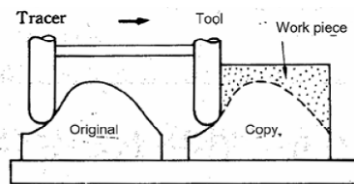
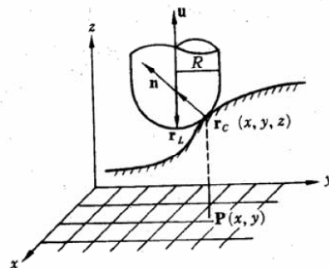




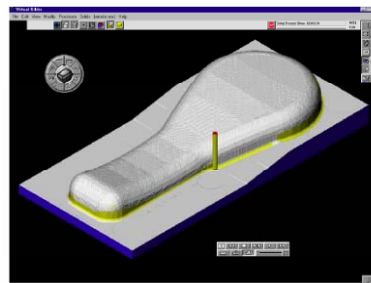
Copy Milling & NC Milling



(a)



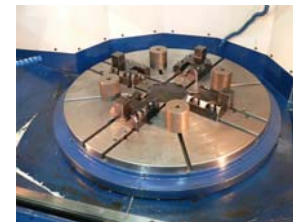
(b)



CNC Machining Example - Lathe



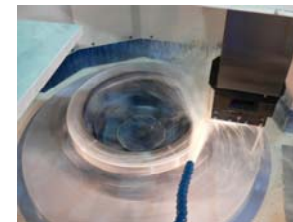
▪ Machining of super alloy



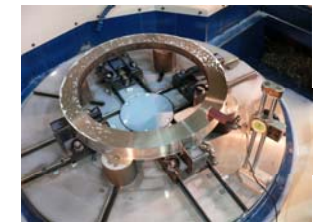
< Fixture setup >



< Stock setup >



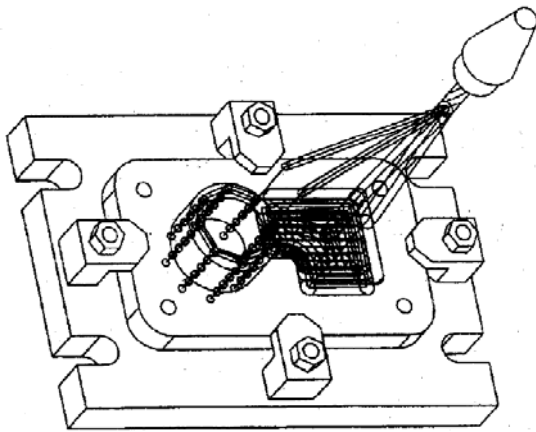
< Machining with coolant >



< Surface roughness measuring after machining >

Tool Path Generation

▪ Concept of pocketing

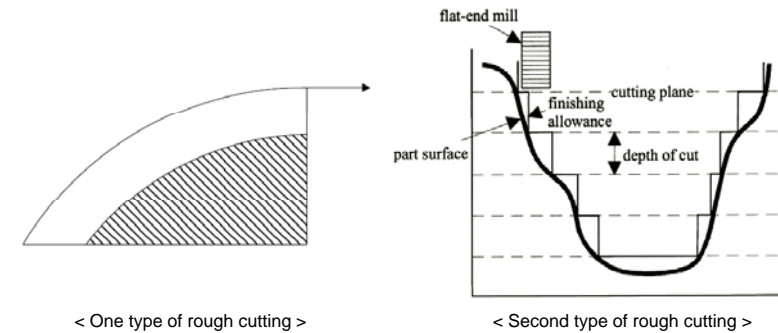


5

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

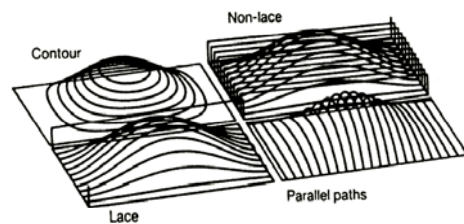


6

Tool Path Generation (cont.)

▪ Finish cutting

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

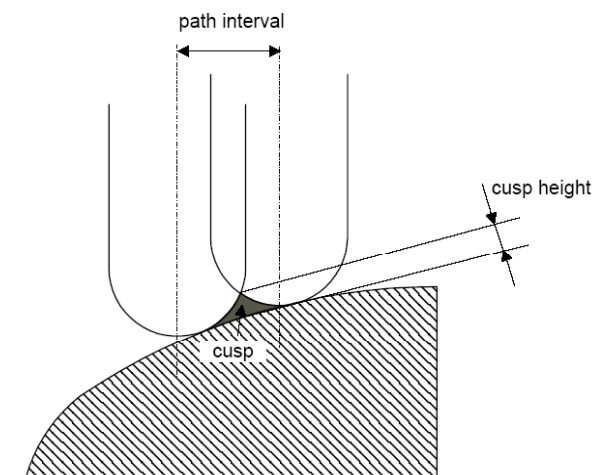


< Various cutter paths on a surface >

7

Tool Path Generation (cont.)

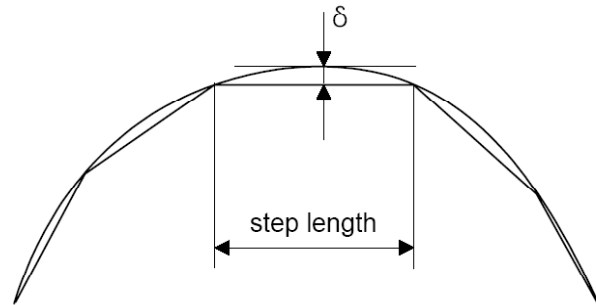
▪ Relationship between path interval and cusp height



8

Tool Path Generation (cont.)

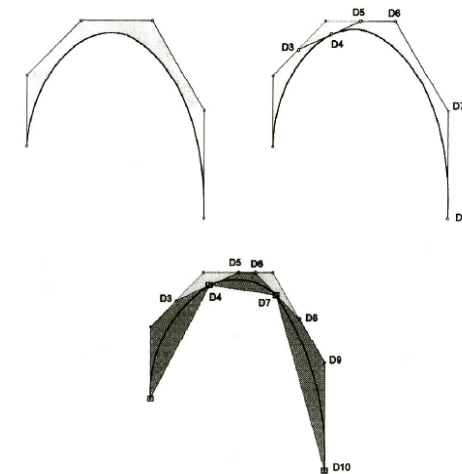
- Relationship between step length and deviation



9

Tool Path Generation (cont.)

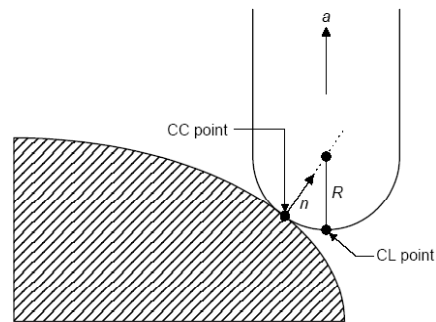
- Generation of CC point by subdivision



10

Tool Path Generation (cont.)

- Relationship between the CC point and the CL point



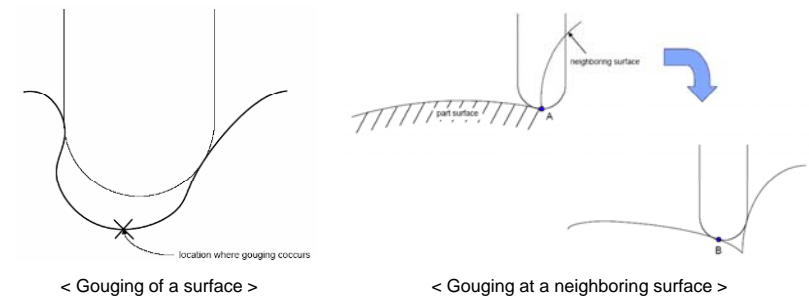
$$\mathbf{r}_{cl} = \mathbf{r}_{cc} + R(\mathbf{n}(u, v) - \mathbf{a})$$

11

Tool Path Generation (cont.)

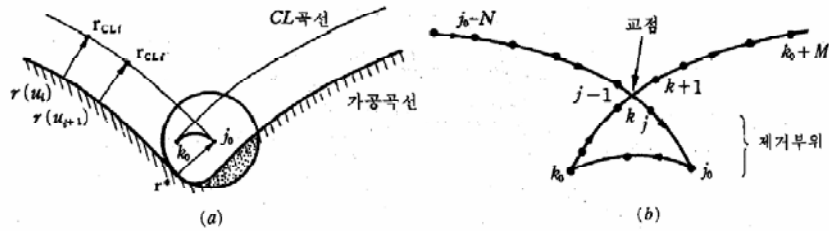
- Gouging Problem

- 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



12

Overcut



13

Overcut (cont.)

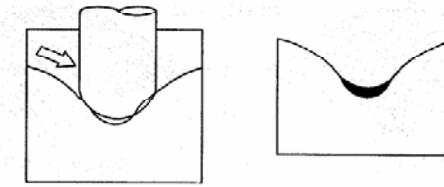


그림 11.24 곡면가공시의 공구간섭 (overcut) 과 undercut.

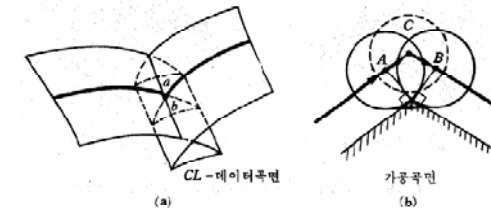
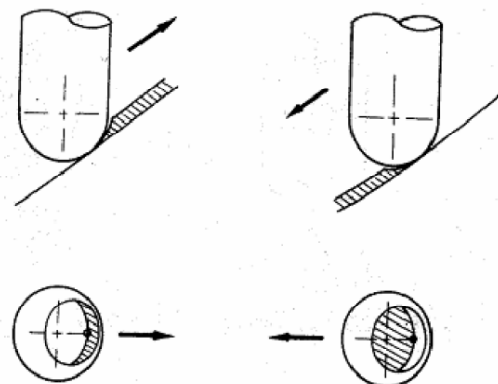


그림 11.25 공구간섭 현상의 발견과 제거

14

Area of Cutting

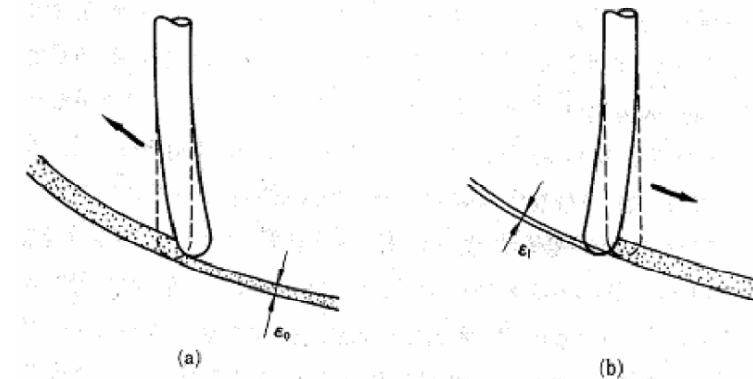
- Upward cutting vs. downward cutting
- Zero velocity zone may occur



15

Deflection of Tool

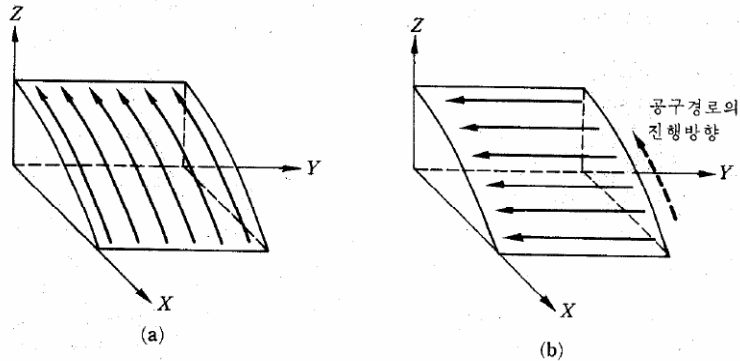
- Undercut vs. overcut



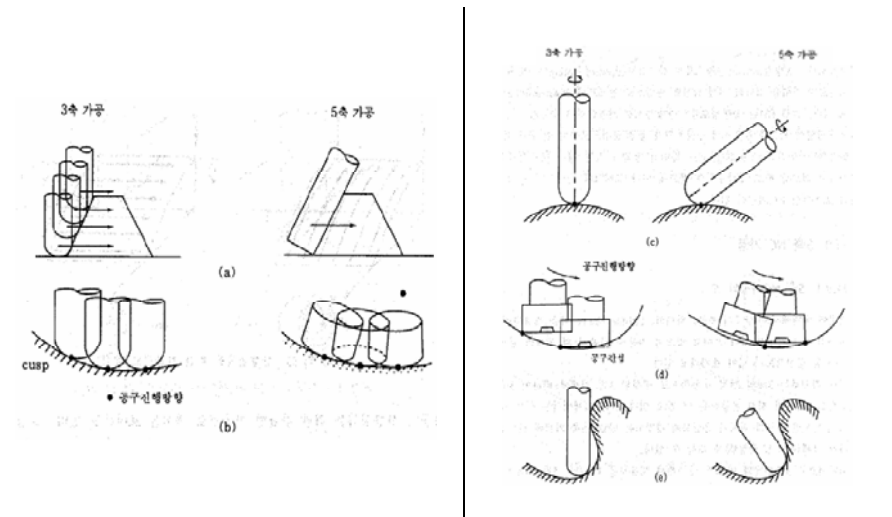
16

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 .

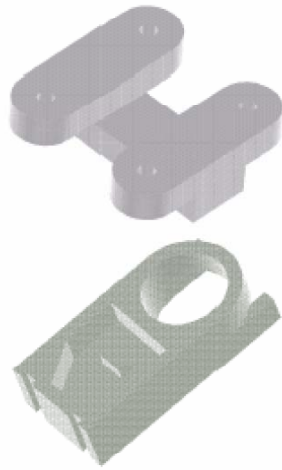
Machining Conditions

- Recommended cutting speeds

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 $\leq 48 HRC$	5-6	100 / 160*	180	280	350	215	325
Hardened steel $\geq 48.56 HRC$	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	40/90*	90	100/80*	110
Hardened steel $\geq 65 HRC$	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 $\le 16\% Si$	16	Max	Max	Max	Max	Max	Max
Aluminium with $\ge 16\% Si$	17	250	280	295	325	300	345
Superalloys	20	50	60	80	120	90	150
Difficult super alloys	21	25	30	40	50	45	75
Titanium based alloys	22	75	90	120	145	90	170
Graphite	600	600	600	600	400	800	500
Plastic soft**	300	400	385	450	Max	Max	Max
Plastic hard**	150	175	190	250	200	200	175
Copper	350	450	450	550	Max	Max	Max

* Data from TORNADO High Speed Tools

Actual Cost and Time for Machining



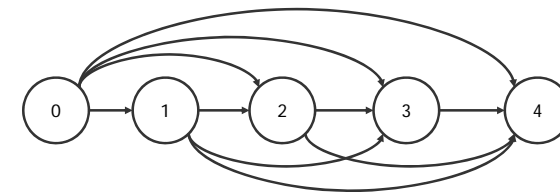
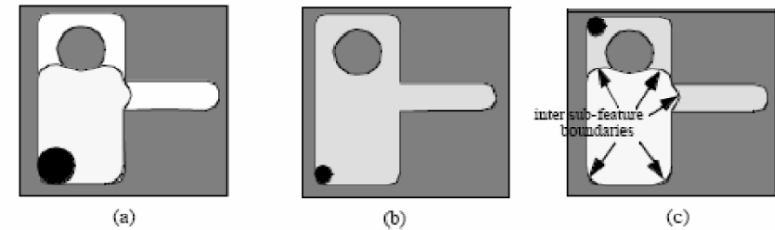
No. of Setups	3	Cost of Material	\$2.69
No. of Features	9	Cost of Tool	\$2.25
Planning Time	0.75	Cost of planning	\$0.36
Setup time	55.22	Cost of setup	\$26.69
Machining Time	33.8	Cost of Machining	\$16.33
Material	ABS	Total Cost	\$48.32

No. of Setups	3	Cost of Material	\$1.34
No. of Features	9	Cost of Tool	\$0.88
Planning Time	0.83	Cost of planning	\$0.40
Setup time	40.6	Cost of setup	\$19.65
Machining Time	13.33	Cost of Machining	\$6.44
Material	ABS	Total Cost	\$28.71

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Selection of tool size

- Considering cost and time



22

Process Selection

- At conceptual design stage

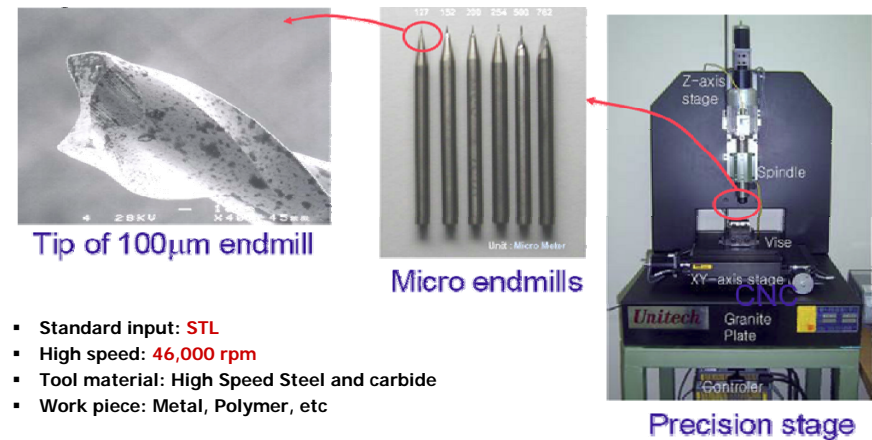
- [Manufacturing Analysis Service \(MAS\)](http://vertex.berkeley.edu/Me221/mas2/html/applet/index.html) at U.C. Berkeley
- [Design for X](http://manufacturing.stanford.edu/) at Stanford Univ.

- For your term project, you may use following processes:

- CNC machining – metal, polymer
 - Micro machining
- Injection molding – polymer
- Rapid Prototyping – polymer

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Micro Machining System (example)



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

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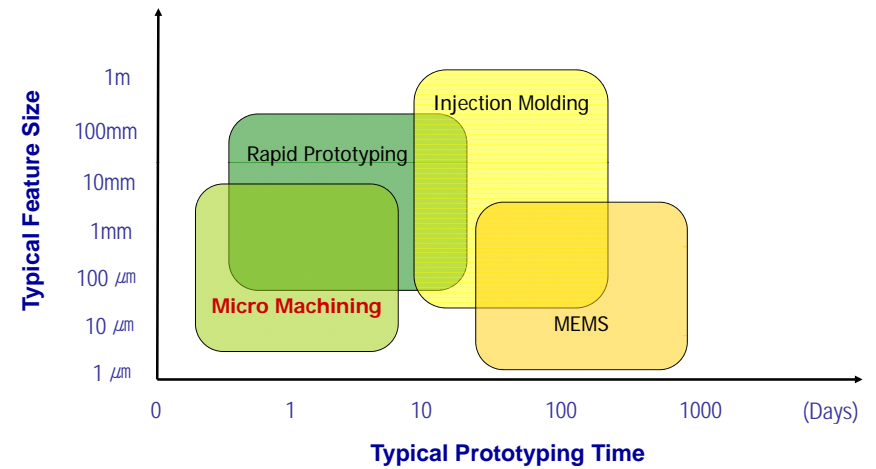
End Mill Machining

End Mill Machining



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Prototyping Size and Time

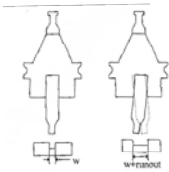


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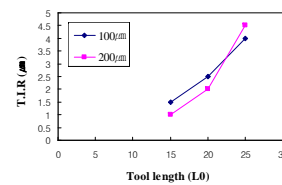
Design for Manuf. (DFM): Micro Milling

10mm endmill

- 10μm stage error
- 0.1% for slot cutting



< Concept of run-out >



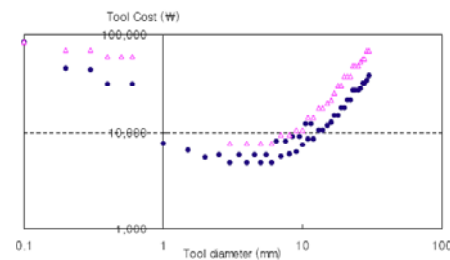
< Result of Total Indicator Reading (TIR) >

100μm endmill

- 10μm stage error
- 10% for slot cutting

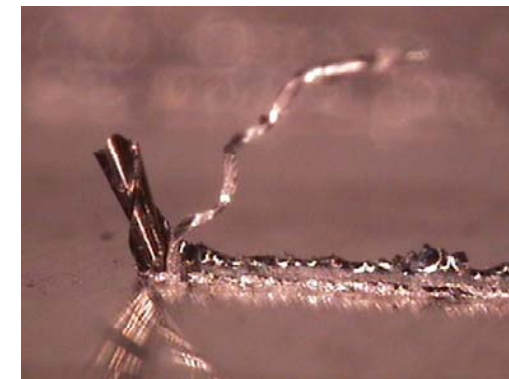
Cost structure is different from macro machining

- Tool cost dominates



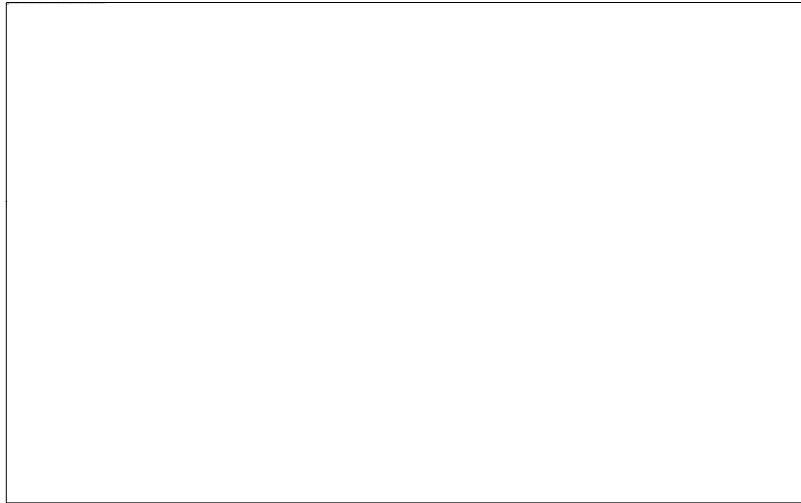
27

Broken Micro Tool



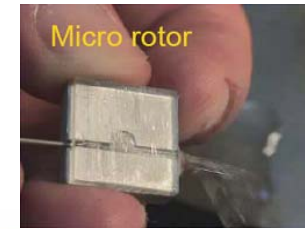
28

From Concept to Part



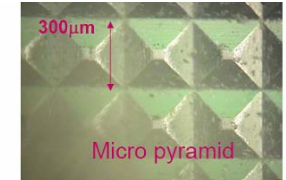
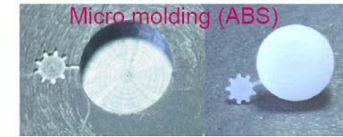
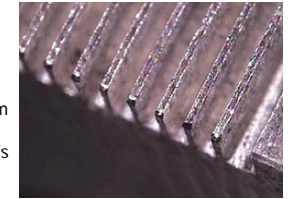
29

More Meso/Micro Parts



Rib width: 60 μ m
Height: 500 μ m
Tool: ϕ 200 μ m

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

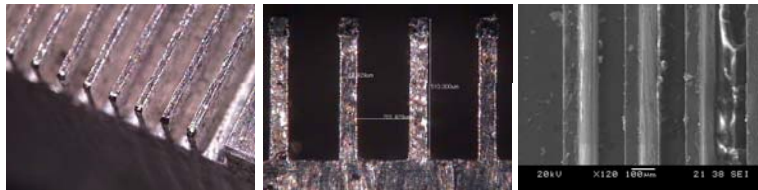


30

More Meso/Micro Parts

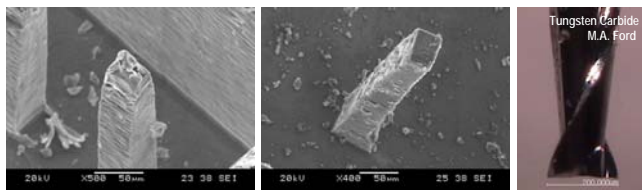


Micro walls



Material: Al 6061
Wall width: 60 μ m
Height: 500 μ m
Tool: ϕ 200 μ m
Spindle: 24,000rpm
DOC: 25 μ m
Feed rate: 100 μ m/s
Time: 3hr 28min

Micro square columns



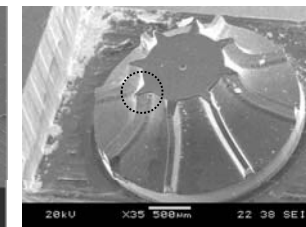
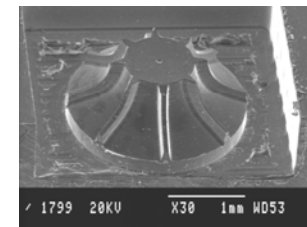
Tungsten Carbide
M.A. Ford
Material: Al 6061
Column width: 50 μ m
Height: 300 μ m
Tool: ϕ 200 μ m
Spindle: 30,000rpm
DOC: 5 μ m
Feed rate: 100 μ m/s
Time: 1hr 30min

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More Meso/Micro Parts



Micro rotor

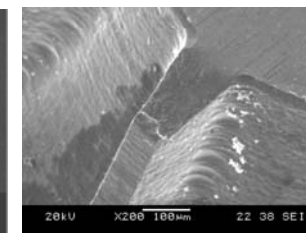
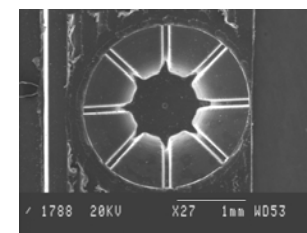


Material: Al 6061
Upper diameter: 1 mm
Lower diameter : 2.5mm
Spindle: 30,000 rpm
Roughing:

500 flat endmill
Feed rate: 1mm/s
DOC: 50 μ m
Time: 2hr 10min

Finishing:

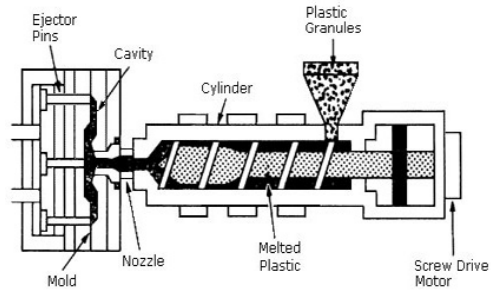
100 ball endmill
Feed rate: 100 μ m/s
DOC: 2 μ m
Time: 4hr



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Injection Molding

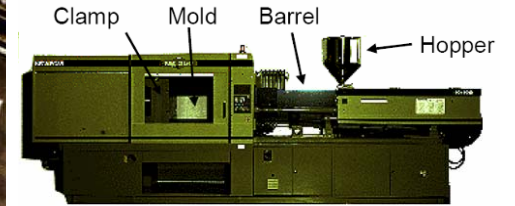
- One of the most common methods of shaping plastic resins
- Accomplished by large machines called injection molding machines



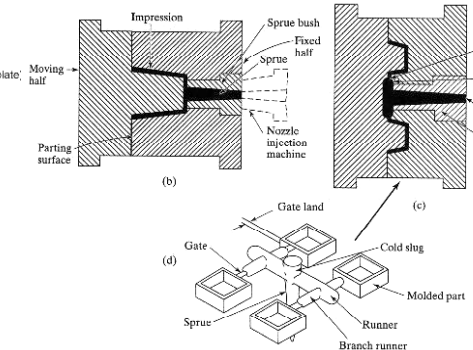
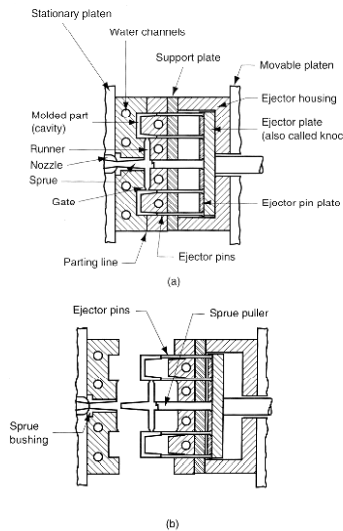
< Diagram of a typical injection molding process >

Injection Molding

- Injection molding machines



Injection Molding (cont.)



Injection Molding (cont.)

- Types of Gate

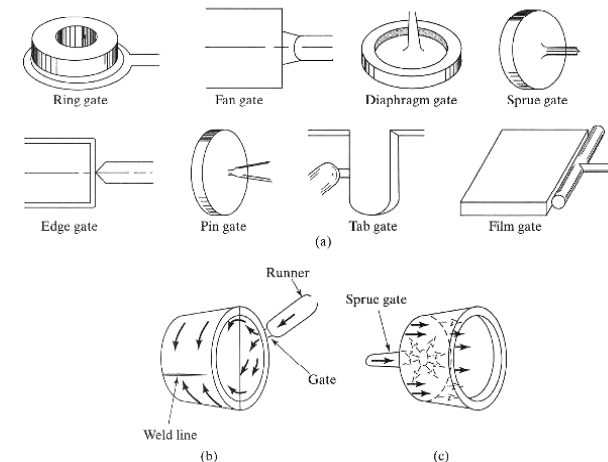


Figure 8.10 (a) Various gate designs in the top figure. The lower figure shows (b) an inefficient gating method and (c) the preferred method (on the right) to fill a cup (adapted from ICI and Pvc).

Injection Molding (cont.)

DFM in injection molding I

1-3 성형품 설계 요령

항목	사용되지 않는 예	없이 사용하는 예	설명
단립사인			기울어진 보스 또는 홈안은 단립의 구조적 적절 또는 대형으로 되기 때문에 적당 사인에 따라 써 주어야 되도록 한다.
코어			코어에 비교적 큰 사인도 코어를 관통하면 고강도 코어의 없으므로 두 방향에서 두 개의 코어를 만들어 주는 것이 좋다.
성형품 모양			모양 변경의 사용처부터 끝은 균일토록서 제작이 되는 것을 권한다.
			원시안은 코어의 손상이나 코어의 형상 치수에 나 용이하다. 코어 호일 구조의 경우나 비스무리한 면에 되도록 그 면 제거 한다.
			같은 부품을 되도록 세로로 된 방향으로 놓도록 한다.
			감행에서 코어용 코어의 형상은 수축에 따른 움직임을 고려한다.

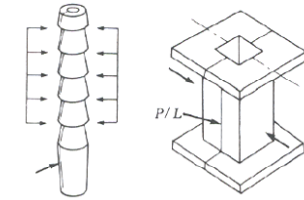
항목	사용되지 않는 예	없이 사용하는 예	설명
상면용 두께			외면의 코어, 즉 두께 단방향의 한쪽 면에 코어가 위치하면, 그 방향이 없는 경우는 사용이 곤란하다.
			코어는 코어에는 최대의 효율을 얻는다.
상면용 두께			상면용 두께는 되도록 균일하게 두께 두께로 한다.
			단면의 양두께가 수직으로 균일하게 되도록 되도록 하고 상면용 두께는 균일하게 한다.
			같이 같은 단면 부분은 재료의 종단 수축이 다르다.
보스			보스가 강도를 강도화 되도록 만들고 외면에 보스 받는다.
리브			같은 코어는 같 배제에 위치 하도록, 되도록 큰 배제에 구 배제 놓일 것

Injection Molding (cont.)

DFM in injection molding II

항목	사용되지 않는 예	없이 사용하는 예	설명
문자			동일한 문자는 들어나온 문자에 의하여 형상이 균일하다. 필드도형 구조는 그 한 대가 된다.
성형품 모양			형에서 형이될 때 코어에 두께의 형이 될지라도 균일하게 있도록 되도록 한다.
			구멍을 관통하기가 곤란한 때에는 적당한 위치를 확인하고 보스 또는 스프로트만 넣는 것이 좋다.

면사도	면사도	설명
		성형을 할 때 면사도를 확인하게 고려하는 것 있도록 한다. 면사도를 확인하고 균형을 맞춘다. 면사도가 균형을 맞춘다.
		면사도 나서는 나사가 성형물에서 맞은 것을 확인하고 보스 또는 스프로트만 넣어야 되도록 한다.

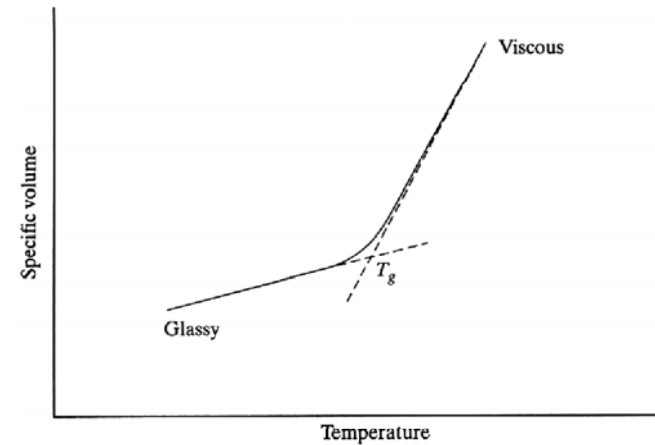


Injection Molding (cont.)

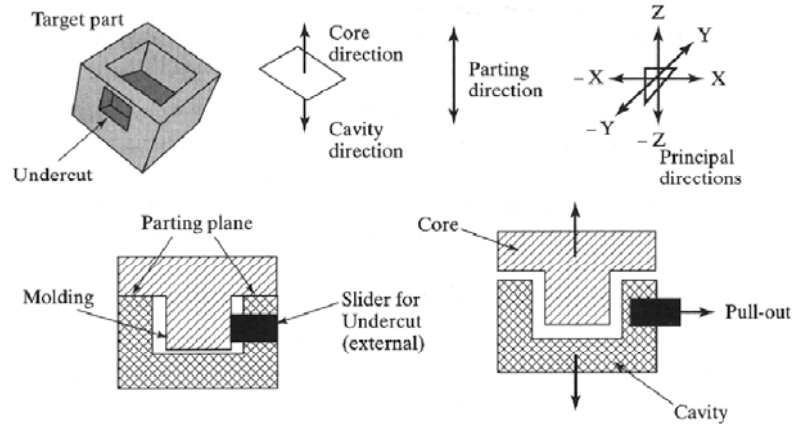
DFM in injection molding III

<p>Don't</p> <p>$t \geq 4mm$</p> <p>Do</p> <p>Use ribs instead</p> <p>$0.065" \leq t \leq 0.5"$</p> <p>Minimize section thickness, cooling time is proportional to the square of the thickness of the part(s), and reducing the cooling time directly reduces costs.</p> <p>(a)</p>	<p>Don't</p> <p>Do</p> <p>No draft</p> <p>2° min</p> <p>Add thickness for draft</p> <p>Always provide a draft angle for easier mold removal.</p> <p>(b)</p>
<p>Don't</p> <p>Do</p> <p>$R = 3/8t \geq 0.06"$</p> <p>Avoid sharp corners, they produce stress concentrations and obstruct material flow.</p> <p>(c)</p>	<p>Don't</p> <p>$t_{rib} = t$</p> <p>Sink marks</p> <p>Do</p> <p>$t_{rib} = \frac{1}{2}t + 3r \text{ min}$</p> <p>Keep rib thickness less than 60% of the part thickness to prevent voids and sinks.</p> <p>(d)</p>

Glass Transition Temperature, T_g



Mold Description

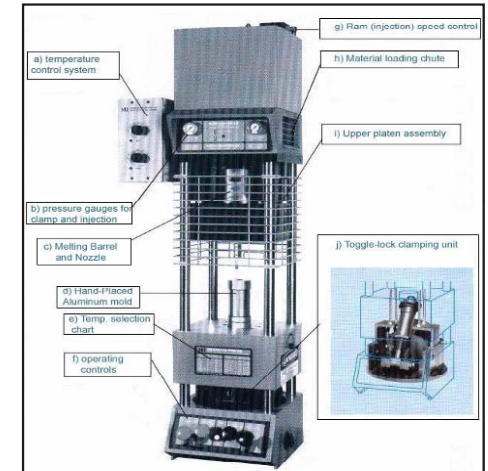


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Injection Molding (cont.)

▪ 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 >

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Thank you for your attention!

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