0/90]	BQ
205_0/90_DW	205	[0/90]	DoWire
205_-45/45_BQ	205	[45/-45]	BQ
205_-45/45_DW	205	[45/-45]	DoWire
215_0/90_BQ	215	[0/90]	BQ
215_-45/45_BQ	215	[45/-45]	BQ

Three tensile tests were carried out per condition using an electromechanical *Impact* tensile test machine TS300 with 50 kN load cell. Load-Displacement plots (Figure 1 and superimposed table) were produced, and maximum load and tensile stress were obtained (Figure 2a).



Specimen	F_{max} [N]	δ_{max} [mm]	σ_R[MPa]
205_-45/45_DW	1225.8 ± 17.9	1.5 ± 0.1	38.6 ± 0.3
205_0/90_DW	1219.4 ± 31.0	1.7 ± 0.1	41.7 ± 1.1
205_-45/45_BQ	1309.2 ± 27.3	1.4 ± 0.1	44.8 ± 0.9
215_-45/45_BQ	1340.2 ± 58.6	1.4 ± 0.1	46.2 ± 2.0
205_0/90_BQ	1377.6 ± 51.5	1.3 ± 0.1	47.4 ± 1.8
215_0/90_BQ	1394.9 ± 45.3	1.4 ± 0.0	48.0 ± 1.6

Figure 1. Example of Load-Displacement plots of DW and BQ specimens, showing DW higher ductility. Superimposed table shows obtained mechanical properties of tested PLA specimens

Overall, specimens manufactured with DW filament (Figure 2b and 2c) show the lower values of maximum tensile stress, regardless of the extrusion temperature. This is expected to result from the inferior material storage conditions, compared to those of BQ filament, which was kept in controlled atmosphere until use, preventing properties degradation by water absorption [4]. Figure 3 shows Differential Scanning Calorimetry (DSC) results, evidencing differences between the two as-supplied PLA plastics. BQ filament shows two endothermic peaks with onset at 57 ºC and 146 ºC, corresponding to glass transition (T_g) and melting (T_m), respectively, and an exothermic peak with onset at 134 ºC, corresponding to cold crystallization (T_{cc}) [5]. DoWire filament shows those phase transitions at 60, 146 and 134 ºC. DoWire filament shows much lower cold crystallization temperature than BQ filament. T_{cc} decrease is usually enhanced by the presence of a higher plasticizer content in the polymer [5], corresponding to increased chain mobility. Higher ductility is thus to be expected in DoWire than in BQ parts produced under the same conditions (Figure 1). Comparison of specimens 205_-45/45_BQ with 205_-0/90_BQ and 215_-45/45_BQ with 215_-0/90_BQ (Figure 2d to 2g) shows a 6 % and 4 % increase on maximum tensile stress between the [45/-45] and [0/90] lay-up. When uniaxially loaded, the [0/90] lay-up showed higher mechanical performance due to the align orientation of the specimen internal extruded polymer chains and the applied stress. Maximum tensile stress is also influenced by extrusion temperature. Comparing specimens 205_-45/45_BQ and 215_-45/45_BQ, a 3 % increase was verified. The same behavior is also present on [0/90] lay-up specimens, increasing the maximum tensile stress up to 48.0 MPa.

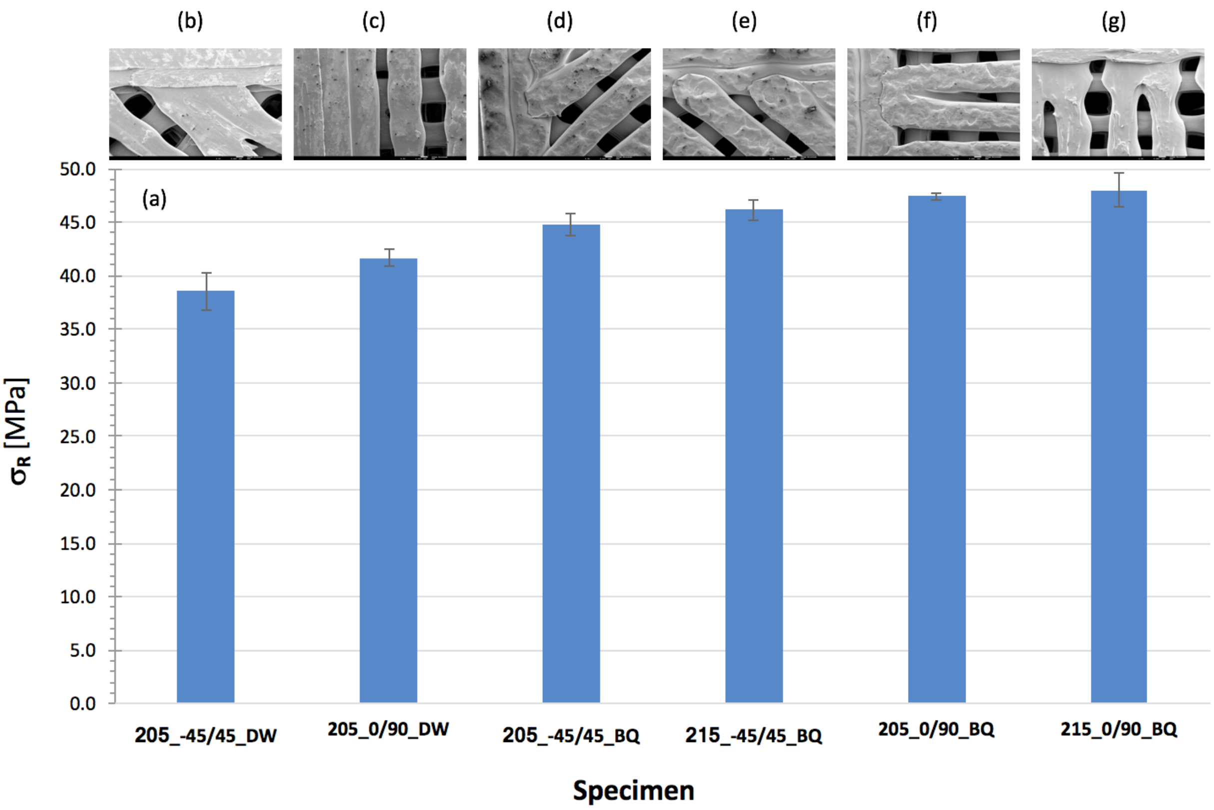


Figure 2. PLA specimens produced with different FFF parameters and equipment: (a) summary of tensile stress results; (b) to (g) low magnification SEM images of extruded specimens, before test.

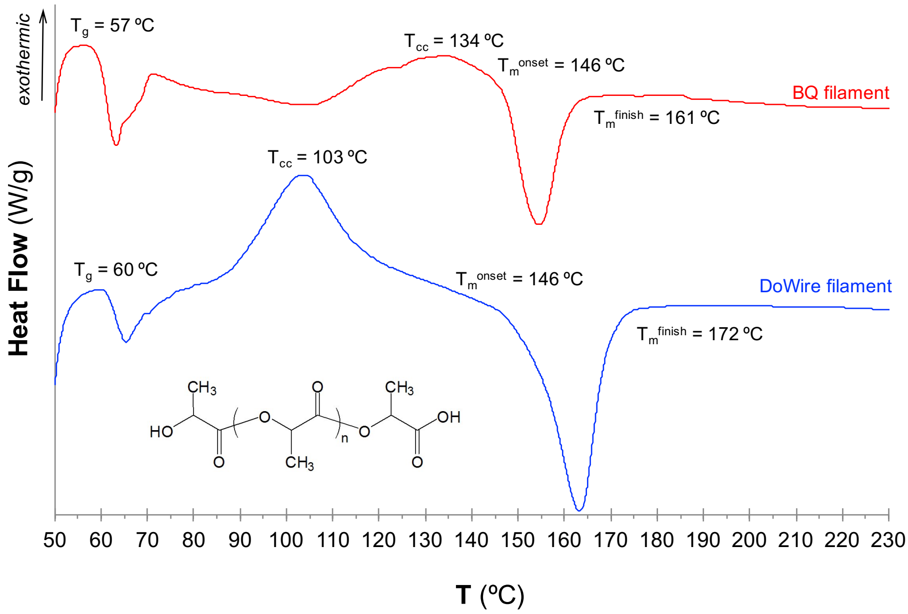


Figure 3. DSC thermal analysis results evidencing the differences between the two PLA plastics (as-supplied). The chemical formula of PLA is superimposed.

CONCLUSIONS

- Storing FFF materials under controlled atmosphere conditions increases the overall performance of the manufactured parts.
- Parts lay-up should be aligned with the principle stresses to increase part performance.
- Increasing extrusion temperature, increases the material maximum tensile stress.

REFERENCES

[1] Gibson I, Rosen D, Stucker B. Additive Manufacturing Technologies, 2nd ed. Springer Science & Business Media, New York, 2015.

[2] Chacón JM, Caminero MA, García-Plaza E, Núñez PJ. Additive manufacturing of PLA structures using fused deposition modelling: Effect of process parameters on mechanical properties and their optimal selection. Mater Des 2017; 124: 143-157.

[3] ASTM D638-14 - Standard Test Method for Tensile Properties of Plastics. ASTM International, West Conshohocken, PA, 2014.

[4] Leite M, Varanda A, Ribeiro AR, Silva A, Vaz MF. Mechanical properties and water absorption of surface modified ABS 3D printed by fused deposition modelling, Rapid Prototyping Journal, 2018; 24: 1, 195-203.

[5] Mounira M, Benaniba MT, Quintard G, Massardier-Nageotte V. Biobased additive plasticizing Polylactic acid (PLA). Polímeros, 2015; 25: 581-590.