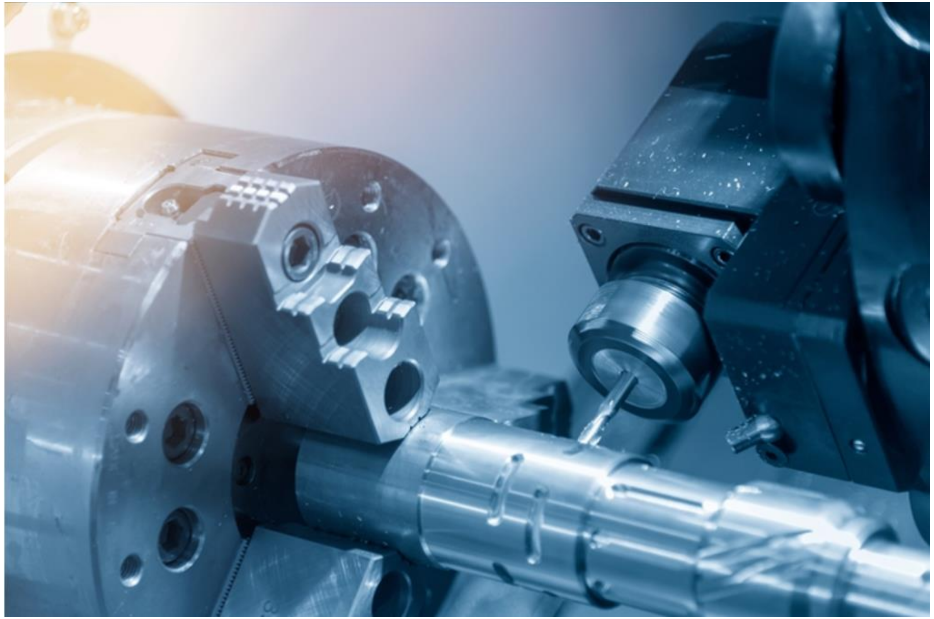
Fundamentals of Machining



Topics

- Welcome
- Common metalworking processes
- Machinability
- Mechanics of cutting
- Chip formation
- Surface finish and integrity
- Tool materials
- Cutting fluids

Welcome to MMAN1130

- This course builds off the engineering design and manufacturing experiences that you learnt in ENGG1000
- Throughout this term we will learn about fundamental metalworking machining methods
- We will also learn about the foundational engineering skills that allow us to design and manufacture
  - CAD
  - CAM
  - Engineering drawings
  - Australian Standards

Who am I?

- Daniel Eggler
- Associate Lecturer within the School of Mechanical and Manufacturing Engineering
- PhD in acoustics, vibration and noise control
- Mechanical Academic for Sunswift
- Things I love
  - My family
  - Going to the gym
  - Gaming (PS not PC)
  - Mamamoo

Course Outline

- The Course Outline can be found in Teams.

- This document contains very important information, please read and make careful note of assessment dates.

- Seriously though, read it! You'd be surprised how much pain can be avoided if you are aware of various policies and deadlines.

Course Communication

- If you want to get in touch with me about the course, best thing to do is to tag me in a channel post
- If your query is more sensitive, send me an email ☺
- If you send me a Teams chat, I’ll just ask you to send me an email or tag me in a channel post. ☺

IMPORTANT: All initial communication must be through email. Your email must contain the following:

- Your name and student number
- An appropriate email subject
- You must use your UNSW email
- A minimum level of email etiquette is expected

Failure to meet these criteria will result in your email remaining unanswered.
suggested template for emails is below:

Dear [Staff Member name],

(Your question/request/concern here)

Regards,

(Your name), z1234567

Textbook and Resources

- It is strongly recommended that you get the following textbook as soon as possible as it you will use it extensively throughout this course
  - You will also use it in every design subject hereafter
  - *Engineering Drawing*, A. W. Boundy, McGraw Hill (7th Edition).
- If you are in the Manufacturing Engineering Stream or have an interest in manufacturing processes, I'd recommend you get this book as well.
  - *Manufacturing Engineering and Technology*, S. Kalpakjian and S R Schmid. Prentice Hall

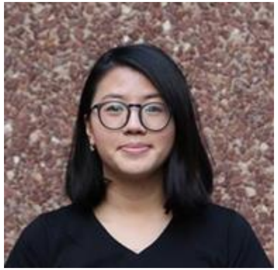
Lecture Schedule

Week	Topic	Delivery Mode
1 (Wed/Fri)	Fundamentals of Machining / Australian Standards and Engineering Drawings	Online
2 (Wed/Fri)	Overview of CAD / Hole Making	Online
3 (Wed/Fri)	Turning Processes/ Milling Processes	Online
4 (Wed/Fri)	Overview of CAM / *Engineering Standards and Engineering Drawings Test*	Online
5 (Wed/Fri)	No Lecture / No Lecture	Online
6 (Wed/Fri)	No Lecture / No Lecture	Online
7 (Wed/Fri)	Process Planning / *CAD/CAM Test*	Online
8 (Wed/Fri)	No Lecture / No Lecture	Online
9 (Wed/Fri)	High Volume Manufacture / No Lecture	Online
10 (Wed/Fri)	No Lecture / No Lecture	Online

Tutorial and CAD/CAM Lab Schedule

Week	Tutorial Topic	CAD/CAM Lab Topic
1	No Class	Sketching
2	Australian Standards and the Engineers Who Love Them	3D Parts
3	Engineers, Technical Operators and the Drawings Bridge That Binds Them	Engineering Drawings
4	No Class	Computer-aided Manufacture
5	No Class	Computer-aided Manufacture
6	No Class	Open Consultation
7	Machining and its Importance in Engineering	Assemblies and Mates
8	You Can Design It… Can You Build It?	Open Consultation
9	Start Ups, Commercial Manufacturers and the Processes That Drive Them	Open Consultation
10	Open Consultation	Open Consultation

Meet the Team – CAD/CAM Consults



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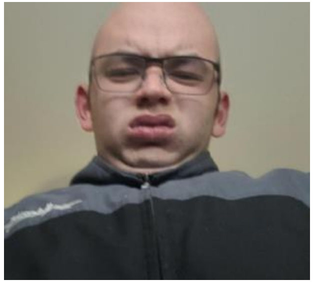

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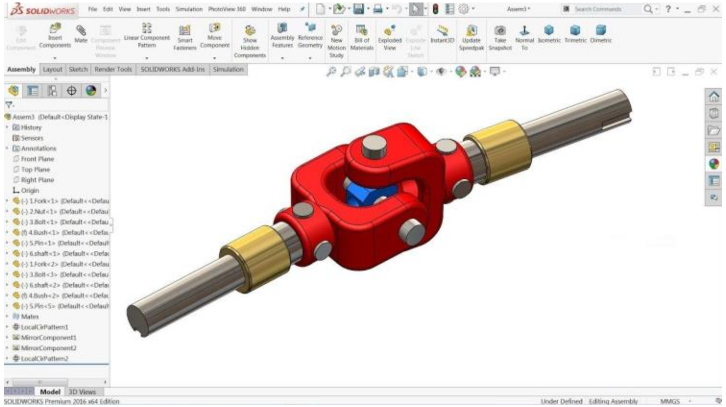
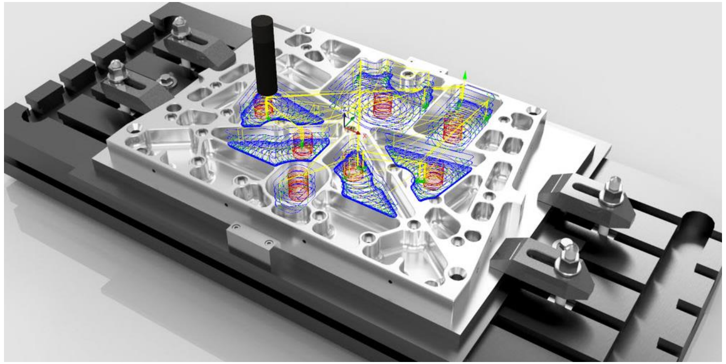
Assessment Schedule

Assessment	**Group Project?** (# Students per group)	Length	Weight	Learning outcomes assessed	Assessment criteria	Due date and submission requirements	Deadline for absolute fail	Marks returned
Computer-aided Design and Manufacturing Tests (2)	No	2 hours	2 x 20%	4,5,6,7	All course content from weeks 1-5 inclusive.	During week 4 and 7 Friday lecture	N/A	Two weeks after test
CNC Machining Assessment	No	N/A	25%	3,4,5,6	All course content from weeks 1-5 inclusive.	File to be submitted in week 8. Compliance testing to be livestreamed in Week 11.	N/A	Two weeks after testing concludes
Assignment	No	Up to 20 pages	35%	1,2,6,7	All course content from weeks 1-10 inclusive.	Week 10 Fri 23:55	Week 11 Fri 23:55	Upon release of final marks

SolidWorks

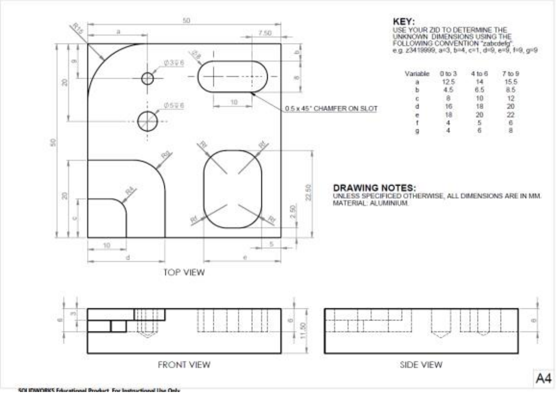
- The computer-aided design (CAD) and computer-aided manufacture (CAM) package that we will be learning is SolidWorks
- You are able to create an account to access MySolidWorks
- This has over 600 self help videos and tutorials
- By completing all the core and advanced videos throughout the CAD labs, you will have 30 out of 44 competencies for a SolidWorks Associate Certification

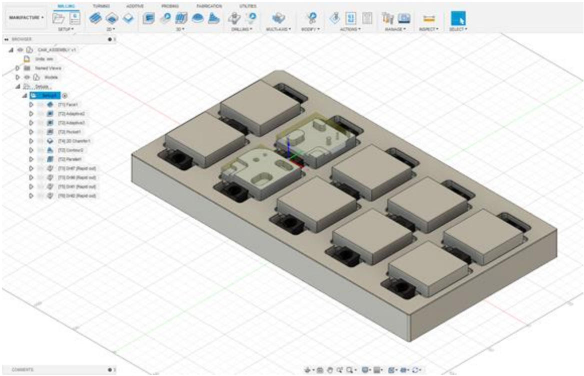




CNC Machining Assessment

- All these skills that you learn will culminate in a practical assessment.





CNC Machining Assessment

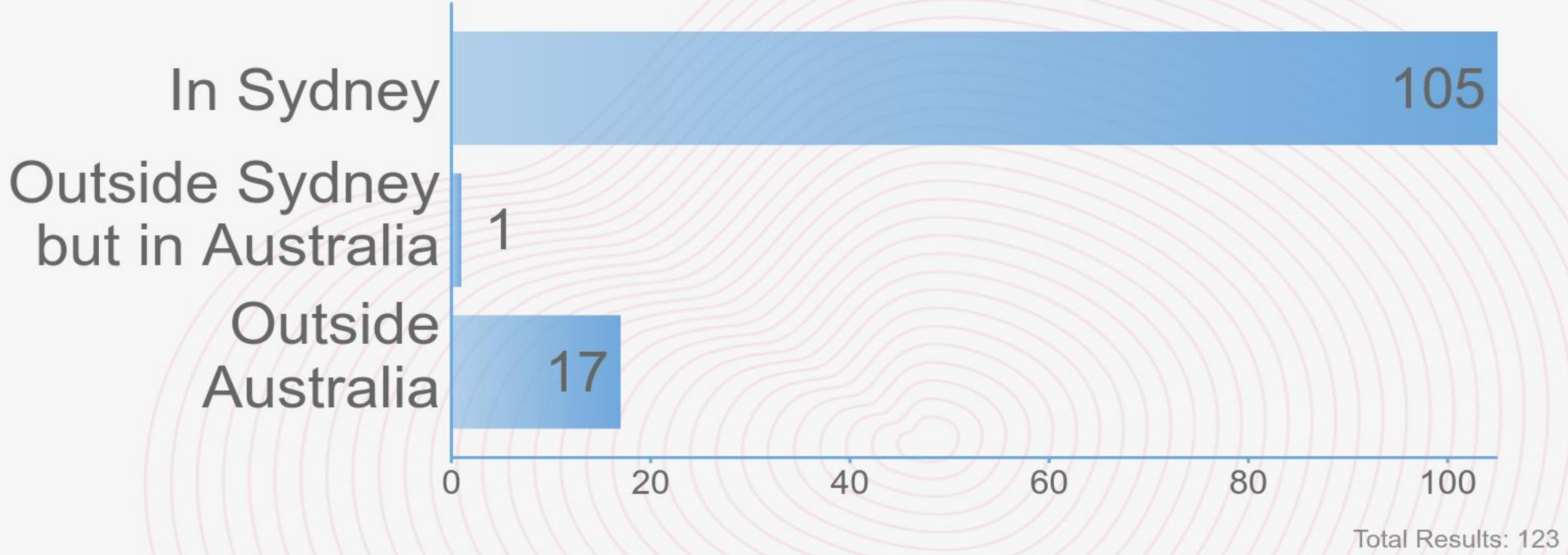
- We will then make it in the Makerspace
  - https://youtu.be/tXLxtUggUSM

- Most importantly, we will test that it was designed and manufactured correctly.
  - The good: https://youtu.be/dpVG-UZ3KIY?t=6388
  - The not so good: https://youtu.be/dpVG-UZ3KIY?t=8000

Poll Everywhere

- Throughout this lecture we will be using Poll Everywhere to gauge our understanding of content in real time.
- Bonus marks are up for grabs. Check this post out for more info!
- There are many different types of activities that I will be using in Poll Everywhere. These include:
  - Multiple choice
  - Word cloud
  - Short answer
  - Picture quiz
- Let's give the others a crack now

Where will you be completing MMAN1130 this term?



How are you feeling about undertaking MMAN1130 this term?

Total Results: 110

Powered by Poll Everywhere

How comfortable are you with manufacturing/prototyping?

“ Not really ”

“ very ”

“ 0 ”

“ Moderate ”

Total Results: 106

Where is Baby Yoda?

Total Results: 125

Powered by Poll Everywhere

Ok, let’s get back to design and manufacturing…

Manufacturing Overview

- As engineers, we solve problems. It is important to be able to design a solution but that is only one half of the solution.
- We also must be able to manufacture the solution.
- There are a large number of manufacturing processes available to us including
  - Casting
  - Forging
  - Injection moulding
  - Joining
  - Shearing
  - Forming

Manufacturing Overview

- In this course, we will focus on metalwork machining processes:
- Hole making
  - Reasonably self-explanatory, this is all about creating holes in metal for various reasons/functions.
  - https://youtu.be/38zFFR-k1pE?t=76
- Turning
  - The workpiece is rotated and a cutting tool removes a layer of material.
  - https://youtu.be/jF4F8Zr2YO8?t=16
- Milling
  - A rotating cutter removes a layer of material from the surface (face milling) or produces a cavity (end milling)
  - https://youtu.be/Sbs5BjM4wgk?t=6

Machinability of Materials

- Not all materials are created equal, so we need to make decisions about a few things
  - How suitable this material is for the proposed design (outside the scope of this course)
  - How the material will respond to the required machining processes we want to do
    - This is called <u>material machinability</u>

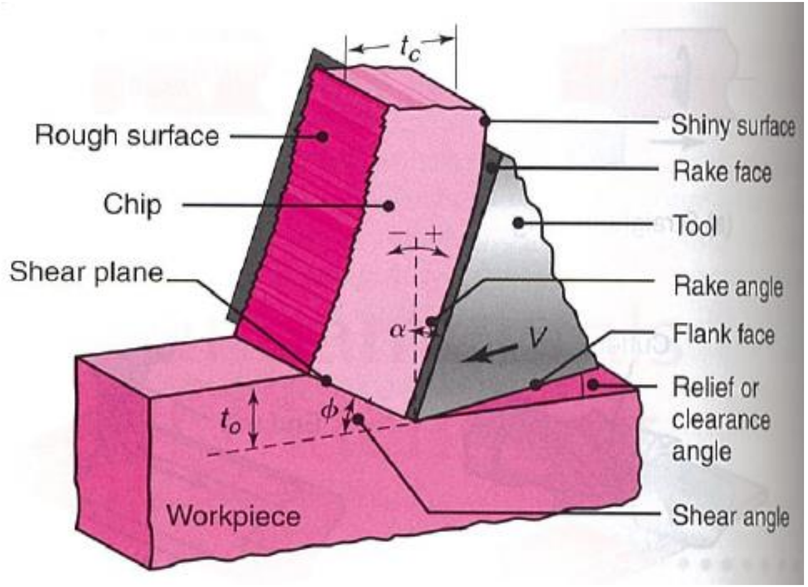
Machinability of Materials

- There are four key factors when considering the machinability of a material

1. Force and power required
2. Difficulty in chip control
3. Surface finish and surface integrity of the machined part
4. Tool life

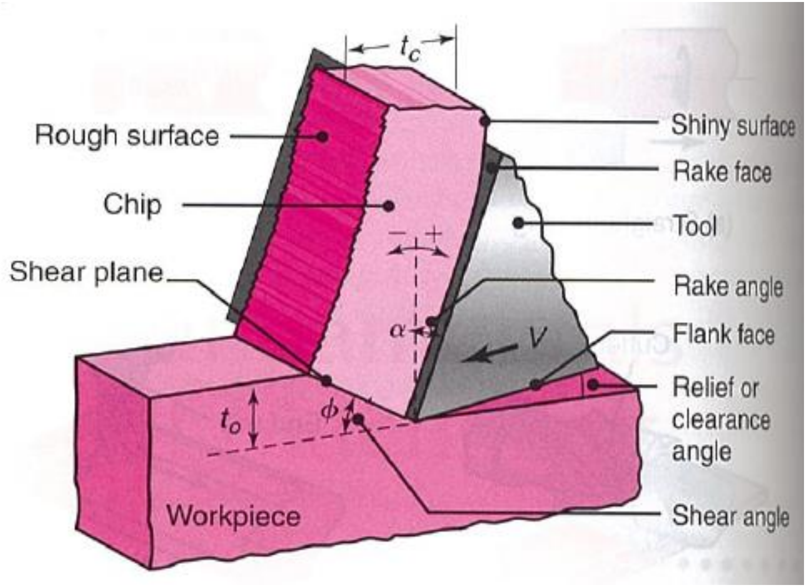
Mechanics of cutting

- The most important parameters to know is the:
  - depth of cut, t_0
  - chip thickness, t_c
  - rake angle, α
- Varying these parameters affect:
  - cutting force/power
  - tool temperature/life
  - chip production
  - surface finish



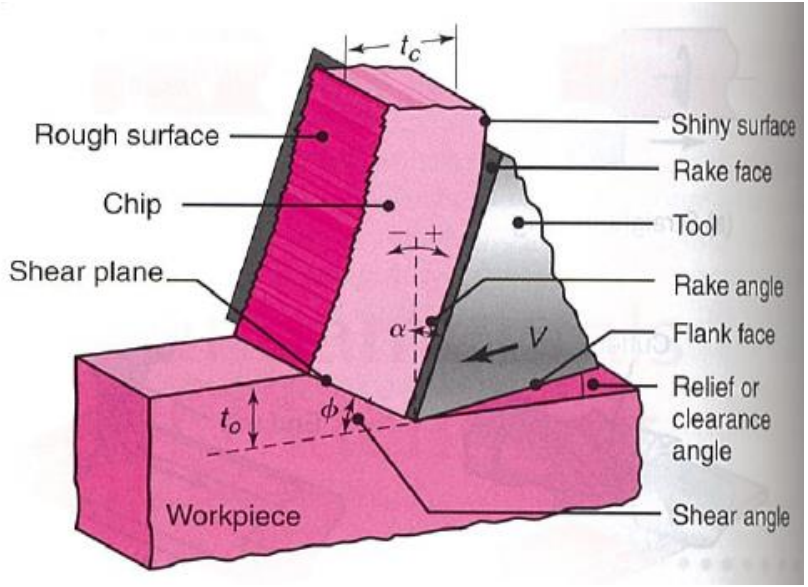
Mechanics of cutting

- By understanding how these parameters are interlinked, we can control them for a desired outcome
- Note, other variables like cutting geometry, tool material and so on will affect outcome but we won’t go too much into this.



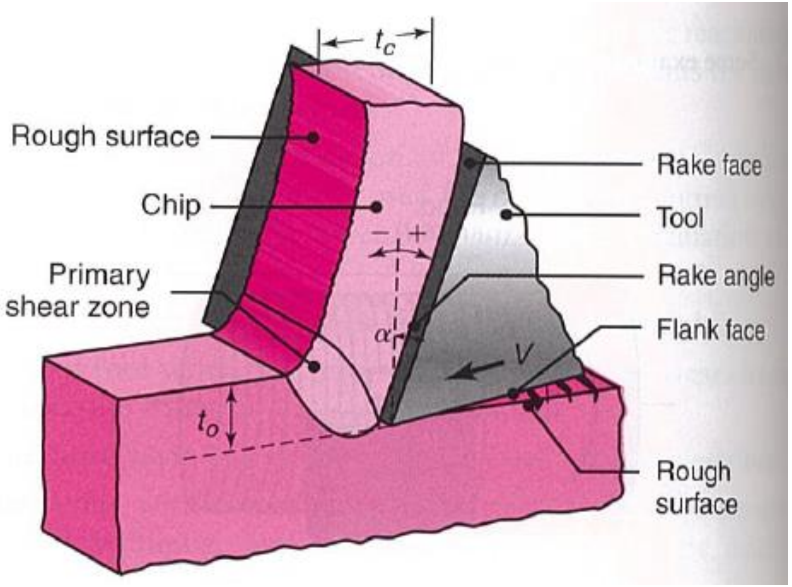
Mechanics of cutting

- The simplest cutting model is called orthogonal cutting.
- This is where the chip slides directly up the tool face.
- The cutting tool uses a positive rake angle and has some kind of relief/clearance angle.
- The cutting mechanism is caused by shearing. This occurs at a shear zone.
  - Most materials have a well-defined plane called the shear plane.

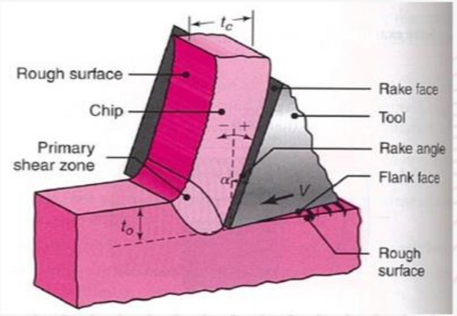


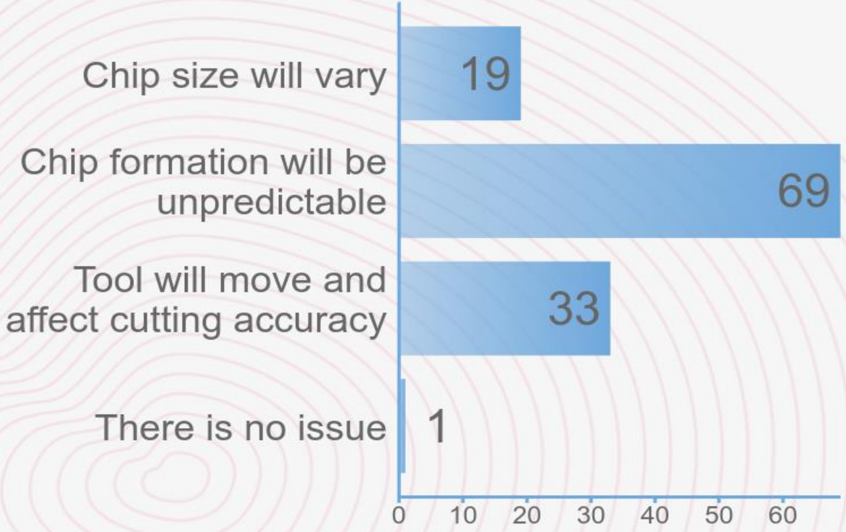
Mechanics of cutting

- Some materials do not shear well but instead shear in a zone.
- What is the issue if a material shears in a zone rather than along a plane?



What is the issue if a material shears in a zone rather than along a plane?





Total Results: 122

Mechanics of cutting

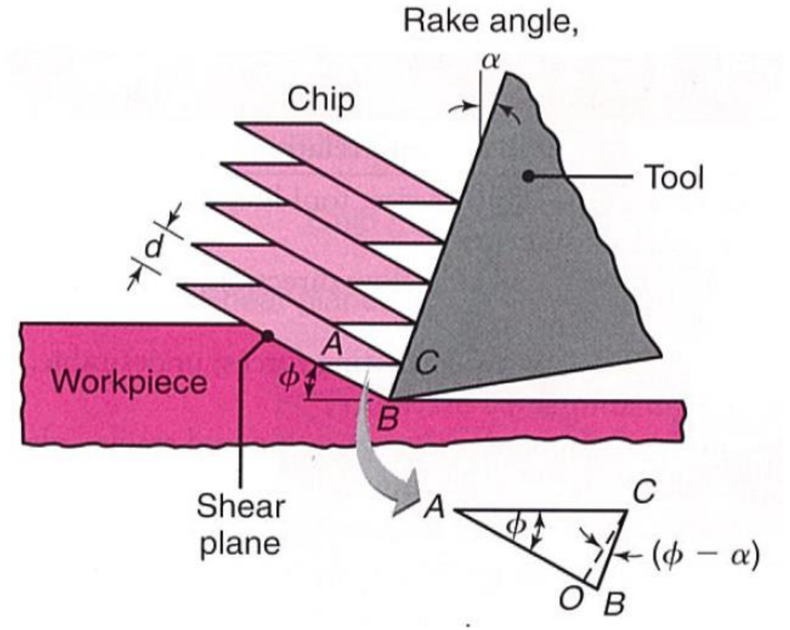
Cutting Ratio

- It is possible to determine a relationship between the cutting depth, chip thickness rake angle and shear angle, ϕ.

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$r = \frac{t_0}{t_c} = \frac{\sin\phi}{\cos(\phi - \alpha)}$$

- The chip thickness is always greater than the depth of the cut.



Cutting Power

- The derivation of cutting power is not really needed as machines come with guides on cutting speed depending on material.
- However, it is important to understand that the faster you intend to cut a material, the more power this requires.
- Tool quality also affects cutting power. The duller the tool, the higher the cutting force and power. Why?

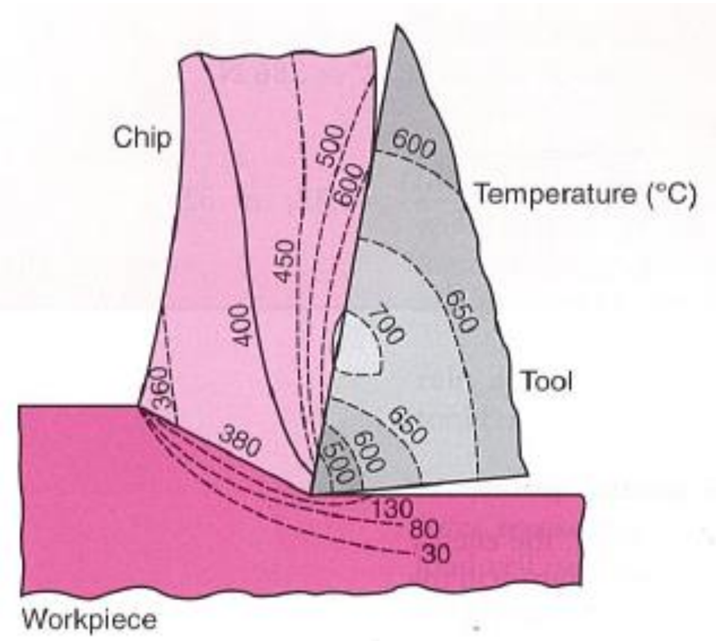
TABLE 21.2

Approximate Range of Energy Requirements in Cutting Operations at the Drive Motor of the Machine Tool (for Dull Tools, Multiply by 1.25)

Material	Specific energy $W \cdot s/mm^3$
Aluminum alloys	0.4–1
Cast irons	1.1–5.4
Copper alloys	1.4–3.2
High-temperature alloys	3.2–8
Magnesium alloys	0.3–0.6
Nickel alloys	4.8–6.7
Refractory alloys	3–9
Stainless steels	2–5
Steels	2–9
Titanium alloys	2–5

Temperature Distribution

- Temperature plays an important part in metalworking processes.
- The energy required to shear the material is dissipated as heat that increases the cutting zone.
  - Excessive temperature lowers strength, hardness, stiffness and wear resistance of the tool. In extreme cases, this can cause plastic deformation of the tool.
  - Excess temperature rise can cause thermal damage to the material.
  - Increased heat can change the dimensions of the part being cut. Why does this matter?



Increased heat can change the dimensions of the part being cut. Why does this matter?

" miss sized shapes "

" tolerance issues "

" Accuracy is affected "

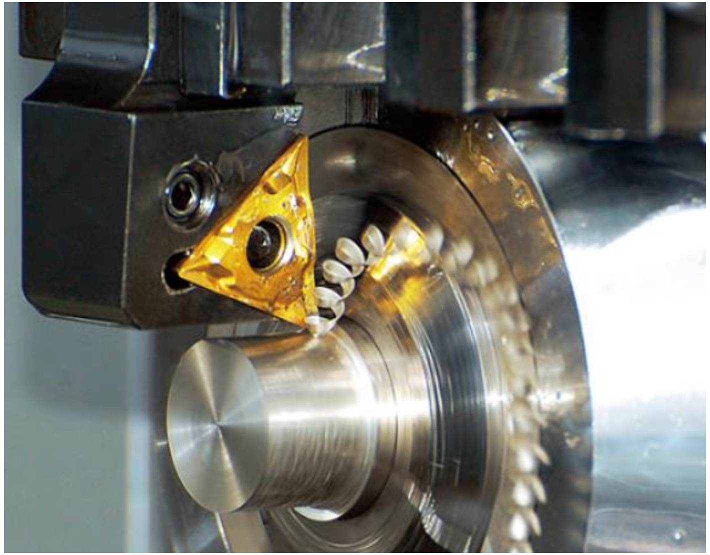
" Accuracy "

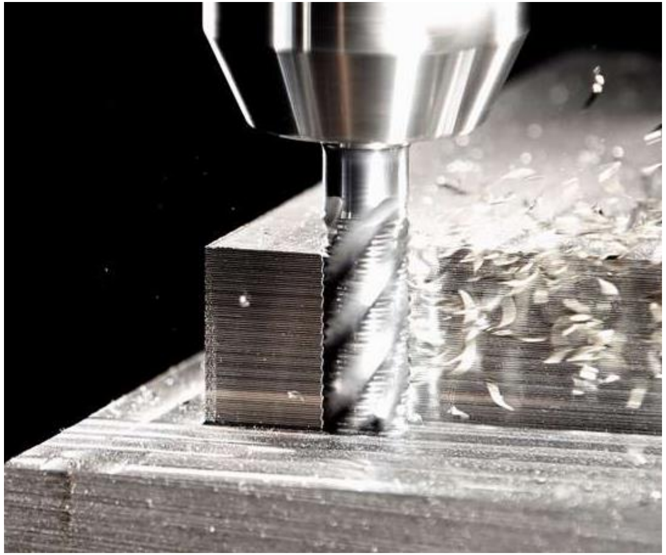
Total Results: 125

Powered by Poll Everywhere

Chip Formation

- When we cut a surface, this material removal process results in chip formation.
- Why do we care?





Why do you think it is important to control chip formation?

" Safety "

" Cleaner Cuts "

" Safety "

" to make sure accurate part "

Total Results: 114

Powered by Poll Everywhere

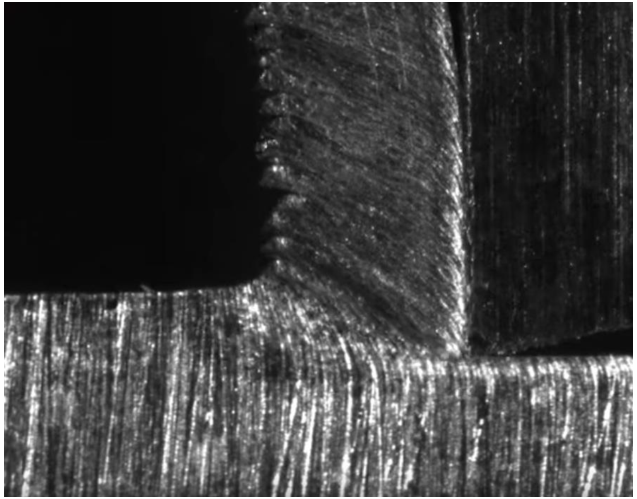
Chip Formation

- Let’s have a look at an example of why it is important.
- There are four common types of chips
  - Continuous
  - Built-up edge
  - Serrated/Segmented
  - Discontinuous

Chip Formation

Continuous chips

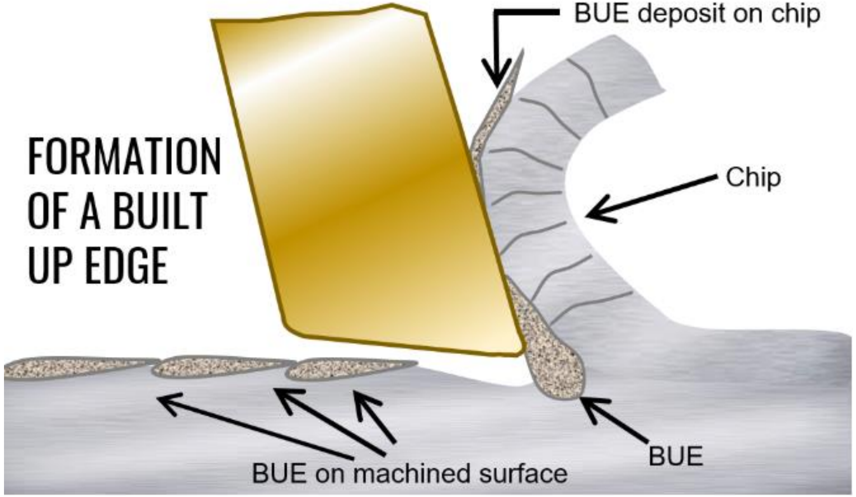
- https://www.youtube.com/watch?v=GghdbT0CyvI
- Usually formed with ductile materials at high cutting speeds.
- Deformation takes place along a narrow shear zone called the primary shear zone
  - A secondary shear zone may develop at the chip-tool interface due to increasing thickness caused by friction.
- Generally produces good surface finish.
- Would they be desirable?



Chip Formation

Built-up Edge (BUE) chips

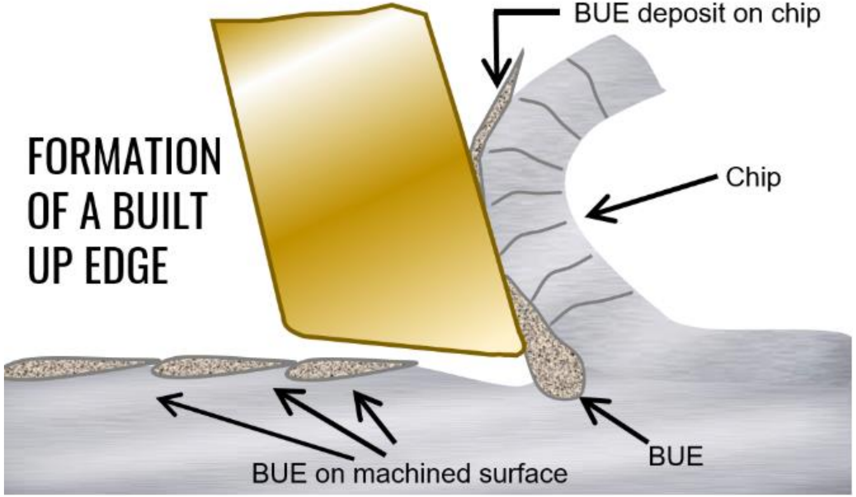
- https://www.youtube.com/watch?v=uwh3ouvzSLk
- This occurs when material builds at the tip of the cutter.
- It eventually grows larger until it breaks away
  - Some is left of the surface of the part, the rest is deposited on the tool surface.
- It can significantly affect surface finish and is usually considered undesirable.



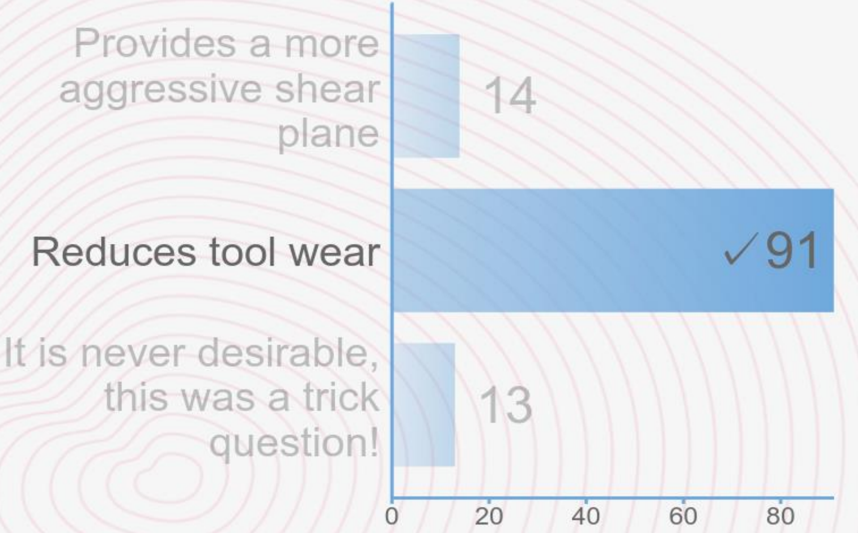
Chip Formation

Built-up Edge (BUE) chips

- However, in some cases it is desirable for a very thin, stable BUE. Why?



Why would very thin, stable Built-up Edge chip formations sometimes be desirable?



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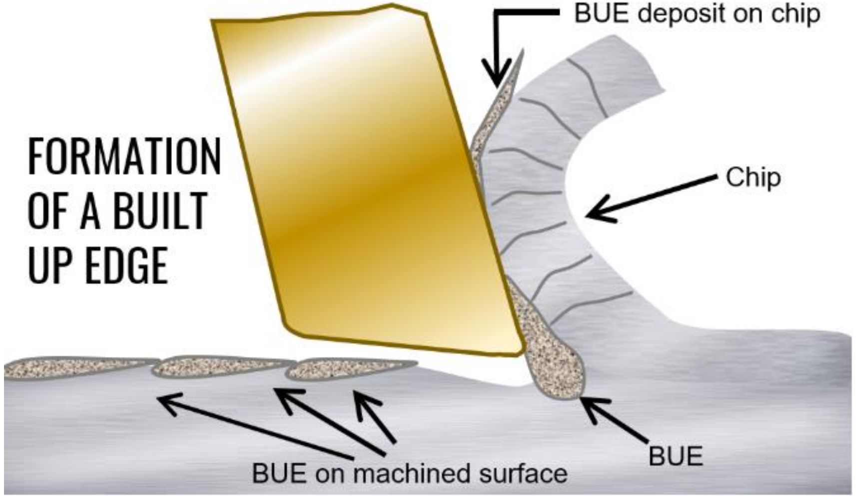
Chip Formation

Built-up Edge (BUE) chips

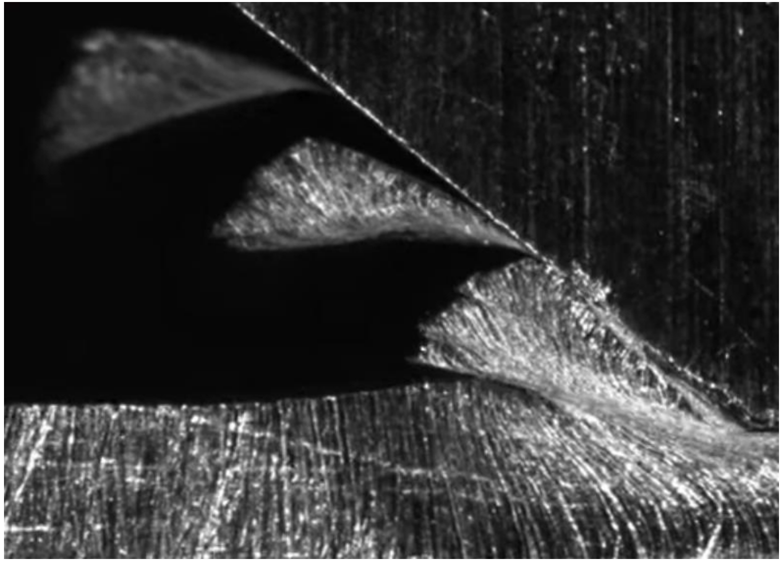
- However, in some cases it is desirable for a very thin, stable BUE. Why?
- BUE can be reduced by increasing cutting speed, decreasing depth of cut, increasing rake angle, checking tool sharpness (sharper the better).



Chip Formation

Serrated chips

- https://www.youtube.com/watch?v=h2pKPpLWwr8
- Materials susceptible to this type of chip formation are
  - Metals with low thermal conductivity
  - Metals that have sharp decreases in strength due to temperature increase (thermal softening)
  - Titanium is notable for this.



Chip Formation

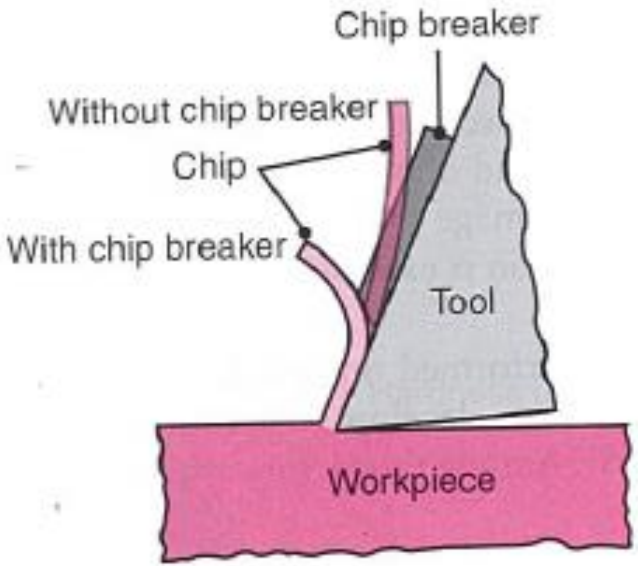
Discontinuous chips

- This is where the chips exhibit varying formation and breakages.
- This affects cutting forces causing them to fluctuate.
- This can result in machine chatter (where the machine vibrates and affects accuracy).
- Materials that are most likely to generate discontinuous chips are
  - Brittle (unable to undergo high strains)
  - Materials with impurities e.g. grey cast iron
- Conditions that contribute to formation are very low or high cutting speeds, large depths of cut and low rake angles

Chip Formation

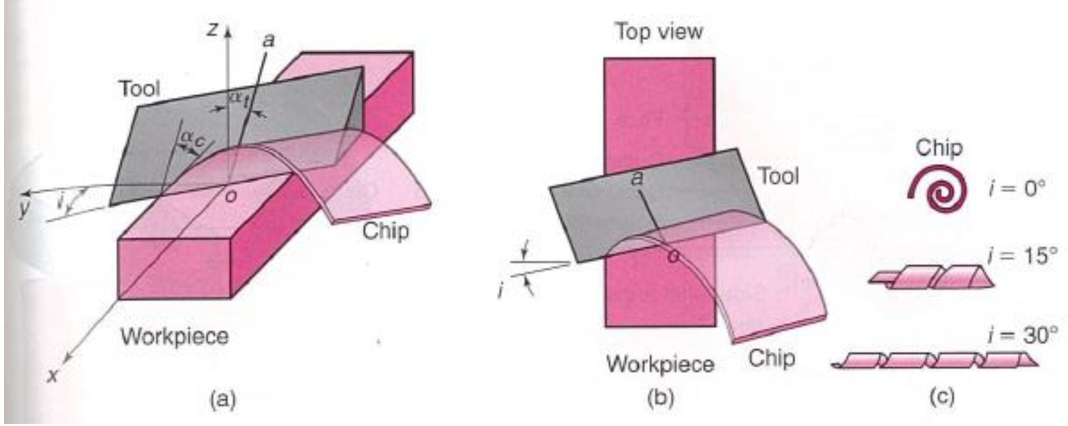
Chip breakers

- If modifying cutting variables is unable to control chip formation, we can use a chip breaker.
- Traditionally was a piece of metal clamped to the tool's rake face and forced the chip to bend and break.
- However, most modern cutters have chip breakers inbuilt.
- https://www.youtube.com/watch?v=1pC4FaLR-QA



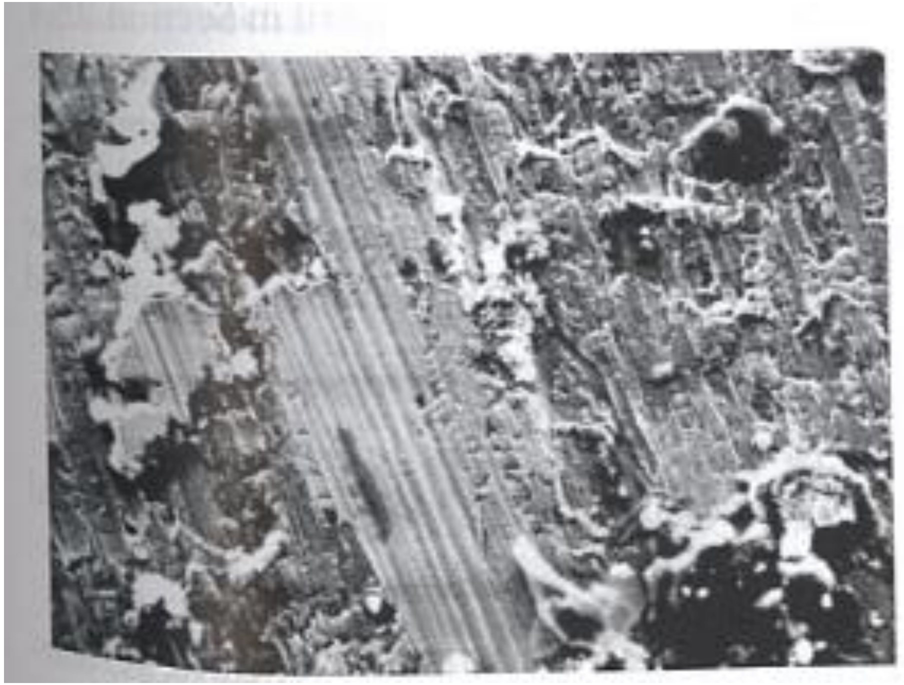
Orthogonal vs Oblique Cutting

- As inclination angle increases, effective rake angle increases.
  - This cause cutting force to decrease.
- Can be an effective means of controlling chip formation



Surface Finish and Integrity

- Surface finish not only affects the dimensional accuracy of machined parts but how they will perform during their service life.
  - Surface finish refers to the geometric features of a surface
  - Surface integrity refers to the resultant material properties e.g. corrosion, fatigue life
- BUE has the greatest influence on surface finish.

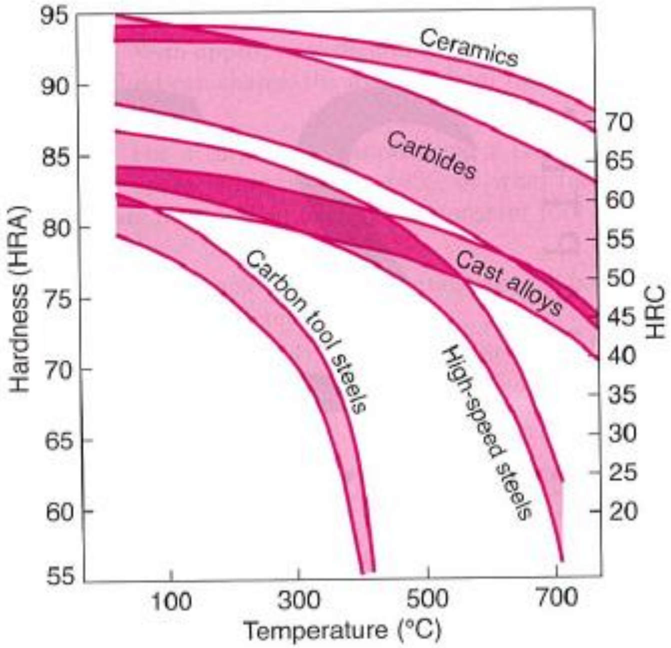


Surface Finish and Integrity

- Vibration and chatter will also affect the surface finish.
- Temperatures, residual stresses and severe plastic deformation will affect surface integrity.
- When machining, different passes perform different functions.
  - Rough passes (roughing) removes larger amount of material and doesn’t dictate surface finish.
  - Finishing passes (finishing) removes much smaller amounts of material and strongly dictates surface finish.

Tool Material Selection

- The cutting tool must consider the following:
- Hot hardness
  - Hardness, strength and wear resistance do not change during cutting temperatures.
- Toughness and impact strength
  - When engaging the tool for a pass in milling or turning, the tool doesn’t chip of fracture.
- Thermal shock resistance.
  - Fluctuating temperatures could damage the tool.



Tool Material Selection

TABLE 22.1

General Characteristics of Tool Materials

Property	High-speed steels	Cast-cobalt alloys	Carbides WC	Carbides TiC	Ceramics	Cubic boron nitride	Single-crystal diamond*
Hardness	83–86 HRA	82–84 HRA 46–62 HRC	90–95 HRA 1800–2400 HK	91–93 HRA 1800–3200 HK	91–95 HRA 2000–3000 HK	4000–5000 HK	7000–8000 HK
Compressive strength, MPa	4100–4500	1500–2300	4100–5850	3100–3850	2750–4500	6900	6900
Transverse rupture strength, MPa	2400–4800	1380–2050	1050–2600	1380–1900	345–950	700	1350
Impact strength, J	1.35–8	0.34–1.25	0.34–1.35	0.79–1.24	<0.1	<0.5	<0.2
Modulus of elasticity, GPa	200	—	520–690	310–450	310–410	850	820–1050
Density, kg/m^3	8600	8000–8700	10,000–15,000	5500–5800	4000–4500	3500	3500
Volume of hard phase, %	7–15	10–20	70–90	—	100	95	95
Melting or decomposition temperature, °C	1300	—	1400	1400	2000	1300	700
Thermal conductivity, W/m K	30–50	—	42–125	17	29	13	500–2000
Coefficient of thermal expansion, $\times 10^{-6}$/°C	12	—	4–6.5	7.5–9	6–8.5	4.8	1.5–4.8

*The values for polycrystalline diamond are generally lower, except for impact strength, which is higher.

Cutting Fluids

- Cutting fluids play a very important role in machining operations by
  - Reducing friction and wear
  - Cooling the cutting zone and reducing thermal distortion of workpiece
  - Reduce forces and energy consumption
  - Flushing chips away from the cutting zone
  - Protecting the machined surface from environmental corrosion

Cutting Fluids

- Cutting fluids may be a coolant, lubricant or both.
- Water is an excellent coolant but a poor lubricant. It can also cause oxidation of certain materials.
- The need for cutting fluids is dependent on the severity of the machining operation.
- Machining processes in increasing order of severity is
  - sawing, turning, milling, drilling, gear cutting, thread cutting, tapping and internal broaching

Cutting Fluids

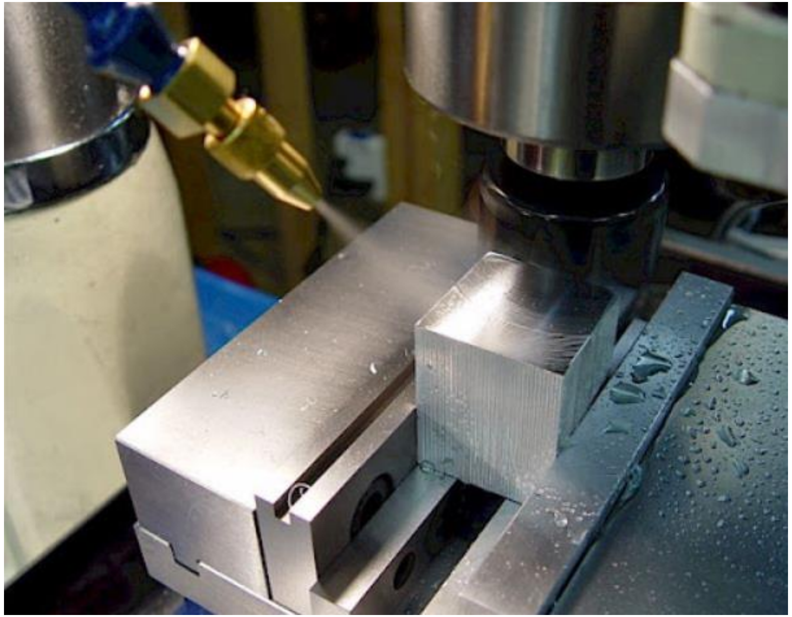
- Types of cutting fluid
  - Oils. Mineral, animal, vegetable compounded and synthetic. Typically used for low speed cutting with no large temperature rise.
  - Emulsions (soluble oils). Mixture of oil, water and additives. Generally for high speed operations due to the significant temperature increase. Presence of water makes them good for cooling. The oil reduces and, in some cases, eliminates the oxidation risk.
  - Semi-synthetics. chemical emulsions with little oil, diluted in water.
  - Synthetics. Chemicals with additives, diluted in water, no oil;
- In general, suppliers will provide you with directions for what application suits which type of cutting fluid.

Cutting Fluids

- There are various ways that cutting fluids are implemented
- The most common method is flooding
  - Flow rates vary from 10L/min to 225L/min
  - Fluid pressures from 700 to 14000 kPa to flush chips.

Cutting Fluids

- Another common method of application is misting the fluid
  - Supplies fluid to inaccessible areas
  - better visibility of workpiece.
  - Limited cooling capacity.
  - OHS issues.



Cutting Fluids

- High-pressure cutting fluid systems operate in a similar manner to flooding.
  - Fluid pressures range between 5.5 to 35 MPa.
  - To avoid damage to the work surface, fluid contaminants should be less than 20 μm
- A less common method is applying the coolant through the cutting tool.
  - Expensive but provides internal access

Next steps

- Ensure that you register for MySolidworks
  - https://www.solidworks.com/media/mysolidworks-students
- It is important to keep up with your CAD pre-lab and lab exercises
  - If you aren’t careful, they add up quickly and you can get overwhelmed
- You will use your CAD and CAM skills in every assessment item
  - Practice, practice, practice!