Size-dependent Failure and Material Properties of Fused Deposition Modeled Acrylonitrile Butadiene Styrene

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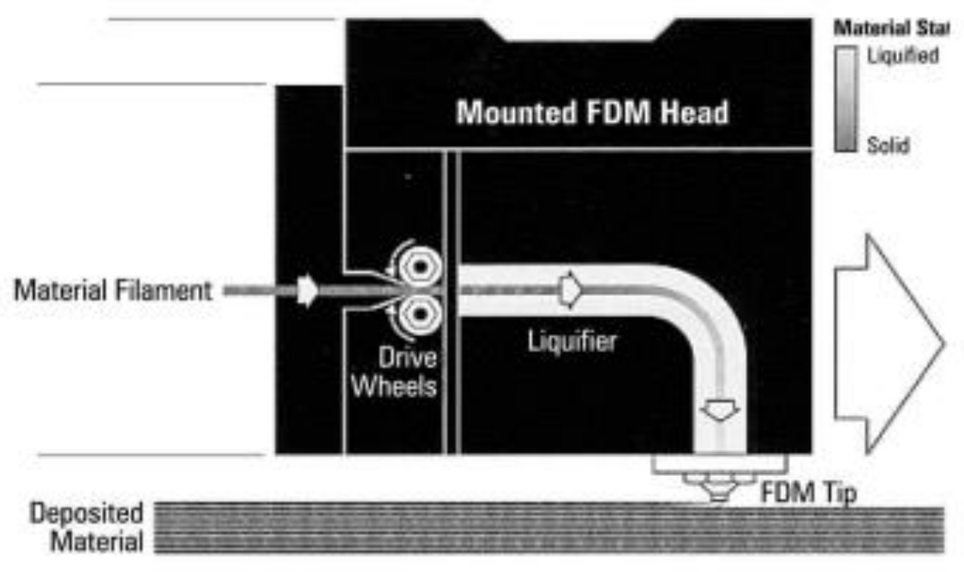
Background:

Fused Deposition Modeling (FDM) Overview:

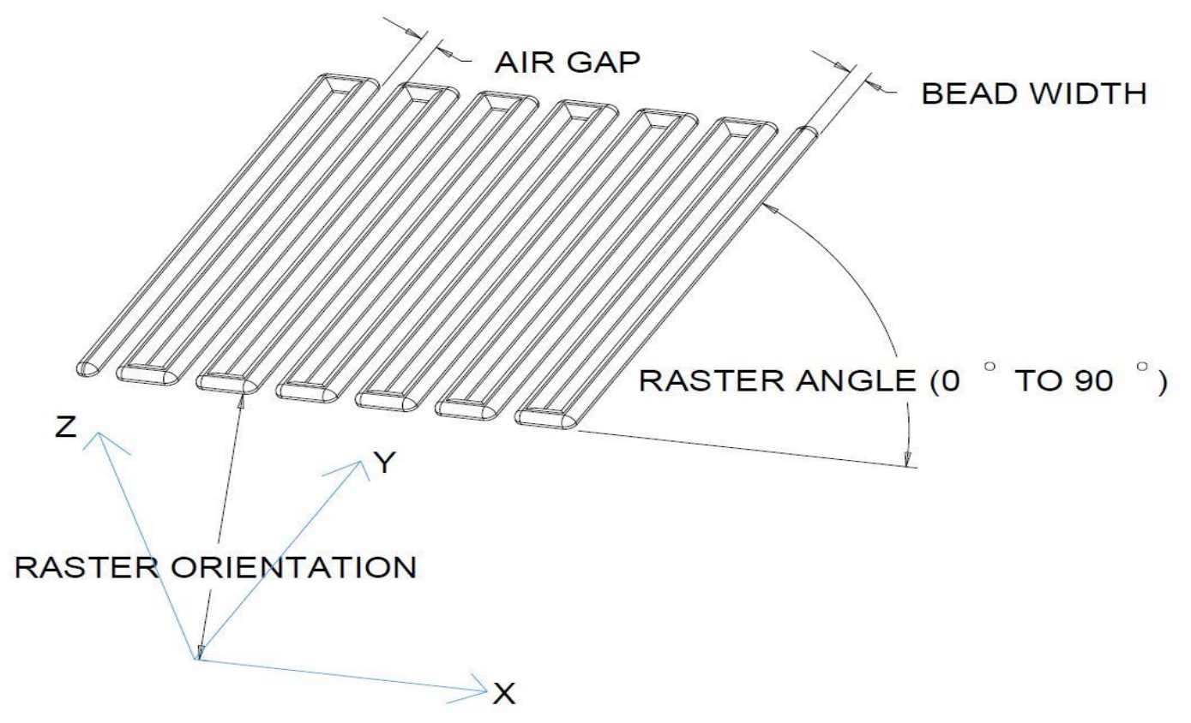
Fused deposition modeling (FDM) is a relatively new 3D-printing manufacturing process. In this process, a solid model of a part is generated in one of the many available computer-assisted design (CAD) programs and converted to the stereolithography (STL) file format. This STL file is then exported to the FDM software being used and the solid model of the part is horizontally sliced into many thin cross-sections of equal thickness. The FDM software then uses this sliced model as print instructions used to control the movement of a heated nozzle that deposits a selected thermoplastic material to form horizontal cross-sections of the part that are then layered to generate the part in its entirety.

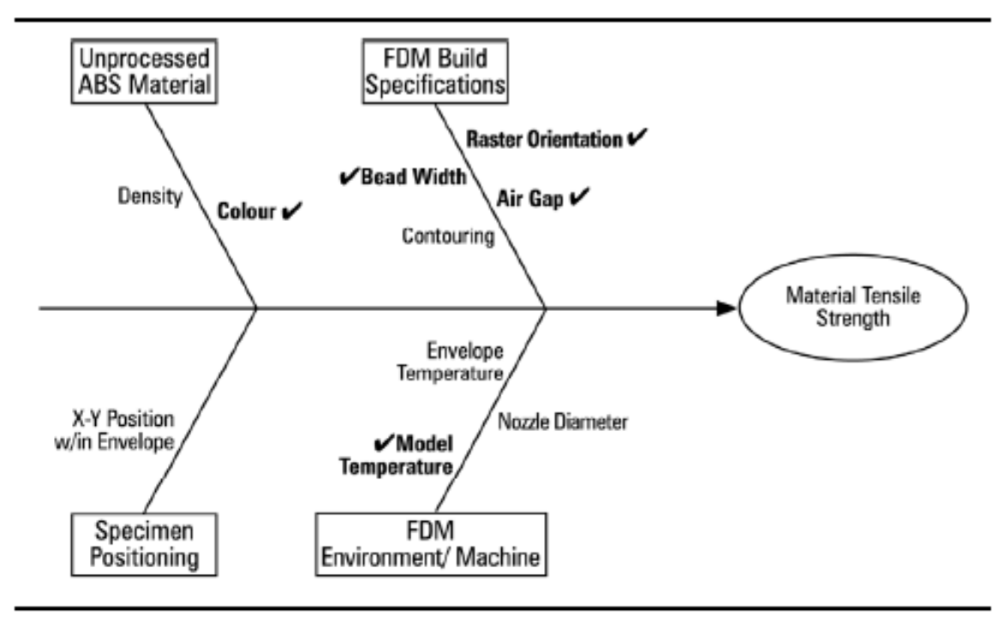


Traditionally, FDM has been used exclusively for the purposes of rapid prototyping due to its low cost, simple setup, and high versatility. That being said, there may be potential for the use of FDM parts in some low-load applications. For designers hoping to use FDM to generate production parts, a thorough understanding of the material properties of FDM-manufactured parts is crucial.

FDM Part Build Parameters:

Before a FDM part is produced, there are a variety of part build parameters that must be selected that can have a significant effect on the final part's material properties. These build parameters include bead width, air gap, model build temperature, raster orientation, color, and number of contouring beads.

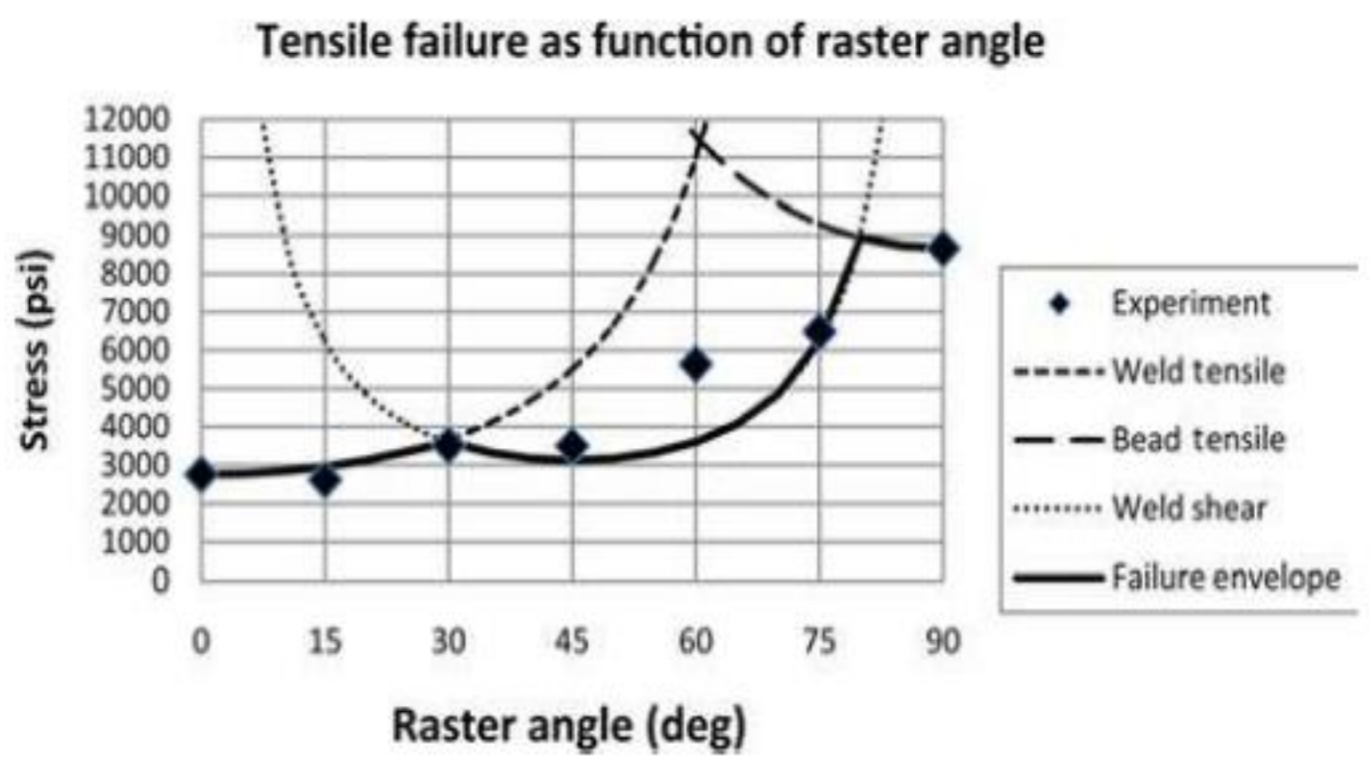




Of the mentioned build parameters, air gap and raster orientation have been shown to have the most significant effect on material properties. Contouring has been shown to have effects on material properties in some cases, but its full effect is not completely understood.

Results of Previous Work with FDM Parts at Cal Poly:

Several prior investigations into the failure of FDM parts have been conducted at Cal Poly Pomona. The first of these series of investigations utilized tensile tests of Polycarbonate (PC) samples and resulted in a simple failure model to predict the ultimate tensile strength (UTS) of these samples as a function of raster orientation.



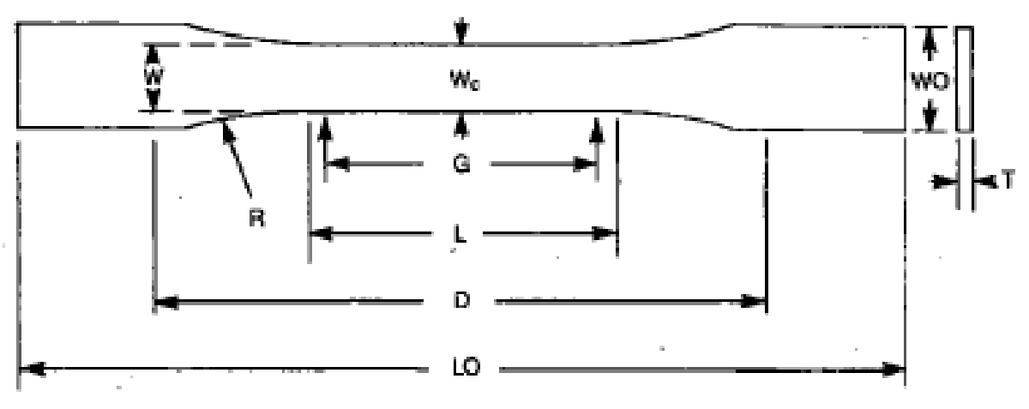
A series of tensile tests were later conducted with acrylonitrile butadiene styrene (ABS) that appeared to validate the proposed failure model. Although both the PC and ABS tests conformed well with the model, all specimens had a single outlining bead of material that had been considered negligible in terms of its effects on material properties. To investigate this assumption, a final series of tensile tests was conducted with smaller-sized ABS samples. The results of this test are the motivation for the investigation presented here as the small ABS samples deviated quite significantly from previous samples in terms of UTS vs. raster orientation.

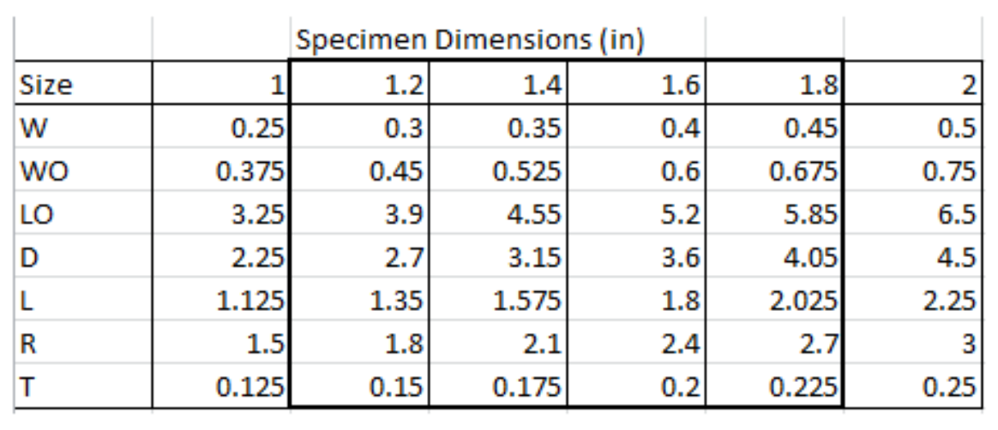
Objective:

As a follow up to the most recent study of FDM part failure produced at Cal Poly Pomona, the objective of this project was to investigate the reason for the deviation of the material properties of smaller ABS samples from those of larger ABS samples tested previously. This investigation involved another round of tensile testing with FDM ABS and research into other studies from outside sources.

Experimental Procedure/Results:

The tensile tests utilized in this project aimed at examining the effect of size on the mechanical properties of ABS specimens by testing specimen sizes between the large and small samples used at Cal Poly. It should be noted that the build parameters for these specimens were kept as they were for previous Cal Poly experiments, including the single outlining bead.

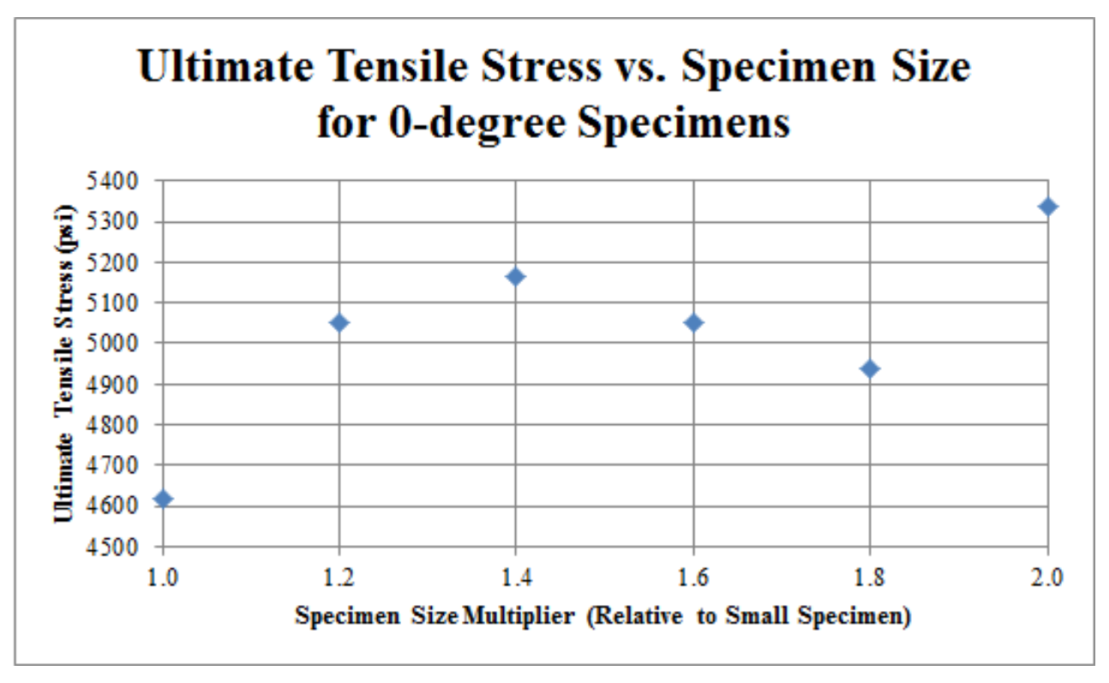


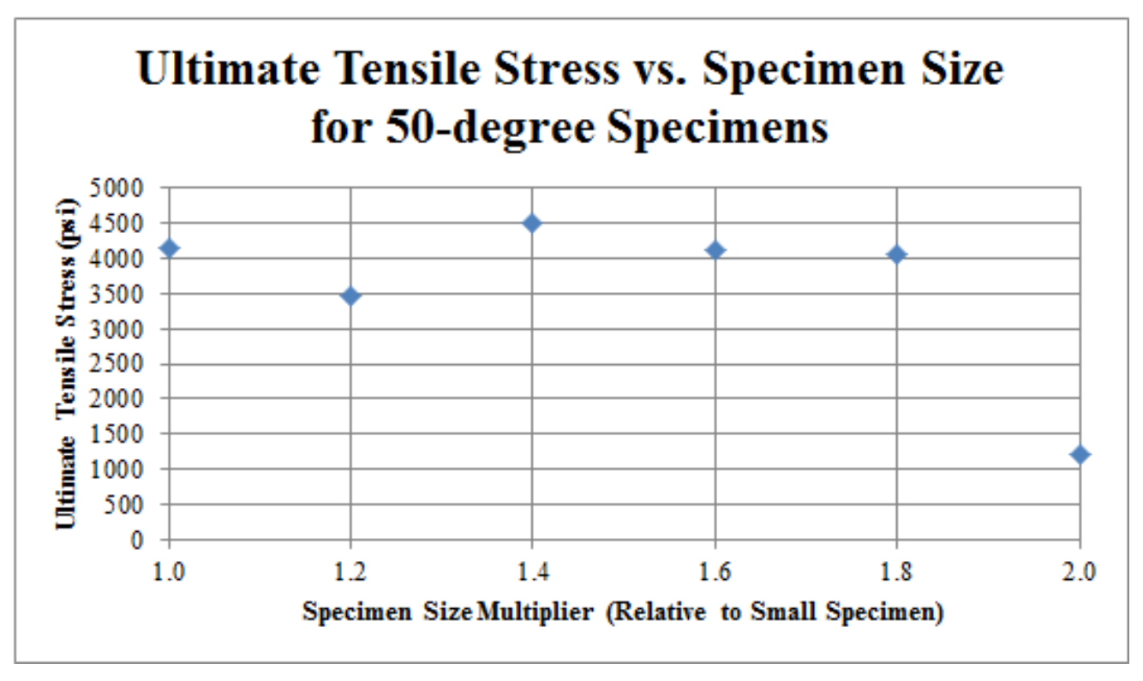


Specimen Dimensions (in)

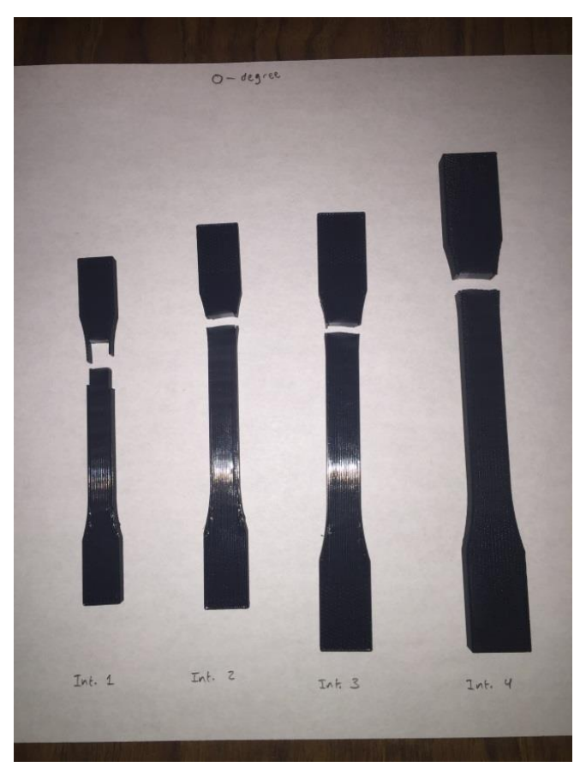
Size	1	1.2	1.4	1.6	1.8	2
W	0.25	0.3	0.35	0.4	0.45	0.5
WO	0.375	0.45	0.525	0.6	0.675	0.75
LO	3.25	3.9	4.55	5.2	5.85	6.5
D	2.25	2.7	3.15	3.6	4.05	4.5
L	1.125	1.35	1.575	1.8	2.025	2.25
R	1.5	1.8	2.1	2.4	2.7	3
T	0.125	0.15	0.175	0.2	0.225	0.25

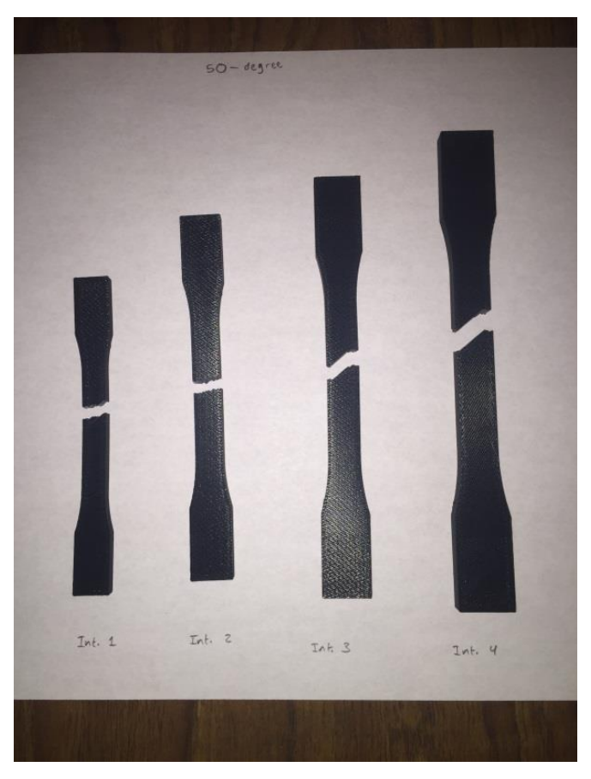
0-degree (fully aligned) and 50-degree raster orientations were used for each specimen size. Plots of several mechanical properties vs. size were produced for each orientation at the conclusion of this testing. Having said this, the most important of these properties for comparative purposes was UTS.





Photos of each specimen after failure were also taken for a qualitative analysis of possible failure mechanics of these specimens.





Conclusions:

Unfortunately this investigation was unable to quantify the effects of part size on a FDM part's material properties. It was concluded that the structure of the test specimens used at Cal Poly Pomona have stress concentrators in the radii that likely lead to the premature failure of fully aligned (0-degree) specimens. This is probably the reason for the variation in the tensile strength of the fully aligned samples, which should in theory not vary at all with size because the outlining contour bead is in the same orientation as the rest of the part (both are fully aligned with the applied force). The 50-degree oriented samples had a more or less constant UTS except for the large samples. Whether this is an indication of a particular part size causing the effects of the outlining bead to be negligible cannot be determined at this time. Further analysis of the impact of size on FDM part material properties should involve more extensive testing at different sizes.