

Prototyping in Mechanical Engineering



Class 2: Fabrication

Movie Break!

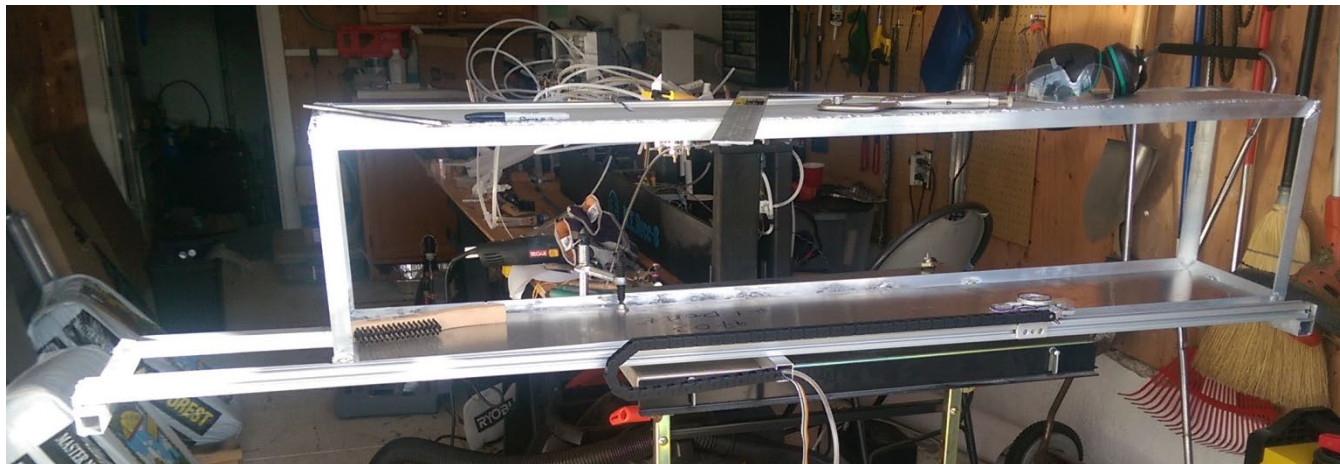
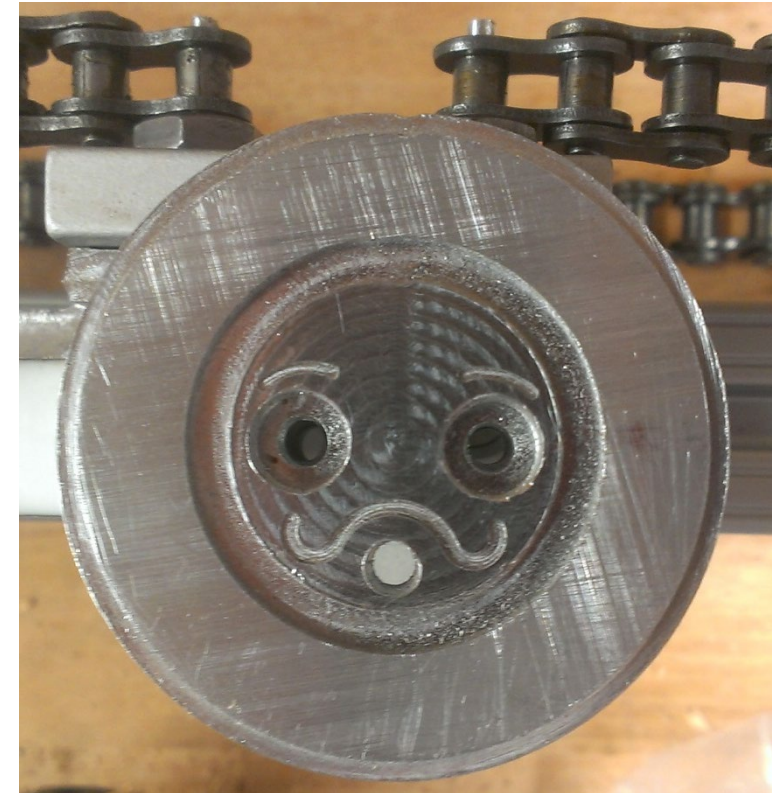
Today's Agenda

- ~~Why is fabrication so important?~~
- Intro to Fabrication
- Additive
- Subtractive
- Forming
- Will's List of Twelve Tools to Own

Intro to Fabrication

Fabrication

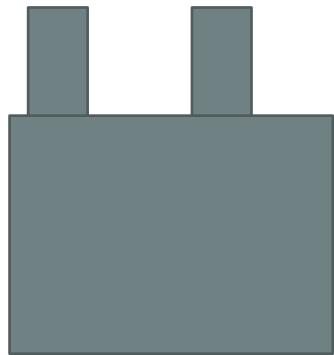
- Building stuff
- Making things
- Getting what you want out of the material you want



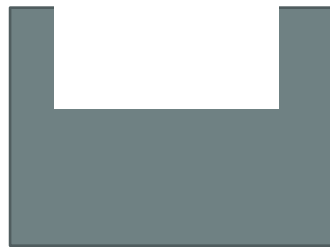
Fabrication



Fabrication



Additive



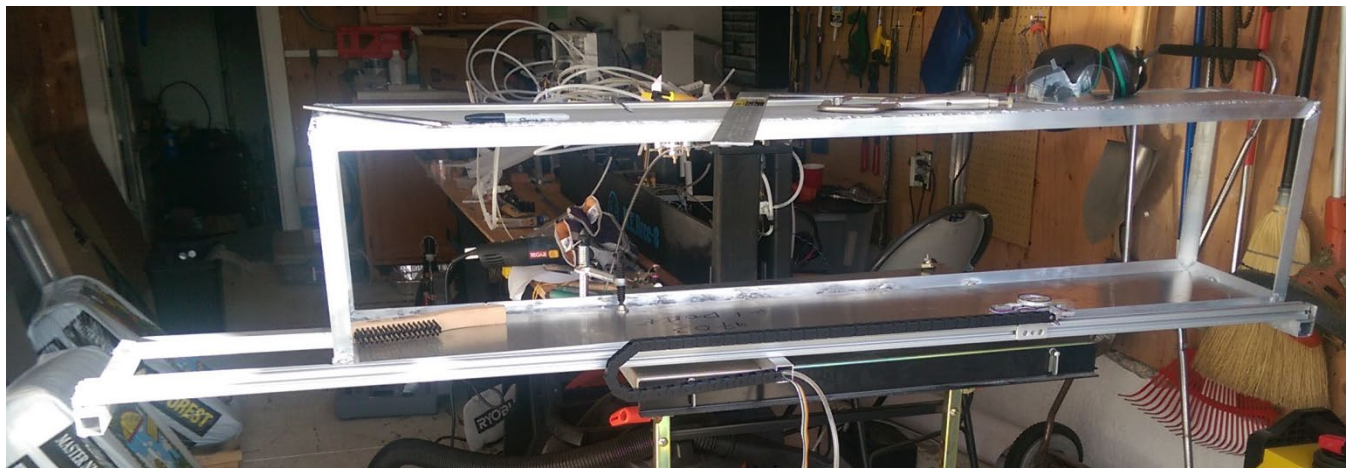
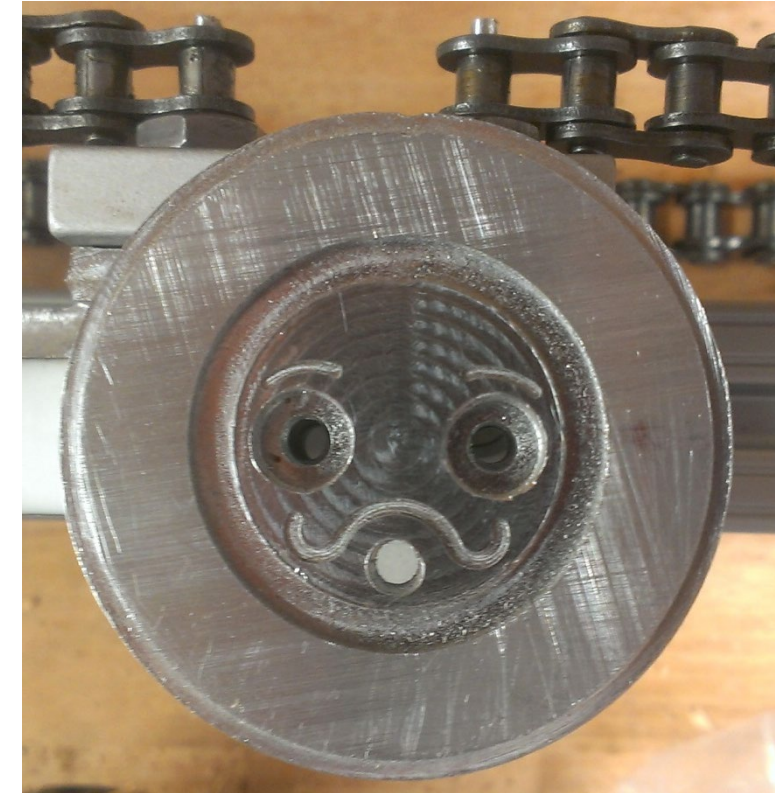
Subtractive



Forming

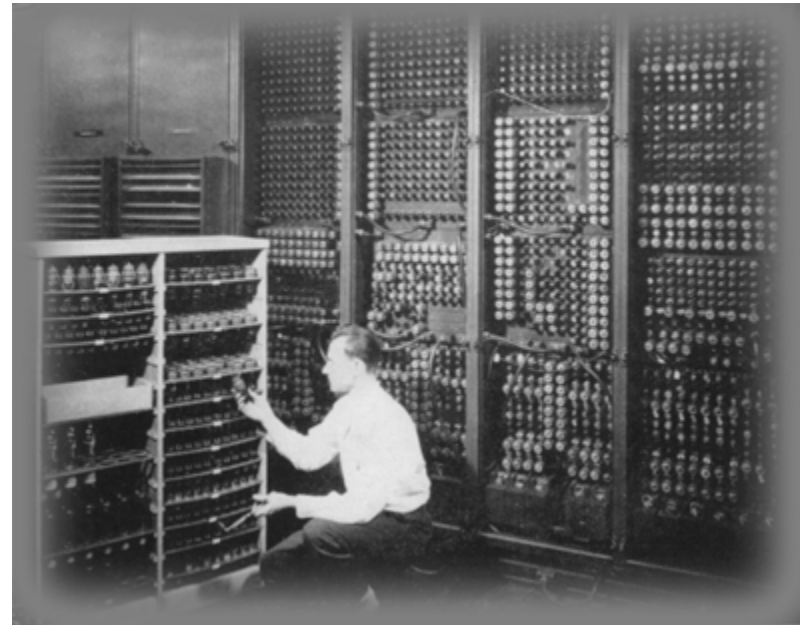
Fabrication

- Additive
- Subtractive
- Forming



CNC: The Game Changer

- Computer Numeric Control
 - Invented 1940s
 - Practical 1970s
 - Universal 2000s



Choosing your method

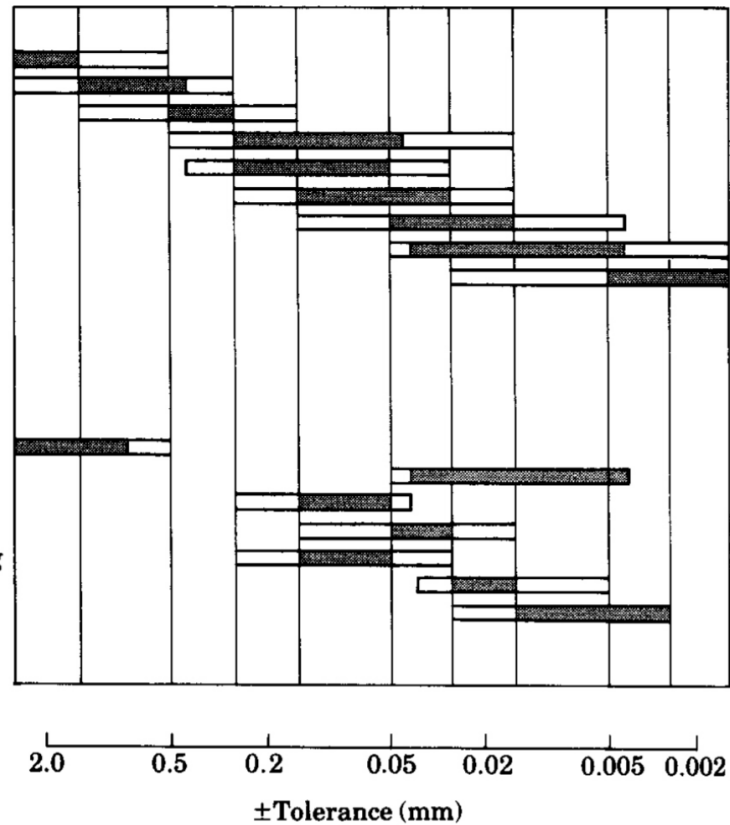
- Tolerance
- Surface finish
- Speed
- Ease of design
- Variability (intentional)
- Material viability
- Availability

Precision

- Traditional**
- Flame cutting
 - Hand grinding
 - Disk grinding or filing
 - Turning, shaping, or milling
 - Drilling
 - Boring
 - Reaming or broaching
 - Grinding
 - Honing, lapping, buffing, or polishing

- Nontraditional**
- Plasma beam machining
 - Electrical discharge machining
 - Chemical machining
 - Electrochemical machining
 - Laser beam or electron beam machining
 - Electrochemical grinding
 - Electropolishing

Less frequent application
 Average application

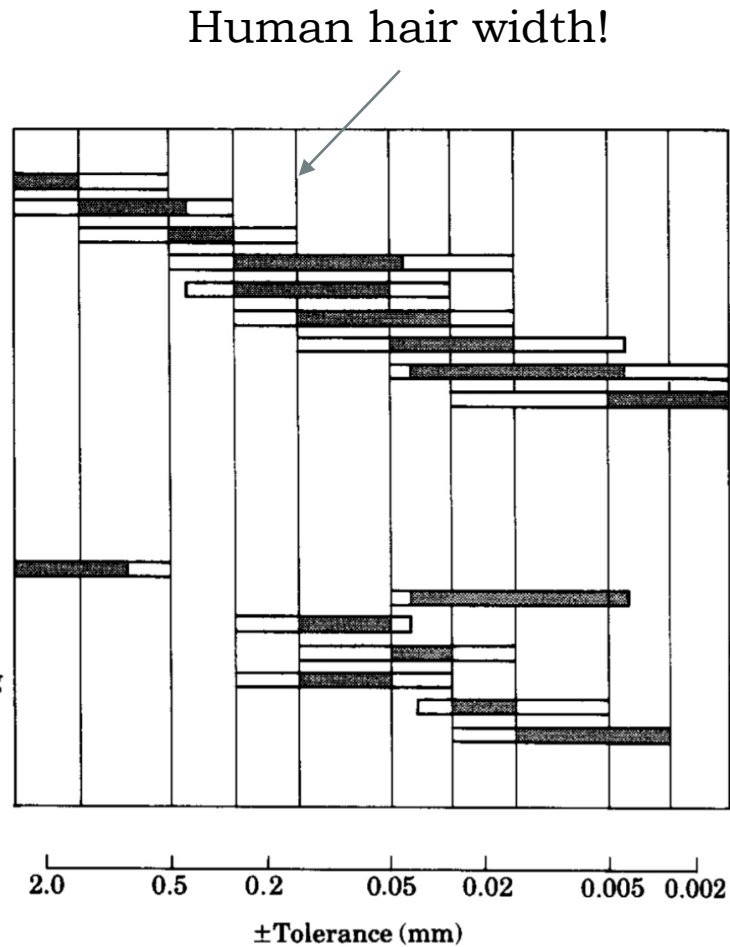


Precision

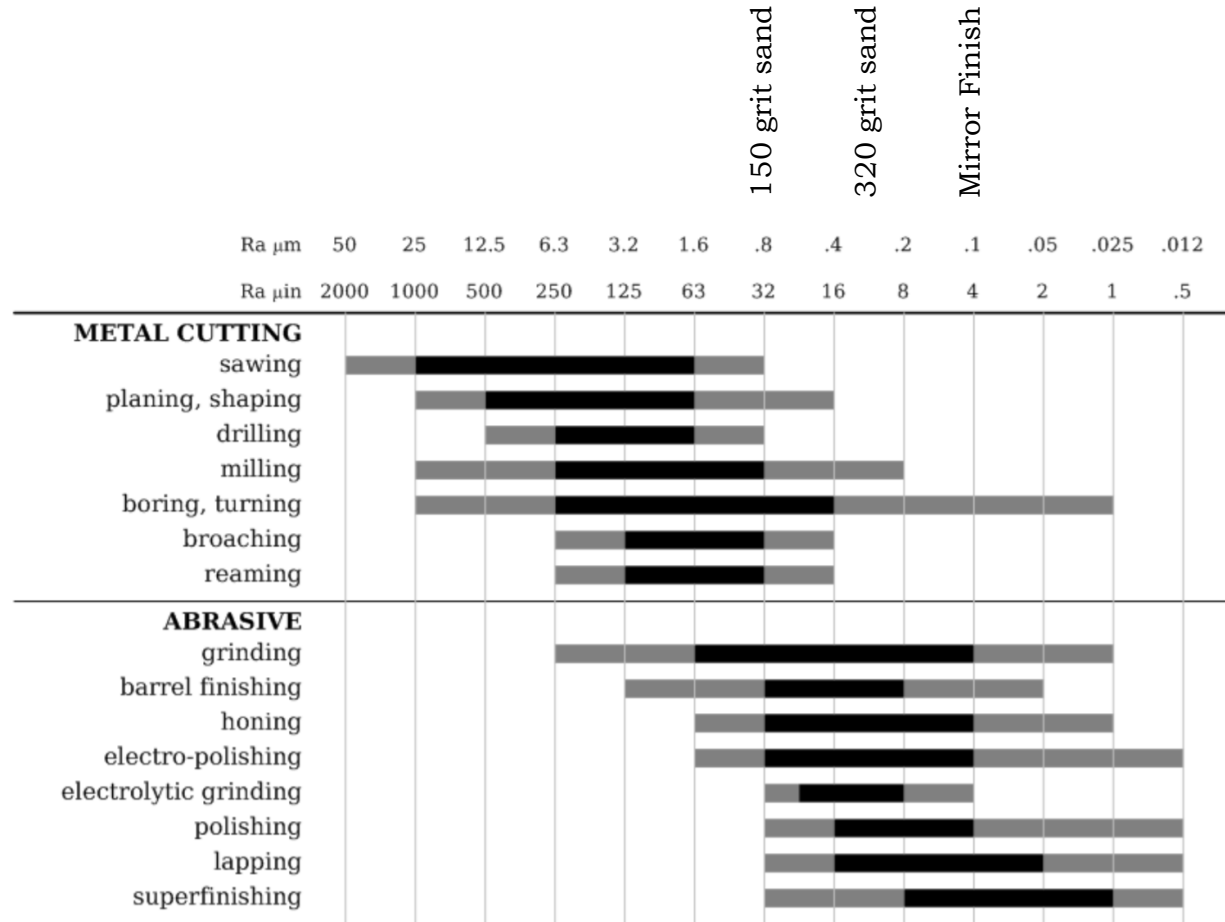
Traditional
 Flame cutting
 Hand grinding
 Disk grinding or filing
 Turning, shaping, or milling
 Drilling
 Boring
 Reaming or broaching
 Grinding
 Honing, lapping, buffing, or polishing

Nontraditional
 Plasma beam machining
 Electrical discharge machining
 Chemical machining
 Electrochemical machining
 Laser beam or electron beam machining
 Electrochemical grinding
 Electropolishing

□ Less frequent application
 ■ Average application



Surface Finish



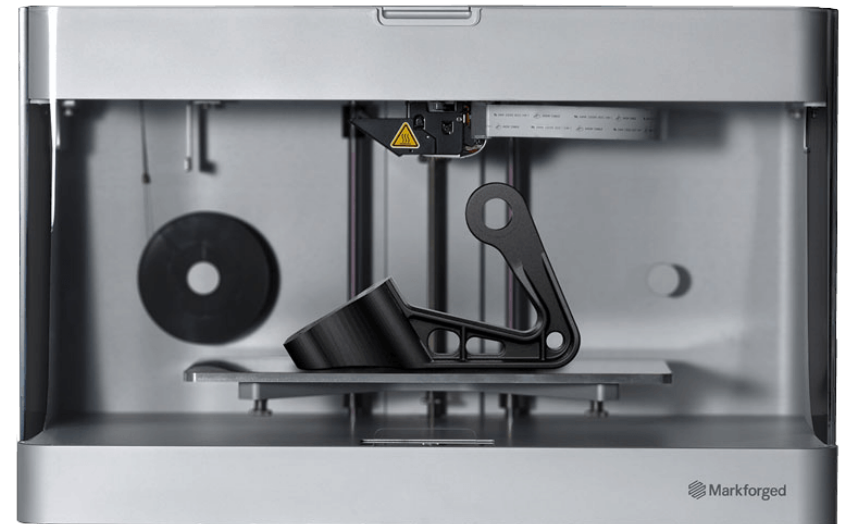
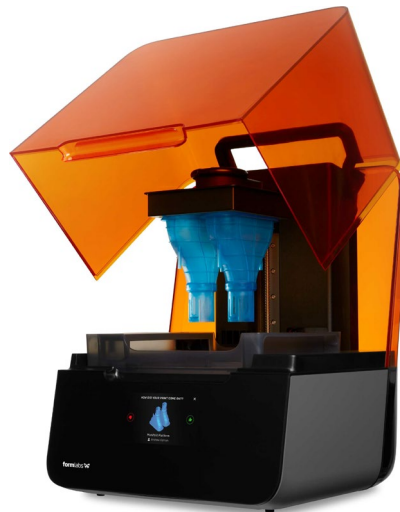
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Additive

Additive Manufacturing

- 3D printing
 - Not covered today
- Welding
 - Covered today!
- Other types of additive manufacturing
 - Not covered today



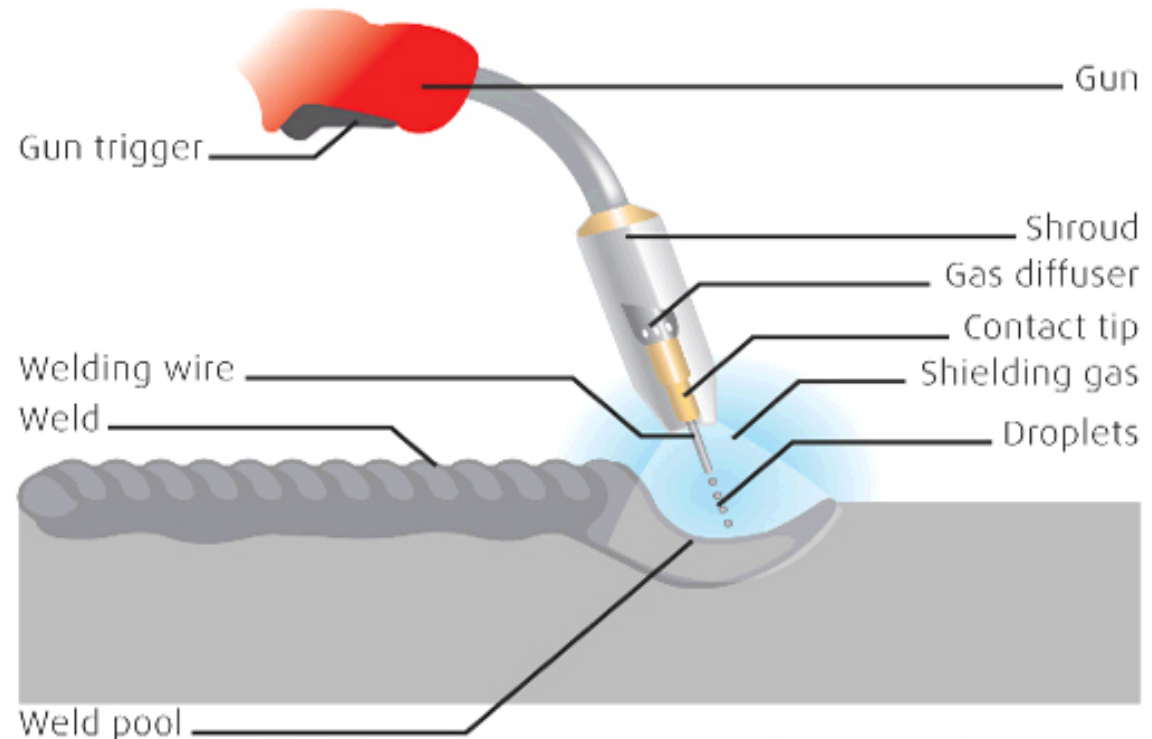
Additive: Welding

- **Using heat to join pieces of same* material with filler****
 - Metal Welding
 - Spot/resistance
 - MIG/Wire Feed*
 - TIG – Tungsten Inert Gas*
 - Oxy-acetylene*
 - Laser
 - Friction
 - Plastic
 - Ultrasonic
 - Thermal
 - Chemical
 - Others



Additive: Welding

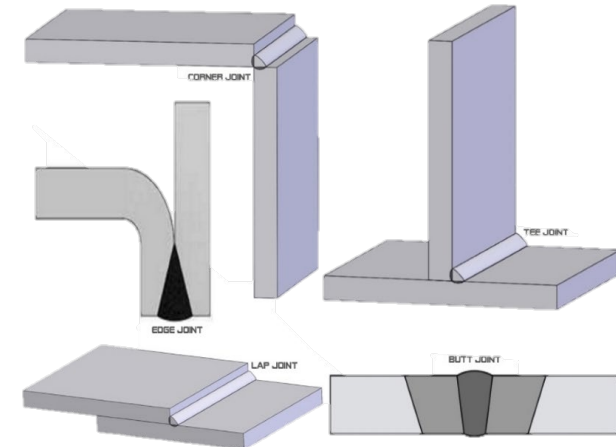
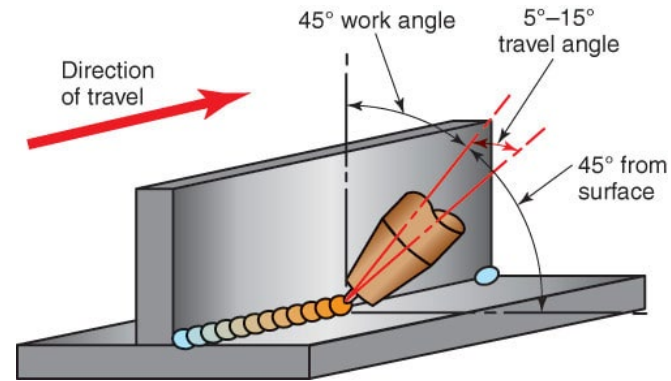
- Heat source
 - Electrical arc
- Shield molten metal
 - Flux
 - Shield gas
- Add material
 - Wire feed
 - Filler rod



The welding circuit consists essentially of the following elements:

Additive: Welding

- Dimensions
 - Weld penetration determines strength
 - 2mm min thickness – wire feed
 - Thinner with TIG
- Prepare, prepare, prepare
 - 1mm max gap
- Torch has to fit
- Different weld shapes
- Material selection
 - Mild steel (such as 1018)
 - Aluminum
 - Stainless
- Thermal Expansion
 - Tack weld



Fit Up Demo

Today's Agenda

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Subtractive

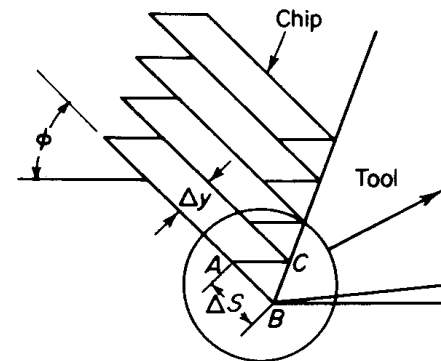
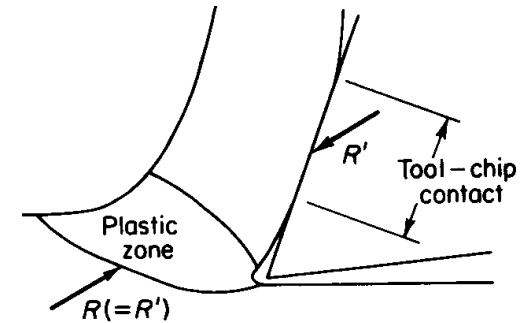
Subtractive Manufacturing

- Cutting
 - Milling
 - Drilling
 - Lathing
 - Sawing
- Grinding
 - Grinder
 - Precision Grinding
 - Polishing
- Others
 - EDM
 - Plasma
 - Laser



Cutting

- Milling & Drilling
 - Sharp spinny thing moves
- Lathing
 - Workpiece moves
- Sawing
 - Saw moves through material



Movie Break!

Swarf

- Not making this up



en.wikipedia.org/wiki/Swarf


WIKIPEDIA The Free Encyclopedia

Article Talk

Swarf

From Wikipedia, the free encyclopedia

This article is about the manufacturing waste. For the English band, see [Swarf \(band\)](#). For the archaic term for waste oil or grease, see [Swarfega](#).

 This article **needs additional citations for verification**. Please help [improve this article](#) by adding citations to reliable sources. Unsourced material may be challenged and removed. (October 2009)

Swarf, also known as **turnings**, **chips**, or **filings**, are shavings and chippings of metal — the debris or waste resulting from [metalworking](#) operations including milling and grinding. It can usually be recycled, and this is the preferred method of disposal due to the [environmental concerns](#) regarding potential contamination with [cutting fluid](#) or [tramp oil](#). The ideal way to remove these liquids is by the use of a [centrifuge](#) which will separate the fluids from the metal, allowing both to be reclaimed and prepared for further treatment.

The terms "swarf" and "chips" are also used to describe the waste shavings, sawdust, and cuttings from woodworking operations, as well as waste in constructed piping, such as welding metal or slag waste that is produced and trapped within the pipe during its assembly, and sometimes in [masonry](#).^[1]

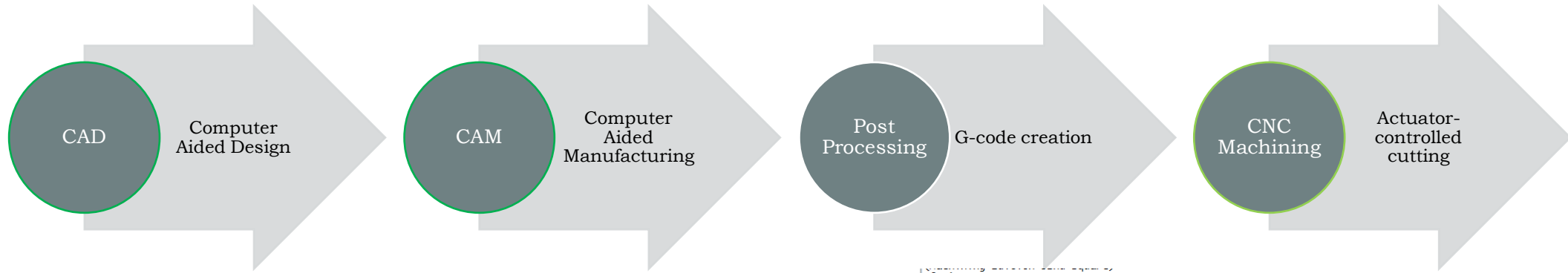
Contents [hide]

- Cutting hazards and safety precautions
 - Cuts, splinters, punctures, airborne chips
- Chip breaking
- Machine cleaning and chip handling
- Recycling
 - Requirements
- References

Various examples of swarf, including a block of compressed swarf

[edit]

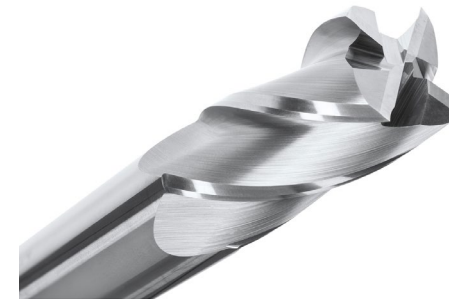
General CNC Workflow



```
M6 T1
M03 S6000
G00 Z0.2500
X-1.2876 Y-1.1030
G01 Z0.0642 F12.0
Z0.0392
X-1.2860 Y-1.1026 Z0.0296
X-1.2804 Z-0.0020
X-1.2789 Y-1.1029 Z-0.0108
X-1.2773 Y-1.1033
X-1.2833 Y-1.0775
X-1.2835
X-1.2896 Y-1.1035
X-1.2889 Y-1.1032
X-1.2860 Y-1.1026
X-1.2804
X-1.2789 Y-1.1029
G00 Z0.0642
X-1.2369 Y-1.2129
G01 Z0.0392 F12.0
X-1.2344 Y-1.2079 Z0.0075
X-1.2361 Y-1.2080 Z-0.0018
X-1.2377 Y-1.2079 Z-0.0108
X-1.2392 Y-1.2077
X-1.2410 Y-1.2071
X-1.2388 Y-1.2167
X-1.2344 Y-1.2079
X-1.2361 Y-1.2080
X-1.2377 Y-1.2079
G00 Z0.0642
X-1.1711 Y-1.1081
G01 Z0.0392 F12.0
X-1.1693 Y-1.1082 Z0.0290
X-1.1639 Y-1.1094 Z-0.0024
X-1.1626 Y-1.1100 Z-0.0108
X-1.1612 Y-1.1106
```

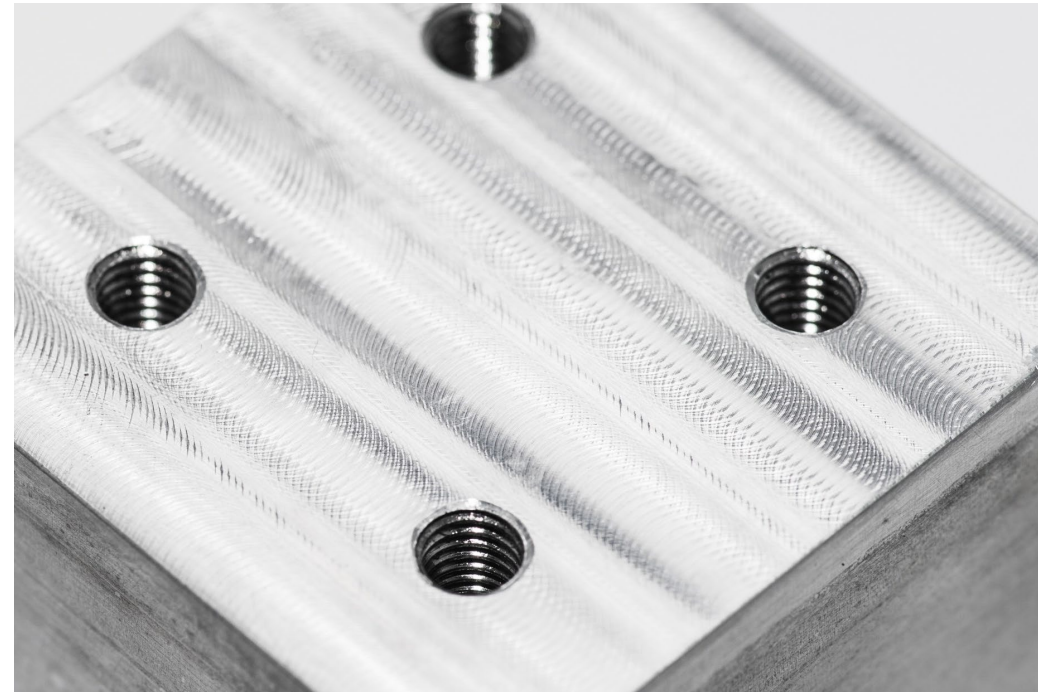
Milling

- Materials*
 - Plastics, Aluminum, Brass: Easy
 - Mild Steel: Hard
 - Tool Steel and Stainless: Really hard
- Tool access
 - External shapes are arbitrary
 - Internal shapes must have curvature
- Clamping
 - Security without deformation



Milling

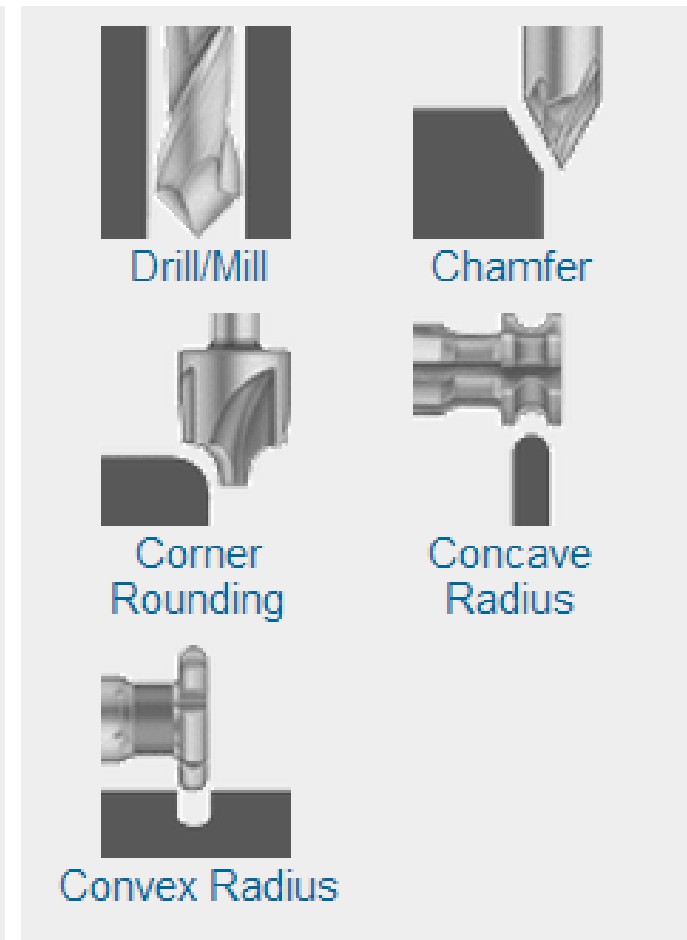
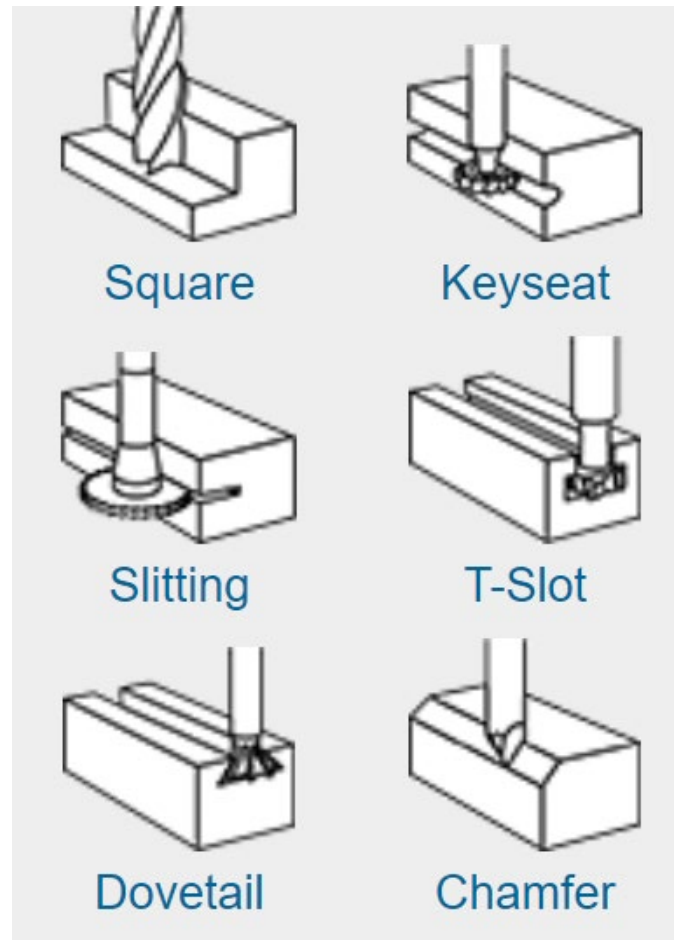
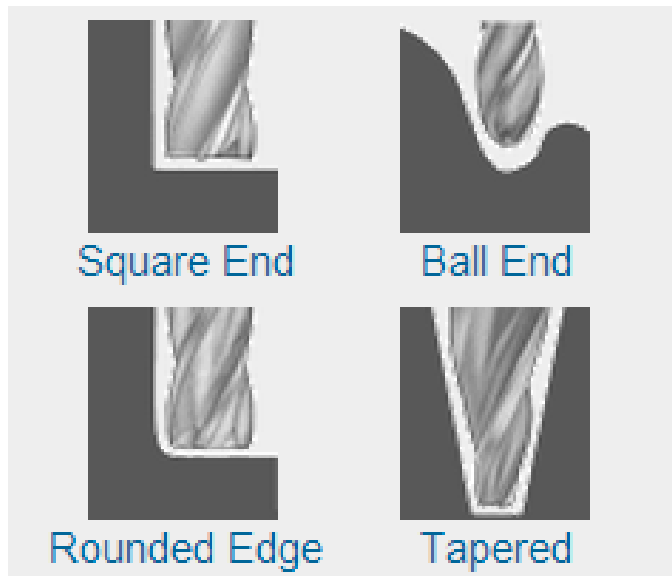
- Factors in fabrication
 - *Feeds & Speeds
 - *DOC – Depth of cut
 - *Chip load
 - Tool size
 - 4:1 aspect ratio
 - 1:3 vertical fillet ratio



Movie Break!

Milling

- Cutter shapes
- Design 'from the side'



Milling



Hooray!



Ehhhhhh

Undercut



Nope nope nope.

Impossible undercut with
adjoining features

Milling



Hooray!



Ehhhhhh

Features on multiple sides

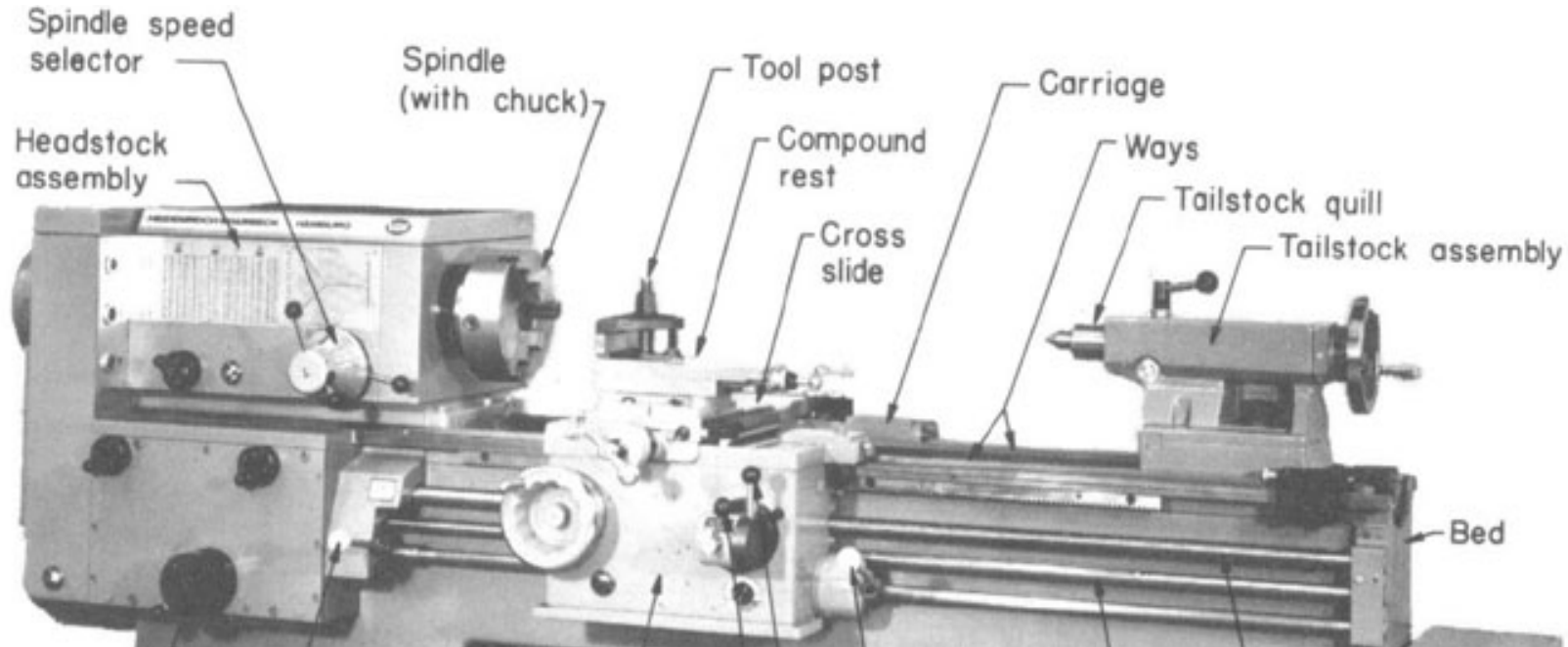


Possible but why

Features on many sides,
undercuts, thin walls

Lathing

- Workpiece moves with fixed cutting tool
- Having a manual lathe is often enough
- Excellent for highly concentric parts
- Design from the center-plane



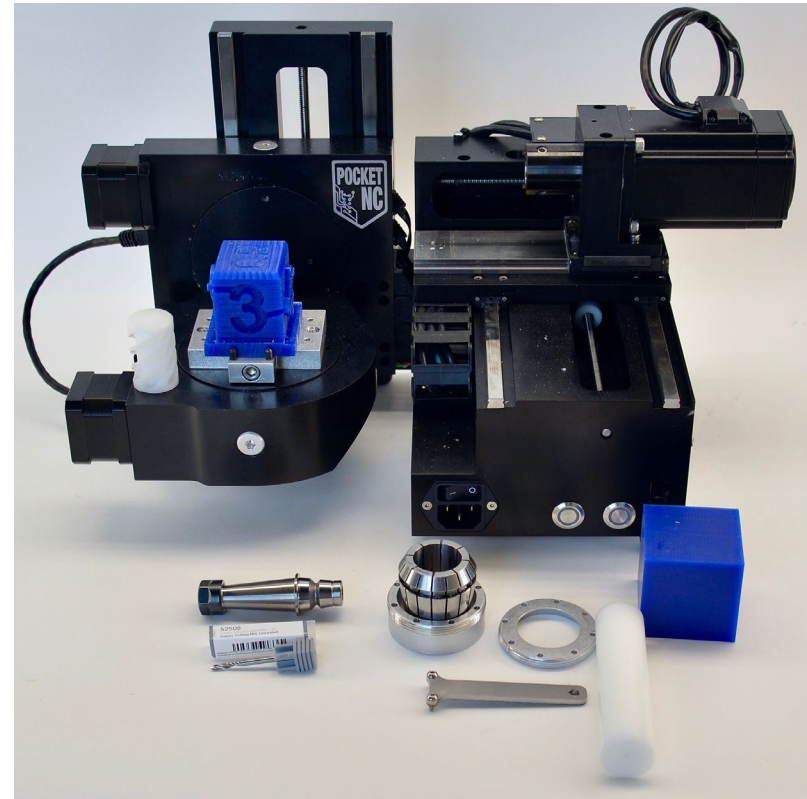
(Optional) Movie Break!

Lathing



Higher Order CNC

- Good for very complex parts
- Many of the same design constraints still apply
- Very difficult to program



Sawing

- Millions of types
- My favorites for metal work
 - Vertical Bandsaw
 - 6-8 teeth engaged
 - Horizontal Bandsaw
 - Miter saw (cutting for aluminum, grinding for steel)



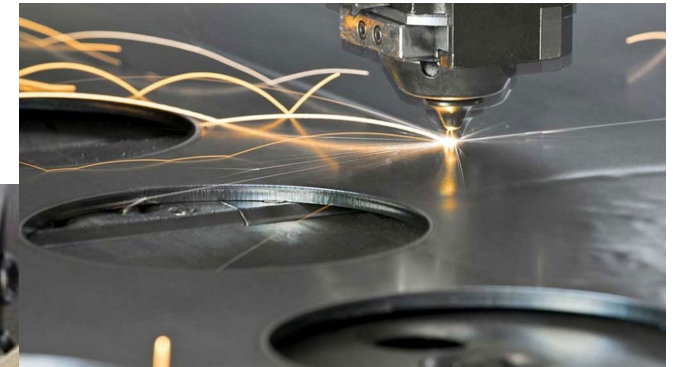
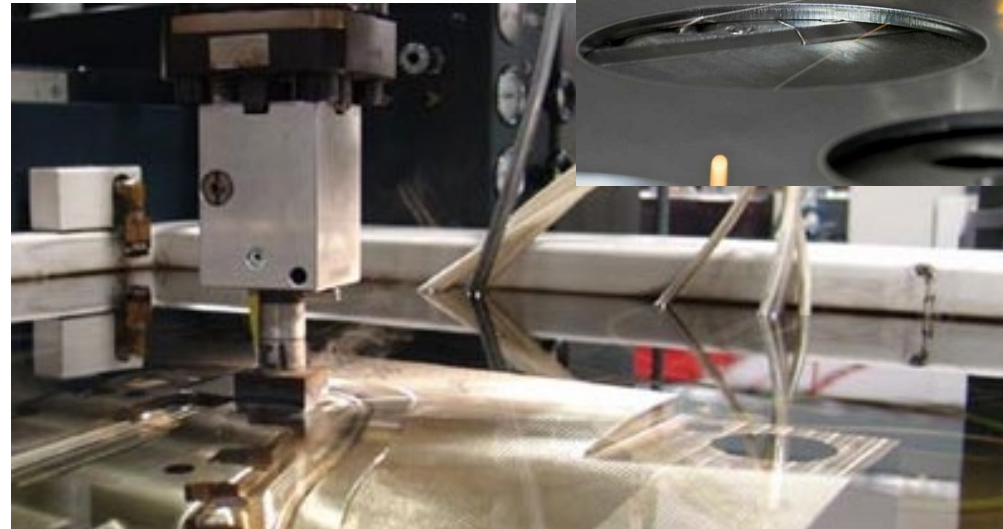
Grinding

- Like cutting, but doesn't rely on ductility
- Angle Grinder
- Bench Grinder
- Precision (CNC) Grinding
 - Finest tolerance of ANY conventional fabrication process
 - 0.002 mm precision!
- Polishing
 - Optical clarity!



Subtractive: Other

- Electro-discharge machining
- Plasma cutting
- Laser cutting
- Water jet cutting
- Other other



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Forming

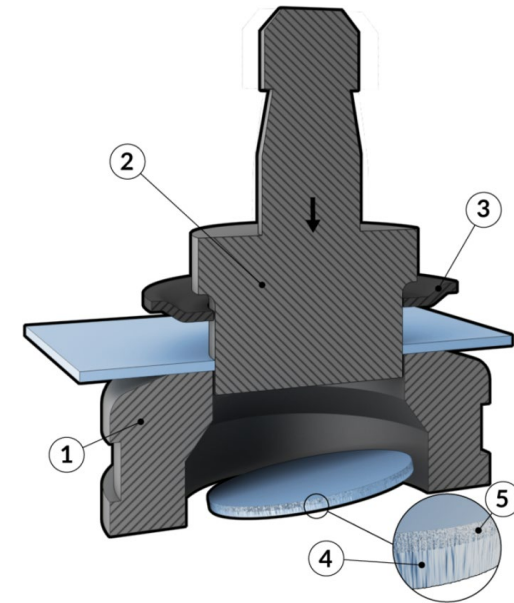
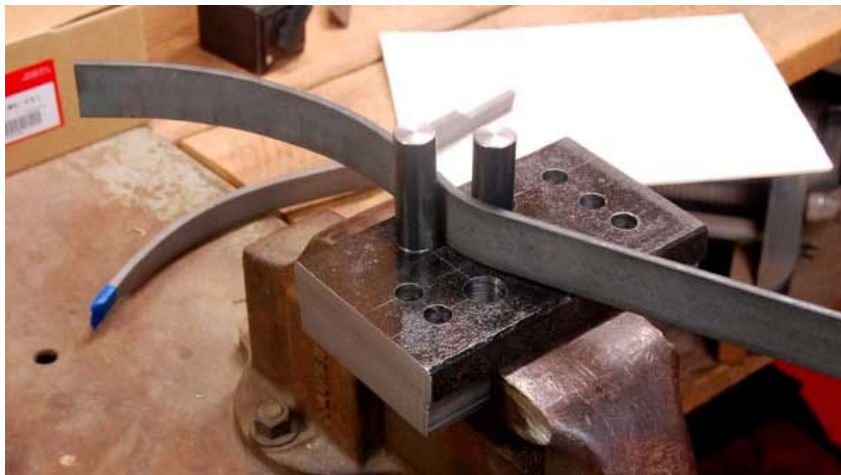
Forming

- Can be done at home
 - Shearing
 - Punching
 - Bending
 - Casting
 - Molding
- Probably not at home
 - Forging
 - Diffusion Bonding
 - Other



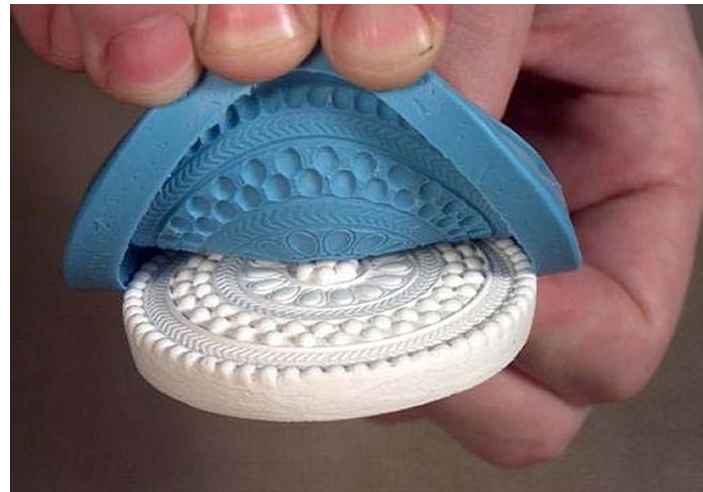
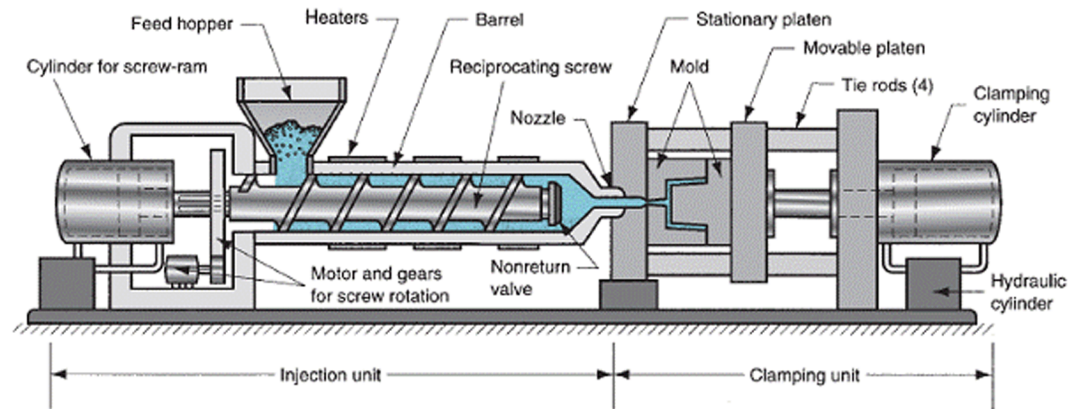
Forming at Home

- Shearing
- Punching
- Bending



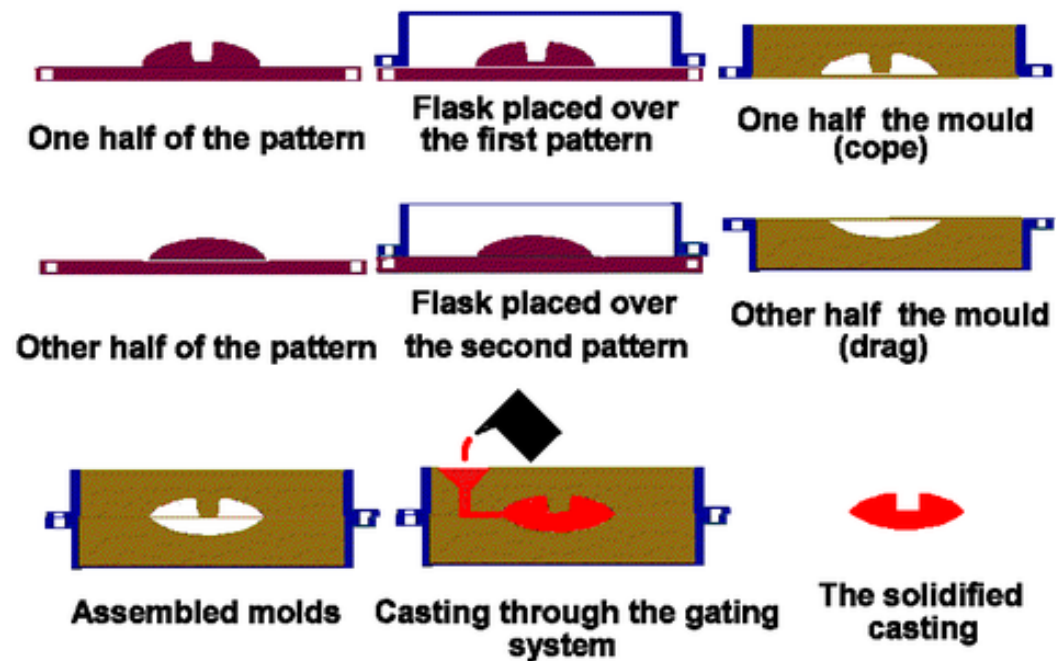
Forming: Molding

- Injection Molding
 - High volume
 - Expensive to get molds
- Hand molding
 - Mill or 3D print molds
 - Thermosets
 - Low temp thermoplastics



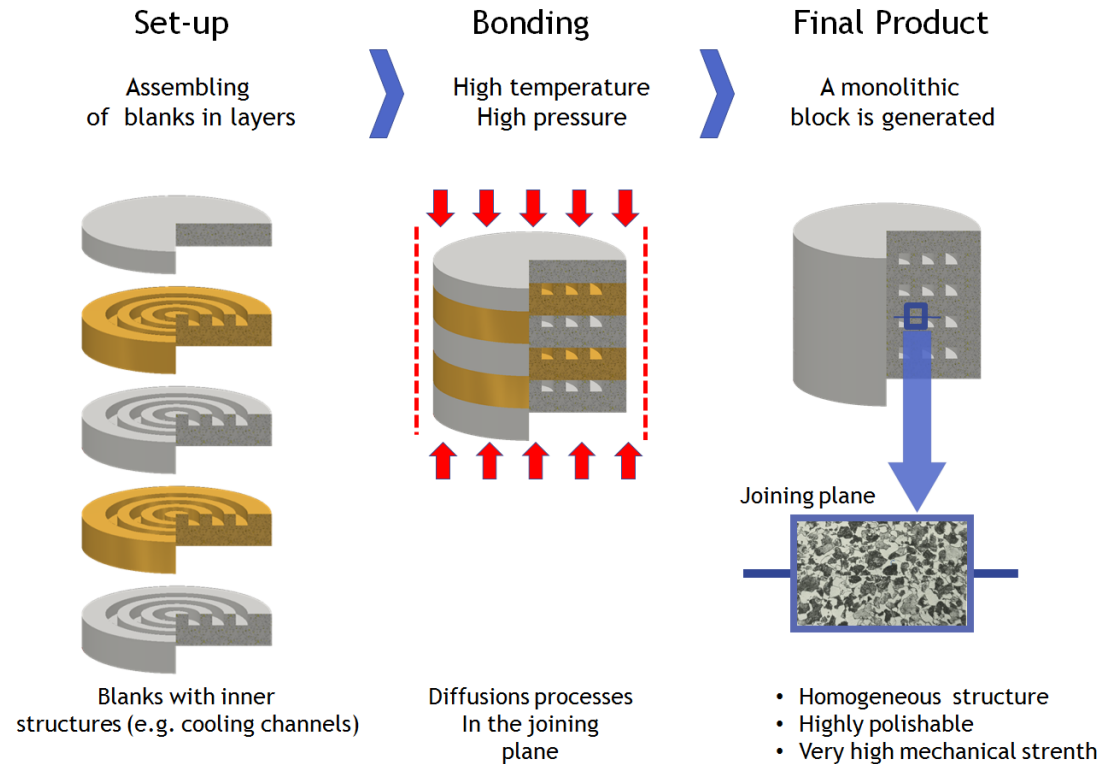
Forming: Casting

- Sand casting
 - Lead
 - Aluminum
- Plaster casting
 - 3D printed 'burnout' filaments/resins



Forming

- Forging
- Diffusion Bonding
- Other



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Will's List of Twelve



Will's List of Twelve



Will's List of Twelve Tools to Own

The List (1-6)

1. Razor blades
2. Good lighting
3. Calipers
4. Driver set
5. Allen key set
6. Tweezers



The List (7-12)

7. Nail file (or key files)
8. Pliers
9. PPE
 - Glasses
 - Hearing protection
 - Gloves
10. Dremel
11. Drill / Impact Driver
12. Soldering station
 - with heat gun

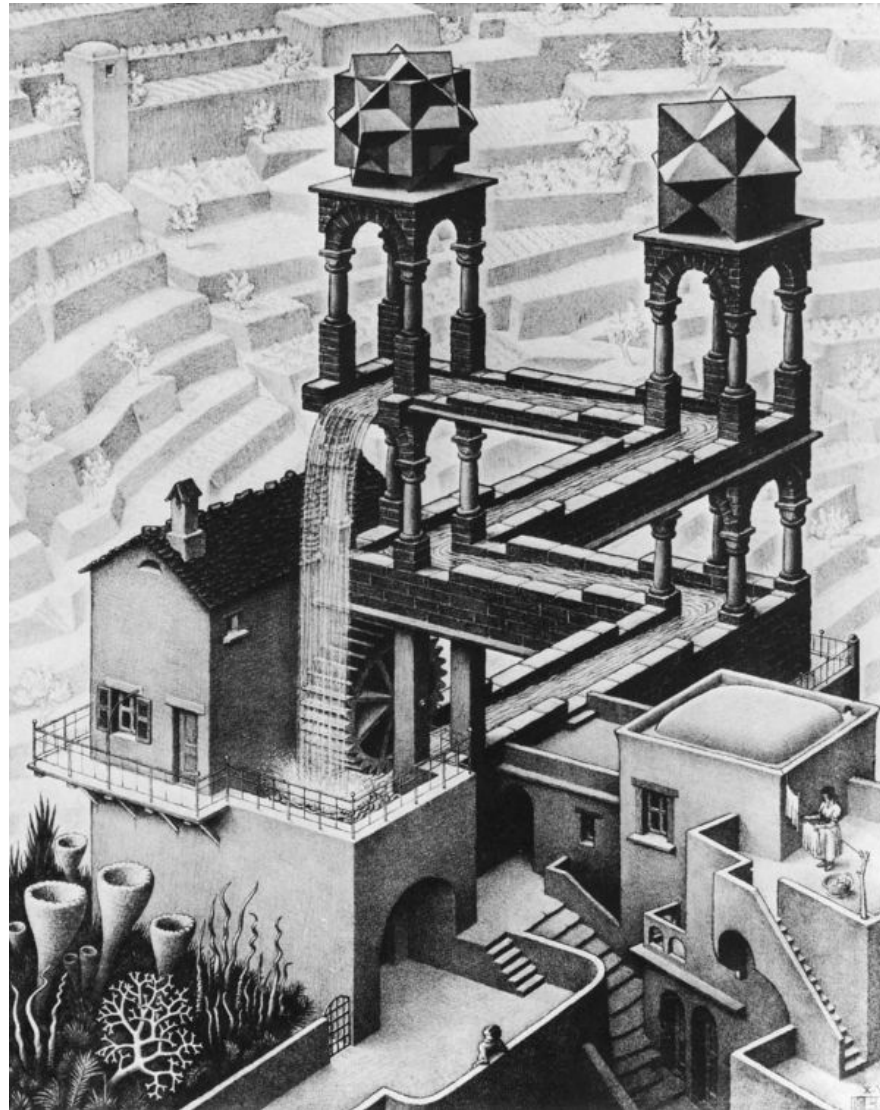


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Engineering is about iteration.

**It's good to try stuff, even if it
doesn't work out the first time.**



Questions? Office Hours!

Will Fischer
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