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Desktop vs Industrial FDM Printers Mechanical Property Comparison using ASA

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Abstract: **This paper compares various 3D printers using fused deposition modeling (FDM) also known as fused filament fabrication (FFF). The comparison is based on the mechanical properties of ASA printed ASTM D638 Type I dog bone samples. The four printers used in the study are the Stratasys F450mc, Stratasys F370, Ultimaker S5, and Bambu X1C. The tensile properties of samples printed with flat, edge, and vertical orientations were measured and reported.**

Keywords: **Additive manufacturing, 3D printing, Engineering design**

I. INTRODUCTION

Additive manufacturing, the industrial application of 3D printing, has grown considerably since the inception of 3D printing in the late 1980's. In 2021, according to the 2022 Wohlers Report, the AM industry grew worldwide to $15.244 billion dollars, a 19.5% increase from 2020 [1]. This includes AM equipment, part production, maintenance, training, etc. Assuming no large influences, such as an economic recession, it is expected to grow to $60.3 billion dollars in 2029 [1].

The use of 3D printing is widespread including applications such as prototypes, end-use parts, tooling, and many more. It is used in many industries such as automotive, health care, aerospace, consumer electronics, and more. The advantages of 3D printing include design freedom, onsite or local production, serialization, weight savings, and several others.

One of the seven categories of additive manufacturing processes according to ISO/ASTM 52900 is material extrusion (MEX) which includes 3D printing known as fused deposition modeling (FDM) or fused filament fabrication (FFF) [1]. In basic FDM printing, a thermoplastic polymer such as PLA (polylactic acid), ASA (acrylonitrile styrene acrylate), ABS (acrylonitrile butadiene styrene) PETG (polyethylene terephthalate glycol), and others, is heated and extruded through a nozzle in a semi-molten form to fabricate a three-dimensional part layer by layer [2]. The head, with affixed nozzles, moves in the X-Y plane depositing one layer at a time on a flat surface or table [3]. The table moves in the Z direction allowing the printer to print subsequent layers. Printers can have a second nozzle to extrude support material, a different polymer, or different color.

Mechanical properties of FDM parts are dependent upon factors such as build direction, infill density, layer thickness, print speed, raster angle, nozzle temperature, and layer orientation [4]. FDM parts historically have a rougher surface finish due to the layer lines and are generally anisotropic. Their interlayer bonds are subject to voids which decrease the mechanical properties of the polymer compared to conventional manufacturing processes [5].

FDM 3D printers range from lower-cost desktop printers from companies such as Bambu Lab, Prusa, Creality, to more expensive FDM printers from Stratasys. The printers have various price points and other attributes making selecting the "right" printer dependent upon the user's needs and expectations for quality, strength, speed, accuracy, and reliability.

This paper discusses the research results of comparing the mechanical properties of dog bones printed on desktop FDM printers vs more expensive FDM industrial printers. ASTM D638 Type I dog bones were printed in ASA in 3 orientations, flat, edge, and vertical. Samples were printed on the Stratasys F450mc, Stratasys F370, Ultimaker S5, and Bambu X1C. Five samples of each orientation were tensile tested with results and corresponding conclusions reported.

II. SAMPLE AND TEST SETUP

The D638 Type I test samples were modeled in Solidworks as shown in Fig 1.

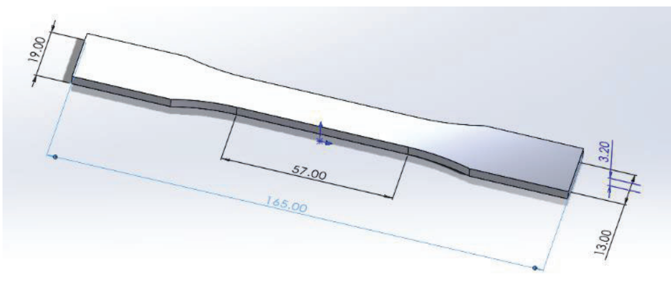

Fig. 1. ASTM D638 Type I Test Sample.

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Table 1 defines the printing parameter for each printer.

TABLE 1. Printing Parameters

	Printer			
Parameter	**F450mc**	**F370**	**Ultimaker S5**	**Bambu X1C**
Material	Stratasys ASA	Stratasys ASA	Polymaker ASA	Polymaker ASA
Filament Diameter (mm)	1.73	1.73	2.85	1.75
Layer height (mm)	0.254	0.254	0.254	0.254
Print head size (mm)	0.254	0.254	0.4	0.4
Print head speed (mm/s)	approx. 150	approx. 100	100	200
Total build time (18 pcs) (hrs)	6:18	8:50	11:59	5:58
Extruder Temp (C°)	216	265	260	260
Bed Temp (C°)	95[1]	90[1]	100	90
Envelope Temp (C°)	95	90	50	50
Infill	Solid	Solid	Solid	Solid
Infill pattern	Rectilinear	Rectilinear	Zigzag	Rectilinear
Infill Direction (deg)	45	45	45	45
Infill/Wall Overlap (%)	10[2]	10[2]	15	15
Top/Bottom thickness (mm)	1	1	1.2	1.2
Wall line count	2	2	2	2

[1] Assumed to be the same as the envelope temperature.
[2] Estimated value

Fig. 2 is a representative test sample layout in the build envelope of the F370. Actual layouts vary depending on the printer and their respective impact on testing will be discussed.

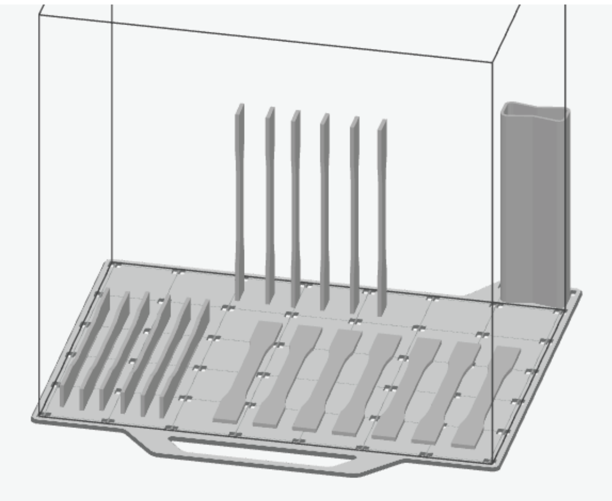

Fig. 2. Test Sample Layout F370.

Samples were tensile tested on a United STM-100KN universal testing machine using a 2.2 kN load cell. The preload speed was 2.5 mm/minute and the pull speed was 5 mm/minute. The setup is shown in Fig. 3.

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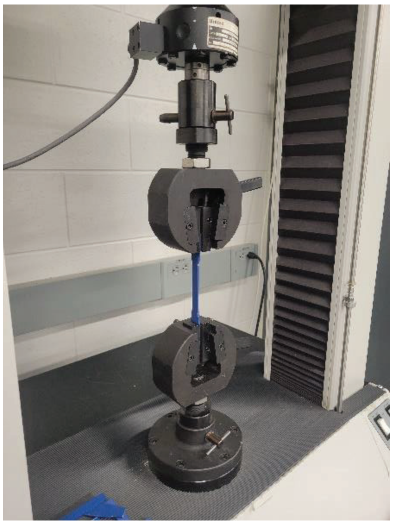

Fig. 3. Tensile Testing.

Table 2 describes the average mechanical properties for samples printed flat on the Stratasys F450mc, Stratasys F370, Ultimaker S5, and the Bambu X1C. Reported values are the average ultimate tensile strength (UTS), UTS standard deviation, average break elongation, and break elongation standard deviation. Table 3 describes the average mechanical properties for samples printed on edge. Table 4 describes the average mechanical properties for samples printed vertically.

Fig 4 illustrates the average mechanical properties for samples printed flat on the Stratasys F450mc, Stratasys F370, Ultimaker S5, and the Bambu X1C. Fig 5 illustrates the average mechanical properties for samples printed on edge. Fig 6 illustrates the average mechanical properties for samples printed vertically.

TABLE 2. Mechanical Data for ASA Samples Printed Flat

ASA Samples Printed Flat				
Printer	Average UTS (MPa)	UTS Standard Deviation	Average Break Elongation (%)	Break Elongation Standard Deviation
Stratasys F450	34.5	0.2	5.7	0.6
Stratasys F370	31.2	0.2	6.9	0.4
Ultimaker S5	37.1	0.1	7.7	0.9
Bambu X1C	36.0	0.1	7.4	0.9

TABLE 3. Mechanical Data for ASA Samples Printed Flat

ASA Samples Printed on Edge				
Printer	Average UTS (MPa)	UTS Standard Deviation	Average Break Elongation (%)	Break Elongation Standard Deviation
Stratasys F450	32.7	0.3	5.3	0.3
Stratasys F370	24.0	0.1	6.4	0.9
Ultimaker S5	35.7	0.8	5.0	0.2
Bambu X1C	39.6	0.4	5.4	0.6

TABLE 4. Mechanical Data for ASA Samples Printed Vertically.

ASA Samples Printed Vertically				
Printer	Average UTS (MPa)	UTS Standard Deviation	Average Break Elongation (%)	Break Elongation Standard Deviation
Stratasys F450	27.0	0.0	4.9	0.4
Stratasys F370	19.8	0.3	3.5	0.3
Ultimaker S5	17.2	0.1	2.5	0.1
Bambu X1C	9.4	0.3	1.9	0.3

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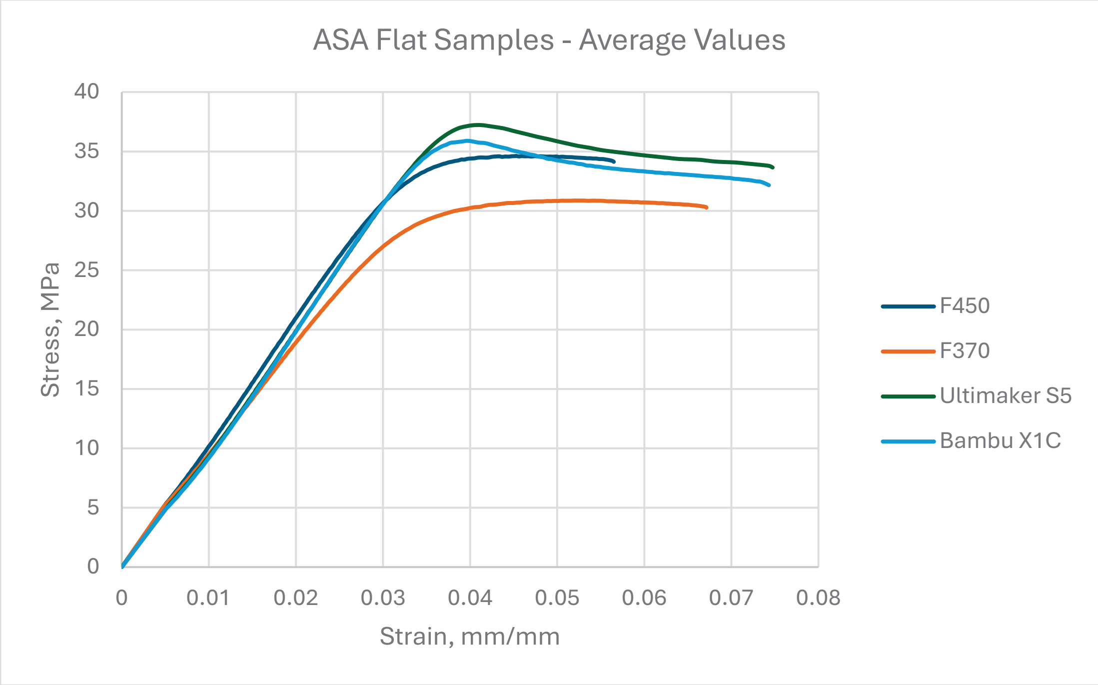

Fig. 4. Average stress-strain curves for ASA samples printed flat.

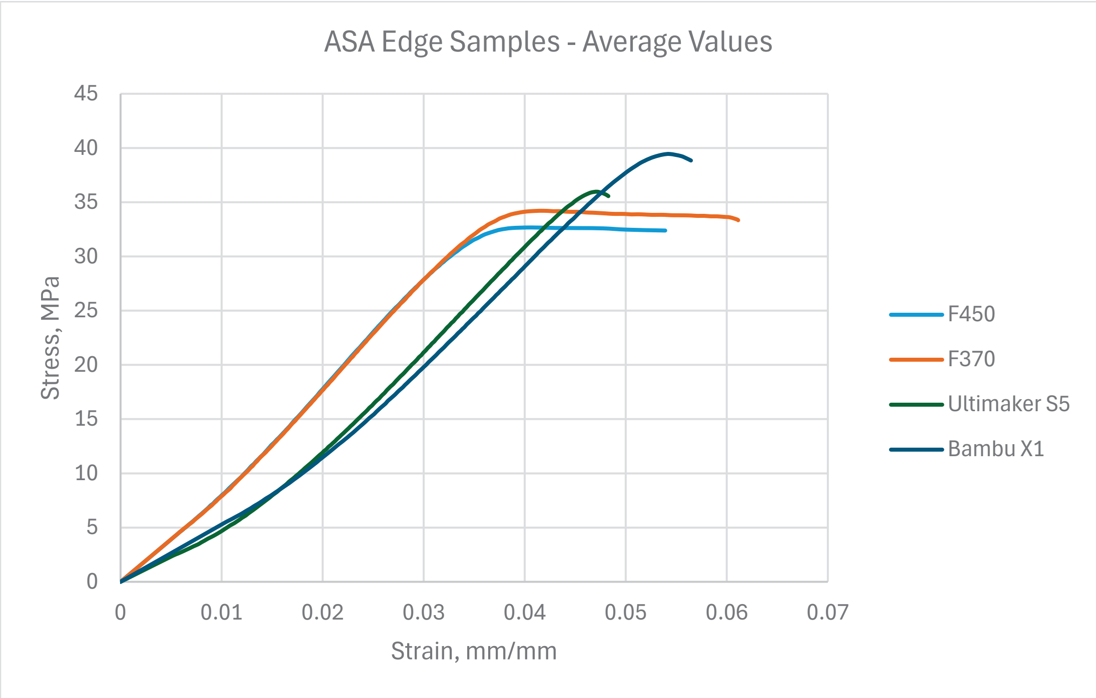

Fig. 5. Average stress-strain curves for ASA samples printed on edge.

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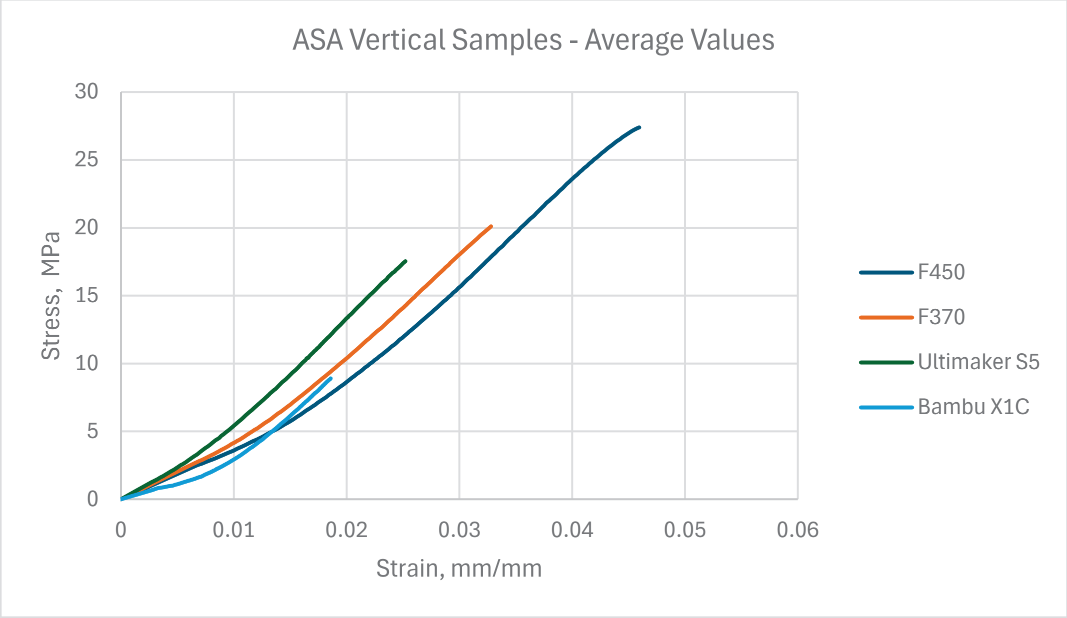

Fig. 6. Average stress-strain curves for ASA samples printed vertically.

V. DATA ANALYSIS

When considering the samples printed flat, the Ultimaker and Bambu printers have a slightly higher tensile strength compared to the F370 and F450mc. The Ultimaker and Bambu have similar stress-strain curves whereas the F370 and F450mc have similar stress-strain curves. This is likely due to the fact that Polymaker ASA was used on the Ultimaker and Bambu and Stratasys ASA was used on the F370 and F450mc. The Polymker ASA has a higher break elongation when printed flat and a higher standard deviation compared to the Stratasys ASA when printed flat.

For the samples printed on edge, the Bambu has the highest average tensile strength. The F370 has the highest average elongation at break. When viewing the graphs in Fig. 5, the Polymaker ASA printed on the Ultimaker and Bambu is distinctly different compared to the Stratasys ASA printed on the F450mc and F370. What is interesting is the elongation standard deviation of the edge samples printed on the F370 is three times higher than those printed on the F450. The F370 flat edge samples also had the lowest average tensile strength of all four printers. The average UTS of edge samples printed on the Ultimaker and Bambu had larger standard deviations compared to their respective flat samples.

Finally, the test results from the samples printed vertically were considerably different across all four printers and from the other print orientations. FDM parts are anisotropic and as expected, have the lowest strength and elongation in the z direction. Vertical parts printed on the Bambu had significantly lower tensile strength and elongation compared to the other printers.

VI. CONCLUSIONS

Many of the results were expected. The mechanical properties of Polymaker ASA are different than the Stratasys ASA. It could explain why samples printed flat and on edge had higher average tensile strength than samples printed with Stratasys ASA. However, it is important to note that with the numerous printing parameters, it was difficult to keep the printing parameters exactly the same across all four printers. For example, in addition to temperatures and printing speed, variables such as top and bottom layer thickness and bead overlap were similar but not identical.

The most curious results are from the samples printed vertically. The F450mc had the highest average tensile strength and elongation, 27.0 MPa and 4.9% respectively. However, the vertical samples printed on the Bambu were significantly lower than all the others at 9.4 MPa average tensile strength and 1.9% break elongation. The extruder temperature was about the same as the other printers. However, the Bambu print speed was the fastest and perhaps reduced the layer-to-layer adhesion. It should be noted that to print six samples vertically on the Bambu, a horizontal stabilizer was used connecting all six samples to prevent vibration and samples tipping over. Perhaps that created an imperfection not visible to the naked eye. Interestingly, the Ultimaker also had vibration issues. Test samples were printed one at a time to prevent them from tipping over. However, the F370 and 450mc had no vibration issues and did not require stabilizers or reduced parts per build. Consequently, the z direction is always going to be the weakest regardless of which printer is used. If strength is a concern, parts should be oriented in the build envelope to mitigate the issue.

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