Department of Mechanical Engineering
University of California, Berkeley

ME 122 – Processing of Materials in Manufacturing

Course information
Spring 2018

Prof. Hayden Taylor (hkt@berkeley.edu)
Updated: March 6, 2018

Welcome

Welcome to Mechanical Engineering 122. The central objective of this course is to help you understand the relationship between the choice of *material* and the choice of *processing route* that is essential when planning the manufacture of mechanical components. We will achieve this objective by:

- studying the physical transformation of material in a range of manufacturing processes;
- considering computational models of several key manufacturing processes;
- researching and reporting the latest technology developments in several processes;
- undertaking a semester project in one of two formats:
    - designing a mechanism for which material and process selection are critical, or
    - studying and modeling the capabilities of a manufacturing process.

Having access to Jacobs Hall will enable you to make physical prototypes and carry out process characterization experiments as necessary. We encourage you to send us your constructive thoughts, comments and suggestions about the class regularly. You can do this by e-mail, in office hours, or by sending the instructors a message through bCourses. Taking the time to tell us what we can improve will help enhance your experience, and also that of students who will take the class in the future. We hope that you enjoy ME 122.

Staff

Course instructor: Prof. Hayden Taylor

E-mail:	hkt@berkeley.edu
Telephone:	510 642-4901
Office:	6159 Etcheverry Hall
Office hours[1]:	Wed 3–5pm, Thurs 4–5pm, and by arrangement, all in 6159 Etcheverry

GSI: Hannah Gramling

E-mail:	gramling@berkeley.edu
Office hours:	Thurs 3.45–4.30pm, in Hesse GSI office

[1] My regular office hours for the semester will begin on Feb 1 and end on May 3. On some occasions I will need to reschedule, in which case I'll make a bCourses announcement.

Lectures

Lectures will take place on Tuesdays and Thursdays, 2–3.30pm, in Moffitt 101. Lectures will be recorded and will be available to watch/listen on Cal Central: https://calcentral.berkeley.edu. If you are registered for ME122, the class will appear under "My Classes" and the videos under "Course Captures" on the right hand side of the ME122 class page. In case of any technical issues in accessing the recordings, please contact Educational Technology Services via the web form at https://www.ets.berkeley.edu/request-support-or-give-feedback-calnet.

Discussions

Discussions will take place in 210 Jacobs on Wednesdays 11am–noon and Fridays 1–2pm. Since project team interactions and progress reviews will take place during the discussions, we ask you to pick one section and attend it regularly. If you need to switch from your current section, please let Hannah know.

Assignments and assessments

For those registered to receive a letter grade, it will be composed in the following way:

- Homeworks: 30%
- Process technology research paper: 25%
- Design for manufacturing project: 45%

There will be no written midterm or final exams in ME122 this semester. In place of exams will be an oral report on project progress in two mid-semester design reviews, and required attendance (2 hours) at ME122's slot at the Jacobs Showcase on May 3 to present the final results of the Design for Manufacturing project. Completion of assignments and participation in design reviews, *etc*, is also required of those registered for ungraded credit.

Homeworks

There will be five homeworks to support learning of the technical material. Homeworks will be due by 5pm on the Friday of the week they are due. Homework assignments will be released on bCourses two weeks before the due date. Homework will be due on bCourses in the format specified in the assignment.

Process technology research paper

Process technologies, particularly for additive manufacturing, are advancing rapidly, and no textbook can fully catalog current industrial capabilities. Therefore, we will pool our efforts as a class to find out what process innovations are new and interesting and how they are being applied in industry. Equally, innovations in software and design techniques are increasingly important in enabling materials to be processed more effectively and efficiently. For example, conventional solid modeling approaches are now being complemented with computational optimization of geometry and material properties.

In the first half of the semester, you will work in teams of 3–5 to research a current topic in process technology, produce a short review paper summarizing recent progress in that technology, and present your findings in class. Therefore, as well as learning in some depth about a process technology, you will gain practice in writing a technical paper and giving a technical presentation.

A non-exhaustive list of suggested research topics will be posted on bCourses before the assignment starts.

Design for manufacturing project

The second major activity of the semester will be the 'design for manufacturing' project. As we conclude the process technology research paper, we will form new teams of 3–5 people aligned along project interests. There are, broadly speaking, two options for this project:

Option A: Design, from scratch, a mechanical product to satisfy a need that you identify. Use what you learn in this class to select materials and manufacturing processes systematically for each critical component in the product. Produce a physical prototype, which, depending on the anticipated market size for your device, may or may not be made with the same materials and processes as the envisaged manufactured product. Where prototyping and final manufacturing processes differ, develop a plan for translating the prototype to manufacturing. Some examples of prior "Option A" projects done by ME122 student teams are below:

Team	Website
Adjustable Desk	https://sites.google.com/view/me122adjustabledesk/home?authuser=1
Auto Syringe	http://www.me122autosyringe.weebly.com/
Extendable Desk	https://sites.google.com/site/extendabledesk/
Grad	http://bike-pack.weebly.com/
Roller Cart	http://me122rollercart.weebly.com/
GripExo	http://gripexo.herokuapp.com
Instructional Robot	http://122robot.weebly.com/the-joints.html
Modular Picture Hanging System	https://sites.google.com/site/modularpicturehangingsystem/
Printed iPhone Cases	https://rajashreeb0.wixsite.com/dfm-cases
Stirr	http://stirr.strikingly.com
The Juicer	https://npanditi.wixsite.com/thebougiejuicer
FarmBot	https://shuen4.wixsite.com/farmbot
Un-flippable Umbrella	http://unflippableumbrella.weebly.com/
Klip	https://sites.google.com/view/klip/home?authuser=0

Option B: Study, experimentally, the capabilities of a manufacturing process, and develop design rules and/or a computational model to help engineers design for that process. Examples of process 'capabilities' that may be important to understand quantitatively are: minimum achievable feature size, processing speed, dimensional variability, and strength of manufactured components. This option is more research-flavored than Option A. The staff will work with interested teams to craft feasible and interesting topics. Projects may build on the subject of the process technology research paper that you do in the first half of the semester, but this is not required. Some possible topics might be:

- Establish, through experimentation, the minimum patternable feature size with the new industrial-grade Carbon 3D printer in Jacobs Hall. Study whether the sizes of printed features deviate from their intended values depending on the presence or absence of surrounding printed geometries, and if so, can these proximity effects be counteracted through informed design or a software tool?
- Extremely geometrically complex designs can be challenging to print because the data files (*e.g.* STL files) become unmanageably large. How can complex designs be transferred more efficiently to 3D printers?
- How strong are components manufactured using the Type A/Objet/Carbon printers in Jacobs Hall, and how does strength depend on printing orientation?
- Is it possible to produce usable 3D printing filament from recycled HDPE?
- Van der Waals-bonded solids such as graphite and MoS_2 have been used as industrial lubricants for many years. Recently, interest has grown in using single-atomic layers of these materials to produce next-generation electronic devices (*e.g.* LEDs, transistors). Can you invent and prototype a manufacturing process to take industrial quantities of powdered graphite or MoS_2 and separate it into single-atomic layer flakes on a solid surface, *e.g.* by a polishing or grinding process?

Examples of prior "Option B" projects are:

Team	**Website**
Carbon Print	https://ucbcarbon.wixsite.com/home
Vacuum forming process characterization	https://rachelieda.wixsite.com/vacuumforming

For Option B projects, we strongly advocate finding an industrial mentor who can help your team to identify true current challenges in materials processing, so that your project can be focused on adding useful understanding. We will help in locating industrial contacts wherever possible.

For additional inspiration, below are some projects done in ME 122 in Spring 2015, before we had access to Jacobs Hall and when projects were conceptual/CAD-based only:

Team	**Website**
Portable Hydro Turbine	https://sites.google.com/site/portablehydroturbine/
Raisecar	https://sites.google.com/site/me122raisecar/
Canfield Joint	https://sites.google.com/site/canfieldjoint/
Auto Blackboard Eraser	https://sites.google.com/site/autoblackboarderaser/home
Team Helping Hands	http://mechatronichand.tumblr.com/
Desk Chair	https://sites.google.com/site/automaticdeskchair/
Bike Dynamo	https://sites.google.com/site/me122bikehubdynamo
Pot Rack	https://sites.google.com/site/motorizedpotholderd/
Airplane tray table	https://redesignedtraytables.wordpress.com
Waterproof Wheelchair	https://sites.google.com/site/waterproofingthewheelchair/
Waterproof Speaker	https://sites.google.com/site/liquidbeats002/

Prosthetic Leg	https://sites.google.com/site/prostheticlegme122/motivation
Grind N Go	https://sites.google.com/site/thegrindngo/
Portable door opener	http://thelumosnox.wix.com/lumos
Hiking boots	https://sites.google.com/site/rshikers/home

More suggestions and guidance will be made available as we form project teams. Whichever project option you select, completion of project milestones and final outcomes will be reported entirely on a website that your team develops. We encourage teams to obtain industrial feedback and mentoring wherever possible, and will work with teams to identify suitable sources of feedback.

A note on fabrication facilities

This class will have access to Jacobs Hall, where we anticipate that the majority of your prototyping activities will happen. Therefore, class participants will need to obtain a Maker Pass. The Jacobs Hall Maker Pass fee is $75 for the semester. Payment can be made online or by check and details are at: http://jacobsinstitute.berkeley.edu/our-space/makerpass/get-maker-pass/. Fee waivers are available to students with financial need and requestable via this form: https://goo.gl/forms/gICZlQ8vBnjXmy4e2. For more information on fee payment, contact Aleta Martinez at aleta@berkeley.edu.

In addition to purchasing the Maker Pass, please complete General Workshop Safety (GWS) training online by Friday January 26: https://bcourses.berkeley.edu/enroll/TY4ETA (requires CalNet authorization).

Jacobs Hall contains an extensive range of facilities: http://jacobsinstitute.berkeley.edu/our-space/labs-and-equipment/ including state-of-the-art additive processes, laser and abrasive-jet cutting, metal-working, wood-working, and a small-scale bench-top milling machine. We think that almost all of your prototyping needs will be met by Jacobs.

We generally find that a significant fraction (over half) of class participants have previously completed Etcheverry Machine Shop training, and therefore have access to those facilities as well. For prototyping of components that cannot be made in Jacobs (*e.g.* where turning is required), students with *pre-existing* access to the Machine Shop will be able to use those facilities. Unfortunately, because the Machine Shop facilities are in heavy demand, ME122 does not come with automatic Shop training for those who have not previously been trained. We therefore recommend forming teams with at least one previously Shop-trained person.

Relationship of ME122 to E27

We usually find that about 50% of those taking this class have previously taken Engineering 27 (Intro to Mfg and Tolerancing). There was introductory coverage of a range of processes in that class, but for the sake of those who have not taken E27, and for those who did and would like a recap, when we begin to discuss a particular process, we will cover the important points from E27 before going into more detail. I will also post the written notes that accompany E27 lectures for people to digest as necessary.

Field trips

We will be organizing a number of optional field trips to visit local manufacturing companies. More details on how to sign up for them will be made available soon.

Additionally, there are a limited number of slots available in a new 1-unit, ungraded class Des Inv 97: Manufacturing Field Trips. This class provides credit for attending a minimum number of trips over the course of the semester (approximately five trips) and writing a brief reflection in blog format after each one. About an extra 15 slots are available for ME122 and E27 students; if you would like to join Des Inv 97, please e-mail me (Hayden) on hkt@berkeley.edu before midnight on Friday January 19th to let me know this, and I will make registration codes available to as many people as possible. Anyone who is already on the Des Inv 97 waitlist and is already registered in ME122 or E27 will be added to the class automatically this week. You only need to sign up for Des Inv 97 if you want the extra unit of credit; there will be some slots available on individual trips for those who are registered *only* in ME122.

Additional reading

There is no required textbook for ME122 this semester, and all the materials needed to succeed in the class will be made available through lecture notes, homework assignments, and other posted materials. For those seeking a good reference book, Kalpakjian offers perhaps the most detail and is supported by experimental data and useful references:

> *Manufacturing Processes for Engineering Materials*, by S. Kalpakjian and S. Schmid, 5th Edition, Prentice Hall. ISBN 978-0132272711. Library call number: TS183.K34 2008.

Kalpakjian has excellent coverage of 'traditional' processes (*e.g.* subtractive, forming, and joining processes), but its coverage of additive manufacturing and micro-/nano-scale materials processing is limited.

Other books of possible interest include the following:

> *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*, by M.P. Groover, Wiley. ISBN 978-1-1182-3146-3. Library call number: TS183.G78 2013.

An excellent text for understanding material and process selection approaches is:

> *Materials Selection in Mechanical Design*, M.F. Ashby, Butterworth-Heinemann, ISBN 978-1-8561-7663-7. Library call number: TA403.6.A74 2011. There is also an electronic version available through the Library.

This 2014 book provides a vision for the future of additive manufacturing:

> *Fabricated: the New World of 3D Printing*, H. Lipson and M. Kurman, Wiley, ISBN 978-1-1183-5063-8

This 2013 book offers a trenchant perspective on the state of manufacturing in the US and its importance to the economy:

> *Made in the USA: The Rise and Retreat of American Manufacturing*, Vaclav Smil, MIT Press. ISBN 978-0-2620-1938-5.

Software and computing

Teams selecting Option A for the Design for Manufacturing project, and possibly those selecting Option B, will need access to CAD software to prepare the design of your project's mechanical assembly. Autodesk software (*e.g*. Fusion 360) is available freely to students through their website. If you prefer to use Solidworks, a reference sheet containing all the information you need in this regard is available on bCourses under Files>Software.

Some projects and assignments will benefit from the use of a scientific computing package such as Matlab, for which a free individual license can be obtained from https://software.berkeley.edu/. Any other software needed will be provided.

Academic integrity

We will be adhering to the Berkeley Honor Code (http://asuc.org/honorcode/index.php). If anyone has any questions about the responsibilities they have as part of this Code, please contact the course instructor.

Lateness and illness policy

Discussion sessions are an integral part of this class and are considered compulsory, partly because they will be the primary venue for getting feedback on the progress of your projects. However, if you fall ill we would prefer you not to come to class so that you can rest and recover. If you fall ill or experience exceptional circumstances, please contact Hannah to arrange an alternative time to complete the relevant work once you have recovered. We will *not* be requiring written excuses from medical personnel.

We do ask that you try to complete assignments by the deadlines. We will be accommodating of occasional slightly late assignment completion, but may penalize frequent or egregious lateness. Please make sure you communicate with the instructors if for any reason you think you need more time for an assignment.

Class, discussion, and assignment schedule

Week	W/C	Lecture		Discussion	Due dates				Optional reading
		Tuesday	Thursday		Homework	Process technology research paper	DFM project Option A	DFM project Option B	
1	1/15	Introduction: Economic significance of manufacturing. Overview of process/material interdependencies. Introduction to class assignments.	Review of material properties and testing concepts.	Introduction to process technology research paper assignment.					Kalpakjian ch. 2; ch. 3 (metals); ch. 10.2-10.9 (plastics); ch. 11 (ceramics)
2	1/22	Review of material properties and testing concepts continued.	Process- and materials-selection charts (Ashby charts).	Introduction to Jacobs facilities; paper topic pitches and team networking.		**Mon 1/22, 11:59pm:** one pitch slide for process technology research paper. **Fri 1/26, 5pm:** Team compositions and paper working titles.			Ashby, *Materials Selection in Mechanical Design*
3	1/29	Process- and materials-selection charts continued	Processing–property relationships in materials.	HW1 material		**Fri 2/2, 5pm:** Process technology review paper outline.			Kalpakjian ch. 8; ch. 9 (subtractive); ch. 14-15 (CAD)
4	2/5	Processing–property relationships in materials continued. Process cost modelling.	Emerging additive manufacturing processes.	Staff consultations on process technology research paper.					Kalpakjian section 10.12
5	2/12	Material and process selection in digital manufacturing: guest lecture from Chris McCoy	Subtractive processes: metal cutting, abrasive, chemical methods etc. Numerical control.	HW2 material		**Fri 2/16, 5pm:** Process technology paper, final manuscript.			Kalpakjian ch. 5-6

Week	W/C	Lecture		Discussion	Due dates				Optional reading
		Tuesday	Thursday		Homework	Process technology research paper	DFM project Option A	DFM project Option B	
6	2/19	Process technology presentations: 10 minutes presentation; 5 minutes questions; *c*. 15–20 teams			**Fri 2/23, 5pm:** HW1 (Processing–property relationships; process selection).				
7	2/26	**Deformation processing of wrought alloys.** Revision of phase diagrams, phase transformations, TTT diagrams, CCT diagrams and hardenability. Wrought alloy processing; microstructure evolution. Modeling of plastic forming processes. Rolling, forging, and extrusion. Sheet metal bending.		DFM project pitches and team networking		**Mon 2/26, 5pm:** Team Pulse surveys (via Sara Beckman) **Fri 3/2, 5pm**: slides from process technology presentations and revised papers	**Mon 2/26, 11:59pm:** pitch slides for DFM projects		Kalpakjian ch. 7, 10
8	3/5	**Casting.** Application of phase diagrams and transformations to solidification. Casting alloys and microstructures. Technologies, including sand, die, and investment casting. Sources of casting defects.	**Powder processing.** Revision of ceramic materials' properties. Manufacturing of powders. Process technologies: sintering, hot isostatic pressing, direct metal laser sintering/melting (including hybrid subtractive/additive machine tools), electron-beam melting, cold spray. Application to fabrication of cermets.	Field trips (distributed through the semester) will take place in lieu of this week's discussions (details to follow).			**Fri 3/9, 5pm:** DFM team compositions and project titles.		Kalpakjian ch. 12

Week	W/C	Lecture		Discussion	Due dates				Optional reading
		Tuesday	Thursday		Homework	PTRP	DFM project Option A	DFM project Option B	
9	3/12	**Composites processing.** Models for mechanical behavior of composites. Examples of laminar, fiber and particulate composites. Technology for carbon fiber production. Examples in aircraft manufacturing. Plus: quick guide to creating project websites.	**Polymer processing.** Revision of thermoplastic, thermoset and elastomer properties. Extrusion of thermoplastics. Application of extrusion to injection molding and fused deposition modeling. Considerations surrounding powder-infused FDM materials. Powder injection molding. Compression molding. Blow molding. Thermoforming/vacuum forming.	HW3&4 material			**Fri 3/16, 5pm:** Project website functional and describing project motivation with initial concepts (either sketches or CAD)	**Fri 3/16, 5pm:** Project website functional and describing project motivation with experimental plan.	Kalpakjian ch. 11
10	3/19	Project review panels			**Fri 3/23, 5pm:** HW2 (Subtractive processes)				
11	3/26	Spring Break							
12	4/2	**Processing with beams of directed energy and matter.** Laser cutting, ablation and deposition. Ion beam milling. Ultrasonic cutting. **Photochemical processing.** Methods of photopolymerization including free radical and cationic polymerization. Application to single- and multi-photon stereolithography, "polyjet" 3D printers, UV-curing adhesives. Positive and negative photolithography for micro- and nano-fabrication. Comparison with electron-beam lithography.	**Joining processes.** Welding technologies based on energy from flames, laser beams, electrical arcs, friction, electrical resistance and ultrasonic excitation. Application of arc welding in freeform additive manufacturing. Brazing and welding, including the nature of inter-metallic interfaces. Adhesives, including adhesive–material interfaces, patterned interfaces, and adhesion testing methods. Anodic wafer bonding in semiconductor manufacturing.	Staff consultation time for DFM projects	**Fri 4/6, 5pm:** HW3 (Additive processes)		**Fri 4/6, 5pm:** Checkpoint 1: Preliminary CAD model of design with renderings on website	**Fri 4/6, 5pm:** Checkpoint 1: Preliminary experimental results online	

Week	W/C	Lecture		Discussion	Due dates				Optional reading
		Tuesday	Thursday		Homework	PTRP	DFM project Option A	DFM project Option B	
13	4/9	Project review panels					**Mon 4/9, 5pm:** Mid-project pulse and LSI (via Sara) **Fri 4/13, 5pm:** Checkpoint 2: Materials and process selection rationale and prototyping plan	**Fri 4/13, 5pm:** Checkpoint 2: Revised experimental plan online	
14	4/16	**Electrical, chemical and electrochemical processing.** Fundamentals of electrochemical corrosion. Technologies: electroplating, anodization, galvanization. Electrochemical etching. Wet chemical etching. Electro-discharge machining. Electrospinning.	**Vapor-phase processing.** Chemical and physical vapor deposition (*e.g.* sputtering). Evaporation of metals. Plasma etching.	HW5 material	**Fri 4/20, 5pm:** HW4 (Forming processes)		**Fri 4/20, 5pm:** Checkpoint 3: Revised CAD model complete, with renderings online	**Fri 4/20, 5pm:** Checkpoint 3: New experimental results online.	Kalpakjian ch. 13
15	4/23	**Design for manufacturing.** Principles for component design to aid assembly. Mold design considerations for casting and injection molding. Software in manufacturing, including computer numerical control ("G-codes"), solid model data formats and management, slicing algorithms for additive processes, design for multiple and graded material properties, and topology optimization.	**Friction and abrasion in material processing.** Abrasive jet cutting. Grinding and polishing. Tribological principles, including wear and friction. Cleaving properties of van der Waals-bonded solids such as graphite and MoS_2 and their applications from lubrication to next-generation electronic devices.	Staff consultation time for DFM projects	**Fri 4/27, 5pm:** HW5 (Joining processes)				

Week	W/C	Lecture		Discussion	Due dates				Optional reading
		Tuesday	Thursday		Homework	PTRP	DFM project Option A	DFM project Option B	
16	4/30	RRR week: no lecture		No discussion			**May 3, 11.45am–1.30pm:** Attendance required at Jacobs Showcase with website and final prototype (option A) or experimental specimens (option B). **Fri 5/4, 5pm:** project website in final form, including reflections. CAD models uploaded to bCourses. **Sun 5/6, 5pm:** final teaming surveys (via Sara)		