Introduction to Mechanical Engineering, Lecture 5

Basics of FDM printing

Innopolis University

Basics of FDM printing

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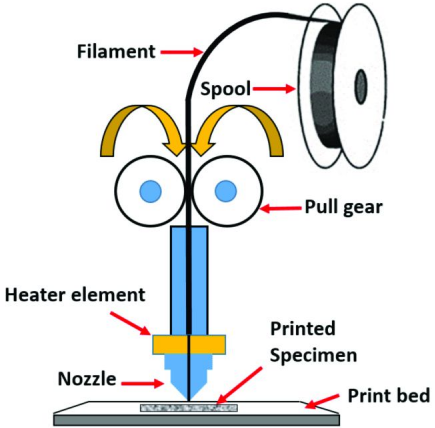
Lecture outline

- Printing process description
- Printer kinematics
  - X, Y, Z movement
  - Extruder
- Printer firmware
- Printer choice
- Slicing process & software
- Post-processing

Printing process description

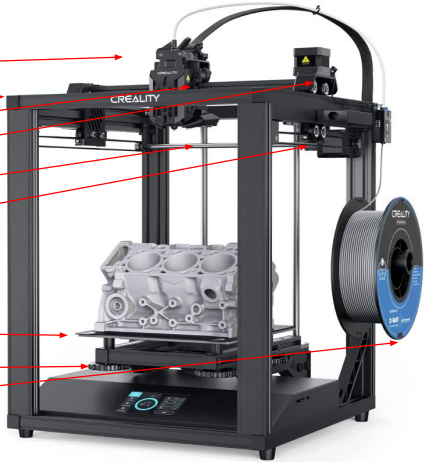
How does the printer print?

- FDM - fused deposition modeling
- Plastic is heated and pushed through a small orifice - nozzle
- Nozzle block (printhead) can move in X, Y, Z directions
- Molten plastic is deposited layer by layer to form solid object



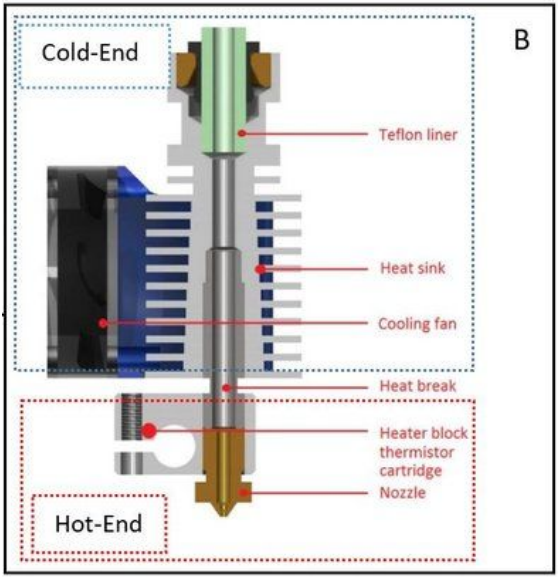
Printer parts

- Printhead
- Chassis
- Gantry
- Stepper
- Rails
- Belts
- Printbed / buildplate
- Printbed screws
- Filament spool/roll



Printer parts

- The printhead consists of several parts which insure that the printer works as intended
- Especially important
  - Heatbrake
  - Cooling



Printer kinematics (X,Y,Z)

Bed-slinger

- Printhead moves in X, Z axis
- Bed moves in Y axis

Bed-slinger

Pros

- Cheap
- Simple

Cons

- Y-axis is slower than X-axis
- Possible artifacts on high accelerations and/or tall parts

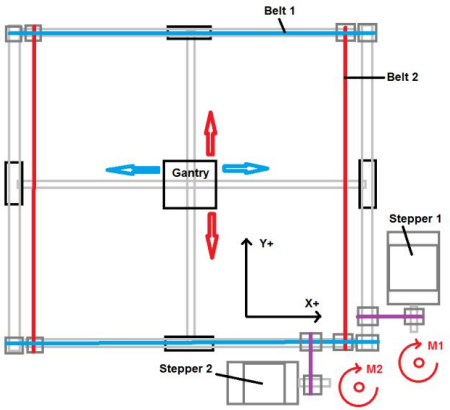
Bed-slinger, specimens

- Ender 3
- Anet A8
- Prusa i3
- **Longer LK4**

Good for someone starting their maker's career or for 3D printer farm

Box design

- Two gantries allow movement in X and Y directions
- Bed moves in Z direction



Box design

Pros

- No print quality degradation on tall models
- Still relatively cheap
- Can have huge print volume

Cons

- More expensive than the Bedslinger
- Not as fast as CoreXY/HBOT

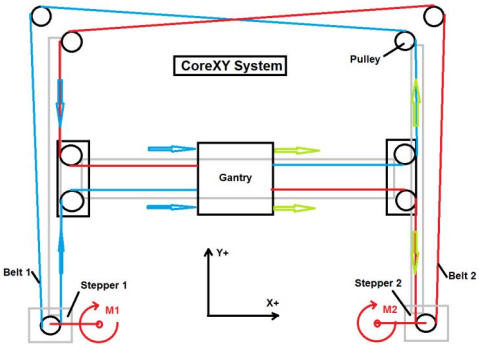
Box design: specimens

- **Ultimaker**
- **Raise 3D**
- Flying bear

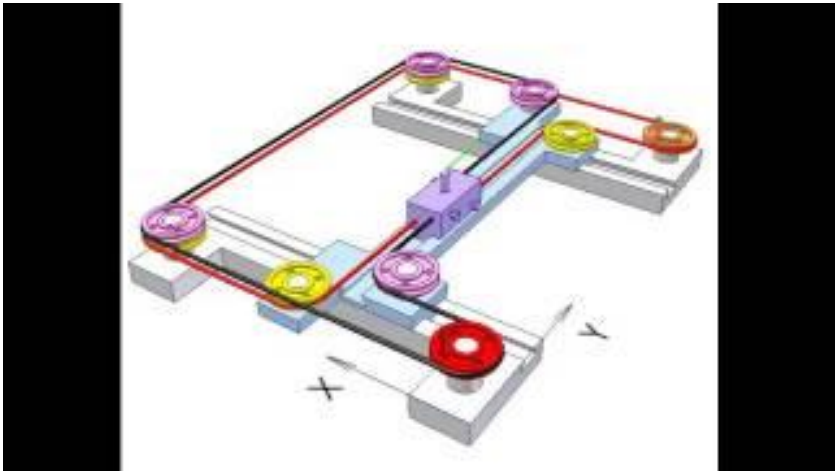
Higher-end printers tend to have really good out-of-the-box performance, and print quality in general. Good for those who want better print quality and ready to pay for it

CoreXY and HBot

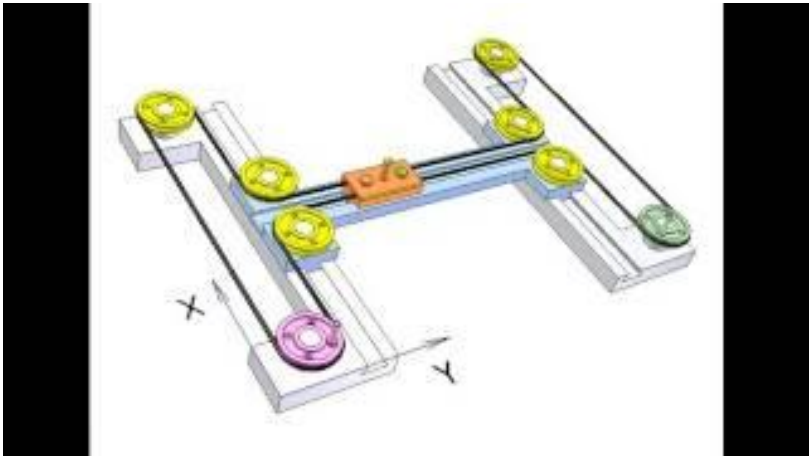
- One gantry that is moved in X direction
- Printhead can slide along the gantry in Y direction
- Bed is moved in Z direction



CoreXY video



Hbot video



CoreXY and HBot

Pros

- Faster than the Box-Style design

Cons

- More expensive than Box-Style
- Require especially tight tolerances when assembling

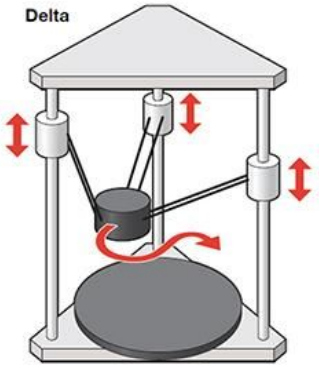
CoreXY and HBot: specimens

- Voron
- **Anisoprint A4**
- Ender 6

For “speed-junkie” type of makers, or for those willing to pay extra for print quality

The mighty Delta

- Instead of gantries, it uses 3 arms arranged in a triangular fashion
- Simultaneous motion of arms controls all 3 axis



Delta

Pros

- Fast
- Can print tall objects
- Compact

Cons

- Calibrating is a royal pain
- Sensitive to arm length irregularities

Delta: specimens

Pros

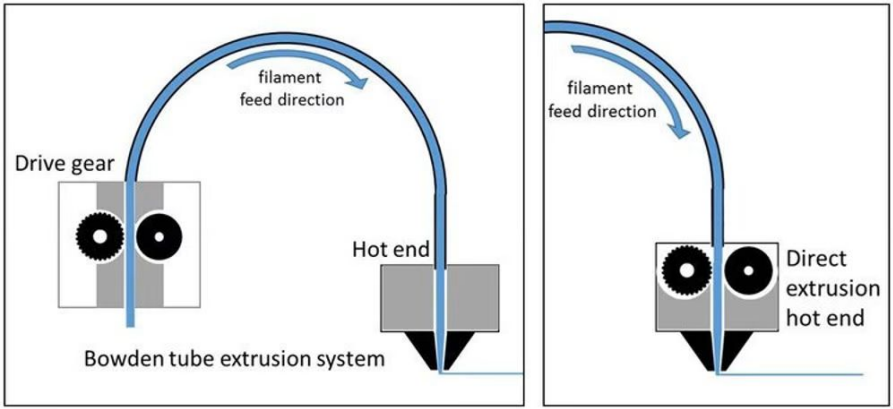
- **Anycubic Kossel**
- Flsun Q5
- Delta Go

For “speed-junkie” type of makers, who are well-versed in the subtle art of 3D printing or for those who want print tall parts.

Aircraft parts, anyone?v

Extruder: Direct vs Bowden

Direct or Bowden?



Bowden pros & cons

Pros

- Lighter printhead
  - Higher speed
  - Flimsier chassis
- Cheaper

Cons

- Problems with retracts due to springiness of the material
- Hard to print with flexible plastics

Entry-level machines are usually bowdens

Direct pros & cons

Pros

- Less problems with the springy filaments
- Able to print even softest of TPU plastics

Cons

- Heavier printhead
- Usually found on higher-end machines

In general, there are less problems with direct extruder

Printer firmware

Printer firmware

- **Klipper**
- Marlin
- Repetier
- Prusa & other proprietary

Printer firmware: Main takeaways

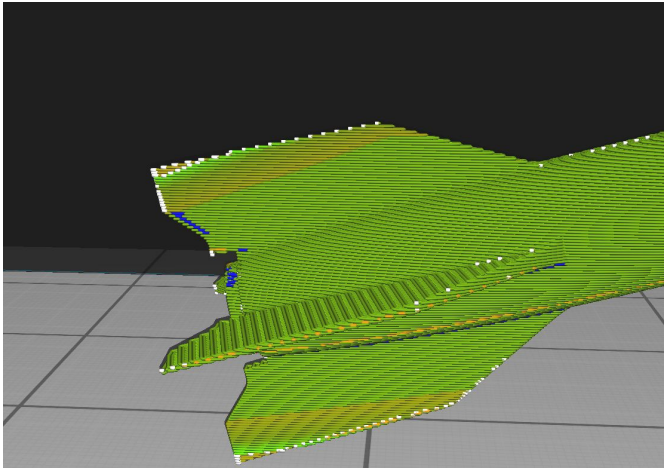
- If your stock firmware works good enough for you, and that is usually the case with higher end machines - just leave it be
- If you want to print faster and possess substantial skill in FDM technomagic, then you can try Klipper
  - Or maybe you want to print over internet

Printer choice

Hard choice

- If you are starting your career in FDM, or want to save money - Bed-slinger printer is a good choice
- From there you will figure out what you want next
  - Tall parts?
  - Fast prints?
  - Superb print quality?

Enough hardware!



Slicing process & Software

Slicing software choice

- Cura (free)
- Simplify 3D (paid)
- Slic3r (free)
- PrusaSlicer (free)

Slicing software choice

- It is a matter of personal choice, I use Cura because it is
  - Feature-rich
  - Extendable via plugins
  - Actively maintained
  - Free

Filaments overview

PLA

+ Easy to print
+ Strong
+ Recyclable
- Not heat resistant
- Hard to machine

PETG

+ Should be flexible
+ Strong
- Hard to print
- Prone to stringing
- Very brittle if not dried

ABS

+ Easy to machine
+ Easy to smooth with solvent
- Extremely poor layer adhesion
- Stinks while printing

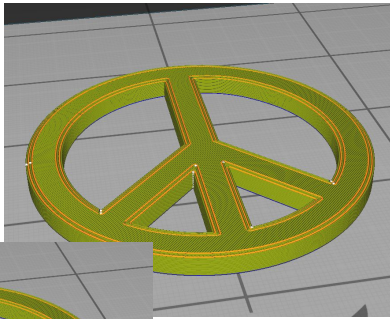
Print part orientation

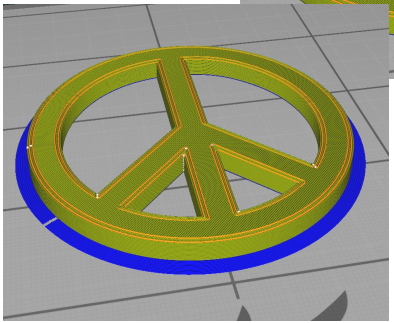
Good part has

- No layers that are either completely or partially not supported by previous layer
- Big print bed contact area
- Such an orientation that the main loading is parallel to the bed

Print part orientation

- Good
- No partially or fully unsupported layers
- Good bed contact area

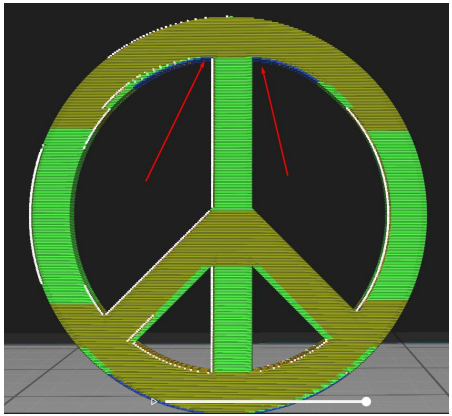




Print part orientation

- Poor
- Some layers are partially unsupported, like green sides
- Some are completely (marked with red arrows)
- Low bed contact area

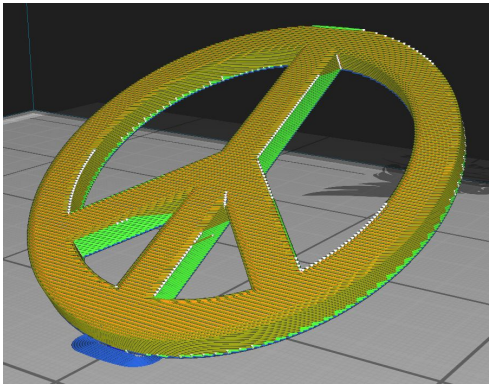
- Don’t do this unless you really know what you are doing



Print part orientation

- Extremely poor
- Many layers are completely unsupported
- Miniscule bed contact area

- Don’t do this. Just don’t.

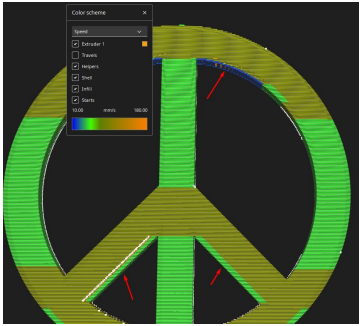


What if you design absolutely needs “bad” parts

If you really want unsupported print lines

- Use overhangs. The main idea is to go slower on partially unsupported lines to prevent sagging
- You might want to boost cooling as well

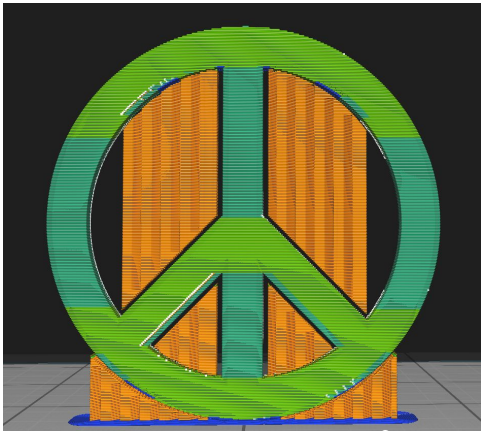
- Here are fields that you can tune in Cura (experimental)



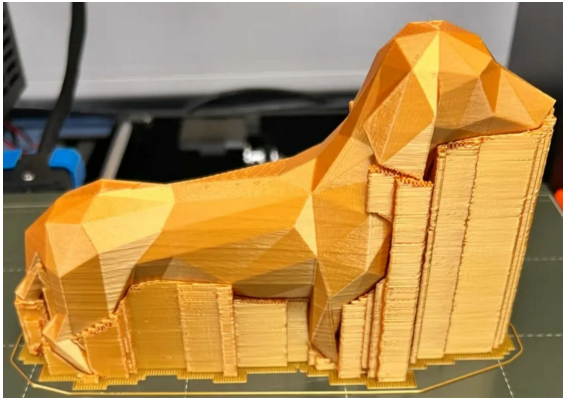
Bad sagging

If you really want unsupported print lines

- Use support. Support is a sacrificial structure that allows you to print “in the air”
- Supports have plethora of parameters, but you should look out for your
  - Support cooling settings
  - Top and bottom clearance
  - Support pattern



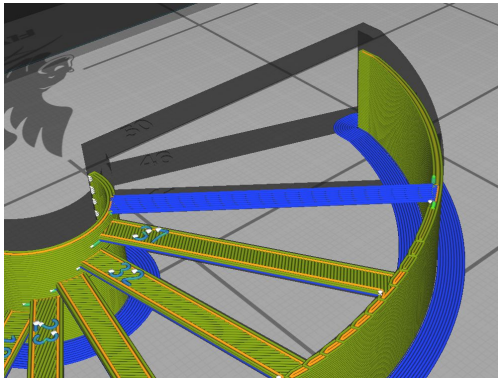
Supports ain’t that bad



If you really want unsupported print lines

- Use bridges. Bridge is printed hanging in the air and is quickly solidified with part cooling fan

- Default parameters from Cura usually work for short bridges (up to 2 cm) and machines with adequate cooling



On strong parts and layer adhesion

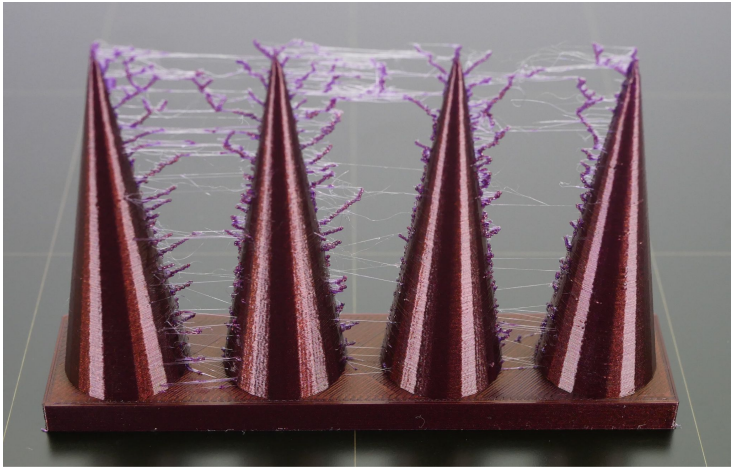
If you want to make your parts stronger and print faster you might

- Ramp up the temperature
- Increase line width, i.e. 0.6 for 0.4 nozzle
- Decrease cooling, but beware of supports and overhangs!

- Some plastics respond better to this technique than others.

  More here: https://www.youtube.com/watch?v=9YaJ0wSKKHA&t=736s

Stringing



Under/over-extrusion

Gaps between the lines

Underextrusion

OK

Too much material in the corner and more visible layers

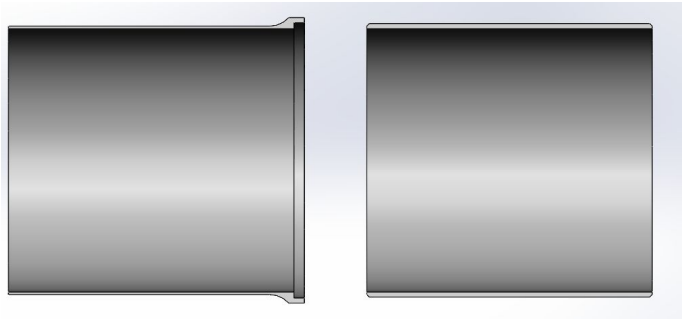
Overextrusion

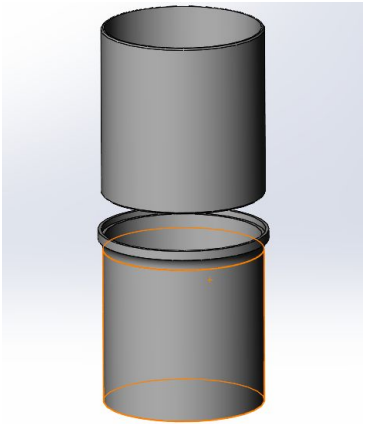
Post-processing: Gluing

Gluing

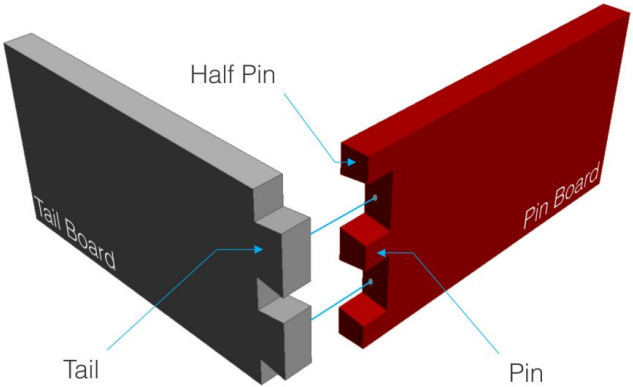
- Dry-fit first
- Maintain high contact surface
- Glues suitable for 3D printed parts
  - CA (possibly with catalyst)
  - Epoxy
  - Hot glue
  - PUR
- Glues not suitable for 3D printed parts
  - UHU Por
  - PVA glue
  - Dissolving glues (Dichloromethane / Dichloroethane)

Gluing: Flanges & Dovetail joint



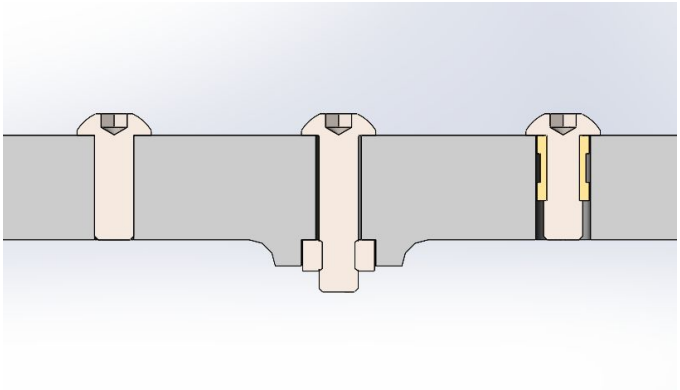


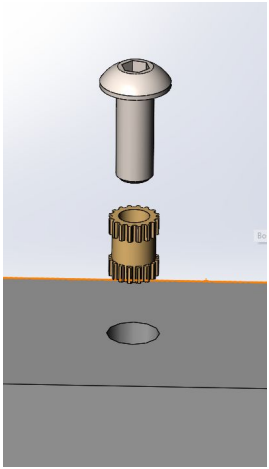
Gluing: Flanges & Dovetail joint

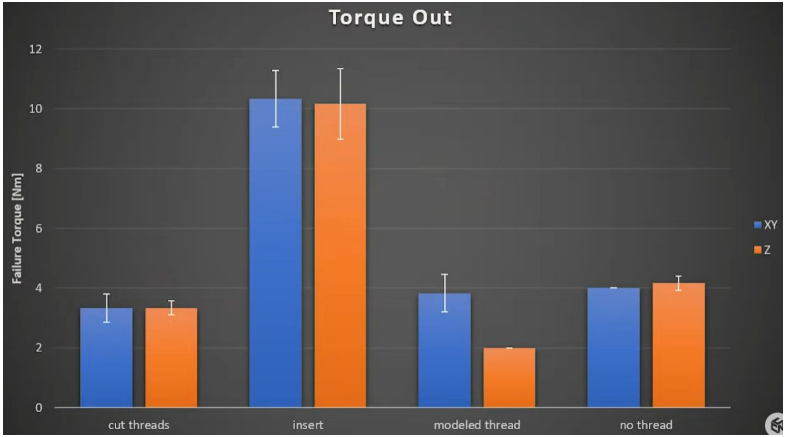


Post-processing: Screwing

Screwing







Taken from: https://www.youtube.com/watch?v=iR6OBlSzp7I&t=19s

Visit for more information and scientific tests

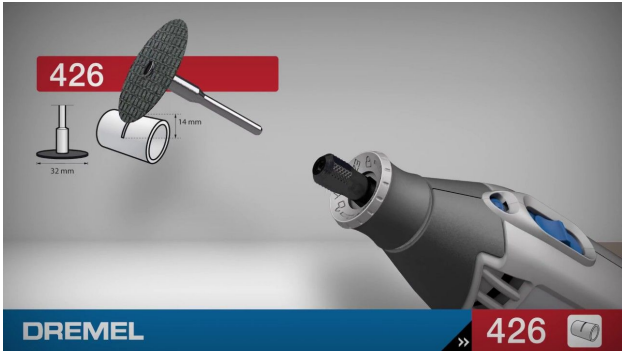
Post-processing:
Cutting Drilling Sanding Bathing

Abrasive machining

- Sanding should be avoided if possible for plastics like PLA and PETG
- If you really want to sand some part- avoid overheating

- Cutting with cutoff discs for rotary tool is easier, even if plastic melts. You are just throwing more power to the problem and it apparently works
- Beware! A disc can shatter if subjected to bending load
- Hand tools like hacksaw will also work

Abrasive machining



Drilling

It is easy to drill 3D printed parts, but there are few caveats

- Watch out for the wall thickness
- Use a good, sharp drill bit, avoid overheating
- Safety first

Drilling

It is easy to drill 3D printed parts, but there are few caveats

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Bathing

Parts are exposed to vapour of a solvent that partially dissolves outer surface

Different plastics require different solvents

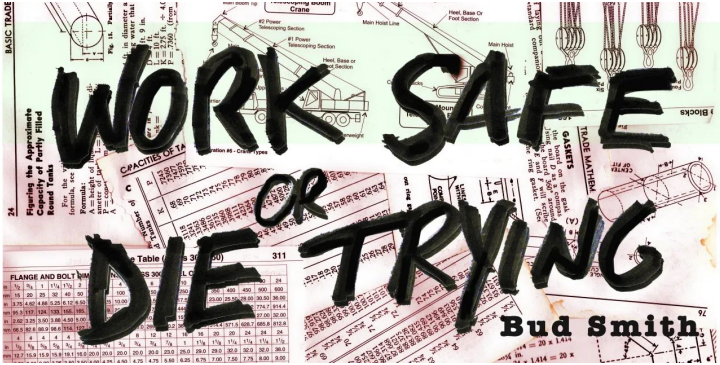
- ABS: acetone, dichloromethane
- PETG: dichloromethane
- PLA: limonel, dichloromethane

Bathing

- Mainly good for decorative parts
- Works best with ABS + acetone

Bathing

- Most solvents used for bathing are toxic and highly flammable

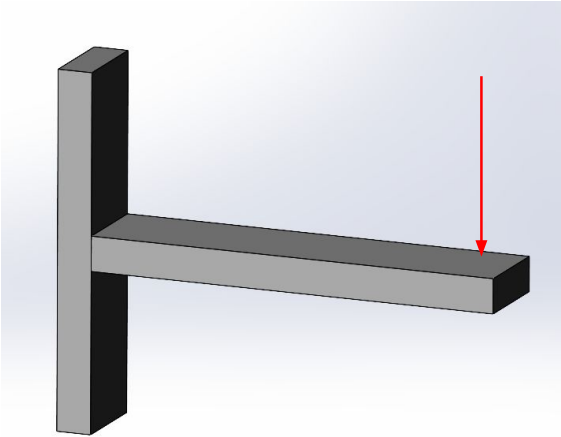


Tasks: 3D printed joint

Your task is to join two parts so that they can be printed and assembled. Please use

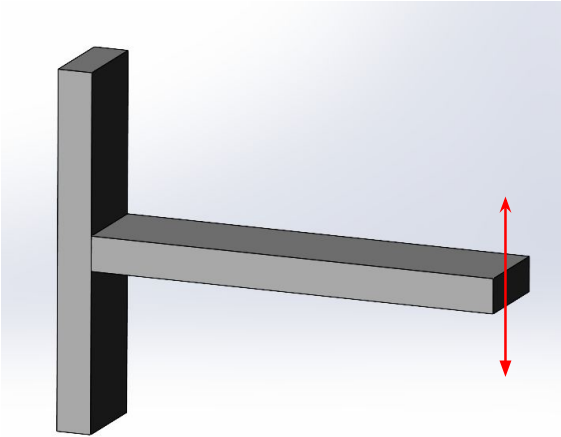
- Two types of screw joints
- Two types of screwless joints

* Take the load applied along the red line into account



Tasks: 3D printed joint

What should you tweak if you want to load your part like this?



That’s it for today!
The Emperor protects!

Do you want to join our lab?

Ever wanted to work on real robotics projects?

- Aerial
  - Ground based
  - Aquatic

Then you can consider joining our lab, please contact either me @ysukhorukov or my team-lead

@devittdv

Invited Lecturer Yuri (RUS)

Video

Deserve “A” grade!

– Oleg Bulichev

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@Lupasic

Room 105 (Underground robotics lab)