<u>Customizing Extrusion-based 3D Printing</u>

Additive and Subtractive Processes in Custom Manufacturing Graduate Level Project:

In this project, my team and I designed a system to 3D print silicone rubber. The material chosen is Dragon Skin 10 Fast from Smooth-on (https://www.smooth-on.com/products/dragon-skin-10-fast/), which is a two-part curing system. We learned how to control the extrusion rate and were tasked to find a proper printing speed for a given extrusion rate. Two sets of experiments were conducted.

Problem Statement & Goal:

Extrusion Rate

Silicone resin is in liquid form, so the extrusion is controlled by pressure in a syringe. In the experiment, a 50 mL plastic syringe, and a 14 Gauge needle (1.55 mm ID and 2.1 mm OD) were used. The needle is about 20 mm long. The mass flow rate was measured at different pressures, and each pressure was repeated four times (5 runs total). All results are shown below:

Table 1 Results of extrusion rate study

Pressure (psig)	Mass (g) in 60 s				
	1	2	3	4	5
30	1.47	1.2	1.28	1.28	1.41
40	7.02	7.31	7.26	8.4	8.49
50	12.48	11.68	10.84	10.4	10.48
60	13.83	13.64	13.93	13.55	13.66
70	14.5	14.54	16.36	15.88	16.05

a. We made a plot showing the average flow velocity (mm/s) vs. the gauge pressure (psig).
b. Produced a theoretical curve on the same plot.
c. Explained the reasons for discrepancies.

Printing Quality

We determine a proper printing speed for a given flow velocity. In theory, the printing speed should be the same as the flow velocity to avoid excessive or lack of material deposited on the platform. However, such a relationship may not hold true for liquid resin. In this experiment, a constant pressure (40 psig) was used to observe the printing quality at various printing speeds from below to above the flow velocity. The printed line was measured with its width, as the results are shown below. Each test was repeated four times (5 runs).

a. We plotted the width (of printed line) vs. printing velocity.

b. Assuming a continuous line, I developed a physical model to predict the line width based on the printing velocity. Found the corresponding flow velocity for 40 psig.

c. Explained the reasons for discrepancies.

Table 2 Results of printing quality study

Pressure (psig)	Printing speed (mm/s)	Width (mm)				
		1	2	3	4	5
40	28.0	2.84	2.63	2.68	2.79	2.68
40	44.7	2.61	2.72	2.83	2.78	2.83
40	53.1	2.29	2.18	2.24	2.18	2.53
40	58.7	2.61	2.50	2.33	2.39	2.28
40	64.3	2.37	2.53	2.53	2.47	2.58
40	69.9	2.20	2.13	2.20	2.13	2.13
40	83.9	0.89	2.56	2.00	1.83	2.22

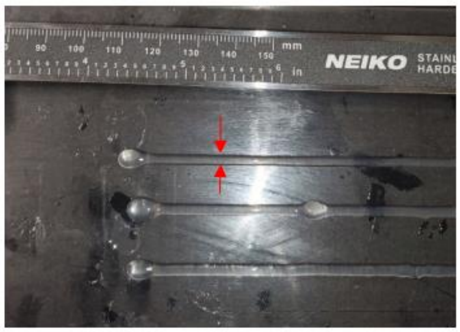

Figure 1 The width measurement

System Design

At this point, we have a set of good models (or data) to control extrusion. However, there is a lot more to do to customize the process. We conducted a literature review and summarized other aspects that determine the "printability" of a material, and then discussed whether printing this material is feasible.

Appendix – Dragon Skin Properties

TECHNICAL OVERVIEW

	Mixed Viscosity (ASTM D-2393)	Specific Gravity (g/cc) (ASTM D-1475)	Specific Volume (cu. in./lb.) (ASTM D-1475)	Pot Life (ASTM D-2471)	Cure Time	Shore A Hardness (ASTM D-2240)	Tensile Strength (ASTM D-412)	100% Modulus (ASTM D-412)	Elongation at Break % (ASTM D-412)	Die B Tear Strength (ASTM D-624)	Shrinkage (in./in.) (ASTM D-2566)
Dragon Skin™ 10 Very Fast	23,000 cps	1.07	25.8	4 min.	30 min.	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Fast	23,000 cps	1.07	25.8	8 min.	75 min.	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Medium	23,000 cps	1.07	25.8	20 min.	5 hours	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 Slow	23,000 cps	1.07	25.8	45 min.	7 hours	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 10 AF	23,000 cps	1.07	25.8	20 min.	5 hours	10A	475 psi	22 psi	1000%	102 pli	< .001 in./in.
Dragon Skin™ 15	21,000 cps	1.07	25.8	40 min.	7 hours	15A	537 psi	40 psi	771%	112 pli	< .001 in./in.
Dragon Skin™ 20	20,000 cps	1.08	25.6	25 min.	4 hours	20A	550 psi	49 psi	620%	120 pli	< .001 in./in.
Dragon Skin™ 30	20,000 cps	1.08	25.7	45 min.	16 hours	30A	500 psi	86 psi	364%	108 pli	< .001 in./in.

Mix Ratio: 1A:1B by volume or weight — ***Useful Temperature Range:*** -65°F to +450°F (-53°C to +232°C)

Color: Translucent — ***Dielectric Strength*** (ASTM D-149)***:*** >350 volts/mil

Concepts learned while working in this project:

- **Select** proper **manufacturing methods** for a custom design.
- Evaluate **pros and cons between subtractive and additive manufacturing** processes.
- Describe the capabilities of traditional and non-traditional machining processes.
- **Analyze the surface finish based on the process and material**.
- Describe the mechanisms of different additive manufacturing processes.
- **Design** and analyze **manufacturing processes** via team projects.