[Molding & Casting]

Individual Assignment:

- design a mold around the process you'll be using, produce it with a smooth surface finish that does not show the production process toolpath, and use it to cast parts
- Can print a mold or machine a mold
    - For machining, wax has magical properties - easy and fast to machine, exquisite surface finish, and meltable to reuse
    - Start with the silicone then hydrostone or drystone for first cast; then go beyond it with other materials

Group Assignment:

- review the safety data sheets for each of your molding and casting materials, then make and compare test casts with each of them
- compare mold making processes

Molding:

- Injection molding: you make a mold and inject it with your material
    - Inset, overmolding
- Insert molding: you put your thing in directly and add material around it
    - Rather than designing case and adding electronics, you can also just cast your electronics directly with insert molding – ie put in your chip and it gets covered in something like silicon
        - Obviously not easily fixable if something breaks but very sealed
- Vacuum molding: heat a plastic, then pull a vacuum and it pulls around
    - Killer application for this is packaging
- Blow molding: inflate plastic and blow it into the mold
- Rotational molding: mix the resin, put it in mold, then tumbles it in every axis so that when it's done instead of solid part you get a shell
- Examples:
    - making a machine remote
        - Made a shell, then flexible material with different colors for the buttons
    - Making cats out of clay and chocolate
    - Making a tesseract – as long as there's a decomposable set of projections, you can mold it
        - Six-part mold, cast in it, pull parts out, and get tesseract
- Can cast directly in rigid material, but in a rigid mold, if you have a vertical face/part it's very hard to get it out – for example, and overhang lip
    - So in soft tooling make a rigid mold that you use to cast a flexible material, then the rigid part in the flexible material so you can bend to get it out easily
- When you take the mold apart, will get flashing and bad parting line if the pieces aren't perfectly aligned

  - Don't recommend adding bumps to align; use the whole perimeter of one mold to constrain the whole perimeter of the other one
  - But bumps would be helpful if you need larger part in smaller area

Vendors

- Smooth-on:
  - Key vendor! Make all sorts of materials for molding and casting
- Many boat vendors are good too bc the world is filled with molding uses; west marine, USG, etc
- Also stone or something? jesmonite?
- Aremco makes high temperature molding and casting for ceramics
- Protolabs = job shop, once design part and do soft tooling testing they'll make injection molding mold and do production run for you

Materials

- Low-temp wax (amaco flexwax): moldable when warm, like clay, then hardens when cool
  - Great to copy parts – push in the part then take it away, then make a cast of a part
- machinablewax.com:
  - For machining, wax has magical properties - easy and fast to machine, exquisite surface finish, and meltable to reuse
- Rigid foam: used for building installations, like bicycle heel
  - When mill it surface is rough, but can use a sealant, epoxy, shrink wrap, and even hot air to cover or melt the surface
  - If cast directly in the foam it's terrible bc casting material bonds with the foam – so need to seal it
- Can mill wood to make molds
- Alginate gel:
  - Killer app for this is that it's biosafe; so for face or hand put it in this – sets to a gel, a one-time wet gooey mold that you can make a cast from
- Urethane:
  - Urethane rubber:
    - PMC series - rubbers, tough plastics, great dimensional tolerance (doesn't shrink) and picks up very fine features → use this to make flexible mold, or if want flexible but tough part
  - Urethane resins:
    - Plastics like smooth-cast, looks and feels like plastic but designed to be tinted (all kinds of fillers that make them look like wood, metal, etc
    - Colorants can be mixed in
  - Can either use urethane molds or plastics – can't mix bc they stick together!
- Clear rubber
  - Epoxy (epoxacast) – clear epoxy for clear parts, or encapsulate LEDS or circuits
- Silicones:

    - Wonderful! Urethane and epoxy need good ventilation, while these are very inert - don't need lab ventilation, use about anywhere
    - Mold star series is great: silicone rubber, not as tough as urethane rubber so unless want soft part wouldn't use for finish (though range of hardness), but really easy to use and friendly
    - High temp (mold max 60): lets you do metal casting
    - PDMS (sylgard
    - Lithography: colleague at harvard pioneered using silicone for nanofabrication and nano scale, make stamps and nanostructures
- Latex:
    - Don't use this for anything! Issue is that others do deep section cures (cures chemically in interior) while this only cures on the surface – have to brush on layer by layer, will get gooey mess if you don't set it right
    - But use case is painting on something - ruin of old temple, copy engraving
- Thermoplastics / thermosets: plastics can melt and reuse, essential for injection molding
- Drystone/calcium sulfate:
    - much cheaper than others ($1/pound), both calcium based, at the base of what becomes cement/concrete, mix it with water and has consistency of runny yogurt; doesn't dry but instead does hydration reaction where the water and calcium compounds grow into an interesting chemical structure
    - Basically making rocks; a thin shell will crack, but great in compression and tough in thicker sections
    - Hydro-stone gypsum: wonderful, low cost, friendly, would recommend for this week
- You can technically mold glass
- Aremco for ceramix
- Smooth-on sorta-clear silicones are food safe! Definitely don't for other materials, and make sure all your steps are food safe
- Metal: example made coins
    - Aluminum melts at ~1000 degrees so to do that need foundry/sand casting
        - But what we use is **cerrotru** - this is $30 a pound, very low temperature alloys that are soft → can melt it in toaster oven
        - Cast material needs to be good enough for 400 degree temps
    - Dust the mold with baby powder! Provides thermal insulation, and helps mold whet the surface
    - It is somewhat brittle but for everyday use looks and feels like metal
- Playdough:
    - Whole family of home DIY make your own playdough as molding material
- Materiom: makes a lot of materials from natural feed stock (egg shells, coffee grounds, seaweed, etc) for sustainable casting

Additives:

- In composites you have a fiber that handles tension, and resin that handles compression; lay up continuous fibers

    - So if you stir in microfibers, prevent microcracking
- Lots of other additives to enhance mechanical properties:
    - Colloidal silicon improves heat transfer
    - Low density filler are glass bubbles that give lots of air pockets that reduce density
    - Graphite powder gives it conductivity
    - Rubber fillers in concrete to make bendable concrete

Processing:

- First thing to know is this is a very messy process - rolls of big paper to cover workspace
- When use resin, open a container, pour it out – don't pour it all over the container and put it away! Aside from being gooey and sticky, it'll also start set and seal the container so can't open it again
    - **So need to be really neat and clean!**
- Materials have a lifetime - polymers have a shelf life (maybe a year, after opening maybe a few weeks) → so be sure to check bc material both doesn't set and not set, just gooey mess
    - **So do test sets! Test material to make sure it's happy before pouring it in**
- Mixing is nontrivial – most by volume, some by weight
    - Oomoo (one of the silicones): first mix in the container, then pour out the 1:1 , then combine them, mix them (**shearing instead of scooping** to avoid driving in air) for a long time until there's no striations (uniform color, often a few minutes)
        - **Bane of molding & casting is bubbles!** Generally sign of shortcuts
        - To fill mold, don't dump it in! Pouring through skinny bead helps pop bubbles on way down
        - Then it sets: specifies by set time, but can accelerate by gently heating
- Filling:
    - Fill mold with water, then put it in measuring cup, and that'll tell you how much you need to fill
    - Very easy to trap air bubbles in sharp corners, so can paint a layer which might help; also can help to tip the mold, leaving a vent for air to escape
        - Example: neil's tippy top, added a vent that would be a little nub on the tip that you can just cut and sand off
    - Can also submerge the whole thing - the mold fully in the resin then take it out, very messy but avoids vents and fills
    - Once you mix everything and think you're done, gently agitate it and wait bubbles will come, then repeat, and repeat again – leave enough time for bubbles to come out
- Curing:
    - Often takes a LONG time - minutes to hours
    - polymerization, epoxies cross linking, polymers hydrating, etc
    - Endothermic: putting heat in
        - 4-hour cure silicone can be ~30min instead if under heat lamp
        - Silicone won't matter much, urethanes it will

- Exothermic: they release heat
    - Some will get warm, then when it cools off (don't rush this) it means it's finished setting and your part is ready
    - Caution is if you do a really big part, there's a horrible sequence that happens to many – mix large amount in plastic container, gets so hot that starts smoking and melts container, then the hot smoking mess dribbles out in the lab
      - For hot concrete bridge, spend 3 weeks cooling it!
    - So need to take heat away - not a problem on scale this week but moving forward for bigger cures will be
- Demolding:
  - Done wrong, if have vertical wall in part and vertical wall in mold they can just stick and can't get it out
    - So **slight draft angle** is important (lego bricks slightly fanned out)
  - Release agents = materials to prevent the mold material from sticking
    - Silicones stick to almost nothing, but 2 kinds of silicones
    - Can make own release agents with dish soap, cooking spray, vaseline, talc, etc
    - Soft ones can just bend to take part out and snap back to same shape

Safety:
- Crystal clear 200 for example - says "CAUTION NOT FOR HOME USE"! Can have serious immune reaction, end up in hospital, and sensitise your body so have permanent strong reaction to chemicals
  - Don't go anywhere near these!
- Oomoo, hydrostone, drystone need protection bc gooey and messy, and don't do in closed room; but materials beyond that fully hazardous
- All come with safety data sheets! Any time using any material, essential you spend quality time with these so you understand how to use it
- Disposal: uncured resin nasty thing to throw away, DEFINITELY don't pour it down the sink → best way to dispose is to mix them, anything unused you should mix and set and dispose in that state where it's inert

Printing
- Not enough to FDM print a mold - will complain if see lines of mold process, need to post-process to seal the finish
- Better than that – compare 3d print to milling a mold; resin printed molds can be so good that increasingly used for molding and casting
  - Can either FDM print and post process, or STL print (though check combination of STL resin and molding material)
- Formlabs increasingly 3d print molds for injection molding
  - With prusa, above 60k parts injection mold but below that print

Machining:

- In the past everyone did machining to learn about three-axis machining
- Start with machinable wax, then mill out
    - Don't throw shavings away! Keep bc can melt down and re-use
    - Smoothness is related to patience of how long willing to make tiny motions
- Then moves to silicone - no bubbles or artifacts, then used drystone
- Can do this on a tabletop mill that's only ~$200! And no nasty resins to deal with
- Machining steps for beautiful surface:
    - Rough cutting = short horizontal passes,
    - Key parameter is rough stepover
    - Then small in one axis
    - Then small in two axes
- 3-axis machining strongly limited by tooling:
    - in earlier week show the CAM process, set up stock and part, pick tool, then pick face, then 3d surfacing operation, zigzag, 10 stepover, sample interval 0.1mm, then run
        - This is after the rough cutting, doing the full three-axis moves
    - Flat end → our usual, used for rough cutting
        - If you machine in layers get steps, but if doing full 3-axis cuts can get smooth surfaces
    - Ball end mills → often used for finishing
        - Can get into smaller area, but don't need for smooth surfaces
    - If have narrow deep feature your endmill can't get into it → need to design mold around the tooling bc the tool might have a shank in a collet inside a spindle which can all collide with your mold → deep features will need enough space or to angle a surface so you don't collide with the milling tools
        - There are extra long tools to go deep, but not as stiff so machine needs to go slower
        - Also micro endmills if making fine features like a coin
- So tradeoff is depth of cut vs size of tooling

Software:
- ShopBot
- Fusion has Moldflow for designing molds
- Solidworks has solidworks plastics
- FreeCAD had example
- If using mods, also knows how to do the rough and finish cutting

So we have a choice!
- If want to learn 3-axis machining use milling
- If want to learn High res printing, do the STL resin printing
- If want to learn finishing, do standard printing

Going from positive to negative to positive is surprisingly easy!
- Many people get to the end and realize it's inside out – that's totally ok