Material Comparison – Metal Application

3D Printed Fasteners

An exploration into metal-composite fasteners

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Introduction – Why Fasteners?

- Fasteners are an integral part of our everyday lives - everything we use contains a fastener, even your phone!
- Fastener research can involve the study of material properties to design and fabricate more efficient fasteners (also includes cheaper, stronger, or even faster-made).
- 3D Printed fasteners have a lot of potential in many different cases: Third-world country support, custom fastener design, or even outer space fastener replacement.

Material Selection & Purpose

- **Material 1:** Zinc-Coated (Galvanized) Stainless Steel
- **Material 2:** Ultrafuse 316L Steel

Material	Yield Strength	Ultimate Tensile Strength	Young's Modulus	Hardness (Vickers Hardness)	Ductility	Fatigue	Cost per Unit Mass	Estimated Weight of Prototype
ZC-SS	510 MPa	555 MPa	190 GPa	900 HV10	60-70%	240 MPa	$0.00068/gram	~5-20 grams/unit
BASF 316L	251 MPa	561 MPa	190 GPa	128 HV10	60-70%	146 MPa	$0.17/gram	~3-15 grams/unit

- The purpose of this study is to compare the differences between off-the-shelf stainless-steel fasteners and 3D printed metal-composite fasteners.
- The purpose of this project is to conclude whether the mechanical property, **joint** strength, of 3D printed fasteners is viable for the production and use of these fasteners in the real world.
  - "Joint strength is usually the yield strength of a casing connection in tension" (Byrom, 2015).

Design & Fabrication

Design:

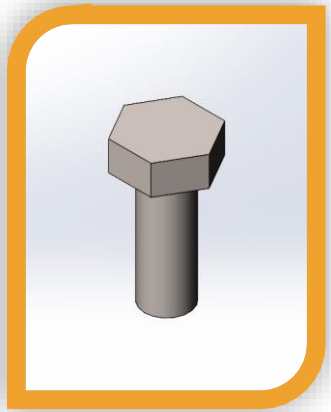
- Design choice was based upon fastener size. I had metric dies available and so I chose to compare metric fasteners (easier fabrication).

Fabrication:

- FDM/FFF 3D printing was the fabrication method of choice. This was required as the metal-composite material I was comparing was only available in a filament. This also allowed fabrication time to be brief and any printing mistakes / broken fasteners could be quickly replaced.
- Because of my partially failed testing in previous studies, I decided to print out a solid bolt and then thread the bolt post-printing. In theory, this will result in cleaner, more robust threads while allowing for an overall stronger and easier-made print.

Print Settings:

- Nozzle Size: 0.4mm (Stainless Steel)
- Layer Height: 0.15mm
- Line Width: 0.3mm
- Shell Thickness: 1.8mm (6 layers)
- Top/Bottom Thickness: 0.9mm (6 layers)
- Infill: 100%, Rectilinear
- Print Temperatures
  - Hotend: 235c
  - Build Plate: 90c
- Flowrate: 100% (density: 7.83g/cm^3)
- Print speed (general): 30-80mm/s
- Support used with raft

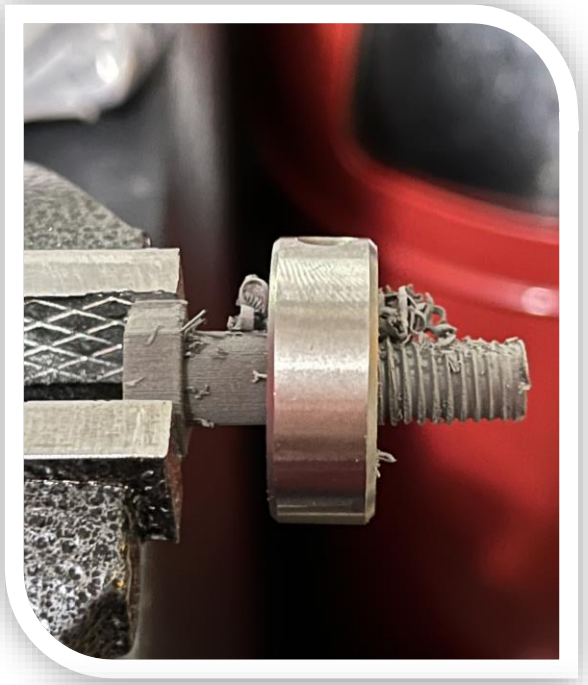


Post-Printing

I printed the model horizontally as to give it the best chance of layer strength.

After model cleaning and support removal, I threaded the bolt with a M6x1.0 die. This produced excellent threads that would only otherwise be achieved using SLA/DLP fabrication.

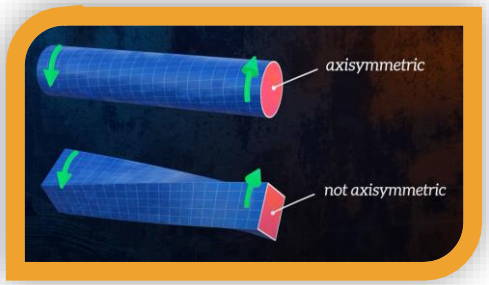
NOTE: Parts are still in "green" state, not post-processed using debinding/sintering methods.



Below:
Left - Model straight off printer
Right - finished model with threads

Test Definition

- Testing of the models will include torsional loading of the fasteners.
  - "Torsion is the twisting of an object caused by a moment acting about the object's longitudinal axis" (The Efficient Engineer, 2020).
- Property tested will be **torque** applied to fastener along longest axis.
  - "Torque is the measurement of the force that causes something to rotate, for example, the turning force needed to spin a nut around the threads of a bolt" (Enerpac, 2021).
  - Nominal Torque Limit for class 8.8 M6 ZC-SS fastener = **9.9Nm / 7.3 ft lb** (FastenerMart, 2022).
- Variables:
  - Independent: Fastener material, fastener size, tooling, fastening speed
  - Dependent: Torque measurement, location of break, details of break
- NOTE: Individual cross sections of the fastener will not distort from twisting, this is because the fastener is axisymmetric.



Axisymmetric vs non-axisymmetric

Testing Setup

Tools Required:

- M6x1.0 Nuts/Bolts (in both testing materials)
- M6x1.0 Taps/Dies (cleaning/preparing nuts/bolts)
- Wrench (preferably fixed, non-adjustable to remove possible tool slack)
- Vice
- Machine Oil
- Scale Gauge (with upper/lower limits within bolt spec)
- Recording device (paper, computer)

First, we will test BASF 316L bolts, record results, then move on to ZC-SS bolts.

All bolts will use the same nut material, only change is bolt material.

All bolts will be rethreaded with M6x1.0 die to remove FOD, prepare threads.

Oil will be applied to threads to ensure smooth application of torque.

Steps:

1. Prepared bolt will have one (1) SS nut hand-tightened until bottoming out on bolt head. Align bolt and nut faces for vice application
   - This will allow for thread joint strength to be tested rather than bolt head joint strength.

2. Bolt with nut will be tightened down into vice until bolt with nut does not move.
   - ~5-20Nm pressure.

3. One (1) SS nut will be hand-tightened until bottoming out on existing SS nut.

4. Wrench with scale gauge attached will be placed onto bolt with existing nuts. It will then be rotated in a tightening motion until bolt limit is reached (bolt breaks/strips)

5. Measurements taken, nuts cleaned, repeat process for subsequent bolts.

Test Results

- After testing each bolt, results were gathered. The below table lists all results:

Test Iteration (1-8: 316L)	1	2	3	4	5	6	7	8	ZC-SS 1:1	ZC-SS 1:2	ZC-SS 1:3	ZC-SS 2:1	ZC-SS 2:2	ZC-SS 2:3
Peak Torque (Nm)	4.1	5.2	3.8	5.4	6.8	5.8	4.9	3.2	15 (no break)	22 (no break)	18 (no break)	20 (no break)	19 (no break)	17 (no break)

What do these results mean?

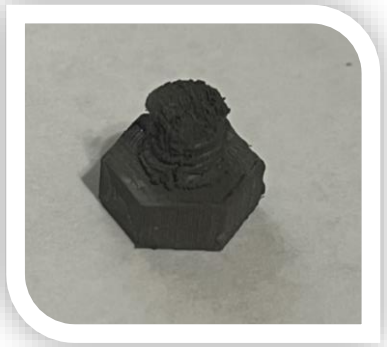
- The above results show that the metal-composite fasteners operate closer to an M5 bolt rather than an M6 in terms of peak torque. They do hold some torque, however, because they are in a green state and have not been post processed, they have a **clay-like feeling/construction and are very malleable**. This resulted in the metal-composite fasteners snapping where the two nuts met whereas the ZC-SS bolts did not break, and the vice moved before the bolts broke.

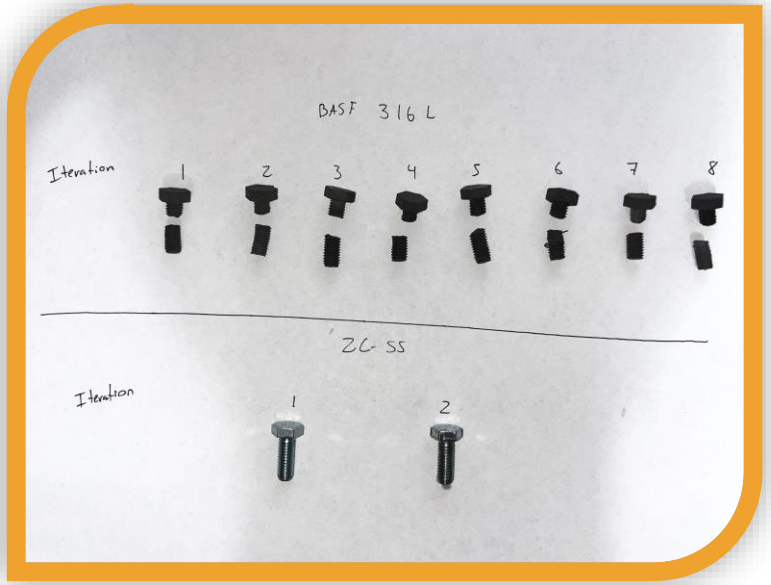
PROPERTY CLASS	TORQUE Ma	M 3	M 4	M 5	M 6
5.6	Nm	0.56	1.28	2.50	4.3
	ft lb.	0.41	0.94	1.84	3.1
8.8	Nm	1.28	2.90	5.75	9.9
	ft lb.	0.94	2.14	4.24	7.3
10.9	Nm	1.80	4.10	8.10	14
	ft lb.	1.33	3.02	5.97	10.3
12.9	Nm	2.15	4.95	9.70	16.5
	ft lb.	1.59	3.65	7.15	12.1

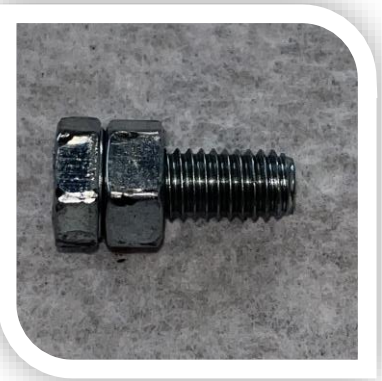
Torque table for 8.8 ZC-SS bolts

Test Evidence

These pictures follow testing and show the damage done to the fasteners.







Conclusions

Practicality

- Metal-composite fasteners do succeed in a few ways

1. Faster manufacture
2. Ease of accessibility
3. High quality/fine threads

- Stronger than traditional polymer fasteners
  - M6x1.0 Nylon Bolt Peak Torque = 1.83Nm (PlasticNutsAndBolts, 2022).
- With post processing, possibly as strong as SS bolts.

Findings and final thoughts

- Post processing would most likely yield better results
- More accurate gauge would provide higher quality results
  - Gauge kept resetting, losing zero point with such low values
- Better test rig would allow for ZC-SS fastener peak torque findings

Thanks for watching!

Max Edward | M3D Designs 2022

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