ASTM D638

* Tension test
* used commonly for 3D printed PLA testing
* This test method is applicable for testing materials of any thickness up to 14 mm

ASTM D790

* Flexural test
* 3 point bend test
* used commonly for 3D printed PLA testing
* specimen width shall not exceed one fourth of the support span for specimens greater than 3.2 mm (1/8 in.) in
* support span-to-depth ratio of 16:1
* Conditioning required
* At least 5 specimen for each sample
* 12.7 mm (0.5 in.) wide, 3.2 mm (0.125 in.) thick, and 127 mm (5.0 in.) long.

Ways we aren't following D790

* Specimens must be solid

[~~https://www.scielo.br/scielo.php?script=sci\_arttext&pid=S1806-11172019000300401~~](https://www.scielo.br/scielo.php?script=sci_arttext&pid=S1806-11172019000300401)

**Equipment:**

• Press: $120 <https://www.amazon.com/Mophorn-Hydraulic-H-Frame-13227lbs-Plates/dp/B07WQVX5B1/ref=sr_1_2?dchild=1&keywords=press&qid=1601933154&sr=8-2>

• S Load cell: $59.95

<https://www.sparkfun.com/products/14282>

• Strain Gauge: 10 pack for $12

<https://www.amazon.com/DAOKI-BF350-3AA-High-Precision-Pressure-Resistance/dp/B07X87CJD8/ref=sr_1_4?dchild=1&keywords=Strain+Gauges&qid=1601586936&sr=8-4>

Replacement: <https://www.amazon.com/Icstation-BF350-Strain-Pressure-Sensor/dp/B01MY6F9EN/ref=nav_ya_signin?dchild=1&keywords=strain+gauge&qid=1606254445&sr=8-6&>

Load Cell Nanoshield: $17

<https://www.tindie.com/products/eletroshields/load-cell-nanoshield-ads1230-load-cell-module/>

Alternative: <https://learn.sparkfun.com/tutorials/load-cell-amplifier-hx711-breakout-hookup-guide/all>

<https://www.sparkfun.com/products/116>

~~Base board uno: $8~~

[~~https://www.tindie.com/products/eletroshields/base-board-uno/~~](https://www.tindie.com/products/eletroshields/base-board-uno/)

Arduino Uno: $22

<https://www.amazon.com/Arduino-A000066-ARDUINO-UNO-R3/dp/B008GRTSV6/ref=sr_1_4?dchild=1&keywords=arduino&qid=1601587317&sr=8-4>

Alternative: <https://www.amazon.com/dp/B01EWOE0UU/>

Super Glue: $12

[https://www.amazon.com/dp/B07MWR845K](https://www.amazon.com/Gorilla-7700108-2-Pack-Super-Clear/dp/B07MWR845K/ref=sr_1_5?crid=2NX69BYQ6KV1T&dchild=1&keywords=cyanoacrylate+adhesives&qid=1602193633&s=industrial&sprefix=cyanoacry%2Cindustrial%2C129&sr=1-5)

350 ohm resistors:

<https://www.sparkfun.com/products/14490> + idk a 20ohm resistor

20 ohm resistor:

<https://www.amazon.com/EDGELEC-Resistor-Tolerance-Multiple-Resistance/dp/B07QG1T8B2/ref=sr_1_3?dchild=1&keywords=20+ohm+resistor&qid=1602194632&sr=8-3>

Wires:

<https://www.amazon.com/EDGELEC-Breadboard-Optional-Assorted-Multicolored/dp/B07GD2BWPY/ref=sr_1_3?dchild=1&keywords=arduino+wires&qid=1602194155&sr=8-3>

<https://www.amazon.com/dp/B07T4SYVYG/>

Breadboard:

<https://www.amazon.com/Breadboards-Solderless-Breadboard-Distribution-Connecting/dp/B07DL13RZH/ref=sr_1_3?dchild=1&keywords=breadboard&qid=1602194425&sr=8-3>

5 volt power cord:

<https://www.amazon.com/ALITOVE-100V-240V-Converter-5-5x2-1mm-Security/dp/B078RXZM4C/ref=sr_1_1?dchild=1&keywords=arduino+power+supply+5+volt&qid=1602195069&sr=8-1>

Longer arduino cord:

<https://www.amazon.com/AmazonBasics-USB-2-0-Cable-Male/dp/B00NH11KIK/ref=sr_1_3?dchild=1&keywords=usb+atob&qid=1602195432&sr=8-3>

Clamps:

<https://www.amazon.com/IRWIN-QUICK-GRIP-1964758-One-Handed-Clamp/dp/B001DSY4QO/ref=sr_1_2?crid=3207POIVAPA0J&dchild=1&keywords=clamps+for+woodworking&qid=1602623531&sprefix=clamps+f%2Caps%2C155&sr=8-2>

Epoxy glue:

<https://www.amazon.com/J-B-Weld-8265S-Cold-Weld-Reinforced/dp/B0006O1ICE#:~:text=J%2DB%20Weld%20is%20The%20Original,to%20a%20dark%20grey%20color>.

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# Experimentation Methodology

* Tensile or Flexural testing depending on sample spec and availability of machines
  + Without access to lab most likely using flexural
  + Compression test could also be conducted with our setup
* 5 parts for each geometry we want to print on
  + 5 control specimens
    - Undamaged prints with the same infill as other parts
* Flexural Testing (3 Point Bend)
  + Needs to be tested to 5% strain
  + support span-to-depth ratio of 16:1
  + Two strain rates: 0.01 mm/mm/min (recommended) and 0.10 mm/mm/min
    - 0.10 mm/mm/min for if the material doesn’t break at 5% strain
  + A test sample bar rests on two supports and is loaded by means of a loading nose midway between the supports

Molding Materials (Thermoplastics and Thermosets)—The preferred specimen dimensions for molding materials is 12.7 mm (0.5 in.) wide, 3.2 mm (0.125 in.) thick, and 127 mm (5.0 in.) long. They are tested flatwise on the support span, resulting in a support span-to-depth ratio of 16:1 (tolerance ±1). Thicker specimens are to be avoided if they exhibit significant sink marks or bubbles when molded.

**Infill Testing**

For each test, 6 samples will be printed to account for mistakes in testing.

| Infill (NOT CURRENT)  SEE TABLE BELOW | Control | T3 (or geometry most similar to damage chosen by sample spec) |
| --- | --- | --- |
| 20% | 6 parts printed with specified infill | 6 parts printed for each infill with repairs done with conformal printing. |
| 40% |  |  |
| 60% |  |  |
| 80% |  |  |
| 100% |  |  |

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**Changed version (Current):**

| Infill |  | T3 (or geometry most similar to damage chosen by sample spec) |
| --- | --- | --- |
| 20% |  | 6 parts printed for each infill with repairs done with conformal printing. |
| 40% |  |  |
| 60% |  |  |
| 80% |  |  |
| 100% |  |  |

| Infill Testing | |
| --- | --- |
| Infill of repair | T1 Geometry |
| 20% | 6 parts |
| 40% | 6 parts |
| 60% | 6 parts |
| 80% | 6 parts |
| 100% | 6 parts |

Control would be 6 rectangles of 100% infill and 6 damaged geometry parts

These tests will be used to compare the ultimate stress of the parts from the stress strain graphs generated by the arduino for the 3 point bend test. The goal of this will be to compare the ultimate stress of these parts with the time it takes to print. This will allow us to see at what point there is diminishing returns to find the optimized infill that will have the best balance of print time with strength. This test will also allow us to see whether the infill's effects on strength are differ between the solid control parts and the conformal printed repairs.

**Damage Testing**

Using the results from the infill testing, these parts will be printed at the infill with the best balance between strength and time.

6 parts will be printed for each test to have an extra part over the required 5 in case of errors in testing or printing.

| Control | T1 | T2 | T3 | T4 |
| --- | --- | --- | --- | --- |
| Used from infill testing | 6 parts printed with conformal repairs facing down at the infill decided in infill testing | 6 parts printed with conformal repairs facing down at the infill decided in infill testing | 6 parts printed with conformal repairs facing down at the infill decided in infill testing | 6 parts printed with conformal repairs facing down at the infill decided in infill testing |
|  |  | 6 parts printed with conformal repairs facing up at the infill decided in infill testing | 6 parts printed with conformal repairs facing up at the infill decided in infill testing | 6 parts printed with conformal repairs facing up at the infill decided in infill testing |
|  |  | 6 parts printed with damaged geometry without conformal repairs | 6 parts printed with damaged geometry without conformal repairs | 6 parts printed with damaged geometry without conformal repairs |

| Tension Vs. Compression | |
| --- | --- |
| T1 | T4 |
| 6 parts printed with conformal repairs facing down at 100% infill (Tension) | 6 parts printed with conformal repairs facing down at 100% infill (Tension) |
| 6 parts printed with conformal repairs facing up at 100% infill (Compression) | 6 parts printed with conformal repairs facing up at 100% infill (Compression) |

| Control | |
| --- | --- |
| Undamaged | Damaged |
| 6 parts printed at 100% with no damage or repairs | 6 parts printed with T1 damage |
|  | 12 parts printed with T4 damage (6 compression, 6 tension) |

| Infill Pattern | |
| --- | --- |
| Hexagonal | Aligned |
| 12 T1 parts printed at 40% infill (6 compression, 6 tension) | 12 T1 parts printed at 40% infill (6 compression, 6 tension) |
| 12 T1 parts printed at 60% infil (6 compression, 6 tension) | 12T1 parts printed at 60% infill (6 compression, 6 tension) |
| 12T1 parts printed at 80% infill (6 compression, 6 tension) | 12 T1 parts printed at 80% infill (6 compression, 6 tension) |

40,60,80

12 total for each

These tests will be used to compare the strength of the parts through the stress strain graphs generated from the arduino from the 3 point bend test. The ultimate stress of these geometries at the infill found from infill testing will be compared to the control. The control will give the upper bound of the ultimate strength while the unrepaired parts will give the lower bound allowing for accurate comparison of the efficacy of the repaired parts. This comparison will give information on how effective conformal repairs are for each geometry and whether conformal repairs in general can be comparable to the ultimate stress of a control part.

In total 102 parts will be printed in PLA for these 2 tests

**INFILL PATTERNS**

Hexagonal

concentric

**Further Testing**

Given the speed of initial PLA tests, further testing using carbon fiber composites or other 3D printed materials may be used to further test stronger materials.

Another avenue of research that can be done time permitting is testing the difference in repair efficacy between conformal repairs using nonplanar printing and repairs using steps.

| Infill Testing | Damage Testing |
| --- | --- |
| * + Parts printed at 20%, 40%, 60%, 80%, 100%     - 6 parts printed with specified infill (Control)     - 6 parts printed with repairs done with conformal printing   + Used to determine the best balance of strength with print time | * + Parts printed at infill determined from Infill Testing     - 6 control Parts     - 4 damaged geometries       * 6 Parts with unrepaired damaged geometry       * 12 Parts with repaired damaged geometry   + Upper and lower bound of ultimate strength from control and unrepaired parts |
| 48 Samples | 78 Samples |

For A Generic Sample

Flexural Test For A Generic Sample (D790)

1. Clean bottom side of part with alcohol
2. Glue strain gauge onto part
   1. Strain gauge will be mounted to bottom of specimen directly below loading point
3. Place part onto press
   1. Part will be supported on either end by D-shafts secured to the press with glue and clamps
   2. S-type load cell will be attached to the press rod, measuring total force on part
4. Run arduino code to monitor loads and strain
5. Press (with strain rate of 0.10 mm/mm/min) until a maximum of 5% strain is reached or until rupture occurs on part
   1. Since press is hand-operated, proper press rate will be estimated by monitoring strain, force, and/or displacement rate as it is being pressed
6. While pressing use video and ruler to record displacement of press
   1. Force, strain, and displacement data will be used to create stress/strain curves, determine strength-to-weight ratio, and create force vs displacement graphs

**Methods of Analysis**

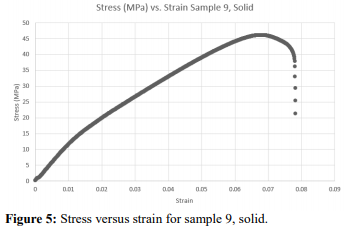
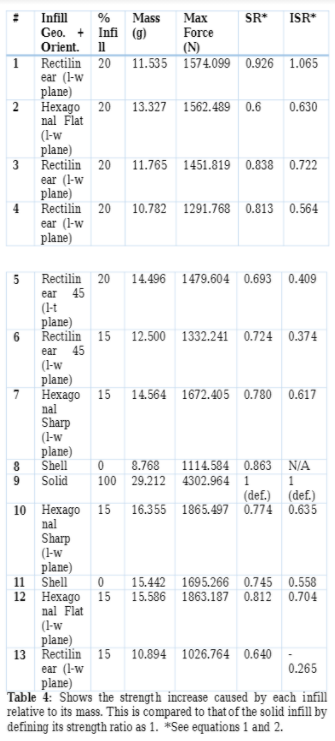
1. Stress/strain curves
2. Strength-to-weight ratio
3. Force vs displacement graphs
4. Comparisons between repaired and control sample specs
   1. Possible variables of analysis
      1. Material type (carbon fiber PLA on bikes?)
      2. Infill %
      3. Interface type
         1. Staircase on conformal
         2. Different print directions

**Keeping track of problems**

1. How to improve repeatability of press rate

# Hypotheses from research:

Parts with lower infill percentages have lower strength to mass ratios. Hexagonal infill are stronger and stiffer than those with rectilinear infill.



<https://www.researchgate.net/publication/308709141_Materials_Testing_of_3D_Printed_ABS_and_PLA_Samples_to_Guide_Mechanical_Design>