446.326A CAD/CAM

CAM (Computer-Aided Manufacturing)

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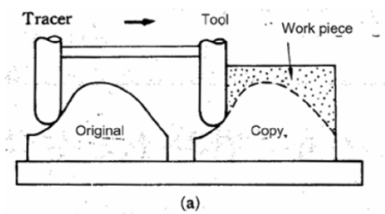
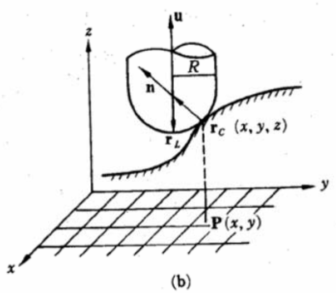
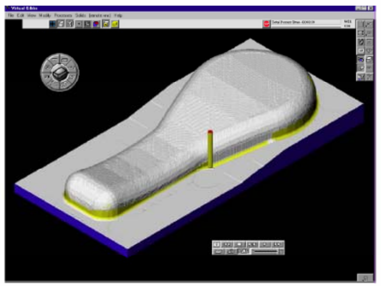
Outline

Copy Milling & NC Milling

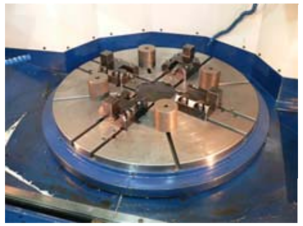


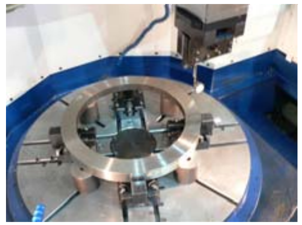


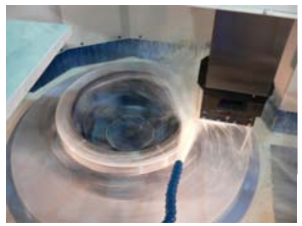


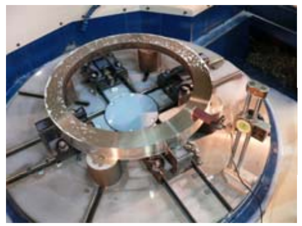
CNC Machining Example - Lathe

- **Machining of super alloy**


< Fixture setup >

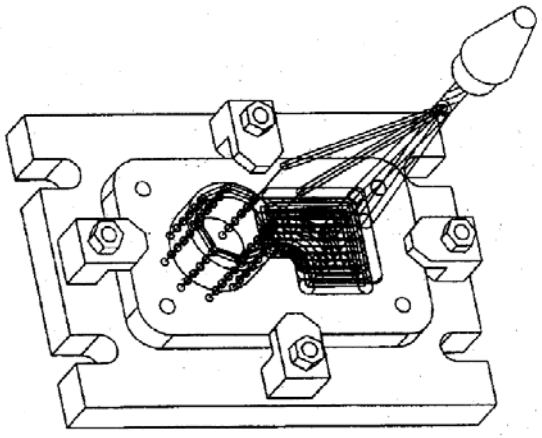

< Stock setup >


< Machining with coolant >


< Surface roughness measuring after machining >

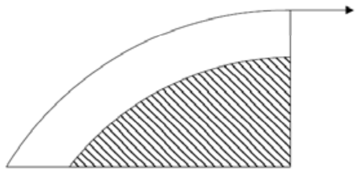
Tool Path Generation

- **Concept of pocketing**

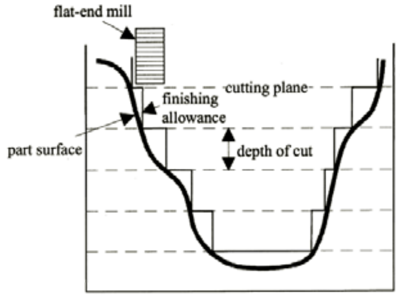


Tool Path Generation (cont.)

- **Rough Cutting**
  - Remove bulk material
  - One type: the raw material has a shape close to the final shape
  - Second type: the raw material is provided in the form of block



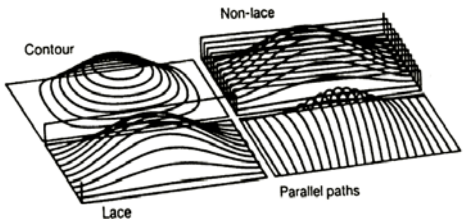
< One type of rough cutting >



< Second type of rough cutting >

Tool Path Generation (cont.)

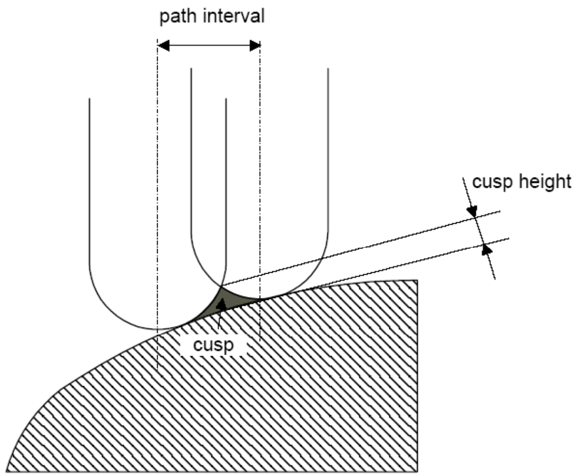
- **Finish cutting**
  - For the machining accuracy, below relationships should be considered
    - Path interval and cups height
    - Step length and deviation
    - Generation of CC points by subdivision
    - CC point and CL point



< Various cutter paths on a surface >

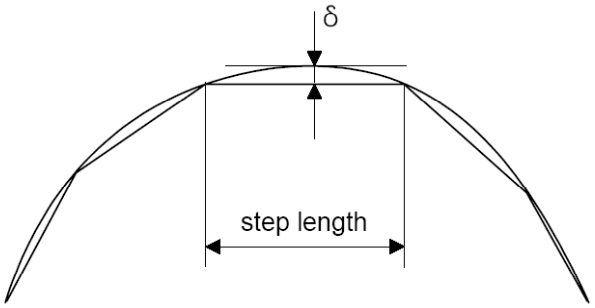
Tool Path Generation (cont.)

- **Relationship between path interval and cusp height**



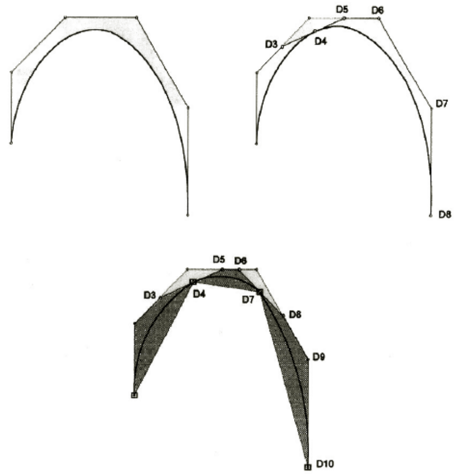
Tool Path Generation (cont.)

- **Relationship between step length and deviation**



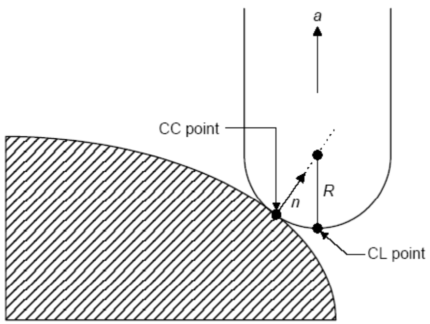
Tool Path Generation (cont.)

- **Generation of CC point by subdivision**



Tool Path Generation (cont.)

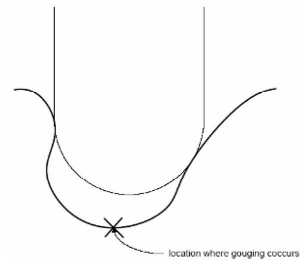
- **Relationship between the CC point and the CL point**



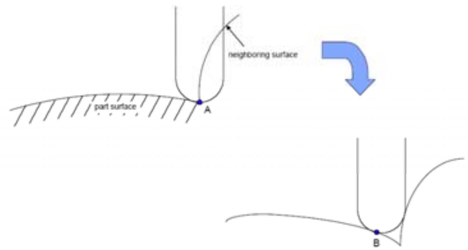
$$\mathbf{r}_{cl} = \mathbf{r}_{cc} + R(\mathbf{n}(u,v) - \mathbf{a})$$

Tool Path Generation (cont.)

- **Gouging Problem**
  - Choosing a tool whose radius is smaller than the minimum radius of curvature of the part surface
  - However, too small tool may result in inefficient machining

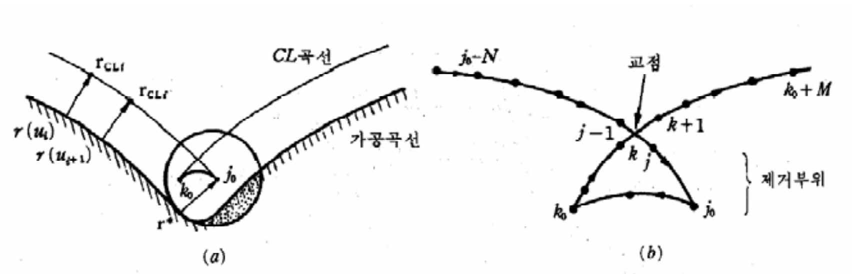


< Gouging of a surface >



< Gouging at a neighboring surface >

Overcut



Overcut (cont.)

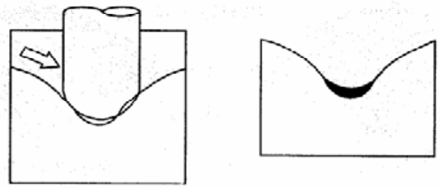


그림 11.24 곡면가공시의 공구간섭(overcut)과 undercut.

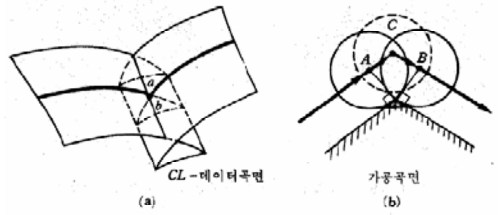
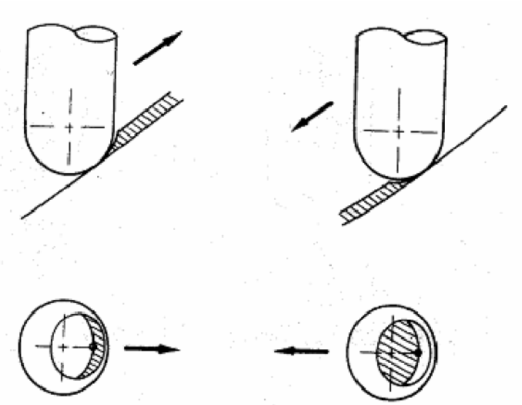


그림 11.25 공구간섭 현상의 발견과 제거

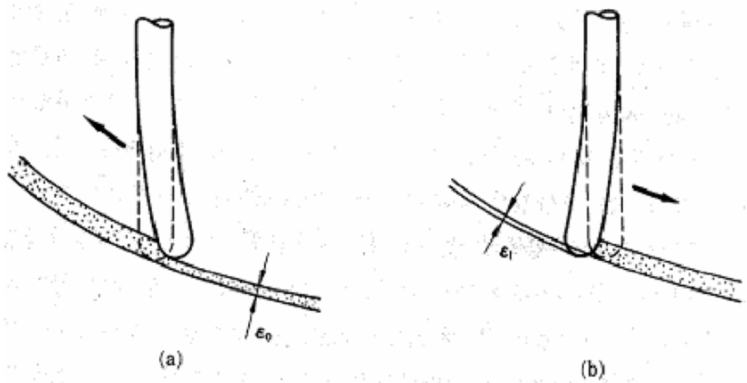
Area of Cutting

- Upward cutting vs. downward cutting
- Zero velocity zone may occur



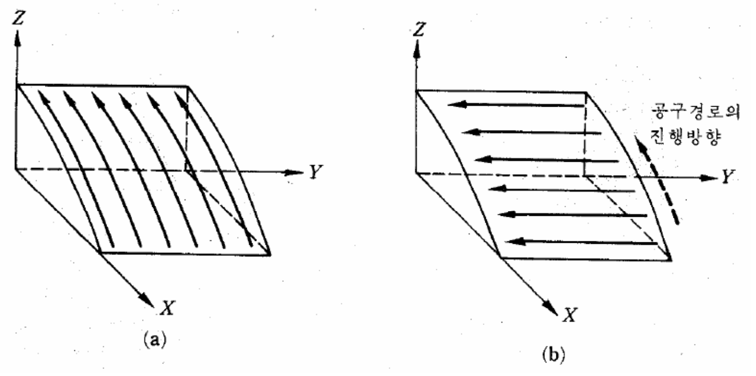
Deflection of Tool

- Undercut vs. overcut

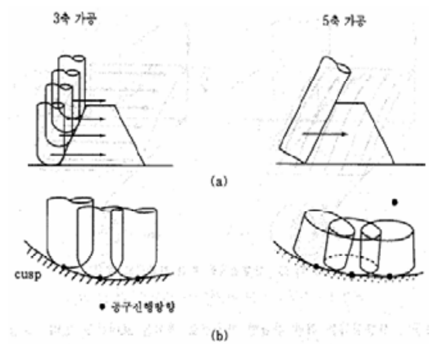


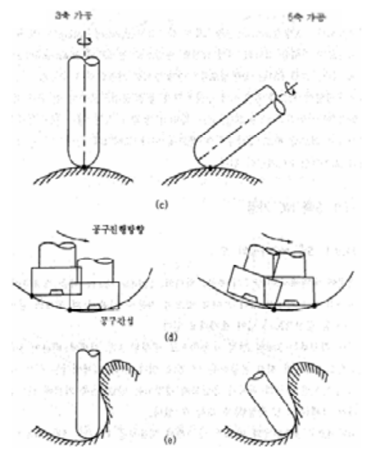
Upward Cutting Tool Path

- Also consider lace vs. non-lace tool paths



5-axis Machining





Cost Estimation for Machining

- The cost to produce each component in a batch is given by

$$C_{PER\ PART} = WT_L + WT_M + WT_R[T_M/T] + y[T_M/T]$$

- In this equation, the symbols include
  - W = the machine operator's wage plus the overhead cost of the machine.
  - WT_L = "nonproductive" costs, which vary depending on loading and fixturing.
  - WT_M = actual costs of cutting metal.
  - WT_R = the tool replacement cost shared by all the components machined. This cost is divided among all the components because each one uses up T_M minutes of total tool life, T, and is allocated of T_M/T of WT_R.
  - Using the same logic, all components use their share T_M/T of the tool cost, y.

Machining Conditions

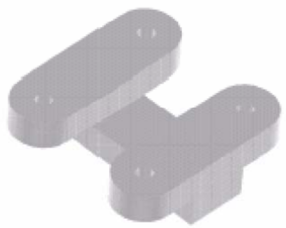
- Recommended cutting speeds

Cutting speed Vc Material	Seco group No.	Slot milling Roughing m/min	Helic./Ramp. Finishing m/min	Side milling Roughing m/min	Side milling Finishing m/min	Copy milling Roughing m/min	Copy milling Finishing m/min
Soft Steel	1-2	150 / 200*	250	350	450	290	500
Normal Steel	3-4	120 / 180*	210	310	390	250	385
Tool steel <48 HRc	5-6	100 / 160*	180	280	350	215	325
Hardened steel >48-56 HRc	7	50/110*	150	70/250*	300	200/170*	280
Hardened steel >56-62 HRc	7	30/70*	90	50/150*	175	120/100*	150
Hardened steel >62-65 HRc	7	20/50*	55	40/80*	90	100/80*	110
Hardened steel >65 HRc	7	15/35*	35	30/55*	60	80/60*	85
Stainless steel	8-9	95	100	155	200	110	210
Difficult stainless steel	10-11	60	70	120	145	70	125
Soft Cast iron	12-13	175	185	250	285	250	345
Hard Cast iron	14-15	150	160	200	245	200	290
Aluminium with <16% Si	16	Max	Max	Max	Max	Max	Max
Aluminium with >16% Si	17	250	280	295	325	300	345
Supperalloys	20	50	60	80	120	90	150
Difficult super alloys	21	25	30	40	50	45	75
Titanium based alloys	22	75	80	120	145	90	170
Graphite		600	600	600	400	800	500
Plastic soft**		300	400	385	450	Max	Max
Plastic hard**		150	175	190	250	200	175
Copper		350	450	450	550	Max	Max

* Refers to alternative tools in the tool selection table.
** In case of melting of the plastic, reduce the cutting speed.

* Data from TORNADO High Speed Tools

Actual Cost and Time for Machining



No. of Setups	3
No. of Features	9
Planning Time	0.75
Setup time	55.22
Machining Time	33.8
Material	ABS

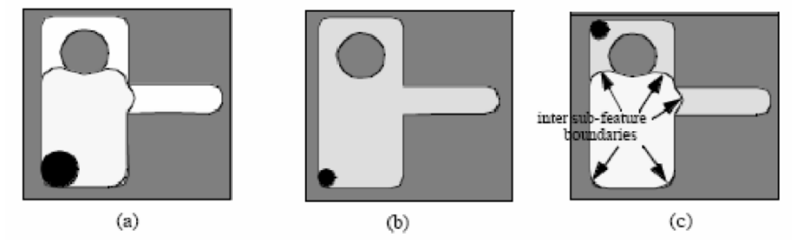
Cost of Material	$2.69
Cost of Tool	$2.25
Cost of planning	$0.36
Cost of setup	$26.69
Cost of Machining	$16.33
Total Cost	$48.32

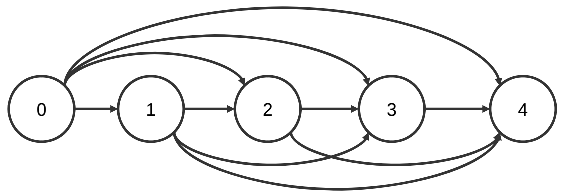
No. of Setups	3
No. of Features	9
Planning Time	0.83
Setup time	40.6
Machining Time	13.33
Material	ABS

Cost of Material	$1.34
Cost of Tool	$0.88
Cost of planning	$0.40
Cost of setup	$19.65
Cost of Machining	$6.44
Total Cost	$28.71

Selection of tool size

- **Considering cost and time**

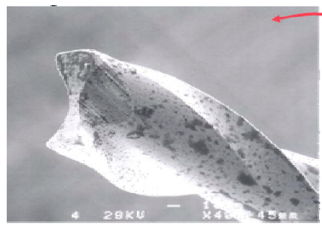




Process Selection

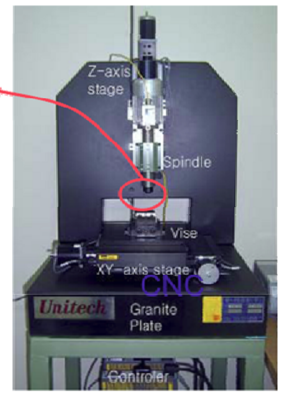
- **At conceptual design stage**
  - Manufacturing Analysis Service (MAS) at U.C. Berkeley
    (http://vertex.berkeley.edu/Me221/mas2/html/applet/index.html)
  - Design for X at Stanford Univ.
    (http://manufacturing.stanford.edu/)
- **For your term project, you may use following processes:**
  - CNC machining – metal, polymer
    - Micro machining
  - Injection molding – polymer
  - Rapid Prototyping – polymer

Micro Machining System (example)



Tip of 100μm endmill

Micro endmills



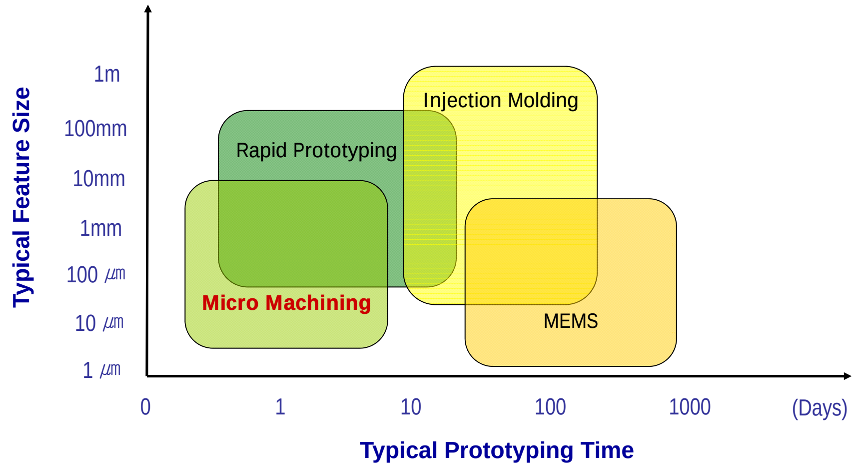
Precision stage

- **Standard input: STL**
- **High speed: 46,000 rpm**
- **Tool material: High Speed Steel and carbide**
- **Work piece: Metal, Polymer, etc**

End Mill Machining

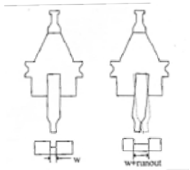
- **End Mill Machining**

Prototyping Size and Time

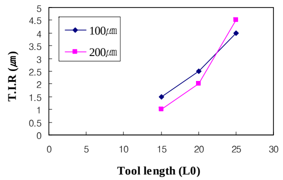


Design for Manuf. (DFM): Micro Milling

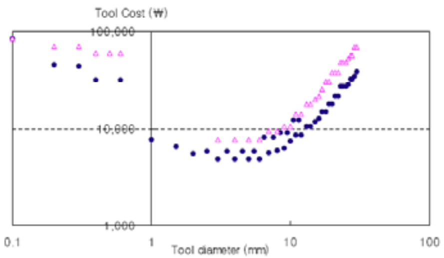
- **10mm endmill**
  - 10µm stage error
  - 0.1% for slot cutting
- **100µm endmill**
  - 10µm stage error
  - 10% for slot cutting
- **Cost structure is different form macro machining**
  - Tool cost dominates



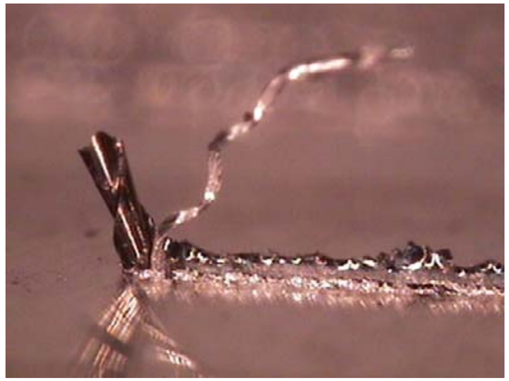
< Concept of run-out>



< Result of Total Indicator Reading (TIR) >

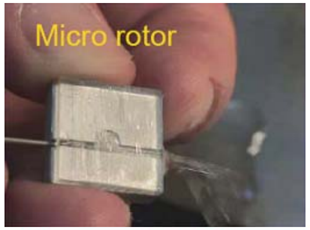


Broken Micro Tool



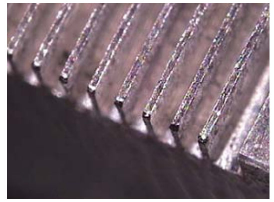
From Concept to Part

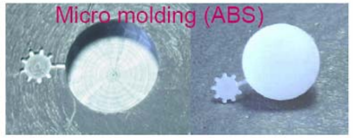
More Meso / Micro Parts

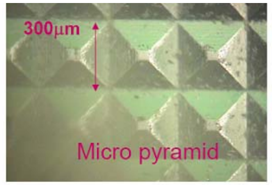


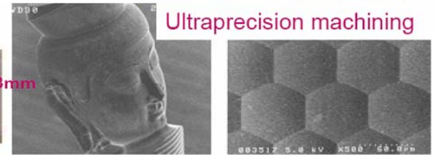
Rib width: 60µm
Height: 500µm
Tool: ϕ200µm

Spindle: 24,000rpm
DOC: 25µm
Feed rate: 100µm/s
Time: 3hr 28min



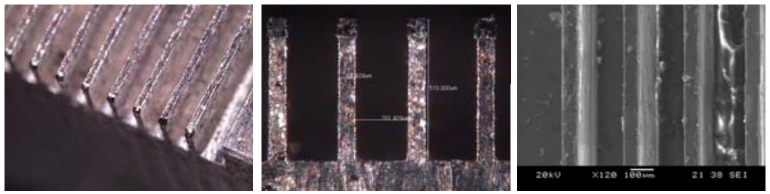






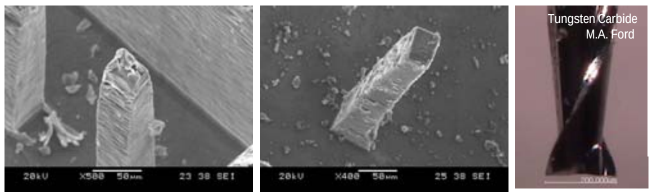
More Meso / Micro Parts

- **Micro walls**



Material: Al 6061
Wall width: 60㎛
Height: 500 ㎛
Tool: φ200 ㎛
Spindle: 24,000rpm
DOC: 25㎛
Feed rate: 100㎛/s
Time: 3hr 28min

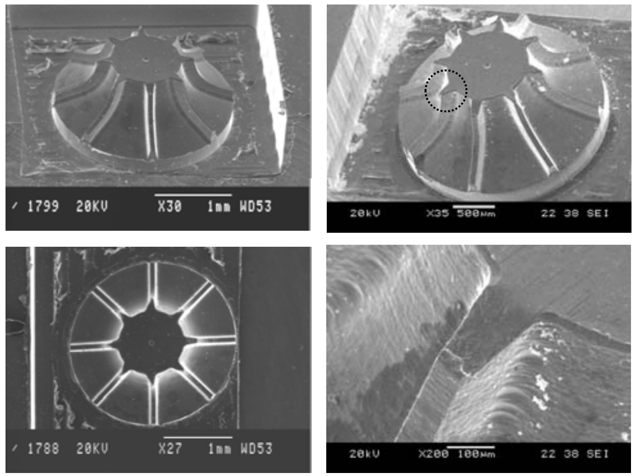
- **Micro square columns**



Material: Al 6061
Column width: 50㎛
Height: 300 ㎛
Tool: φ200 ㎛
Spindle: 30,000rpm
DOC: 5㎛
Feed rate: 100㎛/s
Time: 1hr 30min

More Meso / Micro Parts

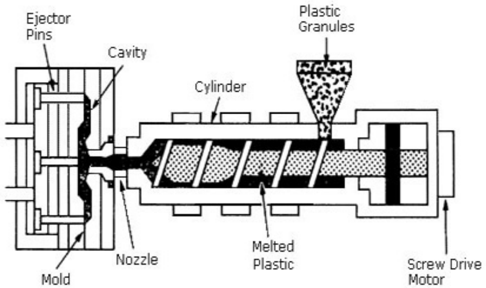
- **Micro rotor**



Material: Al 6061
Upper diameter: 1 mm
Lower diameter : 2.5mm
Spindle: 30,000 rpm
Roughing:
500 flat endmill
Feed rate: 1mm/s
DOC: 50 ㎛
Time: 2hr 10min
Finishing:
100 ball endmill
Feed rate: 100㎛/s
DOC: 2 ㎛
Time: 4hr

Injection Molding

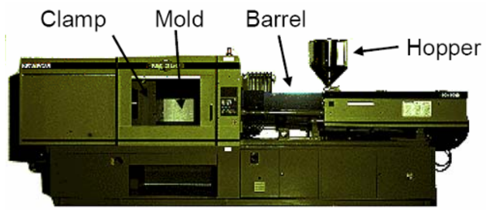
- One of the most common methods of shaping plastic resins
- Accomplished by large machines called injection molding machines



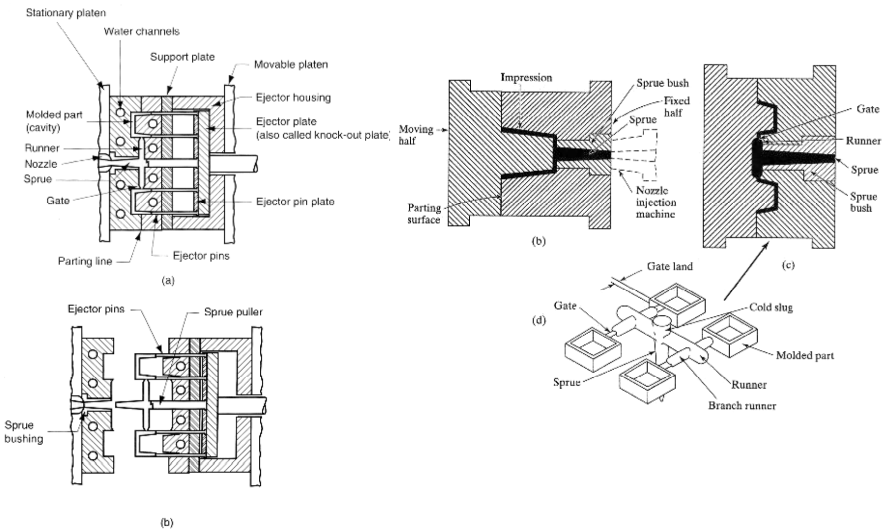
< Diagram of a typical injection molding process >

Injection Molding

- Injection molding machines



Injection Molding (cont.)



Injection Molding (cont.)

- Types of Gate

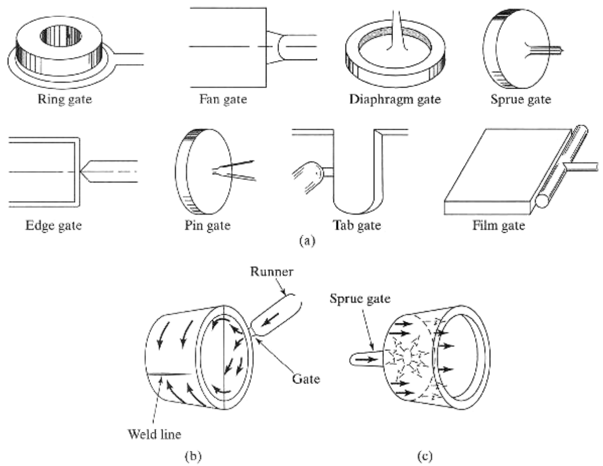
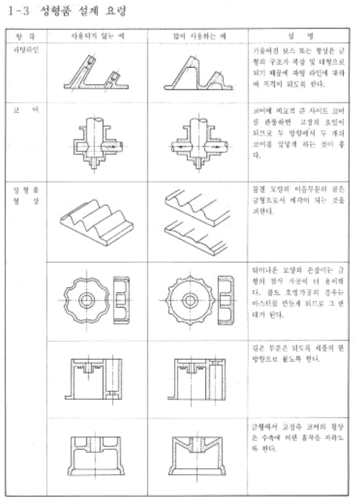
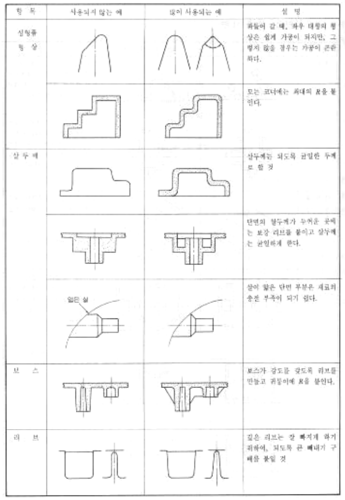


Figure 8.10 (a) Various gate designs in the top figure. The lower figure shows (b) an inefficient gating method and (c) the preferred method (on the right) to fill a cup (adapted from ICI and Pye).

Injection Molding (cont.)

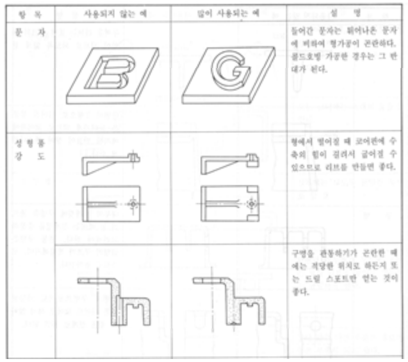
- **DFM in injection molding I**

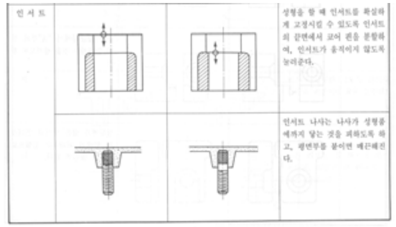


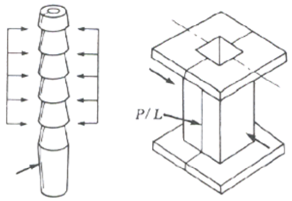


Injection Molding (cont.)

- **DFM in injection molding II**

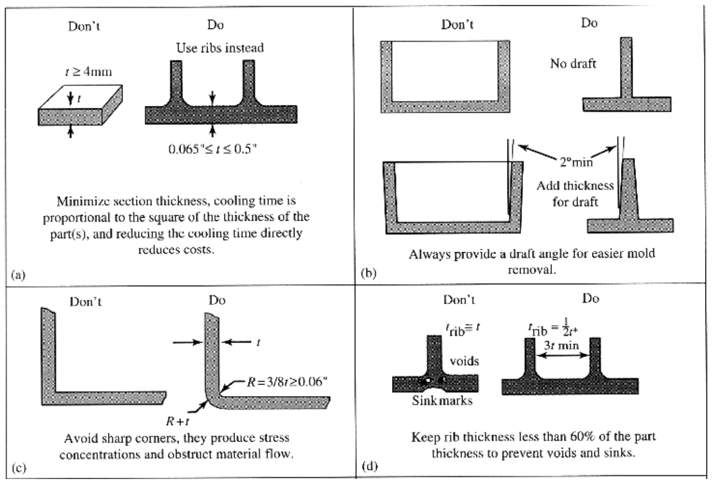




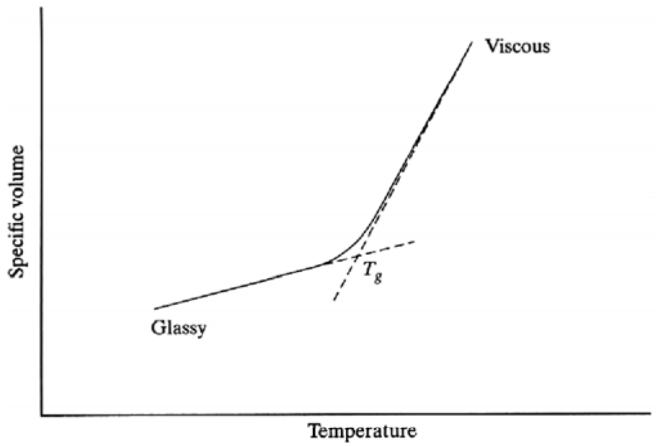


Injection Molding (cont.)

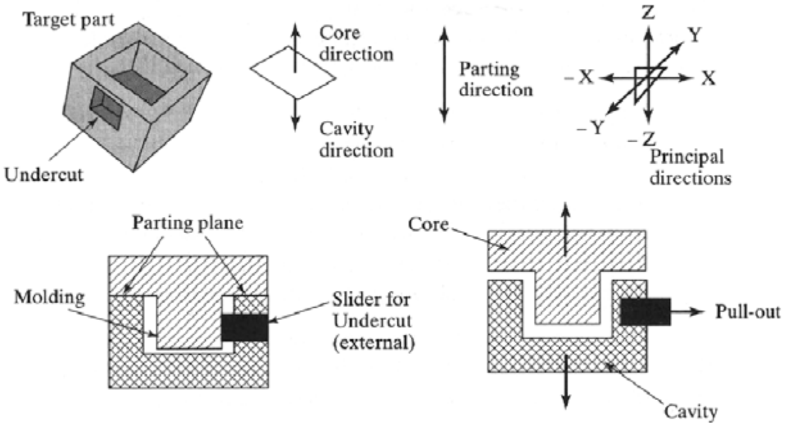
- **DFM in injection molding III**



Glass Transition Temperature, T_g

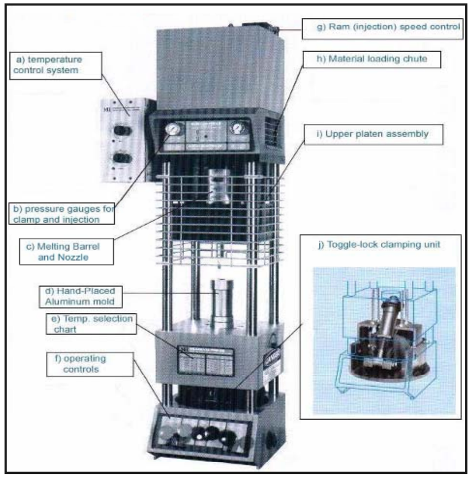


Mold Description



Injection Molding (cont.)

- **Morgan G-100T Press**
  - In IDIM lab. 312-307
  - 6 cu. in. (98.32cm³) (4 oz. (113.40g)) Max.
  - Single shot 20 ton max.
  - Clamping force (toggle).
  - 12,000 psi (83,000 kPa) max. Injection pressure



< Schematic of the Morgan G-100T press >