Design for X (DFX)

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Introduction of DFX

- Success in product manufacturing requires integration between the various phases of the product life cycle.

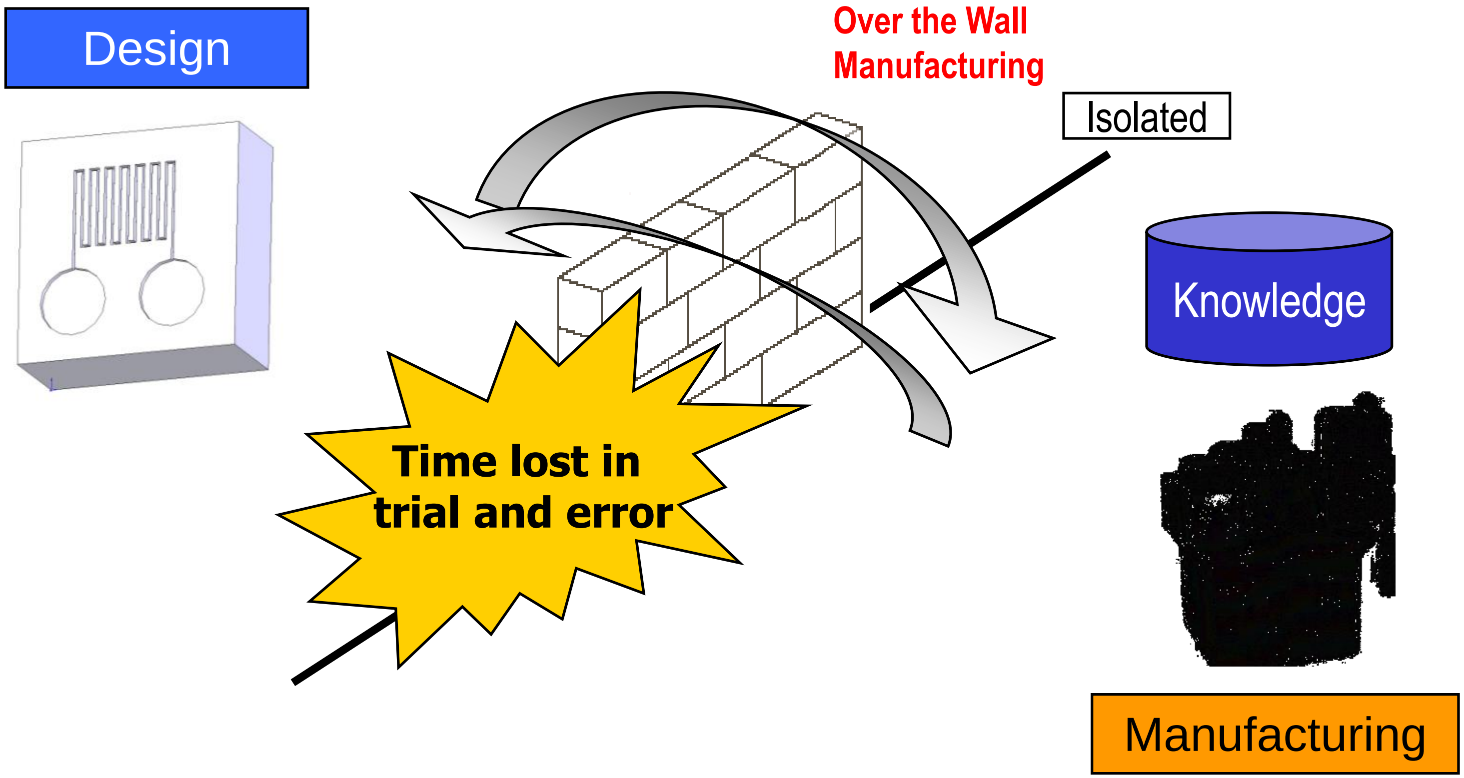
  – Ulrich and Eppinger, 1995

- One of the key aspects of integration during the design process is “Design for X (DFX)”
  - Design for Manufacturing (DFM)
  - Design for Assembly (DFA)
  - Design for Disassembly (DFDA)
  - Design for Environment (DFE)

⋮

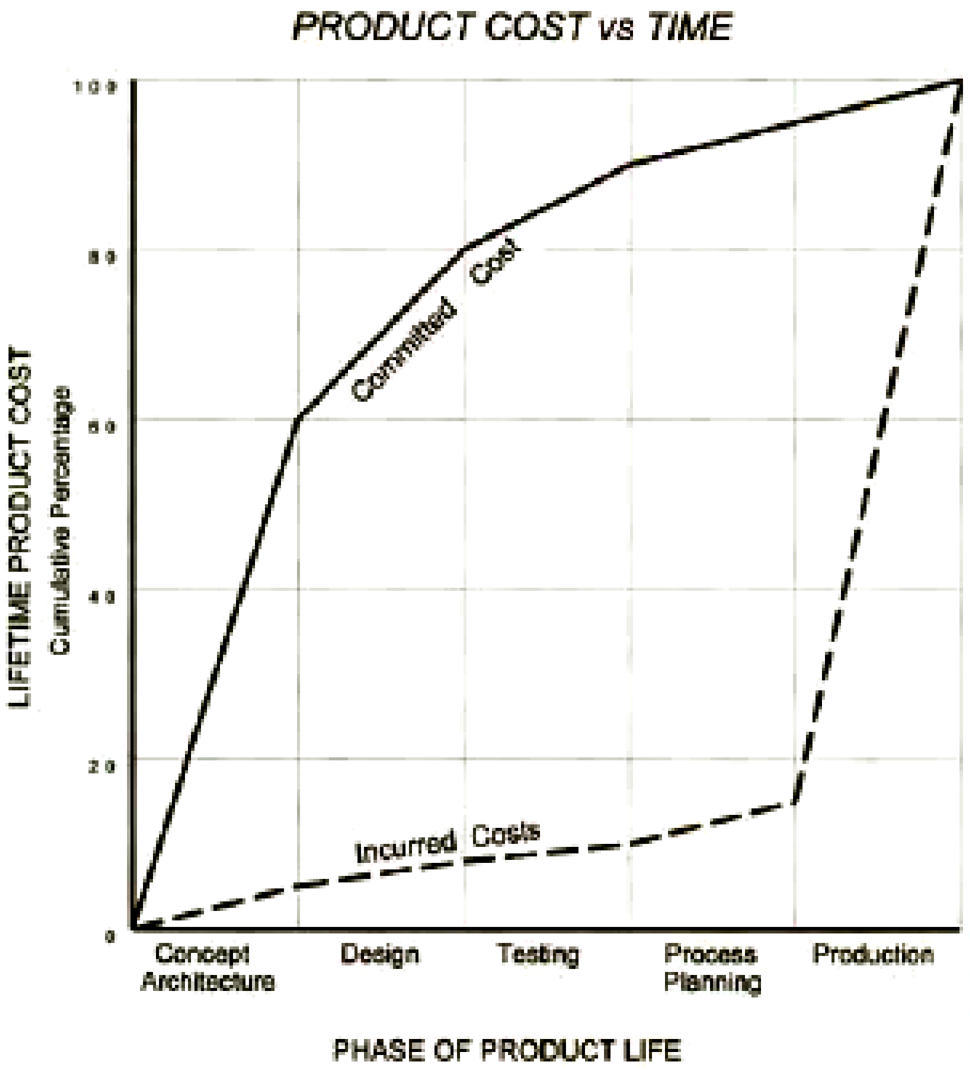
1. Design for Manufacturing (DFM)

- Traditional Design and Manufacturing Process



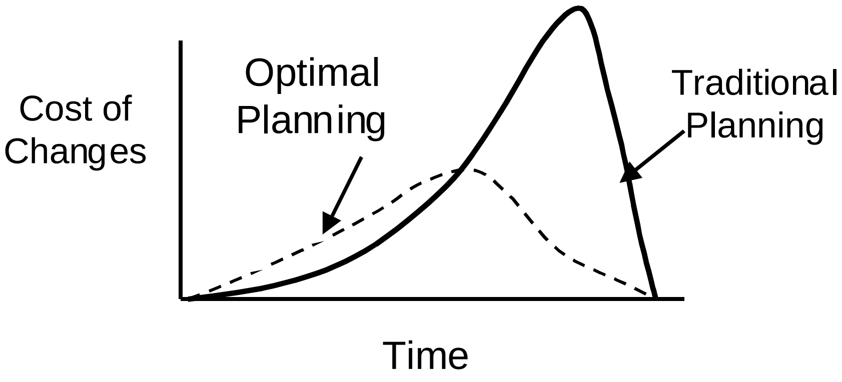
1. Design for Manufacturing (cont.)

- Paradigms of DFM
  - Design decision affects manufacturing cost and productivity
  - Designers play important role not only in shaping, but also in manufacturability, cost, and life cycle of products

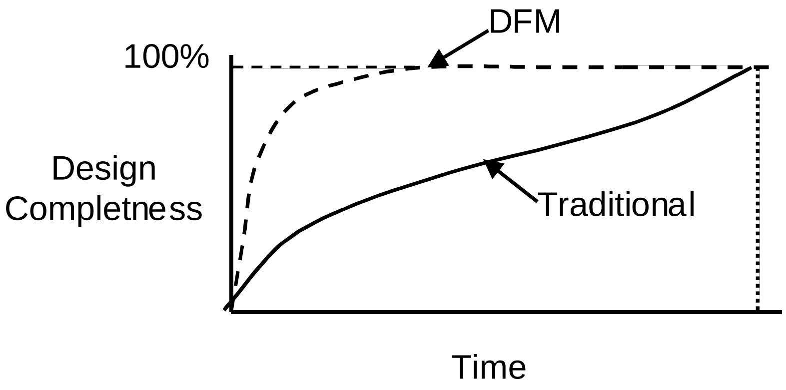


1. Design for Manufacturing (cont.)

- Objectives of DFM
  - Identify product concepts which are inherently easy to manufacture
  - Design components for ease of manufacture.
  - Integrate product and process design to ensure an optimum combination of function and manufacturability.



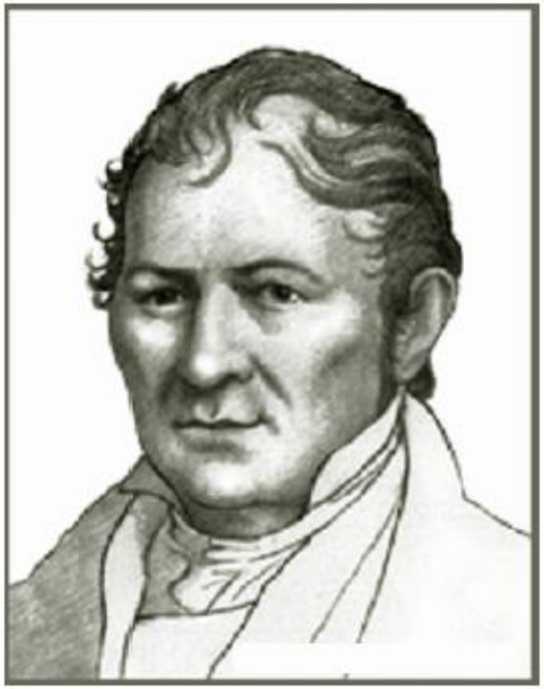
< Costs of change vs. time >



< Design completeness vs. time >

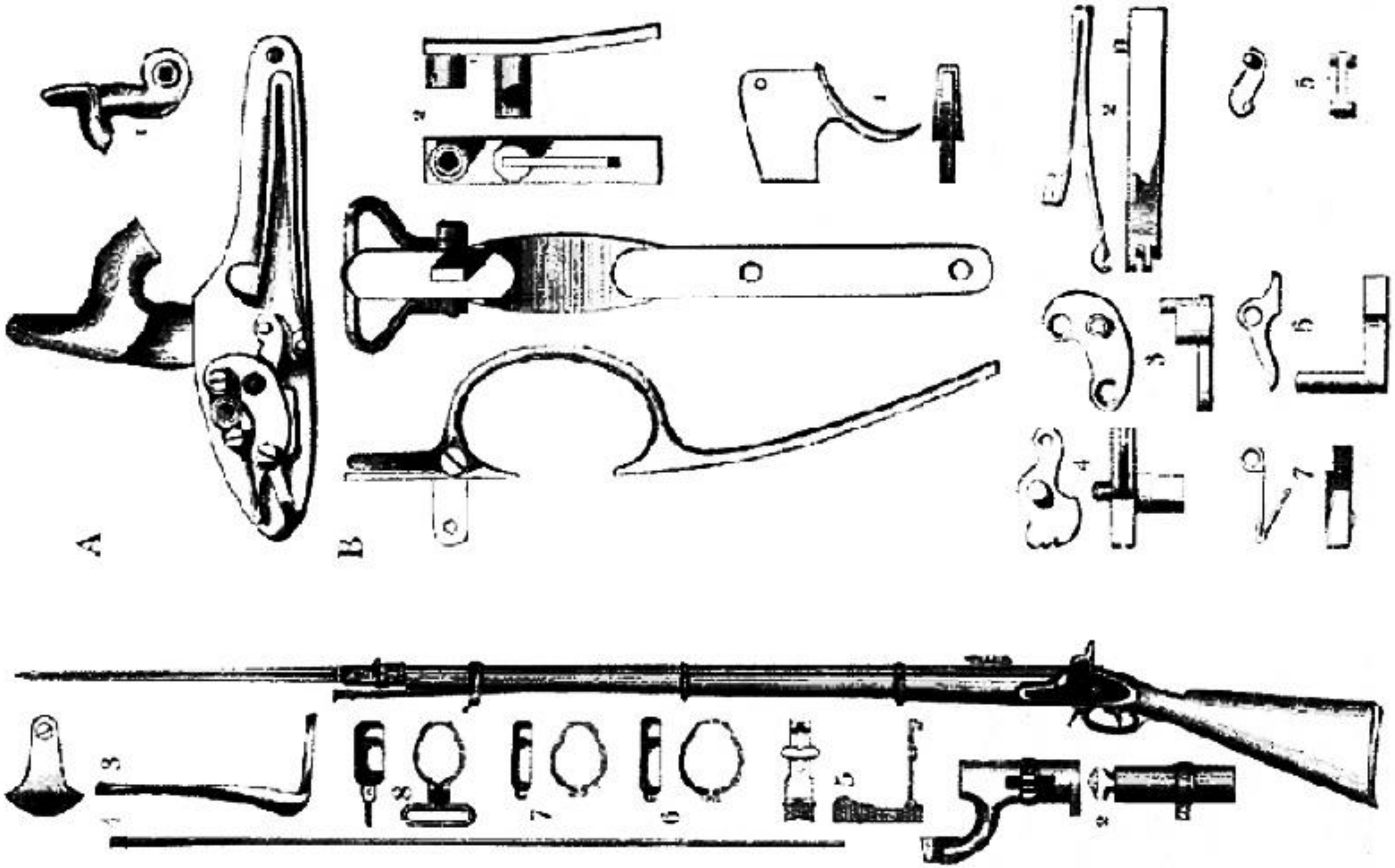
History of DFM I

- Eli Whitney (19C)
    - Musket (gun) manufacturer
    - Redesign each part to a specific *dimension* with a limited *tolerance*
    - Using fixtures, gauges, and specially developed machines, each part could be made by semi-skilled workers (instead of expert artisans) at a faster and less costly rate
    - Changed manufacturing process of parts from sand casting to forging resulted in increased accuracy



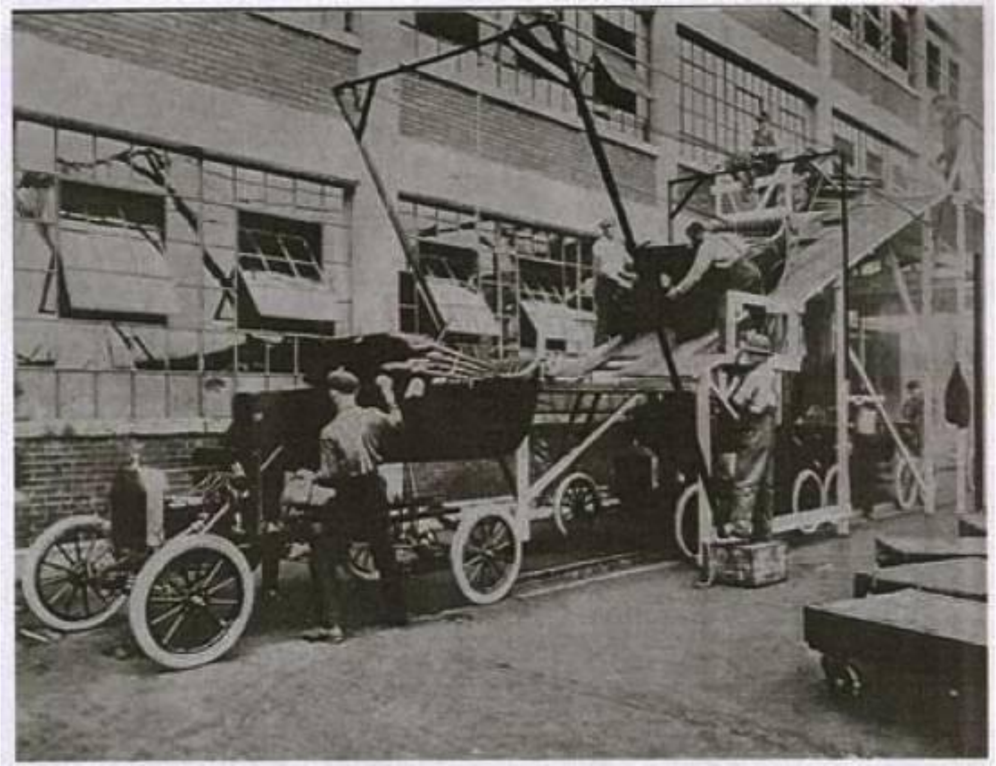
History of DFM I (cont.)

- Whitney’s Musket



History of DFM II

- Henry Ford (1907)
  - Lower cost from standard parts
  - Simple part design
  - Mass production



- *Conveyor system*
  - Price reduction
  - $2000/car → $350/car
  - 1908~1927: 15 million cars sold

DFM category

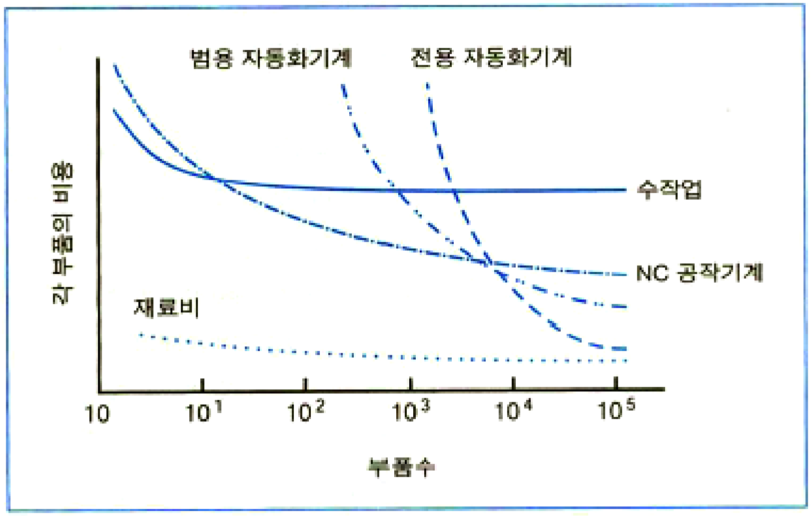
- General
- Process specific
- Product specific
- Design for Assembly (DFA)

General principles of DFM

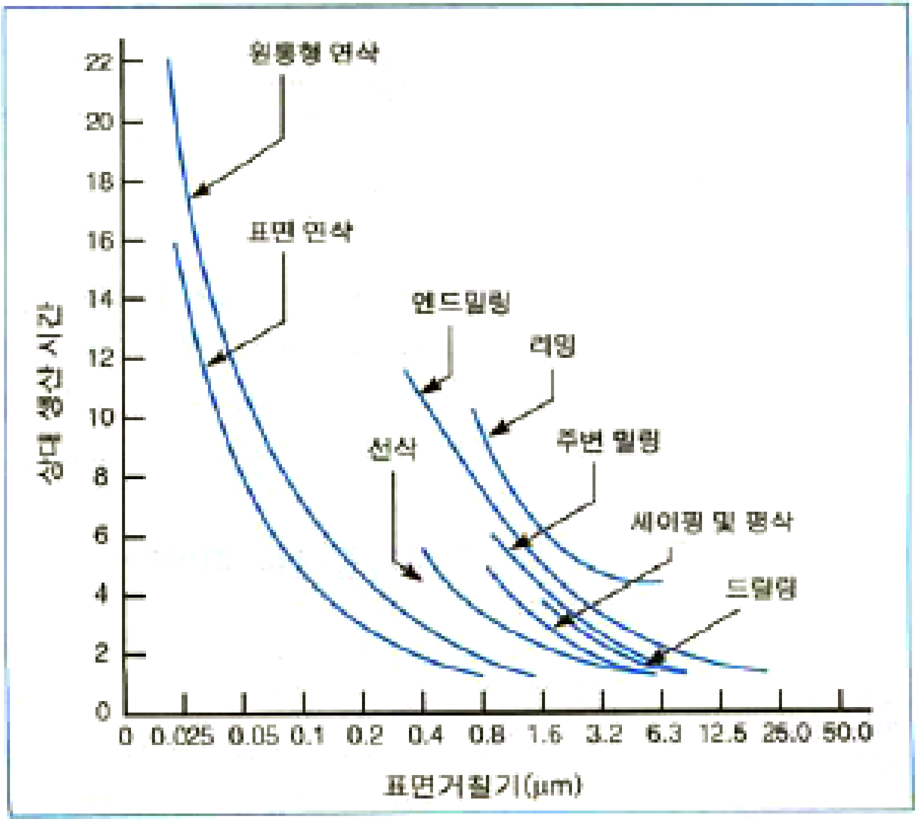
- Minimum number of parts
- Standard parts
- Modular design
- Multi-functional parts
- The same parts to various products
- Maximum surface roughness and tolerance
- Avoid secondary process
- Use materials easy to manufacture
- Consider number of parts to be manufactured
- Avoid many components
- Minimize handling of parts

General principles of DFM (cont.)

- Per part cost

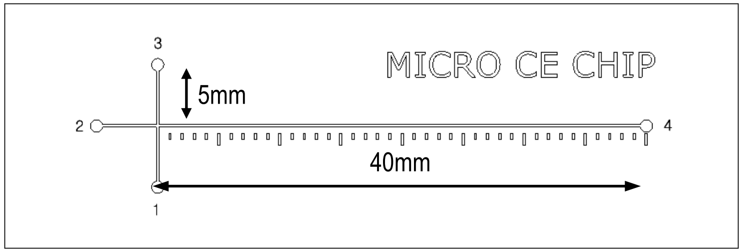


- Manufacturing Time vs. Surface Roughness



Fabrication of Microchip - I

- Microchip for capillary electrophoresis
  - Typical micro component of μ-TAS (Micro Total Analysis System)
  - Dimensions of micro chip
    - Channel width: 200 ㎛
    - Channel height: 300 ㎛
    - Reservoir diameter: 1 mm
    - Reservoir 2 – 4 : 45 mm
    - Reservoir 1 – 3 : 10 mm
- Fabrication via direct machining
  - Machining with φ200 ㎛ endmill on PMMA
  - Machining conditions
    - Feed rate: 0.1 mm/s
    - Spindle speed: 30,000 rpm
    - Depth of cut: 30 ㎛
    - Machining time: 51 min
  - Prototype within 2㎛ dimensional error



The 2-D Drawing of Microchip

➔ Reservoir 1 -4

- Reservoir 1: buffer reservoir
- Reservoir 2: Sample injection
- Reservoir 3: Sample waste
- Reservoir 4: Separation channel

Microchip by direct machining

Comparison of processes

(a) PR patterning on silicon

1h
$6.65

(b) Silicon DRIE for channel

1 hr
$102.66

(c) Hot embossing with PMMA

5 min
$42.78

(d) Detaching the silicon mold

30 min
$6.65

(d) PMMA plate fusion bonding

30 min

- Easy to crack (brittle mold)
- Short life time of mold
- Detach problem

Hot Embossing / Si mold

(a) PR patterning on silicon

30 min
$6.65

(b) Silicon DRIE for channel

1 min
$102.66

(c) Oxide deposition on backside

30 min
$14.26

(d) Ti / Au sputtering

1 hr
$28.52

(d) Ni electroplating

8 – 10 hr
$165.4

(e) Ti/Au/Silicon removal (TMAH / HF)

30 min
$30

(f) Hot embossing with PMMA

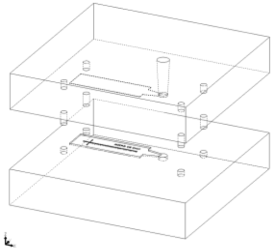
5 min
$42.78

(d) Detaching the Ni mold

30 min
$6.65

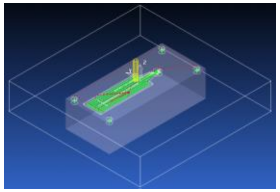
- High cost / long time / complicated process

Hot Embossing / Ni mold



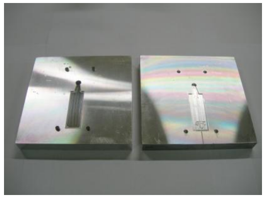
(a) CAD modeling

15 min



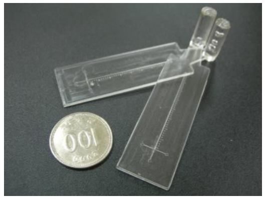
(b) Tool path generate

15 min



(c) Machining

1 hr



(d) Injection molding

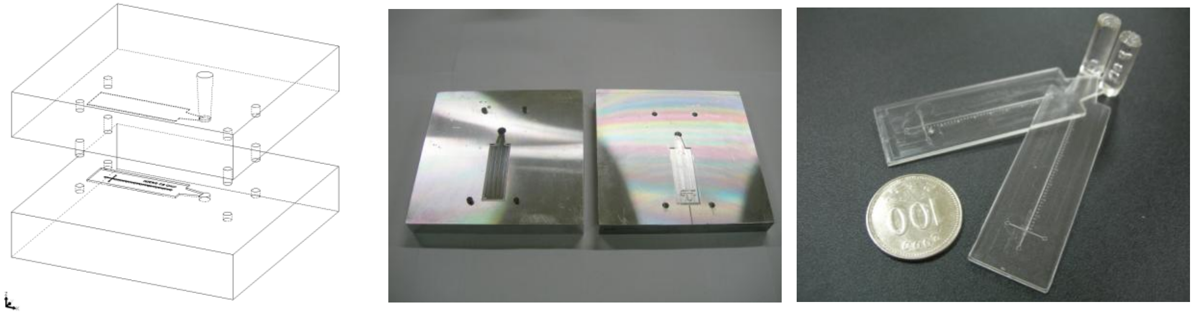
15 min

- Rapid and cheap manufacturing

Injection Molding

Fabrication of Microchip - II

- Injection molding
  - Mold machining
    - Mold size: 150mm×150mm×20mm
    - Roughing: φ4 mm, 30,000 rpm, 1 mm/s, 0.1mm DOC (1 hr 7 min)
    - Finishing: φ200 ㎛, 30,000 rpm, 0.1mm/s, 10㎛ DOC (32min)

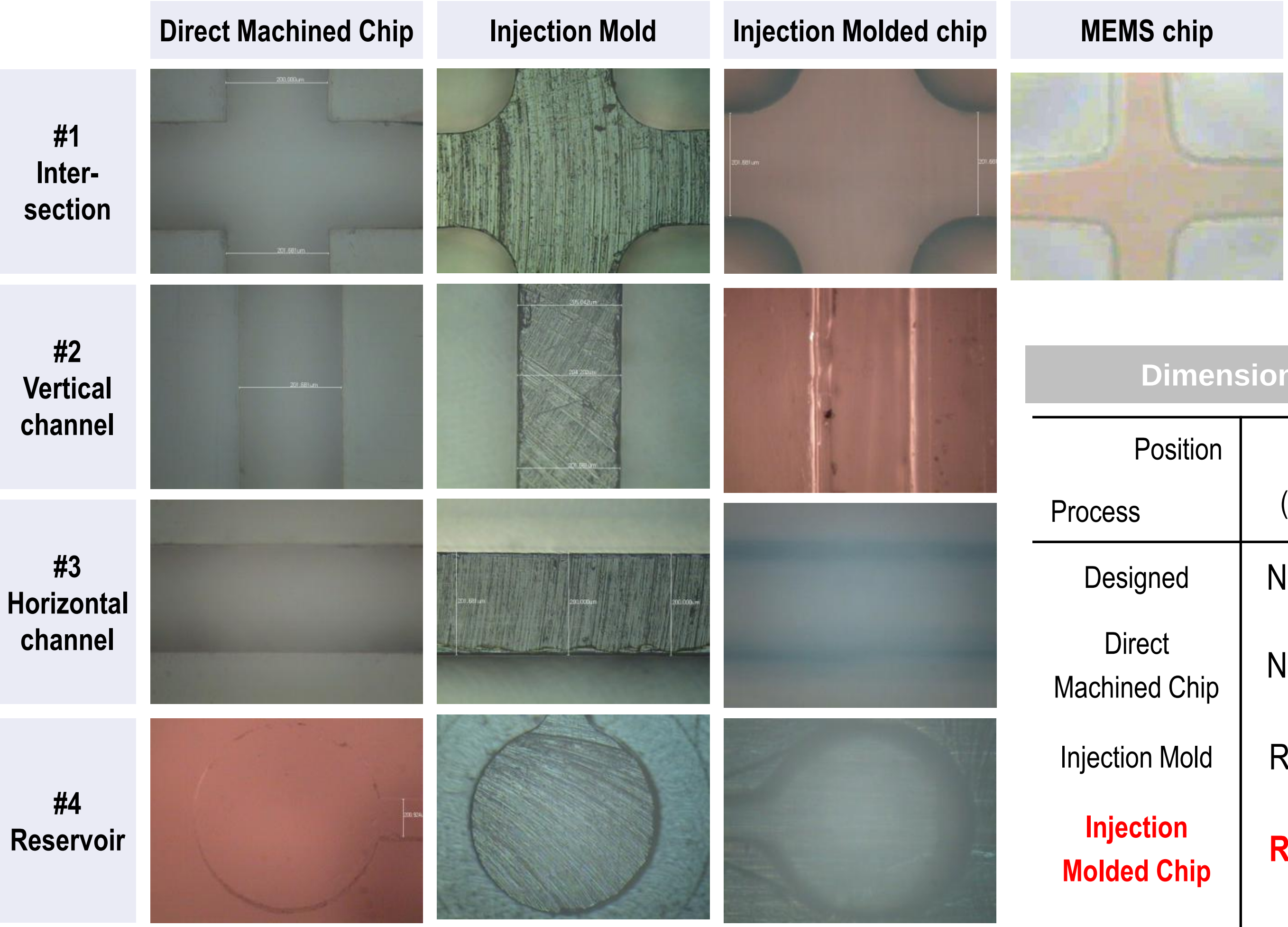


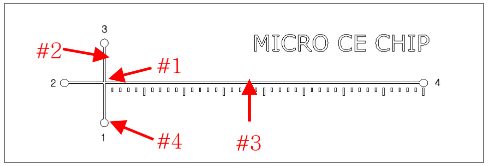
CAD Modeling of Injection Mold and Fabricated Microchip

- Injection molding machine
  - PMMA pellet : IF-850 (LG MMA)
  - Morgan press G-100T (Vertical type)
  - Nozzle and barrel temperature: 210 ℃
  - Clamping force: 14,000 lbf
  - Injection pressure: 6,000 psi (41MPa)

Fabrication of Microchip - III

- Dimensional tolerance of each microchips





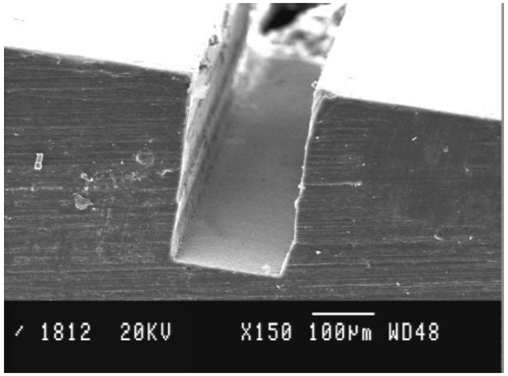
Dimensional Errors of Microchips

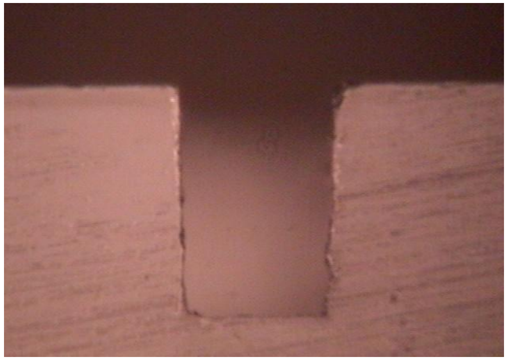
Position Process	#1 (㎛)	#2 (㎛)	#3 (㎛)	#4 (㎛)
Designed	No R.	200	200	1000
Direct Machined Chip	No R.	1.5	2	3
Injection Mold	R100	2	2.5	5.5
Injection Molded Chip	**R100**	**5.5**	**6**	**11**
MEMS Chip	**R50**	**3.5**	**4**	**5**

Fabrication of Microchip - IV

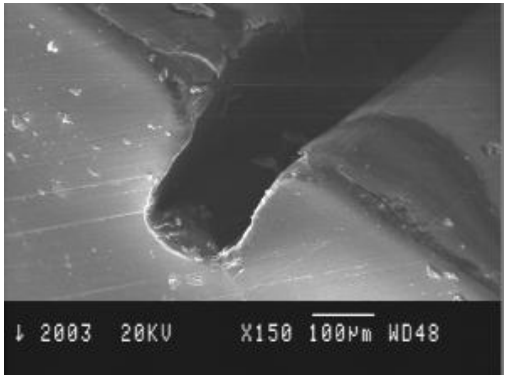
- Cross sections

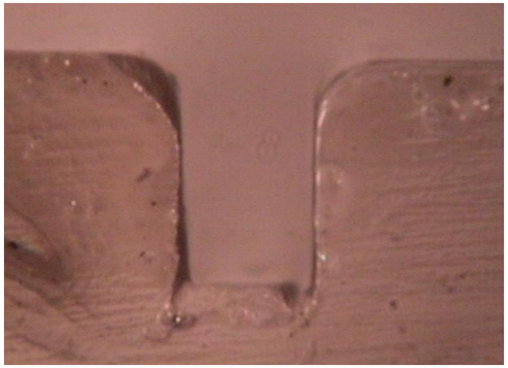
Direct Machined Chip



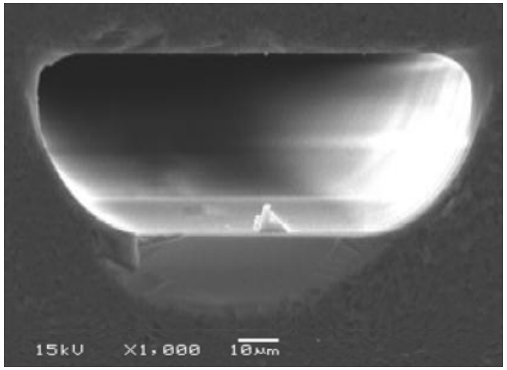


Injection Molded Chip





MEMS Chip



Reference

- Kim, M. S. and Kim, Y. G., "Fabrication of microchip electrophoresis devices and effects of channel surface properties on separation efficiency" , Sensors and Actuators B, 2005.

Evaluation of Cost

- Cost Estimation
  - Total cost of mechanical micro machining: $C_{total} = C_w + C_p + C_m + C_t$

Total Cost of Mechanical Micro Machining

Material Cost

C_w

$$C_w = V\rho C_{um}$$

V: volume
ρ: density
C_{um}: mass per unit

Preparation Cost

C_p

$$C_p = WT_p$$

W: wage per hour
T_p: preparation time (hour)

Machining Cost

C_m

$$C_m = T_m\left(W + B_m\right)$$

$$B_m = M_t + M_t\left(\frac{machine\_overhead[\%]}{100}\right)$$

$$M_t = \left(\frac{initial\_purchase\_machine\_cost}{working\_hours \times repayment\_period}\right)$$

W: wage per hour
T_m: machining time (hour)
B_m : Indirect cost
M_t: Depreciation rate

Tool Cost

C_t

$$C_t = y\left(\frac{T_m}{T}\right)$$

$$T = \left(\frac{C}{V}\right)^{\frac{1}{n}}$$

y: initial tool cost
T_m: machining time (hour)
T: tool life
V: cutting speed

Evaluation of Cost - II

- Cost Evaluation
  - B_m (Indirect cost)

$$B_m = M_t + M_t\left(\frac{machine\_overhead[\%]}{100}\right)$$

  - M_t (Depreciation rate)

$$M_t = \left(\frac{initial\_purchase\_cost\_of\_machine}{working\_hours \times repayment\_period}\right)$$

  - Tool life of macro scale

$$T = \left(\frac{C}{V}\right)^{\frac{1}{n}}$$

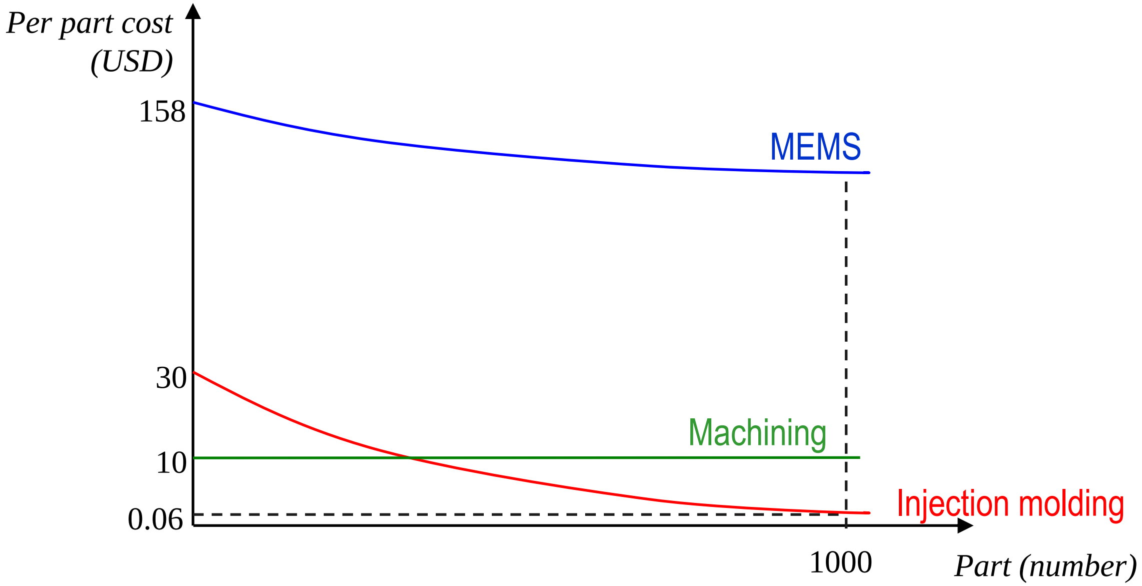
C, n: empirical constant
V: cutting speed

  - Reference of rental fee (MEMS)
    - Inter-university Semiconductor Research Center (SNU)

Item	***Direct machining***		***Injection molding***		***MEMS***
C_w	PMMA	$0.02	Al	$7.78	Wafer $28.52 PR patterning $6.65 Mask $266 DRIE $96.05 Oxidation $14.26 Ti/Au sputtering $28.52 Ni electro-plating $165.4 Si/Au/Ti removal $28.53 Total $632.92 /4ea
C_p	T_p	10 min	$T_{p,machining.}$ $T_{p,injection.}$	10 min 30 min	
	W	$2.37 /hr	W	$2.37/hr	
Subtotal		$0.4		$1.58	
C_m	T_m	51 min	$T_{m,roughing.}$ $T_{m,finishing}$ $T_{m,injection}$	67 min 32 min 1 min	
	M_t	$1.81	$M_{t,machining}$ $M_{t,injection}$	$1.81 $0.48	
	B_m	$5.42	$B_{m,machining}$ $B_{m,injection}$	$5.42 $1.43	
	W	$2.37 /hr	W	$2.37/hr	
Subtotal		$6.62		$15.36	
C_t	y	$43 /ea	$y_{roughing}$ $y_{finishng}$	$4/ea $43/ea	
	T_m	51 min	$T_{m,roughing}$ $T_{m,finishing}$	67 min 32 min	
	C	600	$C_{roughing}$ $C_{finishing}$	600 -	
	V	300m/min	$V_{roughing}$ $V_{finishing}$	300m/min -	
	n	0.14	$n_{roughing}$ $n_{finishing}$	0.14 -	
	T	9hr: at 0.1mm/s	$T_{roughing}$ $T_{finishing}$	141min 545min	
Subtotal		$4		$4.65	
Total		***$11.04/ea***		***$29.37/ea***	***$158.23/ea***

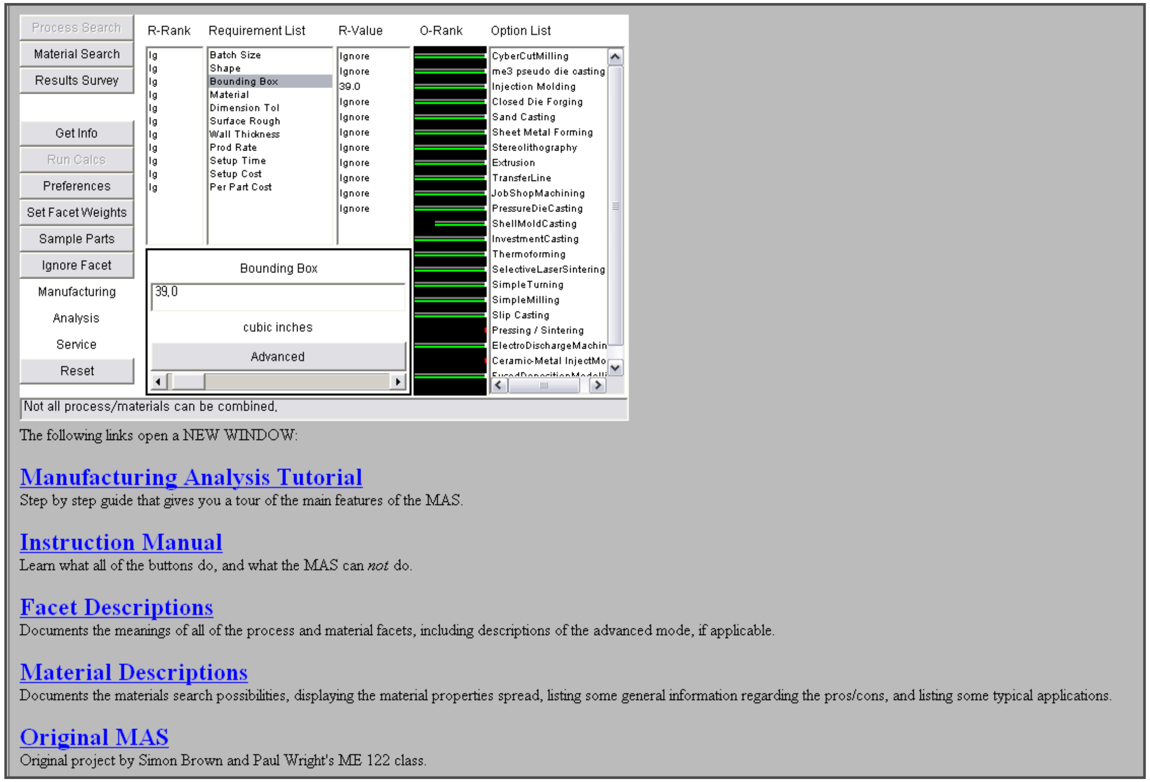
Evaluation of Cost - III

- Per part cost of mass production
- Cost of injection molding
  - Batch size: 1000 unit per 1 mold
  - Mass production cost of 1000 unit
    - Material cost: \$0.02 × 1,000 = \$20
    - Injection molding: $C_{m,injection} = T_{m,injection}(B_m + W) = 2.7 \times (1.43 + 2.37) =$ \$10.26
    - $C_{total,1000ea} = C_{total,1part} + 10.26 = 29.37 + (20 + 10.26) =$ \$ 59.63
    - Therefore, per part cost = \$0.06



MAS

- Manufacturing Advisory Service
- DFM at conceptual design stage
    - Suggestion of manufacturing processes
    - Suggestion of materials



R-Rank	Requirement List	R-Value
Ig	Batch Size	Ignore
Ig	Shape	Ignore
Ig	Bounding Box	39.0
Ig	Material	Ignore
Ig	Dimension Tol	Ignore
Ig	Surface Rough	Ignore
Ig	Wall Thickness	Ignore
Ig	Prod Rate	Ignore
Ig	Setup Time	Ignore
Ig	Setup Cost	Ignore
Ig	Per Part Cost	Ignore

Bounding Box: 39.0 cubic inches

Option List
CyberCutMilling
me3 pseudo die casting
Injection Molding
Closed Die Forging
Sand Casting
Sheet Metal Forming
Stereolithography
Extrusion
TransferLine
JobShopMachining
PressureDieCasting
ShellMoldCasting
InvestmentCasting
Thermoforming
SelectiveLaserSintering
SimpleTurning
SimpleMilling
Slip Casting
Pressing / Sintering
ElectroDischargeMachin
Ceramic-Metal InjectMo

Not all process/materials can be combined.

The following links open a NEW WINDOW:

Manufacturing Analysis Tutorial
Step by step guide that gives you a tour of the main features of the MAS.

Instruction Manual
Learn what all of the buttons do, and what the MAS can *not* do.

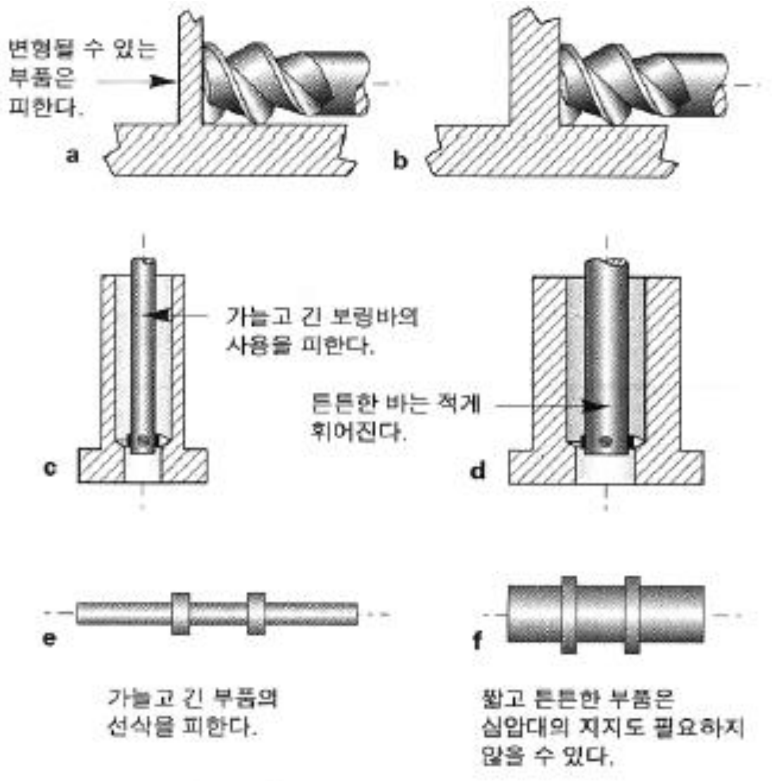
Facet Descriptions
Documents the meanings of all of the process and material facets, including descriptions of the advanced mode, if applicable.

Material Descriptions
Documents the materials search possibilities, displaying the material properties spread, listing some general information regarding the pros/cons, and listing some typical applications.

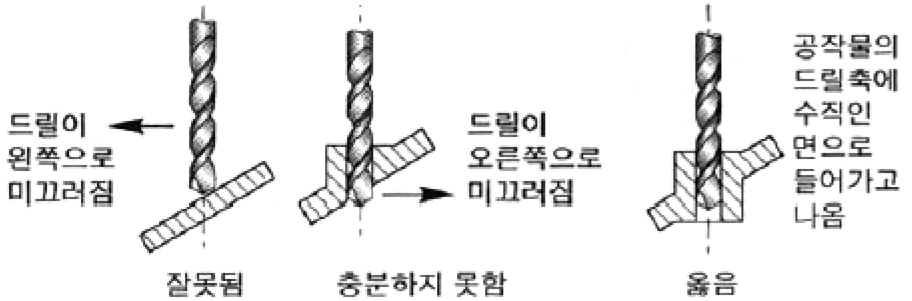
Original MAS
Original project by Simon Brown and Paul Wright's ME 122 class.

Process specific DFM

- Machining



- Drilling

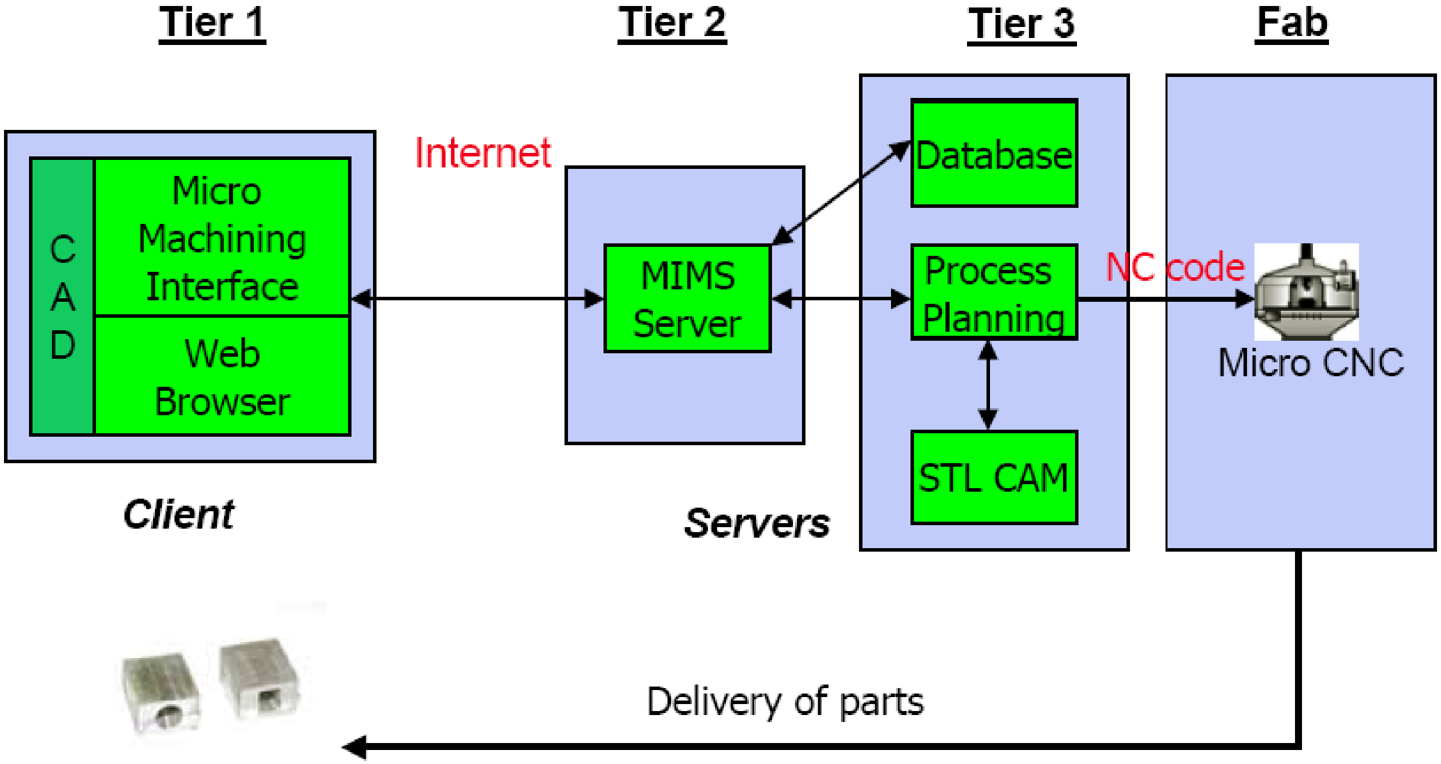


Web-based DFM systems - MIMS

- MIcro Machining System
- To bridge design and manufacturing
  - Guaranteed manufacturability
    - 3 axis micro milling
    - Design for Manufacturing (DFM)
  - Shared information and resources
  - Faster product development
  - Lower prototyping cost

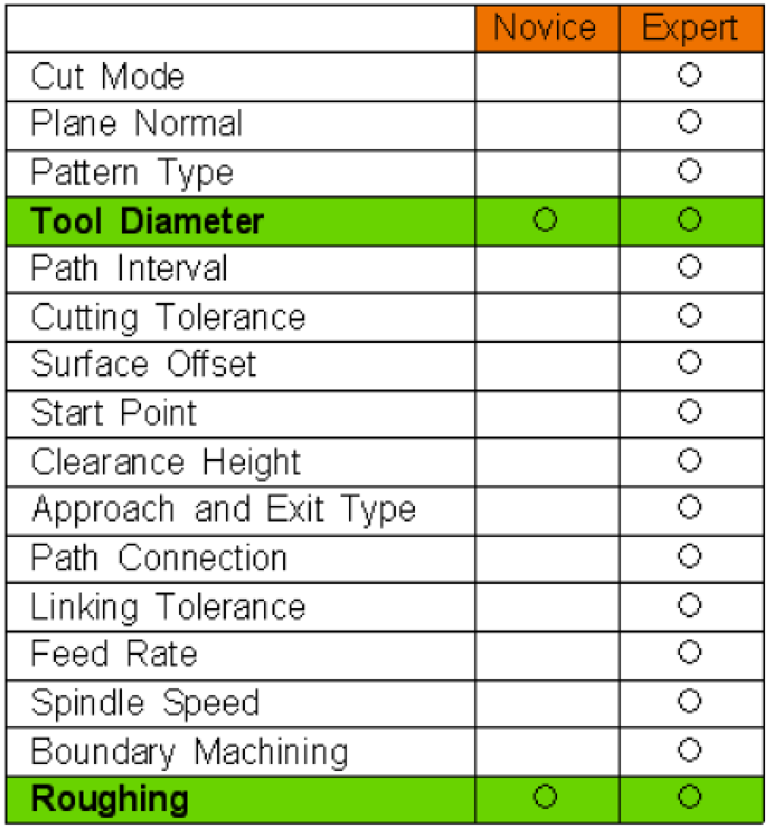
Web-based DFM systems - MIMS

- Architecture
  - Web-based system



Web-based DFM systems - MIMS

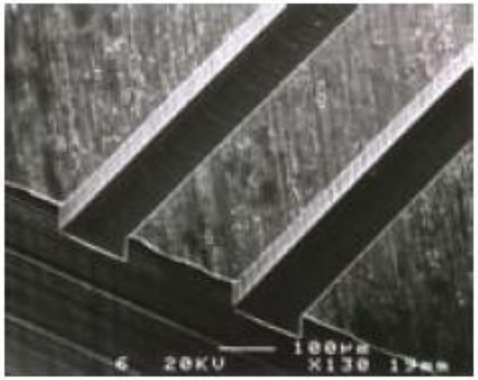
- DFM in machining: User Level
  - Expert mode:
    - 16 parameters
    - Max. control
  - Novice mode:
    - 2 parameters
      - Roughing
      - Tool diameter
    - Easy interface

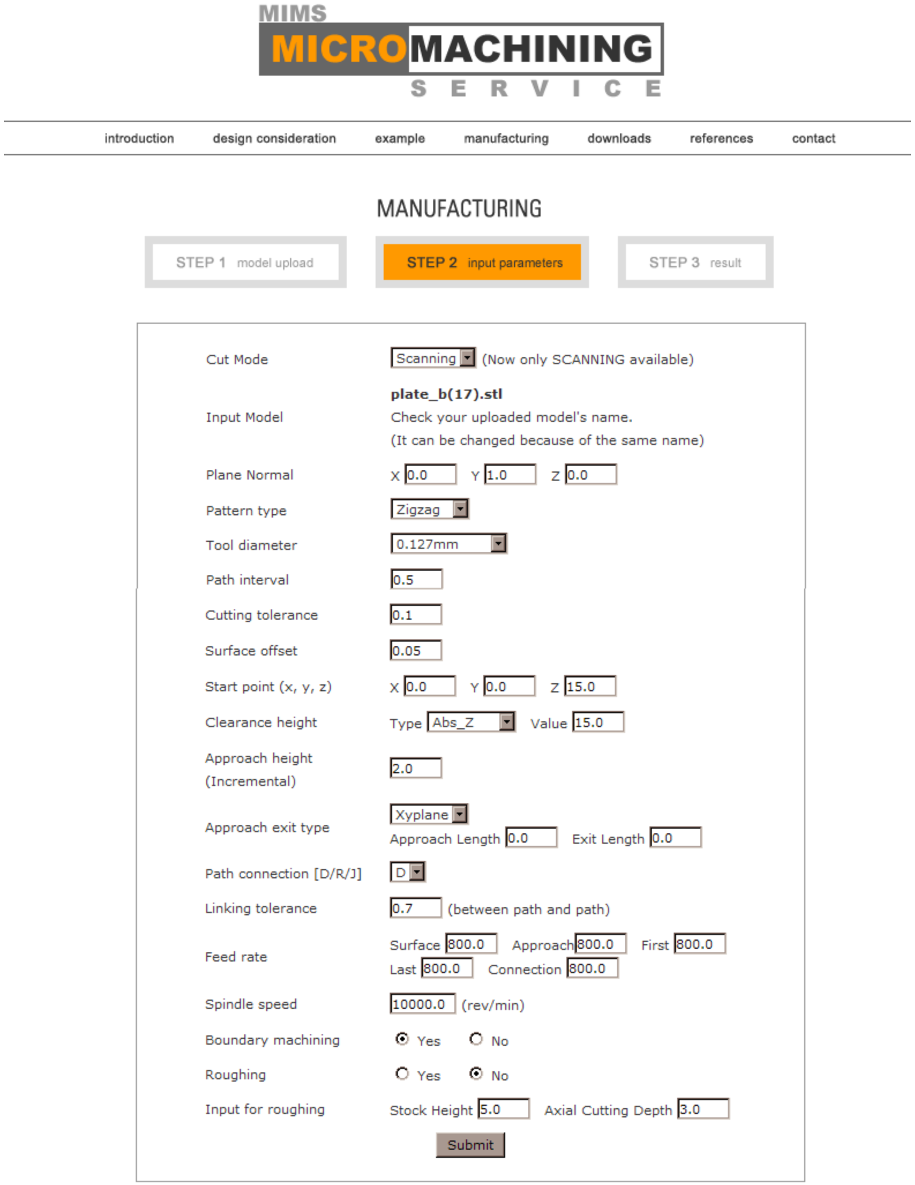


	Novice	Expert
Cut Mode		○
Plane Normal		○
Pattern Type		○
Tool Diameter	○	○
Path Interval		○
Cutting Tolerance		○
Surface Offset		○
Start Point		○
Clearance Height		○
Approach and Exit Type		○
Path Connection		○
Linking Tolerance		○
Feed Rate		○
Spindle Speed		○
Boundary Machining		○
Roughing	○	○

Web-based DFM systems - MIMS

- DFM: Thin Client UI
  - HTML form
  - Tool database
  - Interpolation tolerance 1㎛



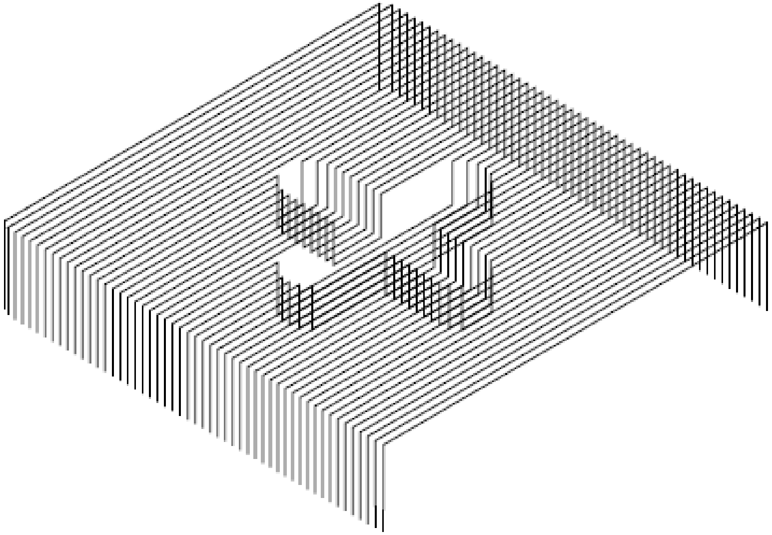


MANUFACTURING

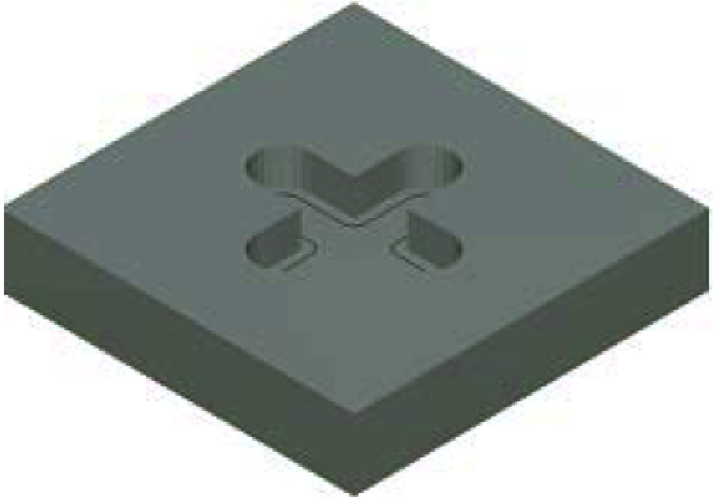
Cut Mode	Scanning (Now only SCANNING available)
Input Model	**plate_b(17).stl** Check your uploaded model's name. (It can be changed because of the same name)
Plane Normal	X 0.0 Y 1.0 Z 0.0
Pattern type	Zigzag
Tool diameter	0.127mm
Path interval	0.5
Cutting tolerance	0.1
Surface offset	0.05
Start point (x, y, z)	X 0.0 Y 0.0 Z 15.0
Clearance height	Type Abs_Z Value 15.0
Approach height (Incremental)	2.0
Approach exit type	Xyplane Approach Length 0.0 Exit Length 0.0
Path connection [D/R/J]	D
Linking tolerance	0.7 (between path and path)
Feed rate	Surface 800.0 Approach 800.0 First 800.0 Last 800.0 Connection 800.0
Spindle speed	10000.0 (rev/min)
Boundary machining	● Yes ○ No
Roughing	○ Yes ● No
Input for roughing	Stock Height 5.0 Axial Cutting Depth 3.0

Web-based DFM systems - MIMS

- DFM: NC Code Simulation



Scanning



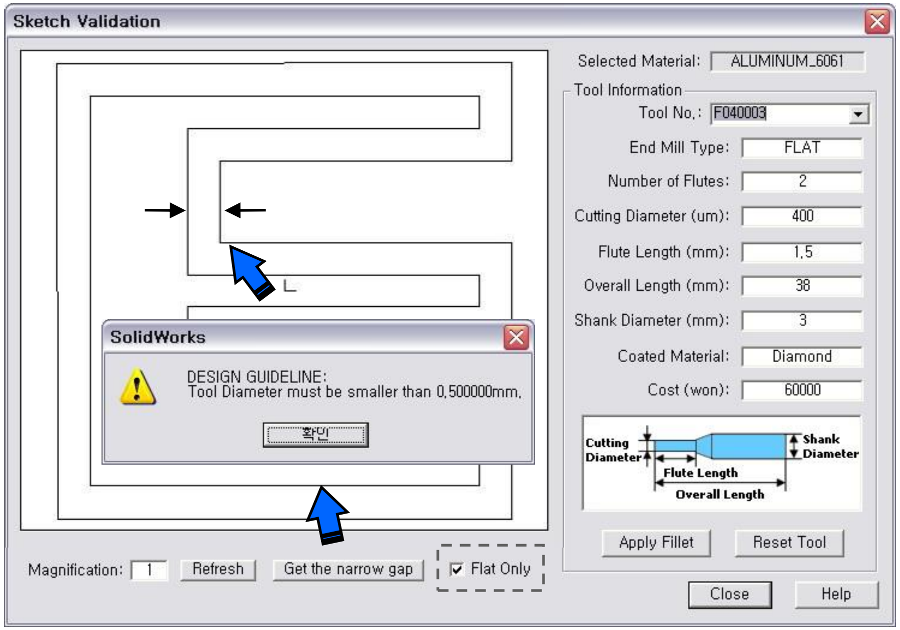
Pencil Cut

Issues in micro regime

- ✓ Run-out
- ✓ Tolerance of software

Web-based DFM systems - SmartFab

- Works in SolidWorks during channel or pocket modeling
- Sketch Validation
  - Improve machinability
  - Based on the tool information and DFM philosophy



Sketch Validation

Selected Material: ALUMINUM_6061

Tool Information

Tool No.: F040003

End Mill Type: FLAT

Number of Flutes: 2

Cutting Diameter (um): 400

Flute Length (mm): 1,5

Overall Length (mm): 38

Shank Diameter (mm): 3

Coated Material: Diamond

Cost (won): 60000

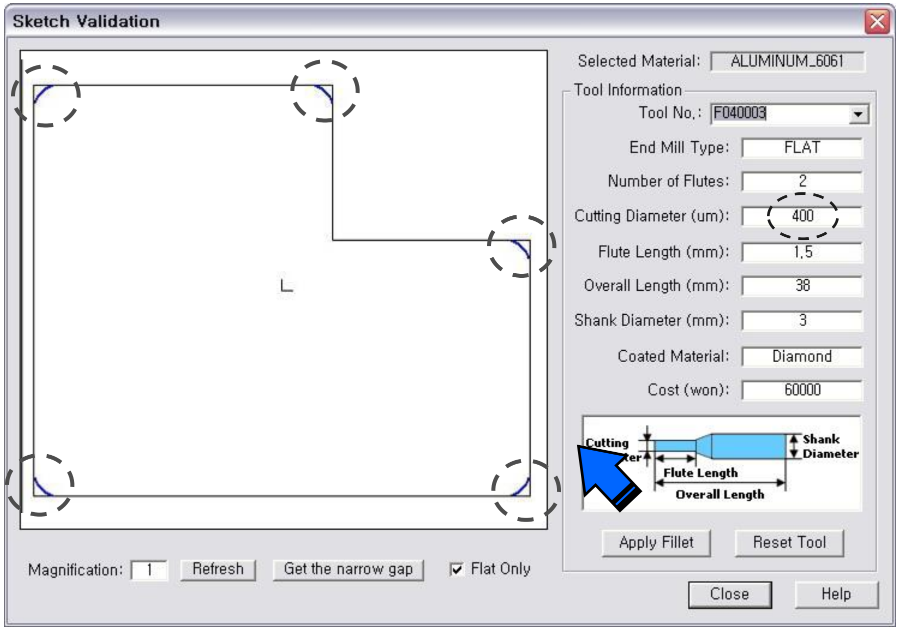
Magnification: 1

☑ Flat Only

SolidWorks

DESIGN GUIDELINE:
Tool Diameter must be smaller than 0,500000mm,

Check for minimum Gap



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Flute Length (mm): 1,5

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Coated Material: Diamond

Cost (won): 60000

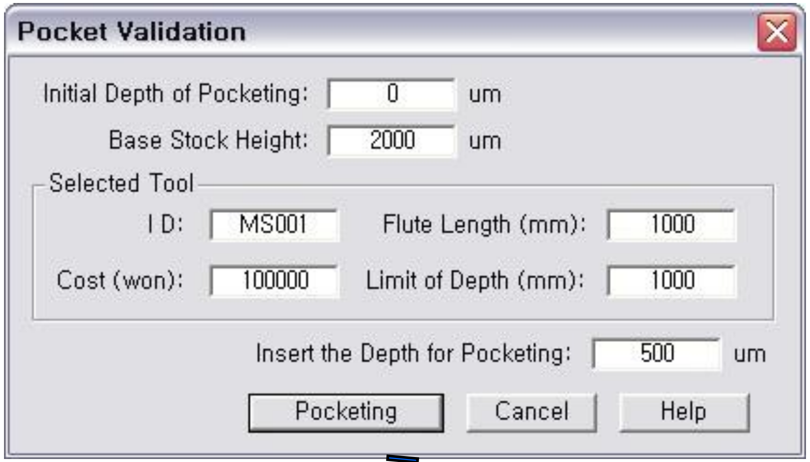
Magnification: 1

☑ Flat Only

Check for fillet

Web-based DFM systems - SmartFab

- Pocket Validation



Pocket Validation

Initial Depth of Pocketing: 0 um

Base Stock Height: 2000 um

Selected Tool

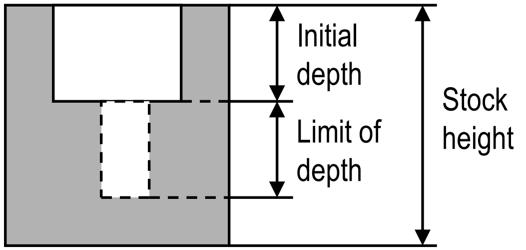
I D: MS001

Flute Length (mm): 1000

Cost (won): 100000

Limit of Depth (mm): 1000

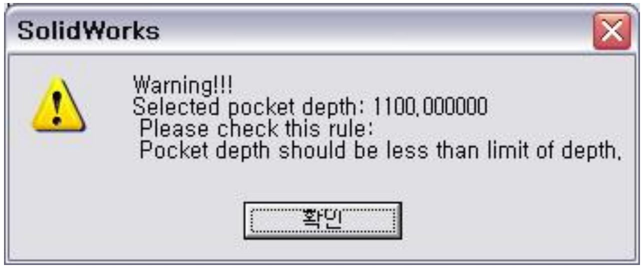
Insert the Depth for Pocketing: 500 um



For Multiple Pocketing:

Limit of depth <
stock height – initial depth

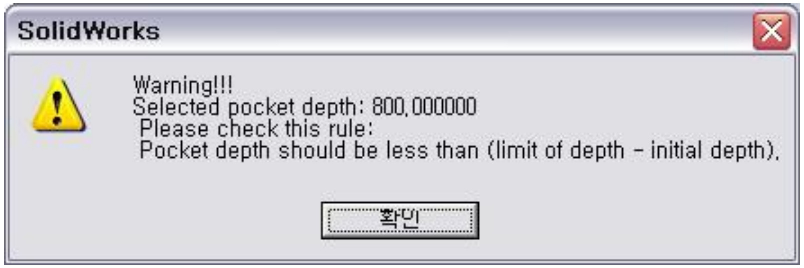
Fig 7. DFM in pocketing



SolidWorks

Warning!!!
Selected pocket depth: 1100.000000
Please check this rule:
Pocket depth should be less than limit of depth.

Case I. Depth limit



SolidWorks

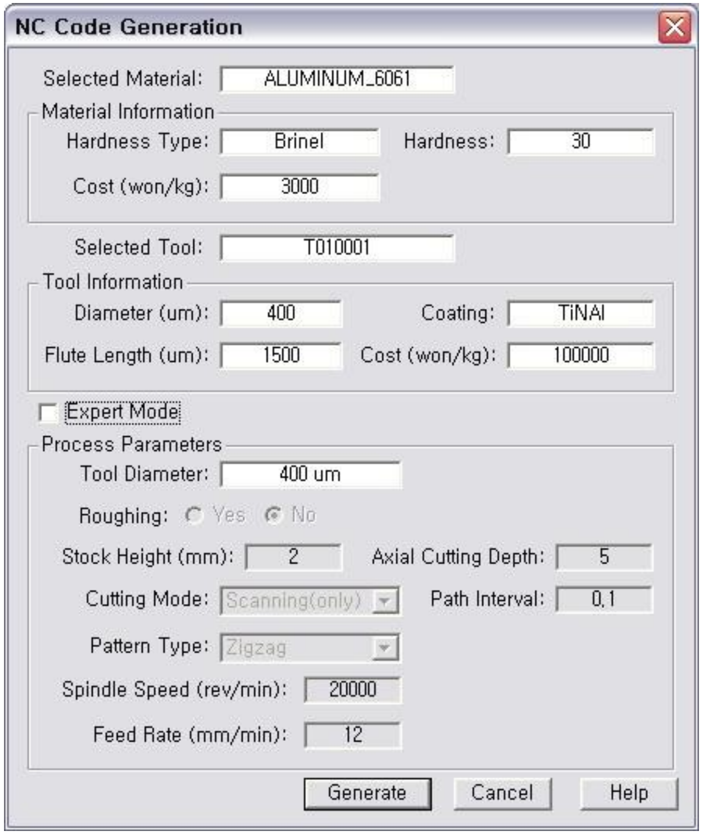
Warning!!!
Selected pocket depth: 800.000000
Please check this rule:
Pocket depth should be less than (limit of depth - initial depth).

Case II. Depth limit and initial depth

Examples of DFM in pocketing

Web-based DFM systems - SmartFab

- Convenience setting for NC code generation



NC Code Generation

Selected Material: ALUMINUM_6061

Material Information
Hardness Type: Brinel
Hardness: 30
Cost (won/kg): 3000

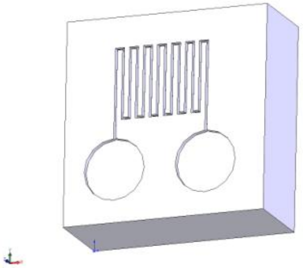
Selected Tool: T010001

Tool Information
Diameter (um): 400
Coating: TiNAl
Flute Length (um): 1500
Cost (won/kg): 100000

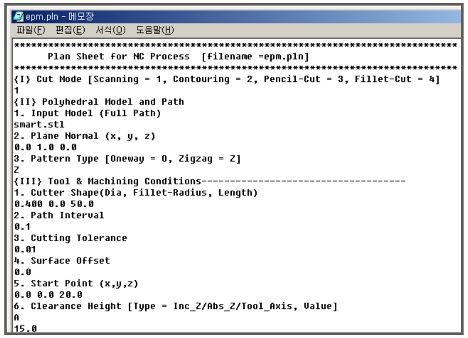
☐ Expert Mode

Process Parameters
Tool Diameter: 400 um
Roughing: ○ Yes ● No
Stock Height (mm): 2
Axial Cutting Depth: 5
Cutting Mode: Scanning(only)
Path Interval: 0,1
Pattern Type: Zigzag
Spindle Speed (rev/min): 20000
Feed Rate (mm/min): 12

Setting for NC generation



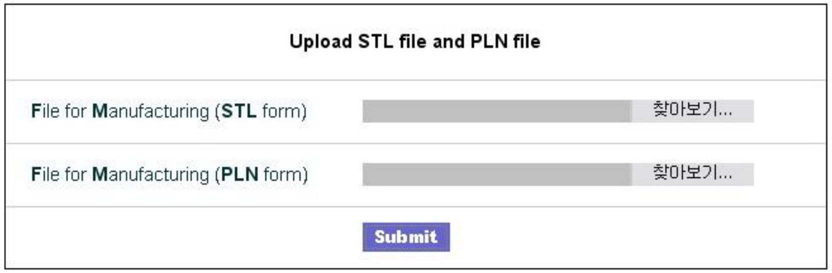
(a) STL model



```
******************************************************************************
      Plan Sheet for NC Process  [filename =epm.pln]
******************************************************************************
{I} Cut Mode [Scanning = 1, Contouring = 2, Pencil-Cut = 3, Fillet-Cut = 4]
1
{II} Polyhedral Model and Path
1. Input Model (Full Path)
smart.stl
2. Plane Normal (x, y, z)
0.0 1.0 0.0
3. Pattern Type [Oneway = 0, Zigzag = 2]
2
{III} Tool & Machining Conditions------------------------------------
1. Cutter Shape(Dia, Fillet-Radius, Length)
0.400 0.0 50.0
2. Path Interval
0.1
3. Cutting Tolerance
0.01
4. Surface Offset
0.0
5. Start Point (x,y,z)
0.0 0.0 20.0
6. Clearance Height [Type = Inc_Z/Abs_Z/Tool_Axis, Value]
A
15.0
```

(b) Machine setting

Results of DFM module



Upload STL file and PLN file

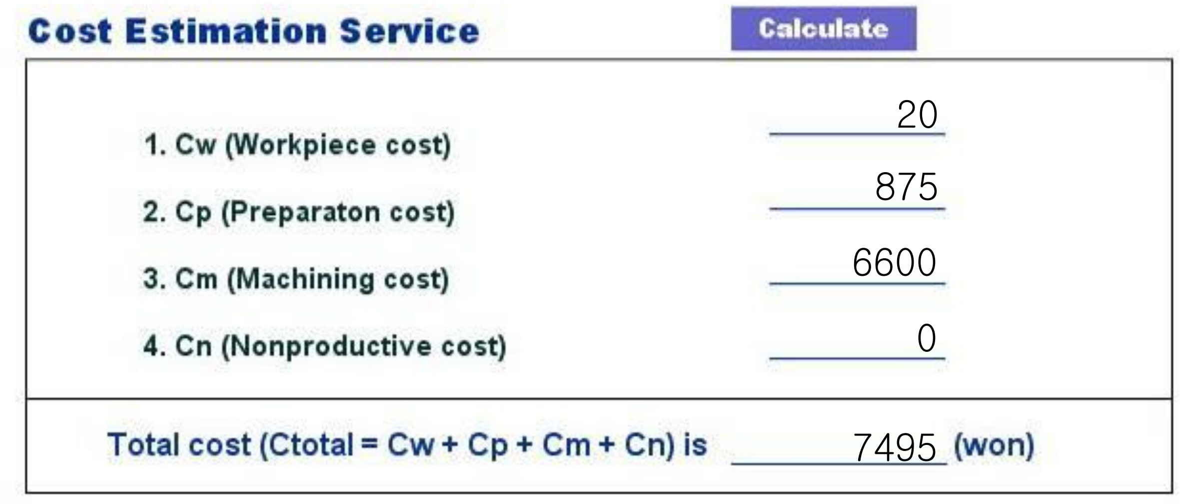
File for **M**anufacturing (**STL** form)

File for **M**anufacturing (**PLN** form)

Upload form: model and setting

Web-based DFM systems - SmartFab

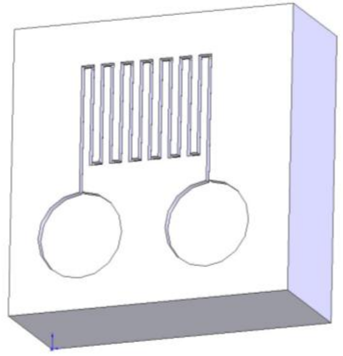
- For micro machining



Cost Estimation Service

1. Cw (Workpiece cost) 20
2. Cp (Preparaton cost) 875
3. Cm (Machining cost) 6600
4. Cn (Nonproductive cost) 0

Total cost (Ctotal = Cw + Cp + Cm + Cn) is 7495 (won)



Cp = Tp*W

Tp: Preparation time (0.35 hr)
W : Operator’s wage (2500/hr)

Cm = Com+Ct = Tm*W+Ct

Tm: Machining time (0.24 hr)
W: Operator’s wage (2500/hr)

Ct = y*(Tm/T)

(7995 won, 88% of total cost)

Ct: Tool usage cost
T: Tool life (4 hr)
y: tool cost (100,000)

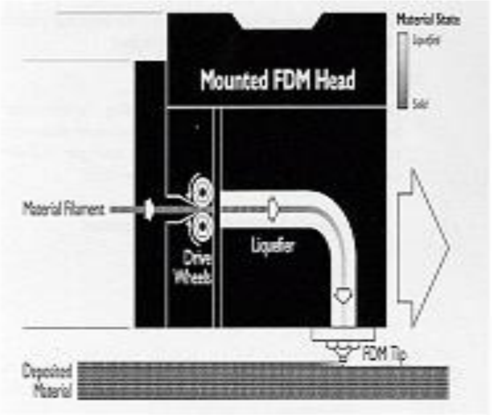
DFM for RP

- Issues in FDM material (ABS)
- Porous & directional
- Build rule
- …

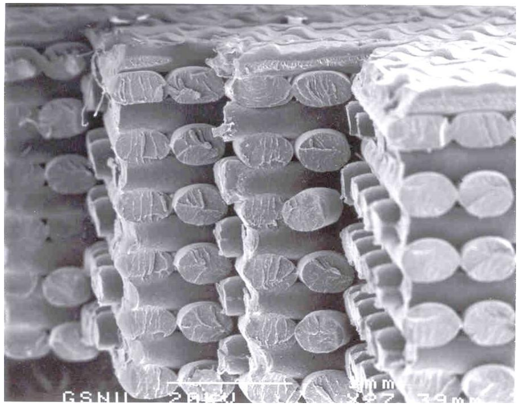
Issues in FDM Material (ABS)

- Functional Properties
  - Strength
  - Nude style package

- Approach
  - Resin infiltration
  - Increase strength & transmissivity of light

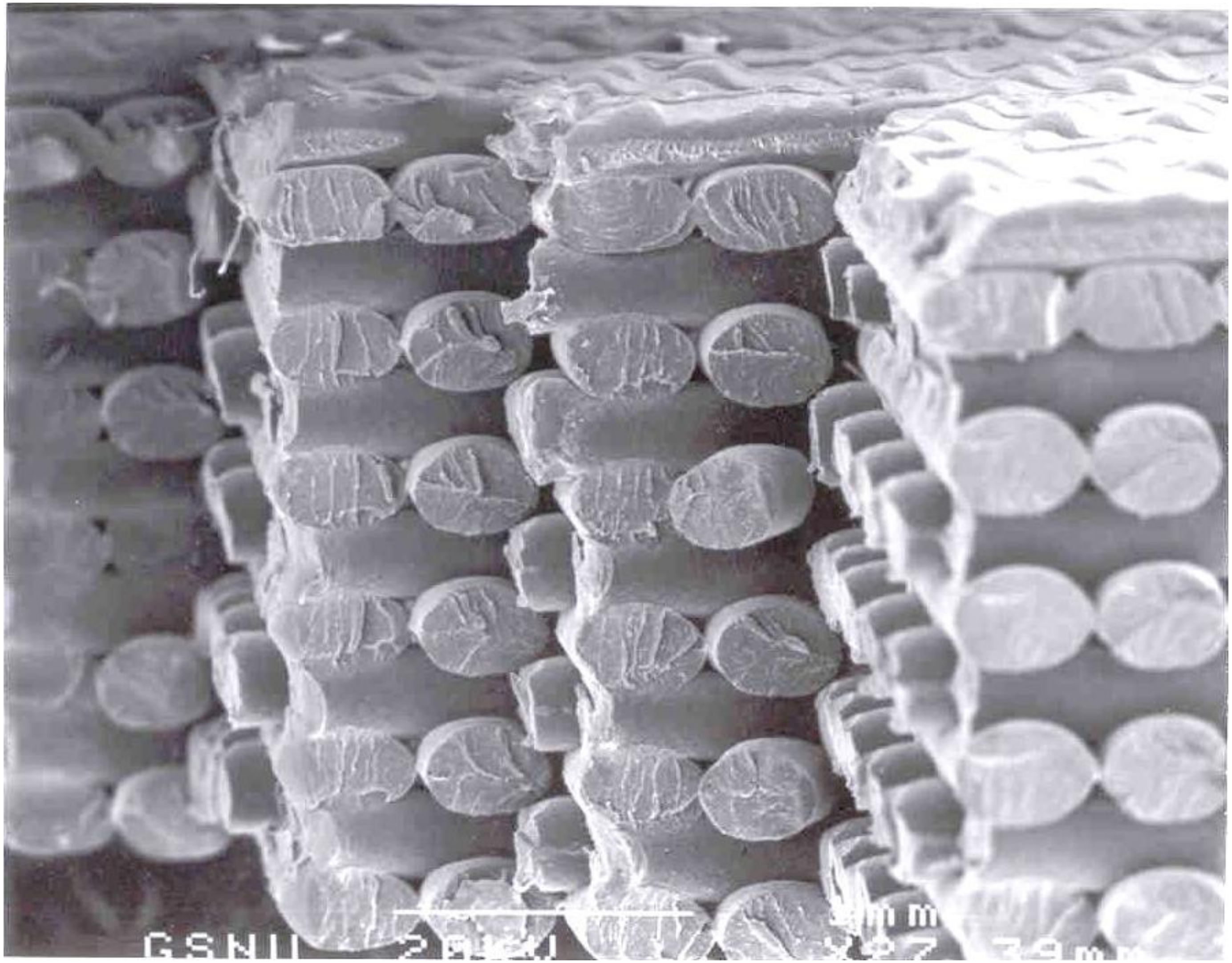


FDM process

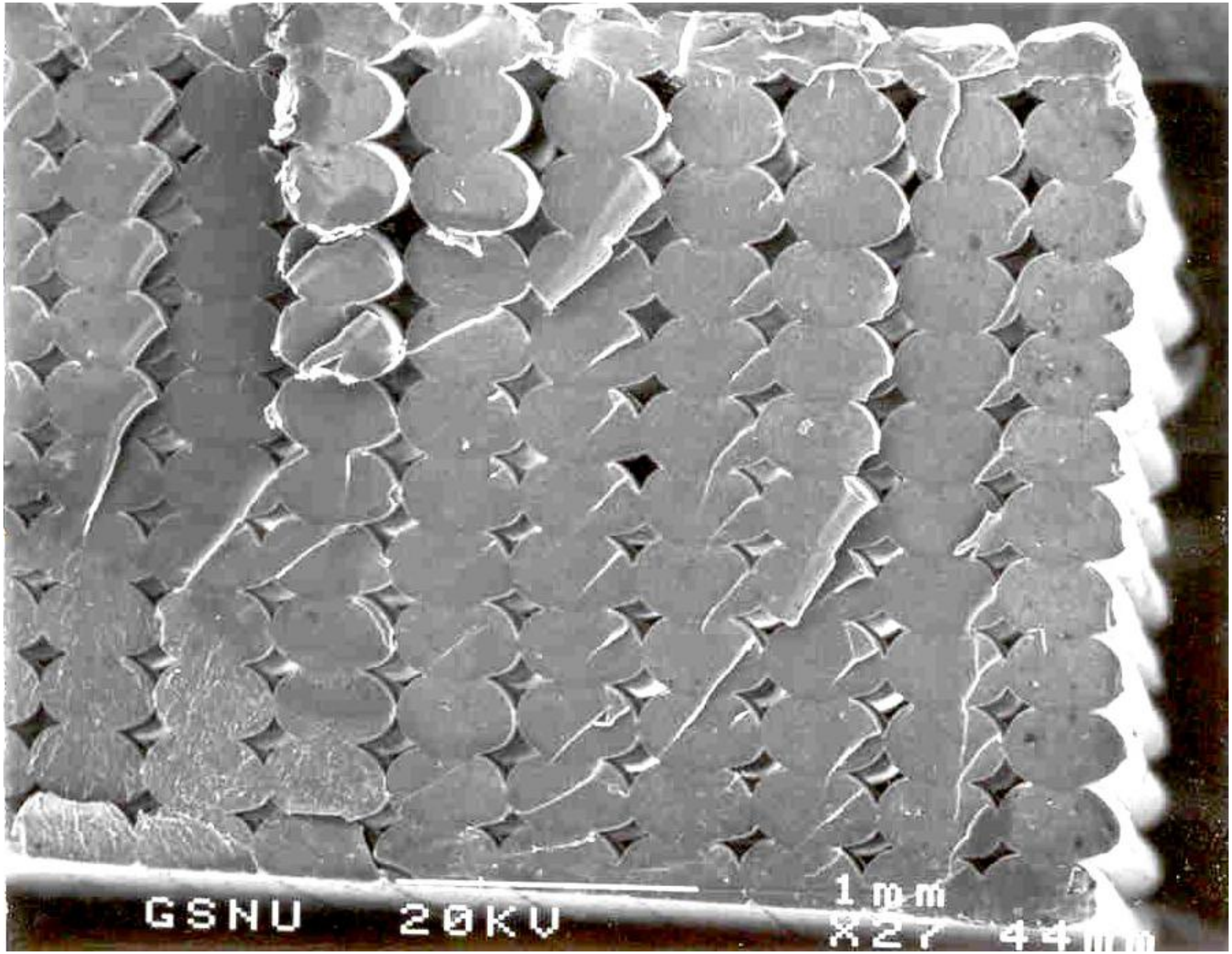


Porous micro structure

Micro Structure of FDM Part

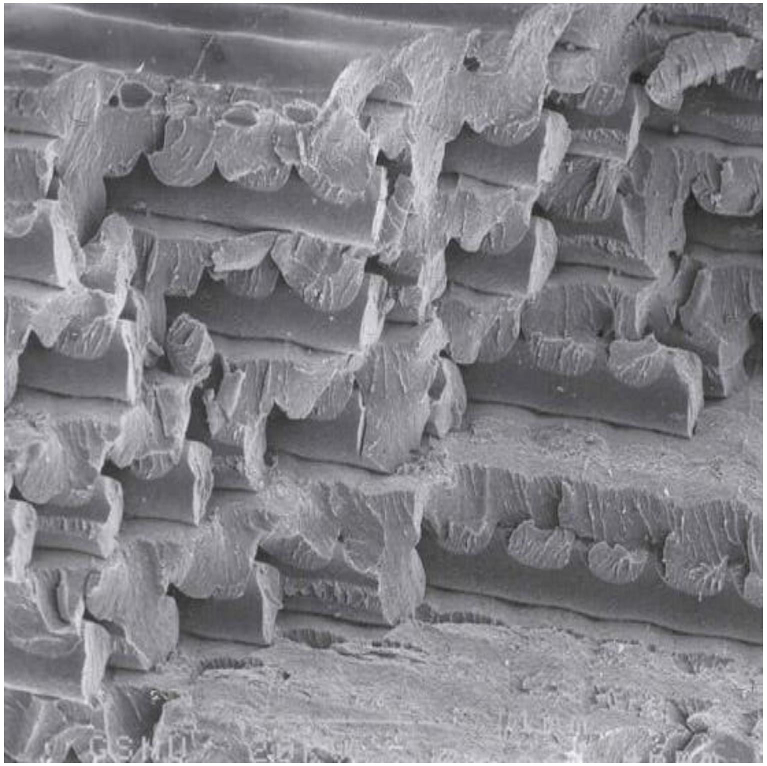


Porous & Directional

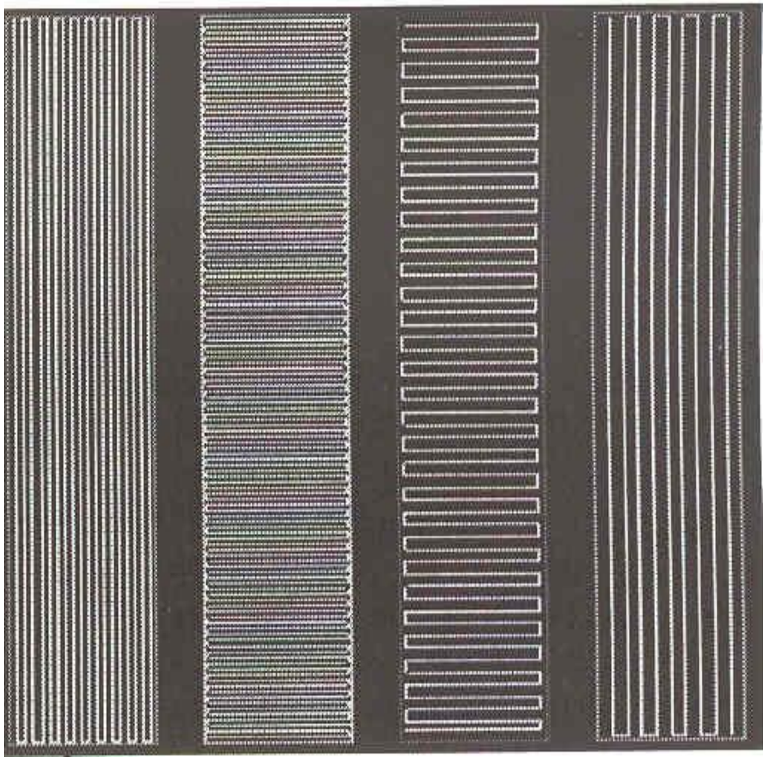


Anisotropy in FDM Parts

- "Raster Orientation" is the direction of deposition

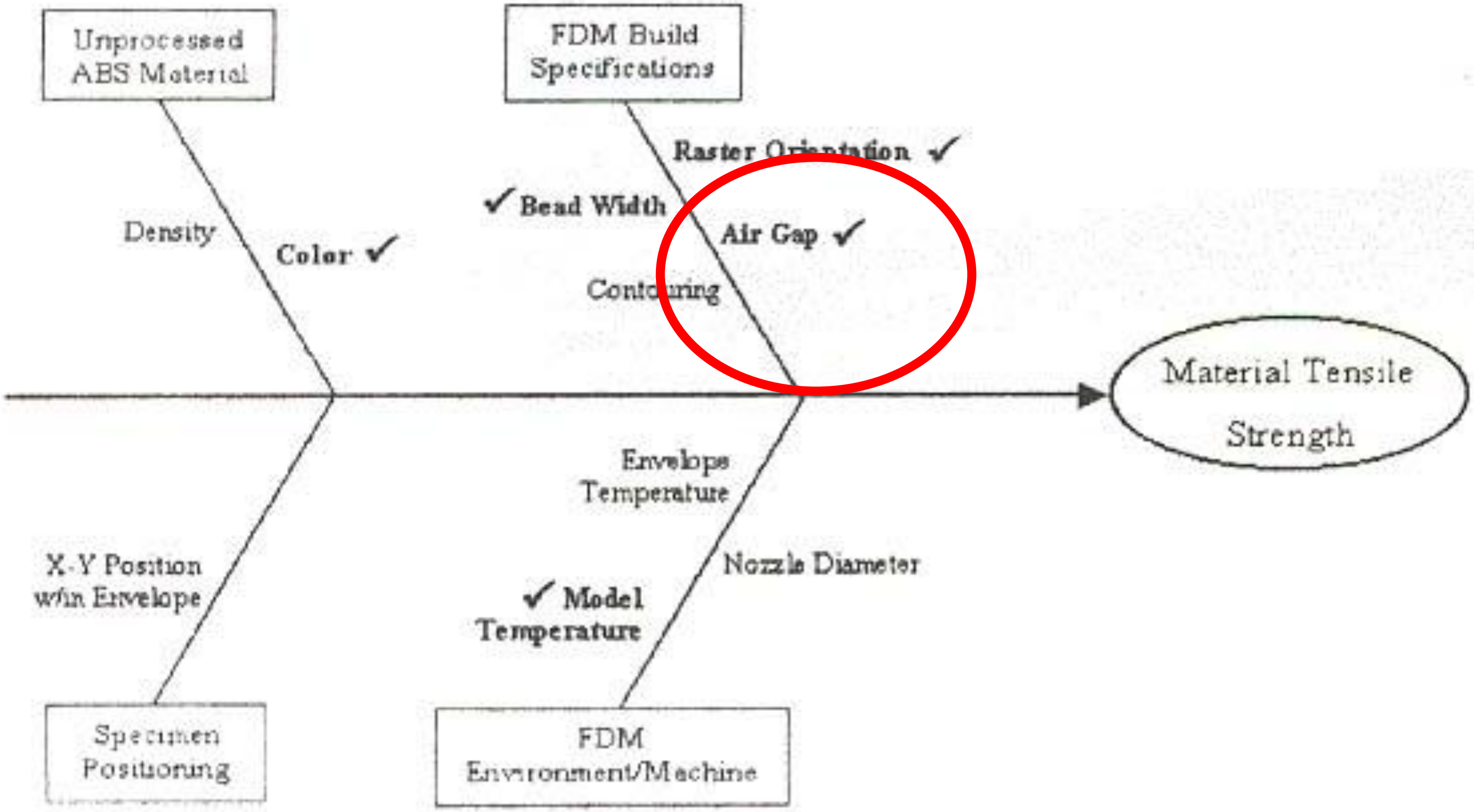


SEM picture of FDM specimen.

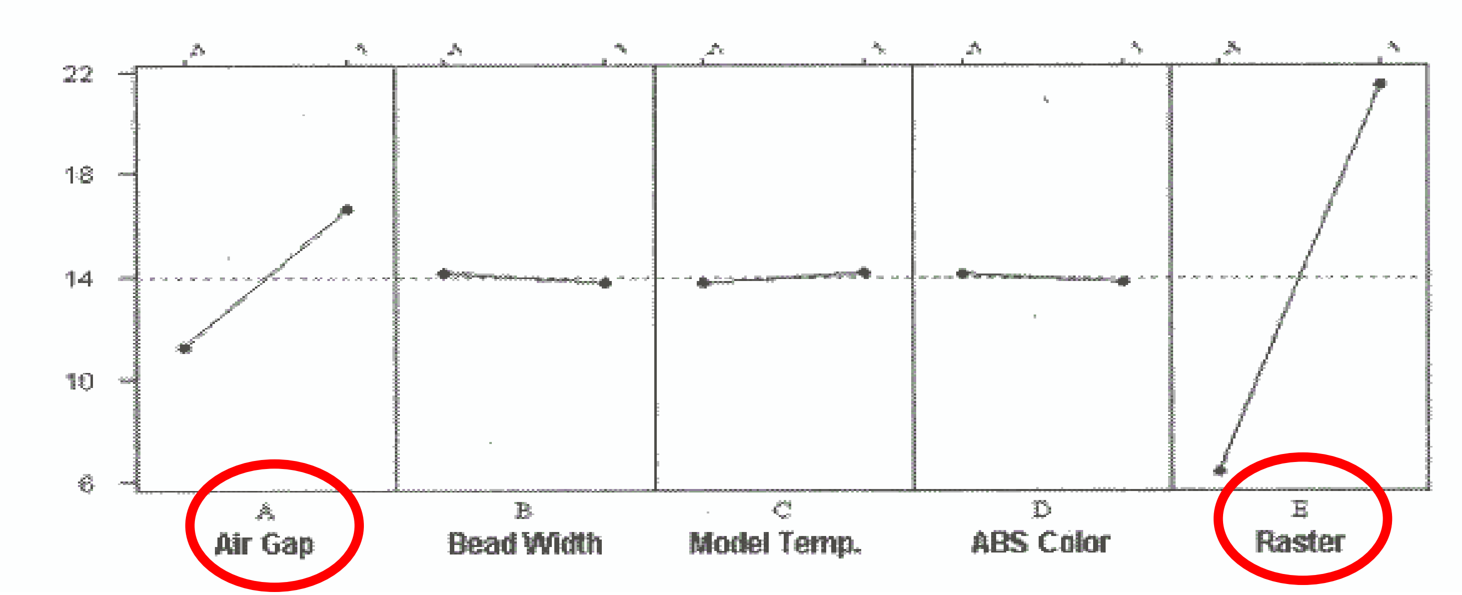


Quickslice SML file.

Design of Experiment (DOE)

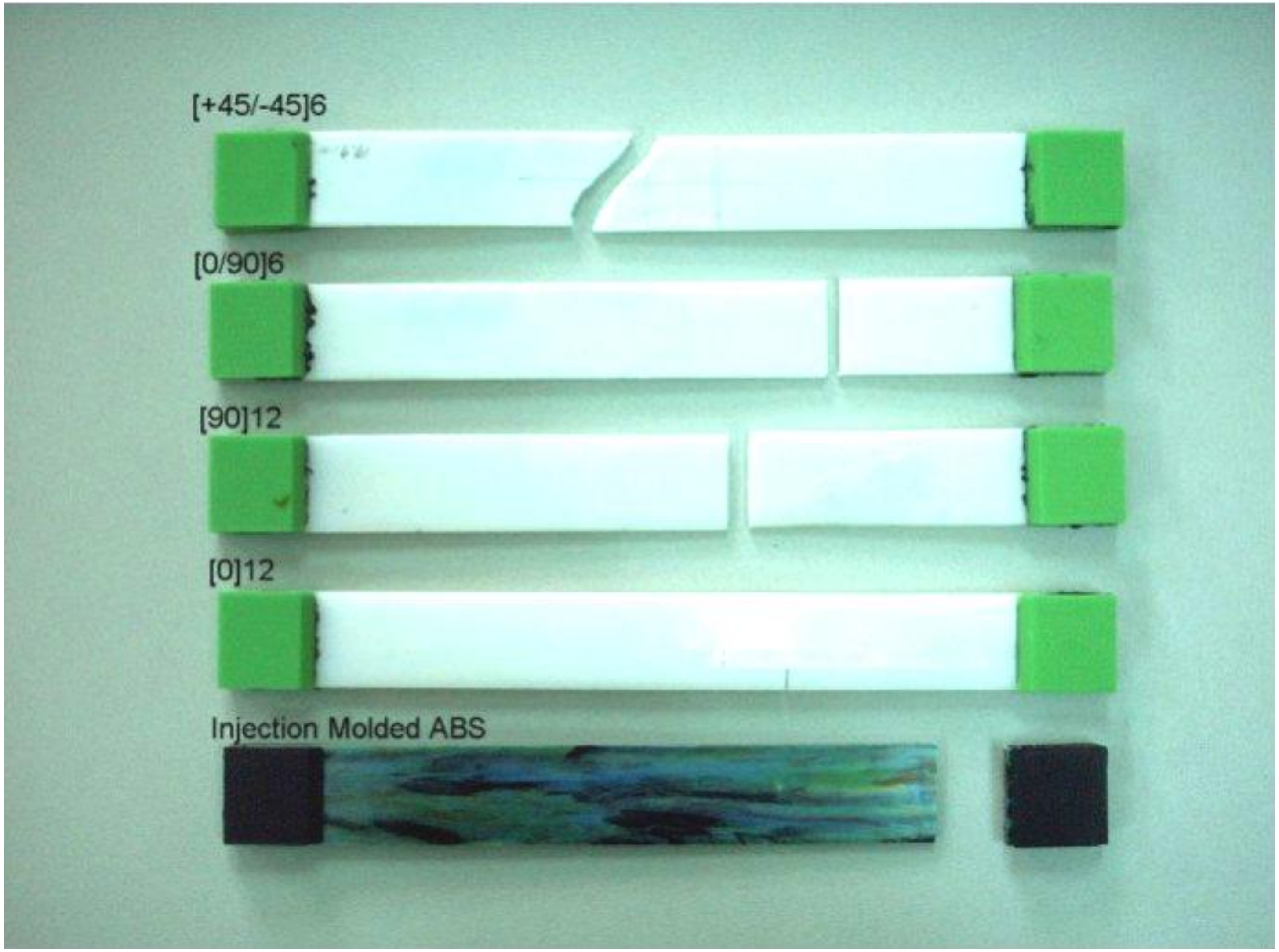


Results



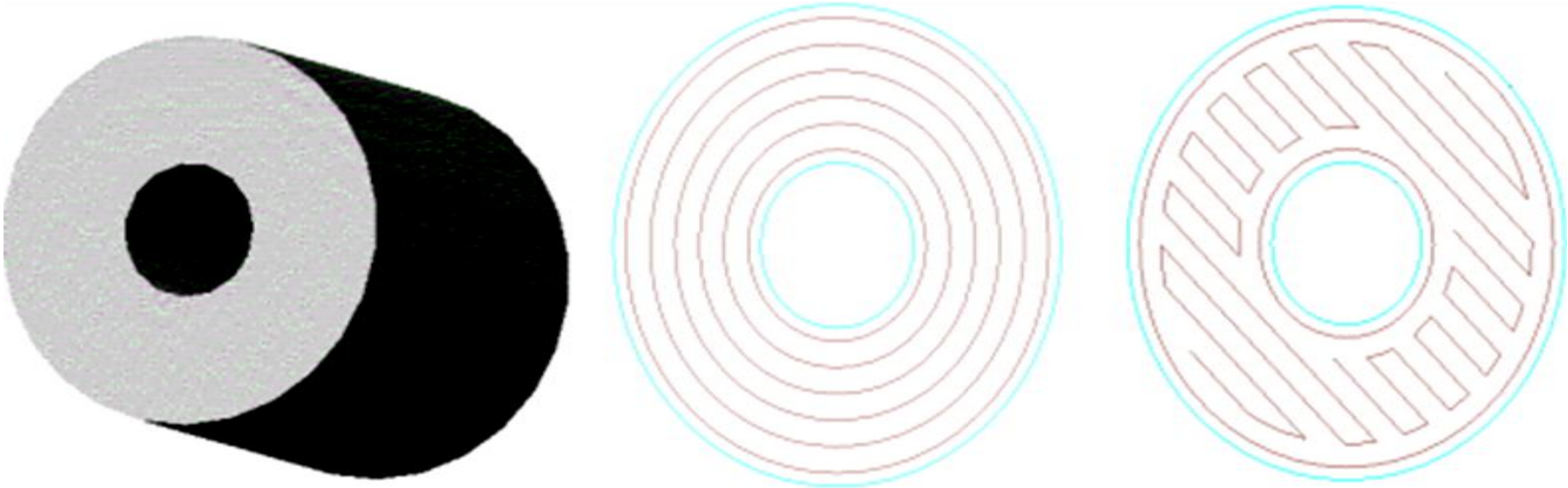
Variable	Symbol	Low(-)	High(+)
Air Gap (in.)	A	0.0000	-0.0020
Bead Width (in.)	B	0.0200	0.0396
Model Temperature(℃)	C	270	280
ABS Color	D	Blue	White
Orientation of Raster	E	Transverse	Axial

Failed Specimens



Build Rule #1

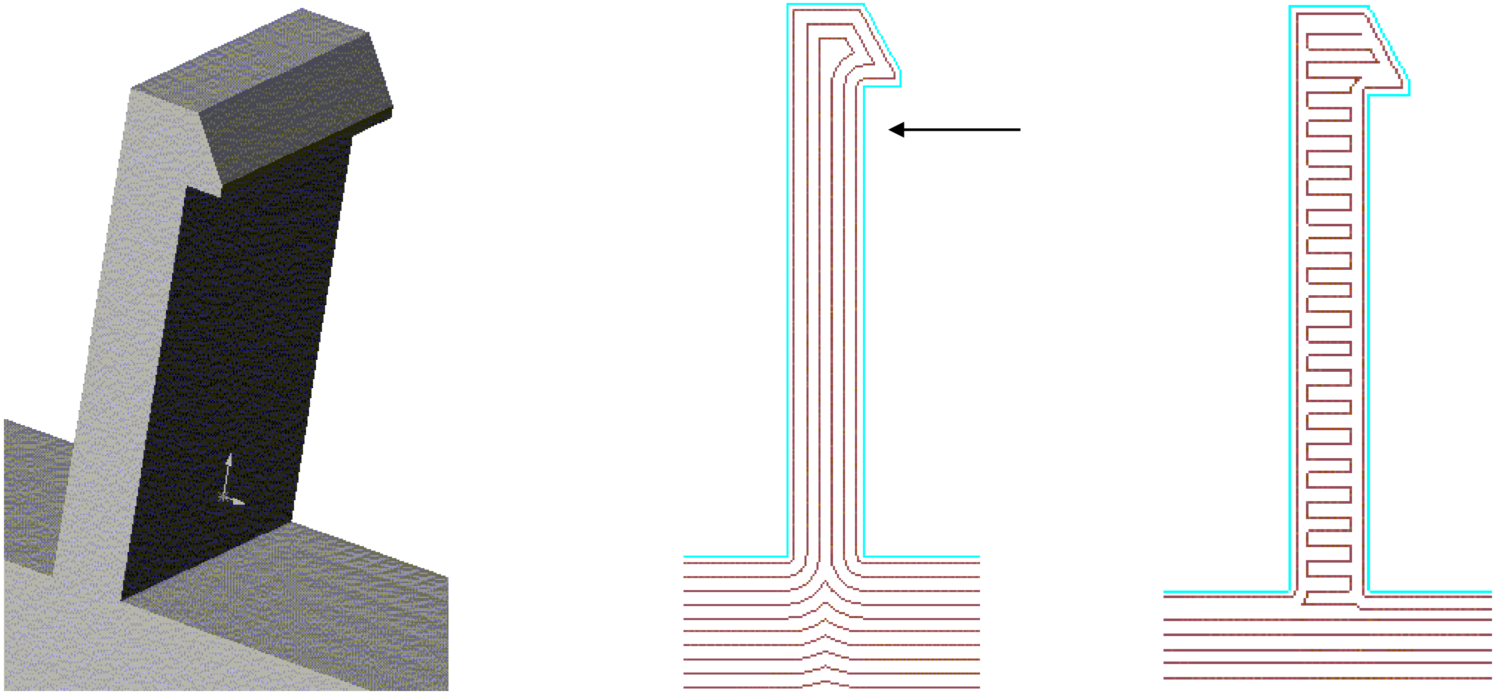
- Build parts such that tensile loads will be carried axially along the fibers.


Cross Section 1

Cross Section 2

Two different road orientations for boss design

Build Rule #1 cont’d



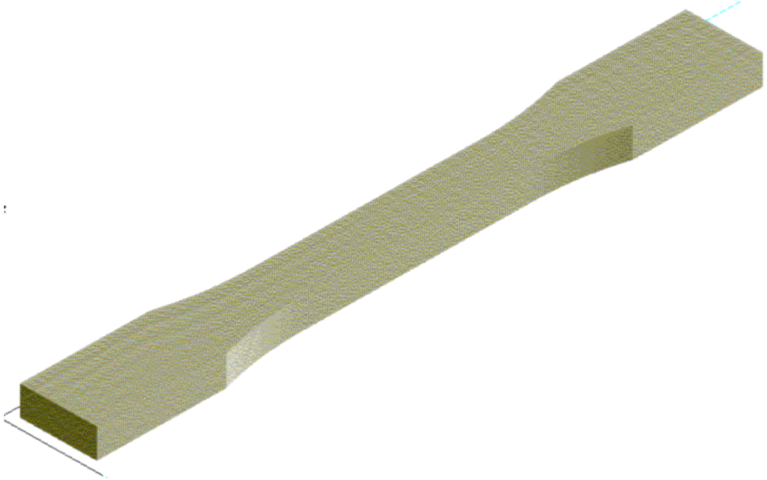
Cross Section 1

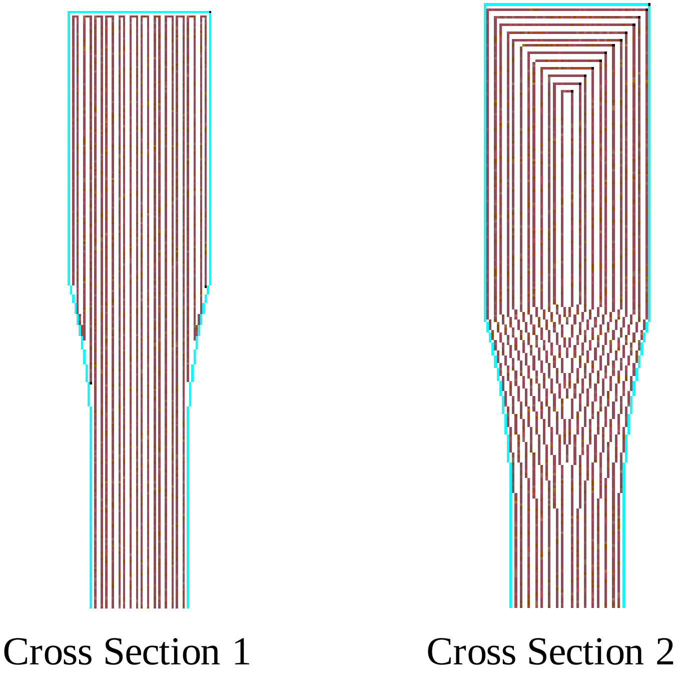
Cross Section 2

Two different road orientations for cantilever snap-fit design.

Build Rule #2

- The stress concentrations associated with a radius can be misleading. If a radius area will carry a load, building the radius with contours is probably best.





Cross Section 1

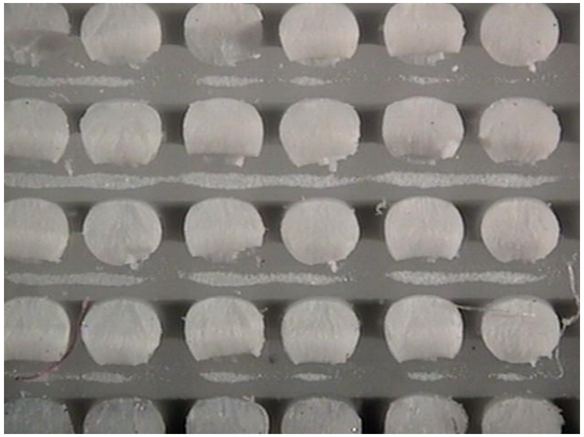
Cross Section 2

Two different road orientations for dog-bone design.

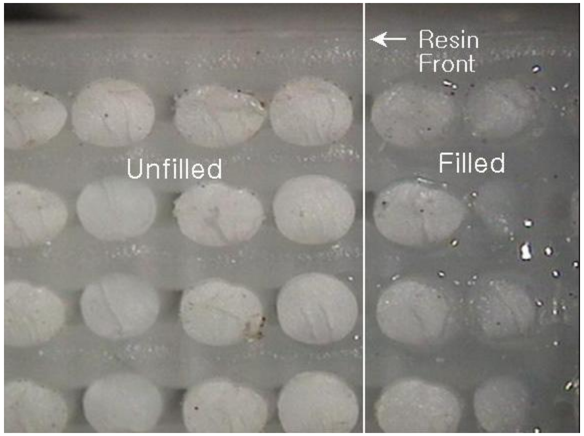
Build Rule #3~5

- Rule 3. A negative air gap increases both strength and stiffness
- Rule 4. Shear strength between layers is greater than shear strength between roads.
- Rule 5. Bead width and temperature do not affect strength, but the following considerations are important.
  - Small bead width increases build time.
  - Small bead width increases surface quality.
  - Wall thickness of the part should be an integer multiple of the bead width

Resin Infiltration

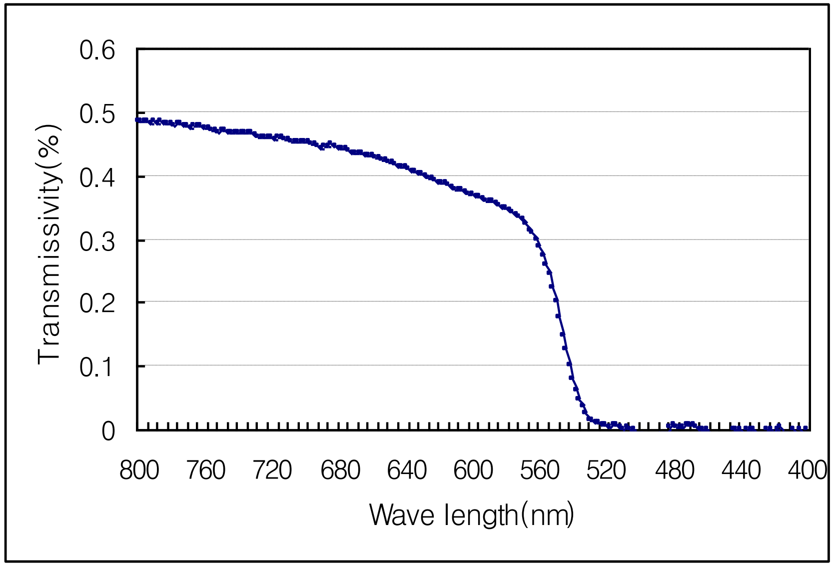


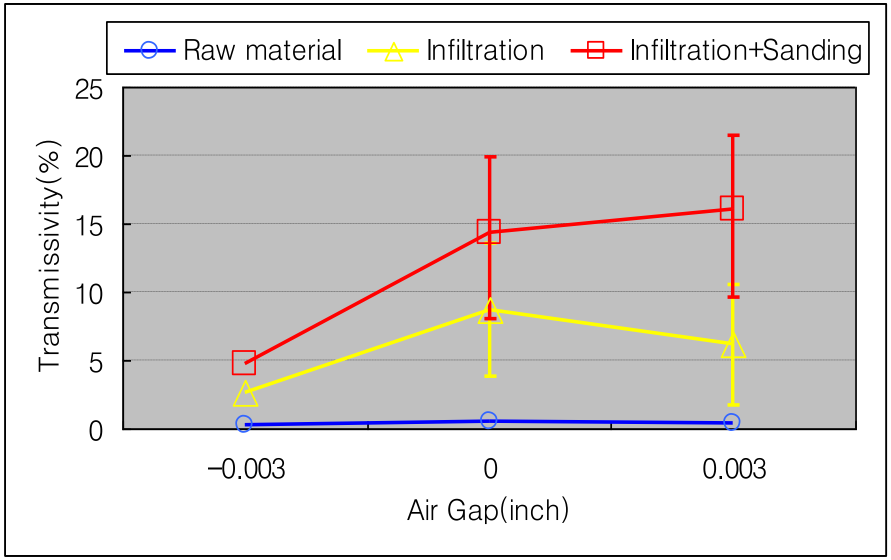
Raw FDM ABSi



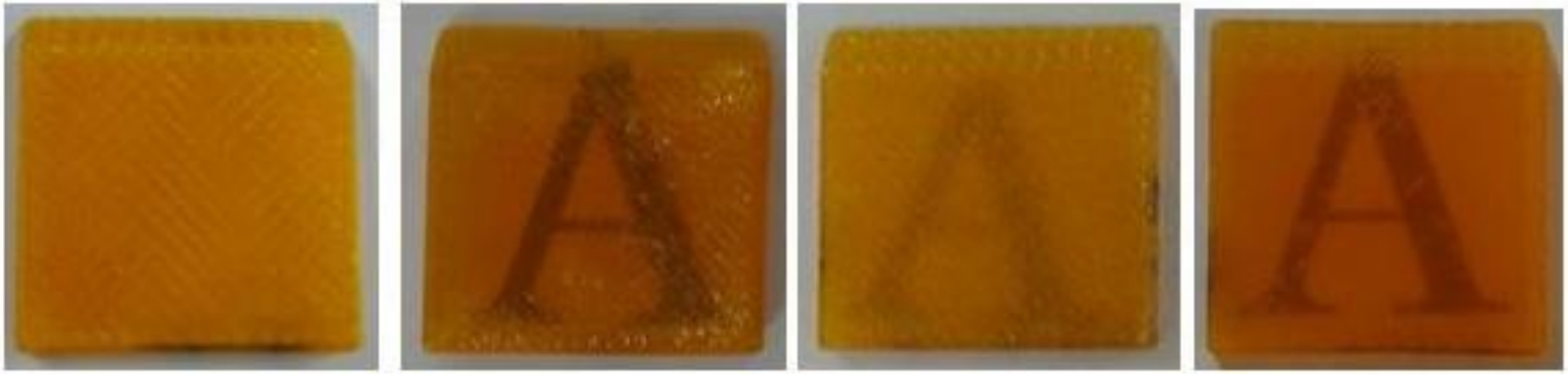
During Infiltration

After Infiltration





Relative Transmissivity


(a) Raw Material T=0.2%

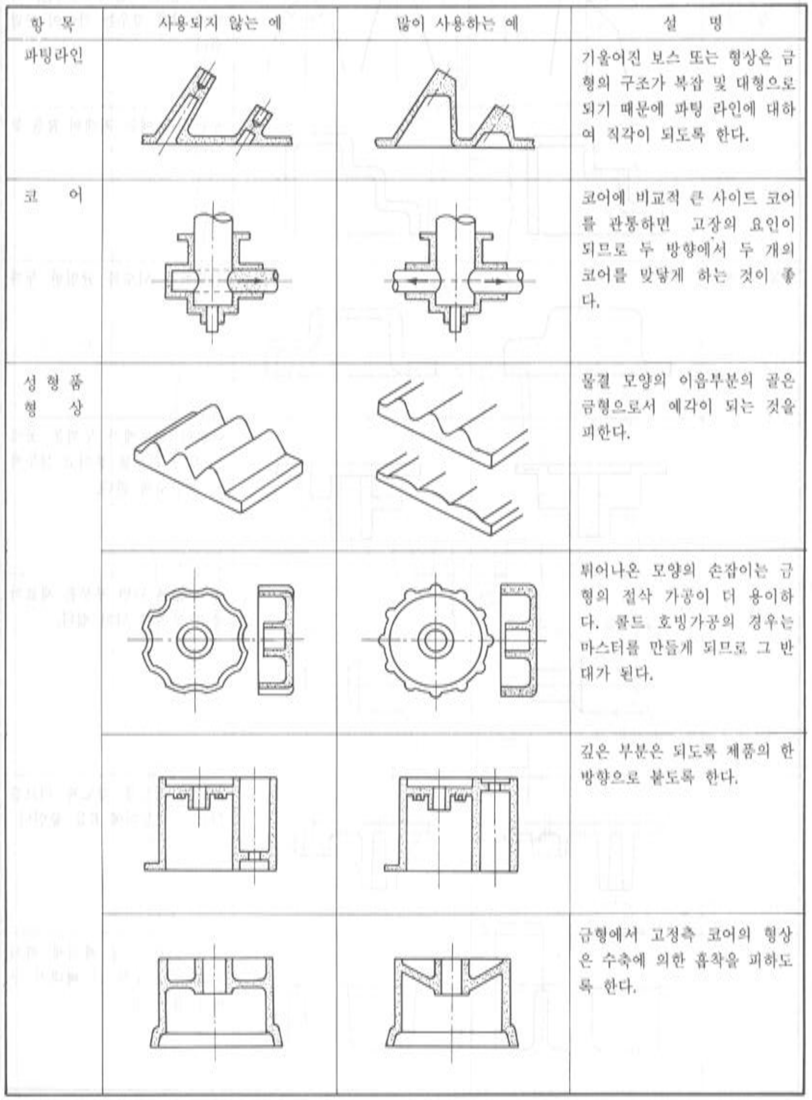
(b) Temperature(180°c) T=8.4%

(C) Acryl T=1.8%

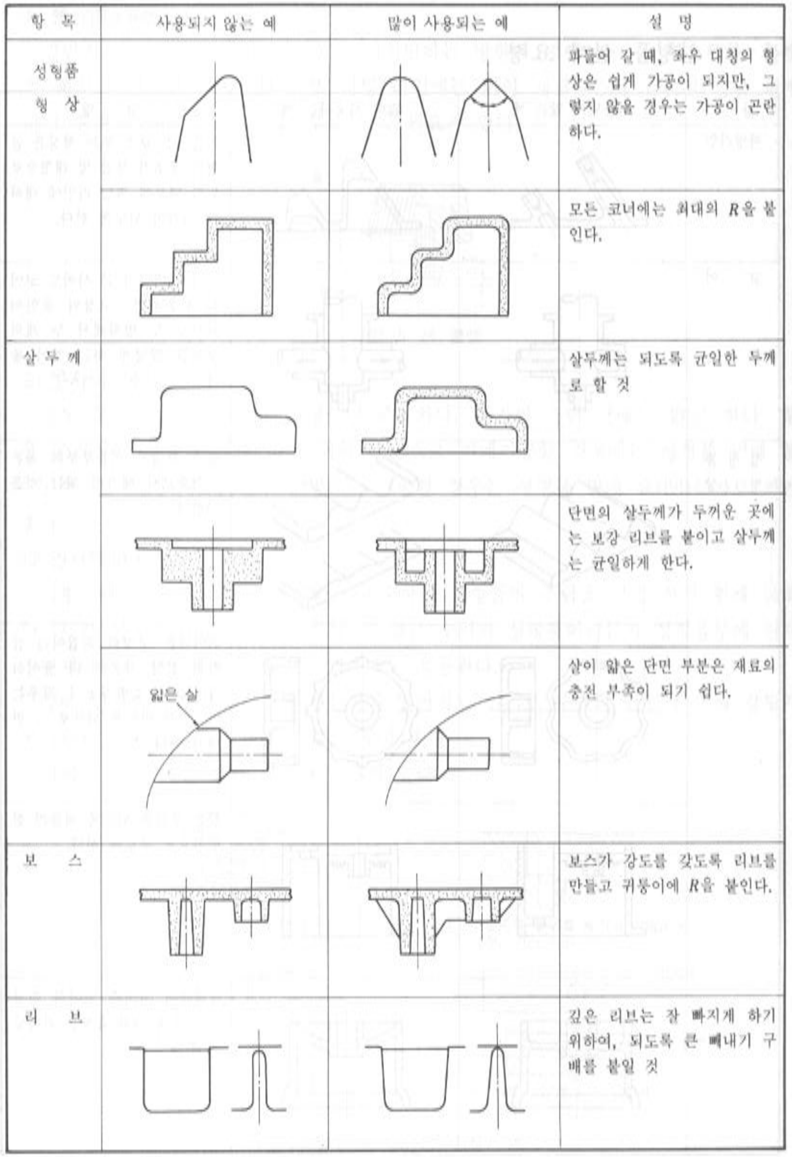
(d) Acryl+Sanding T=22.4%

	ABSi	Acryl	Cyano Acrylate
Index of Refraction	1.57	1.69	1.51

DFM in Injection Molding

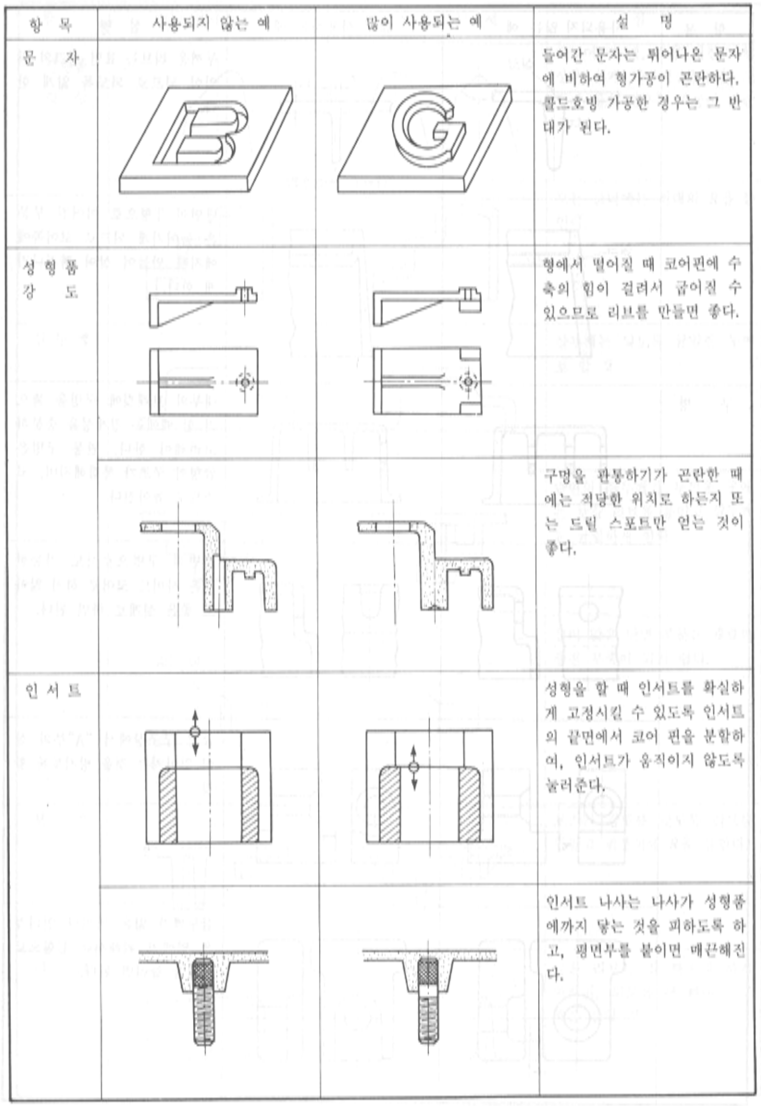


항 목	사용되지 않는 예	많이 사용하는 예	설 명
파팅라인			기울어진 보스 또는 형상은 금형의 구조가 복잡 및 대형으로 되기 때문에 파팅 라인에 대하여 직각이 되도록 한다.
코 어			코어에 비교적 큰 사이드 코어를 관통하면 고장의 요인이 되므로 두 방향에서 두 개의 코어를 맞닿게 하는 것이 좋다.
성 형 품 형 상			물결 모양의 이음부분의 골은 금형으로서 예각이 되는 것을 피한다.
			튀어나온 모양의 손잡이는 금형의 절삭 가공이 더 용이하다. 콜드 호빙가공의 경우는 마스터를 만들게 되므로 그 반대가 된다.
			깊은 부분은 되도록 제품의 한 방향으로 붙도록 한다.
			금형에서 고정측 코어의 형상은 수축에 의한 흡착을 피하도록 한다.

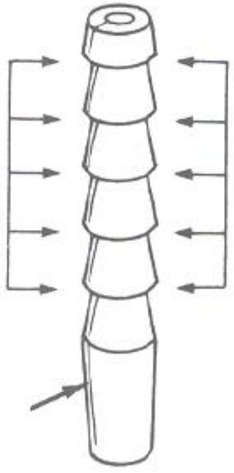


항 목	사용되지 않는 예	많이 사용되는 예	설 명
성형품 형 상			파들어 갈 때, 좌우 대칭의 형상은 쉽게 가공이 되지만, 그렇지 않을 경우는 가공이 곤란하다.
			모든 코너에는 최대의 *R*을 붙인다.
살 두 께			살두께는 되도록 균일한 두께로 할 것
			단면의 살두께가 두꺼운 곳에는 보강 리브를 붙이고 살두께는 균일하게 한다.
	얇은 살		살이 얇은 단면 부분은 재료의 충전 부족이 되기 쉽다.
보 스			보스가 강도를 갖도록 리브를 만들고 귀퉁이에 *R*을 붙인다.
리 브			깊은 리브는 잘 빠지게 하기 위하여, 되도록 큰 빼내기 구배를 붙일 것

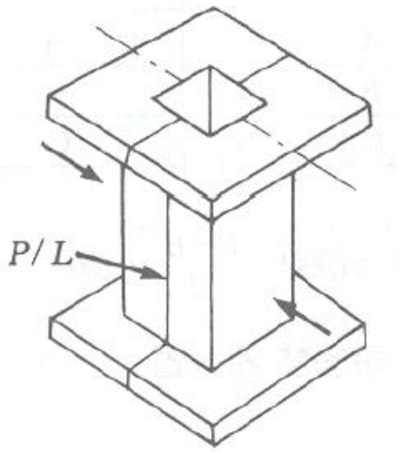
DFM in Injection Molding (cont.)



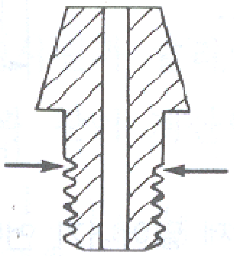
항 목	사용되지 않는 예	많이 사용되는 예	설 명
문 자			들어간 문자는 튀어나온 문자에 비하여 형가공이 곤란하다. 콜드호빙 가공한 경우는 그 반대가 된다.
성 형 품 강 도			형에서 떨어질 때 코어핀에 수축의 힘이 걸려서 굽어질 수 있으므로 리브를 만들면 좋다.
			구멍을 관통하기가 곤란한 때에는 적당한 위치로 하든지 또는 드릴 스포트만 얻는 것이 좋다.
인 서 트			성형을 할 때 인서트를 확실하게 고정시킬 수 있도록 인서트의 끝면에서 코어 핀을 분할하여, 인서트가 움직이지 않도록 눌러준다.
			인서트 나사는 나사가 성형품에까지 닿는 것을 피하도록 하고, 평면부를 붙이면 매끈해진다.



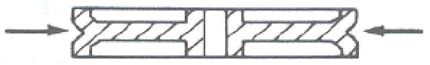
(a) 니플



(b) 스프루 형상



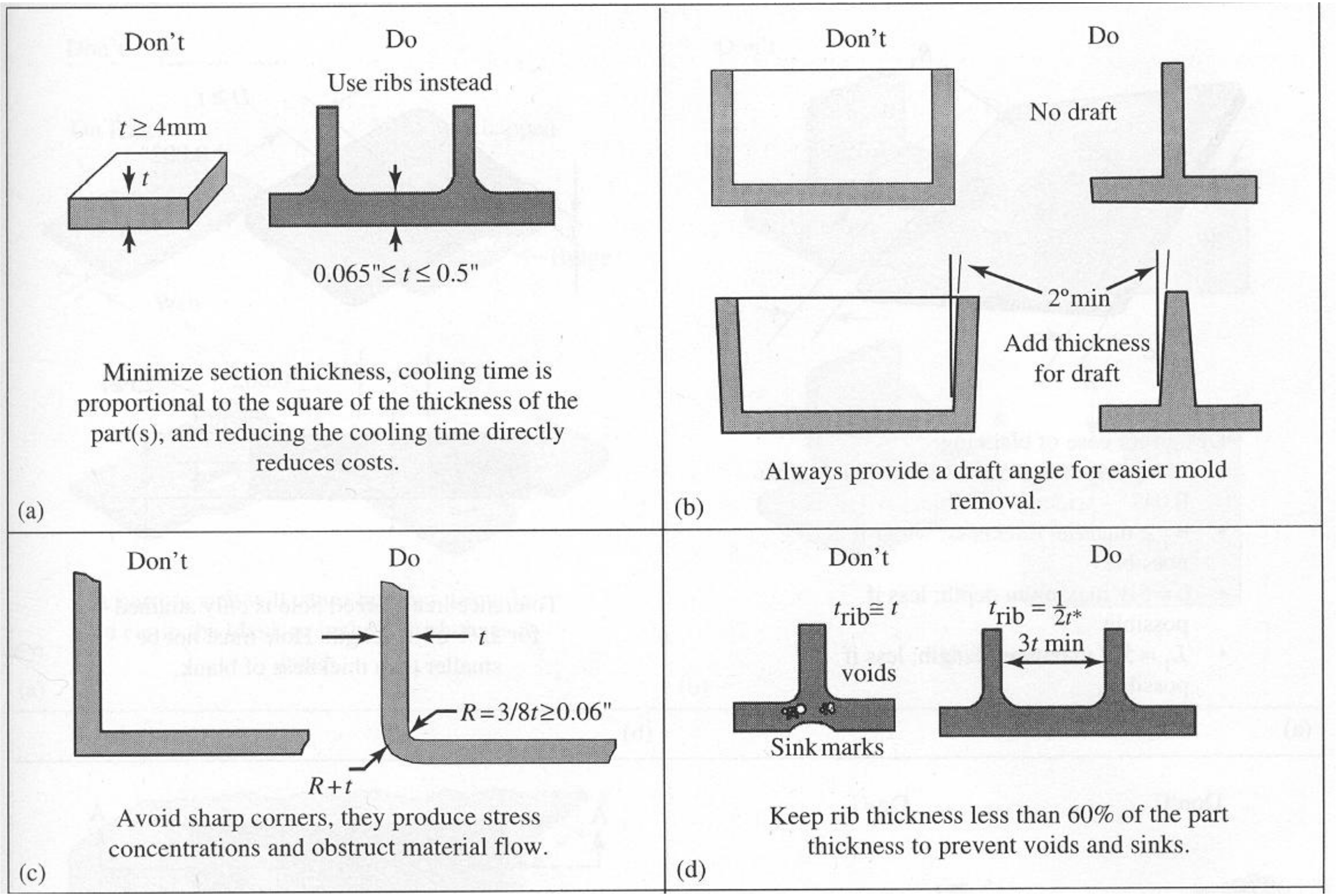
(c) 스크루



(d) 풀리

Prevent undercut

DFM in Injection Molding (cont.)



(a) 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.

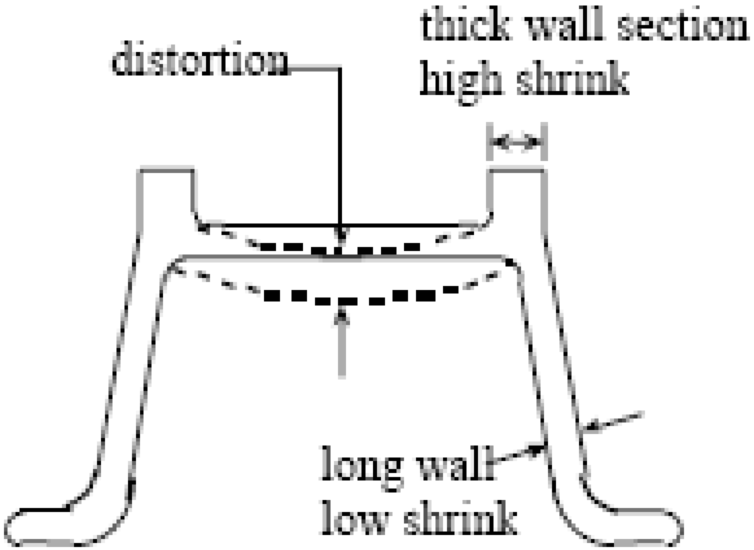
(b) Always provide a draft angle for easier mold removal.

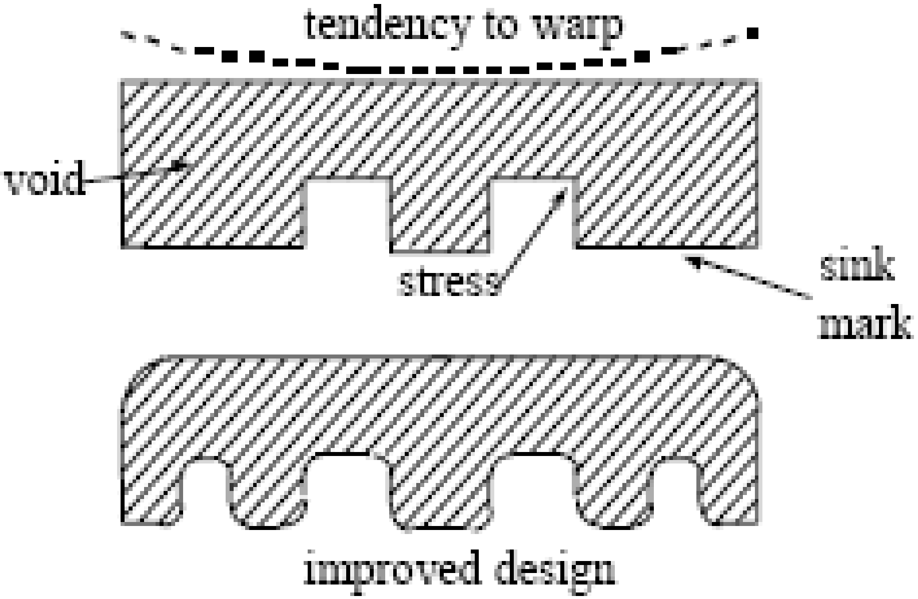
(c) Avoid sharp corners, they produce stress concentrations and obstruct material flow.

(d) Keep rib thickness less than 60% of the part thickness to prevent voids and sinks.

Warpage and sinkmarks

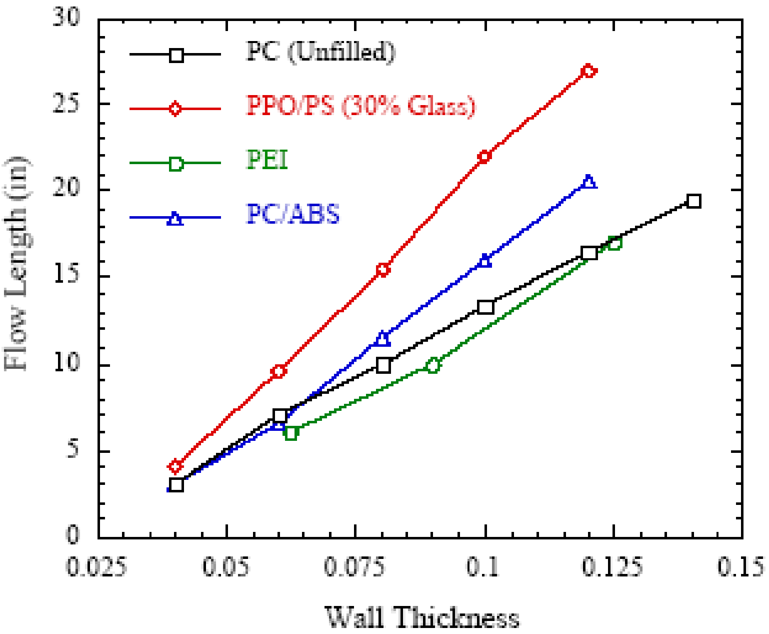
- Avoid thick “hot spots”

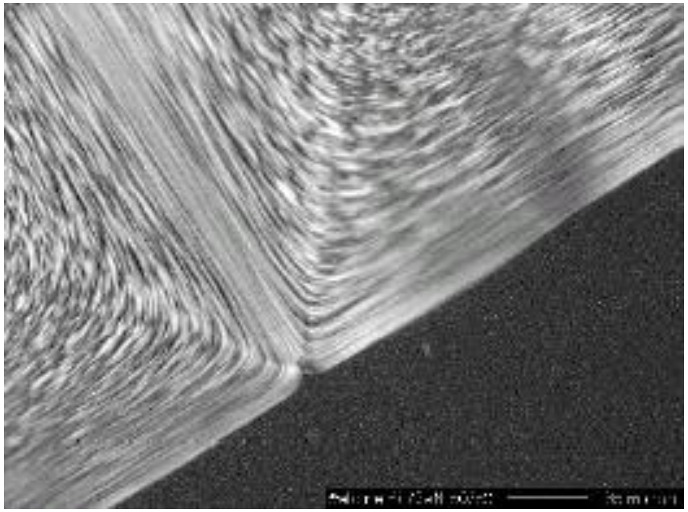




Injection and flow

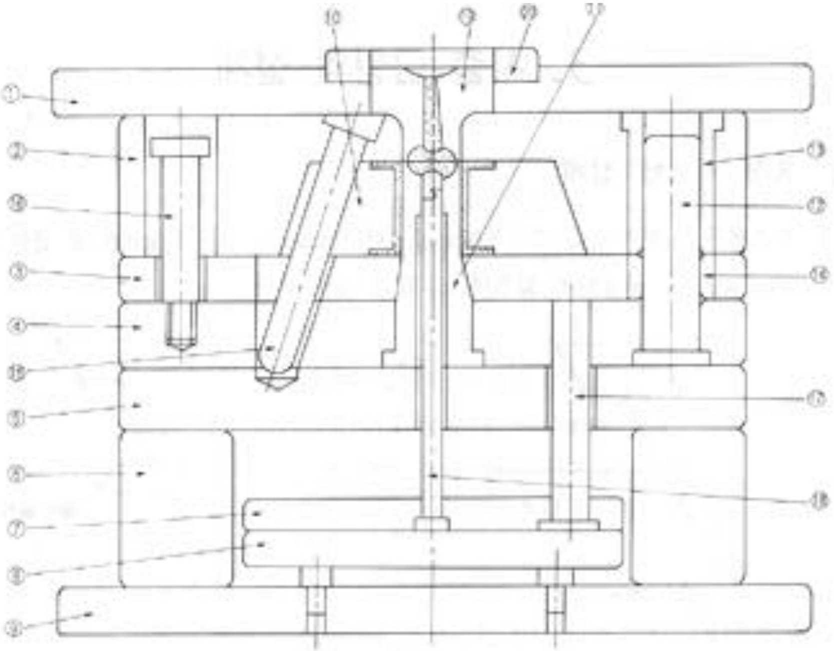
- Max length of flow
  - Part Thickness
  - Material
- Influences decision on
  - Part Geometry
  - Number of gates
  - Location of gates
    - Weldline

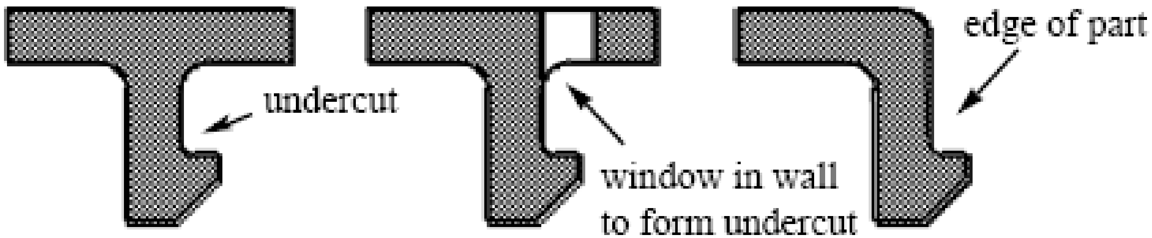


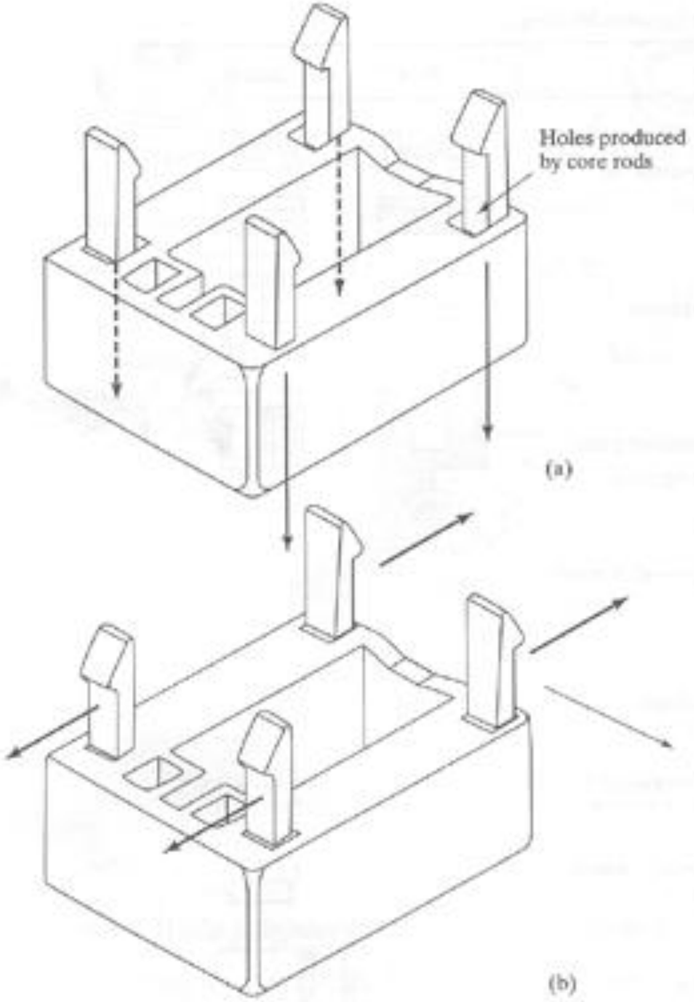


Avoid undercut

- Undercut requires cam pin, slider, or lifter







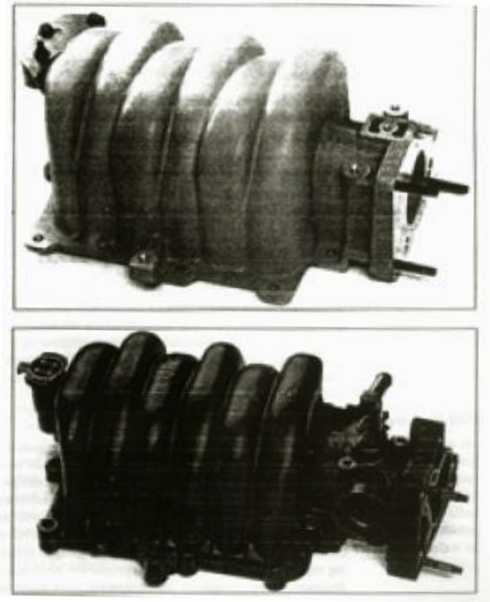
Key issues for each sub-process

- Injection
  - Flow Length Limit, Weldlines, and Density Dist.
  - Gating Scheme (number and location)
  - Thickness
- Packing and Cooling
  - Differential Cooling, Warpage, and Sinkmarks
  - Geometry Design
- Ejection (Tooling)
  - Parting Plane (Undercut)
  - Ejector Pins
- Assembly
  - Integral hinges and fasteners, Welding

Product specific DFM

- Example: GM 3.8 liter V6 engine

- Airintake manifolds
    - Original : Cast Al
    - Redesigned : molded thermoplastic composite



Design for Assembly (DFA)

- Benefit of DFA
  - Fewer Parts
  - Easier Assembly
  - Shorter Assembly Time
  - Major Concurrent Engineering Driver
    - Major Cost Savings (Parts and Labor)
    - Reduced Defects
    - Improved Quality
    - Increased Reliability

Design for Assembly (cont.)

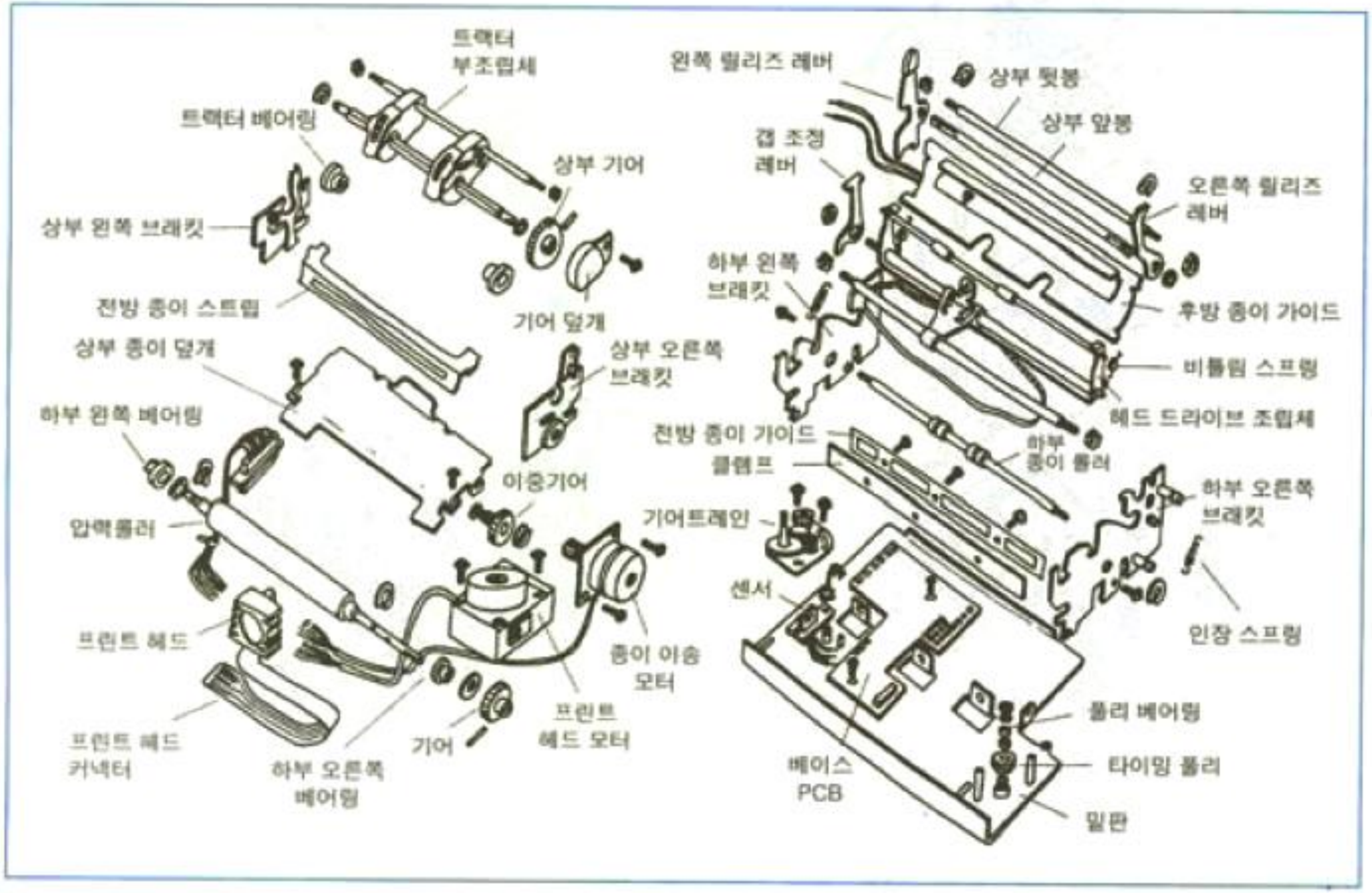


그림 13.21

Epson MX80 도트프린터의 주요 부조립품의 분해도(제공: Assembly Engineering, January 1987).

부품 수: 49

조립작업: 57회

조립시간: 552초

인건비: $3.83

Design for Assembly (cont.)

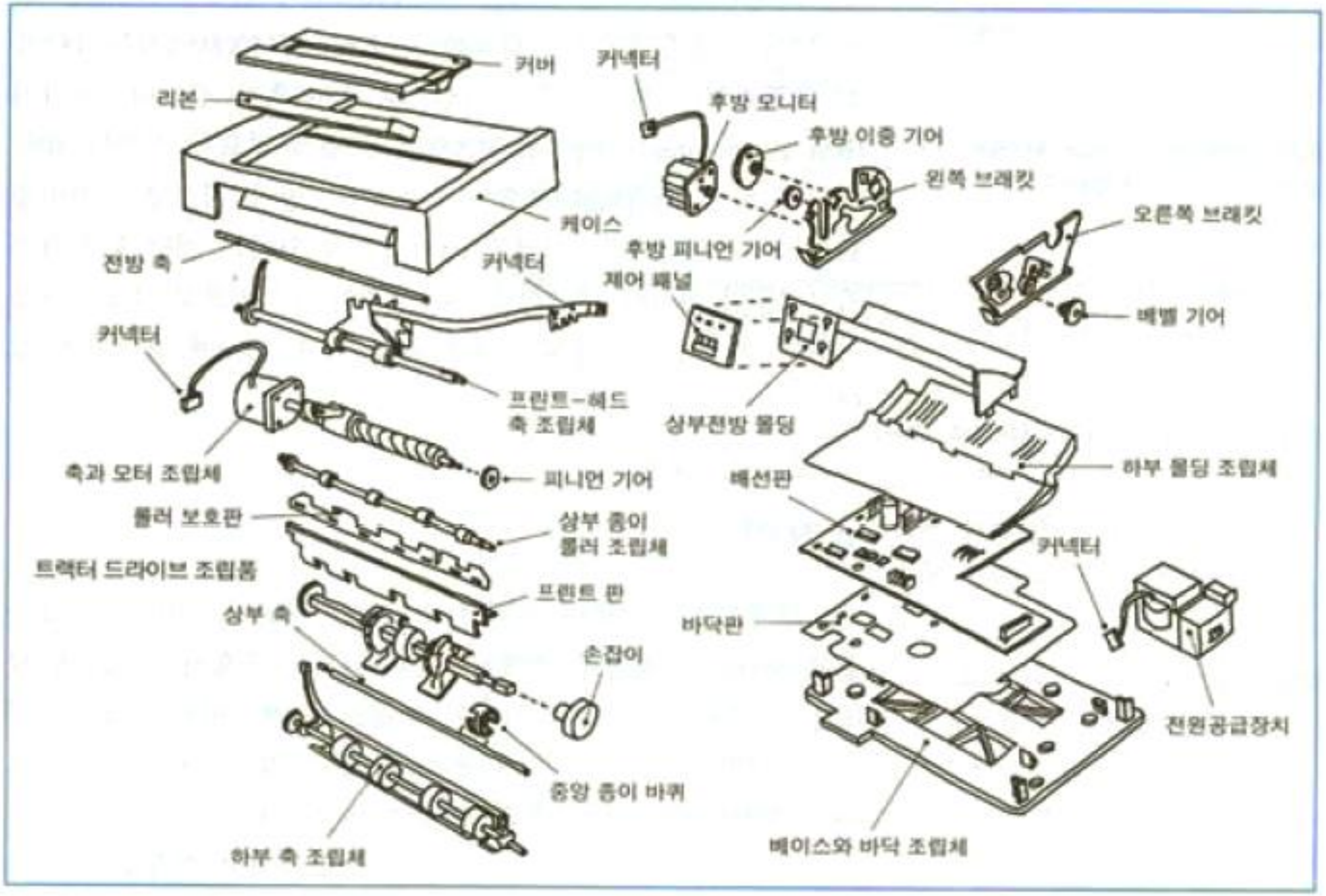


그림 13.22

32개의 부품 혹은 부조립품을 포함하고 있고 32개의 조립작업이 필요한 IBM Proprinter의 분해도 (제공: Assembly Engineering, January 1987).

부품 수: 32

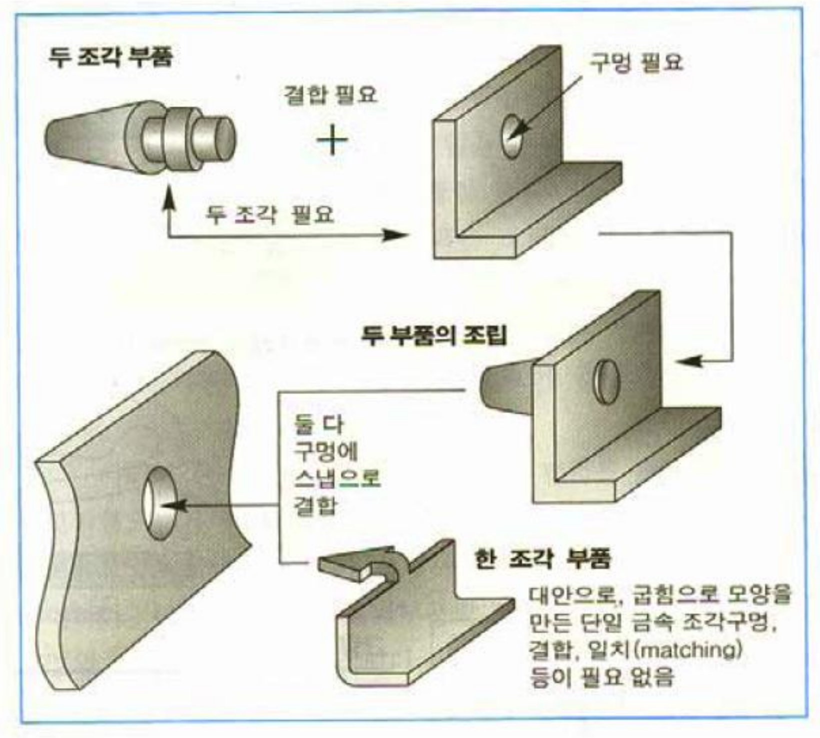
조립작업: 32회

조립시간: 170초

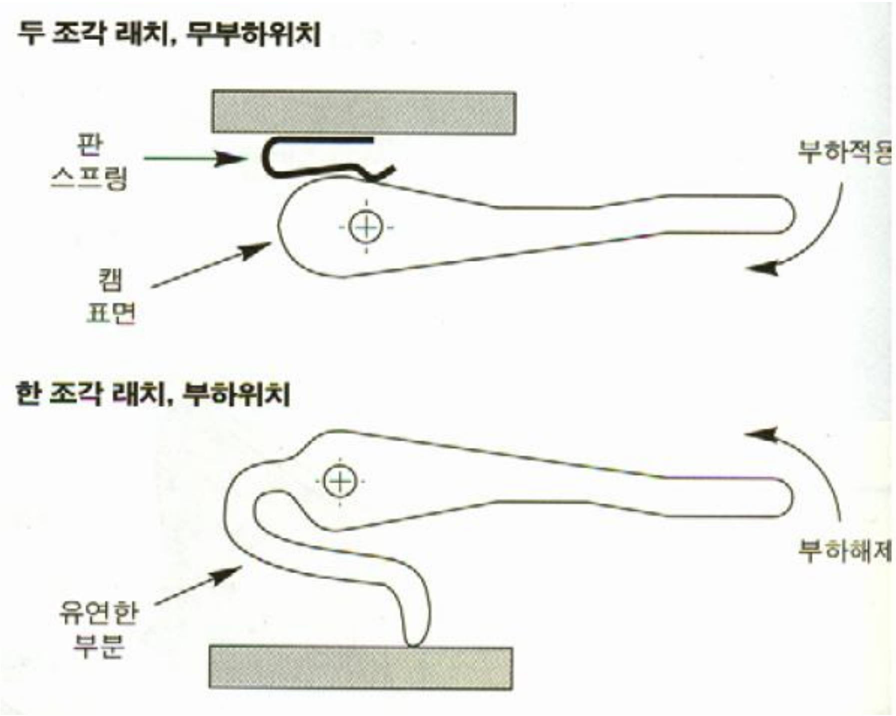
인건비: $1.18

Design for Assembly (cont.)

- Minimum number

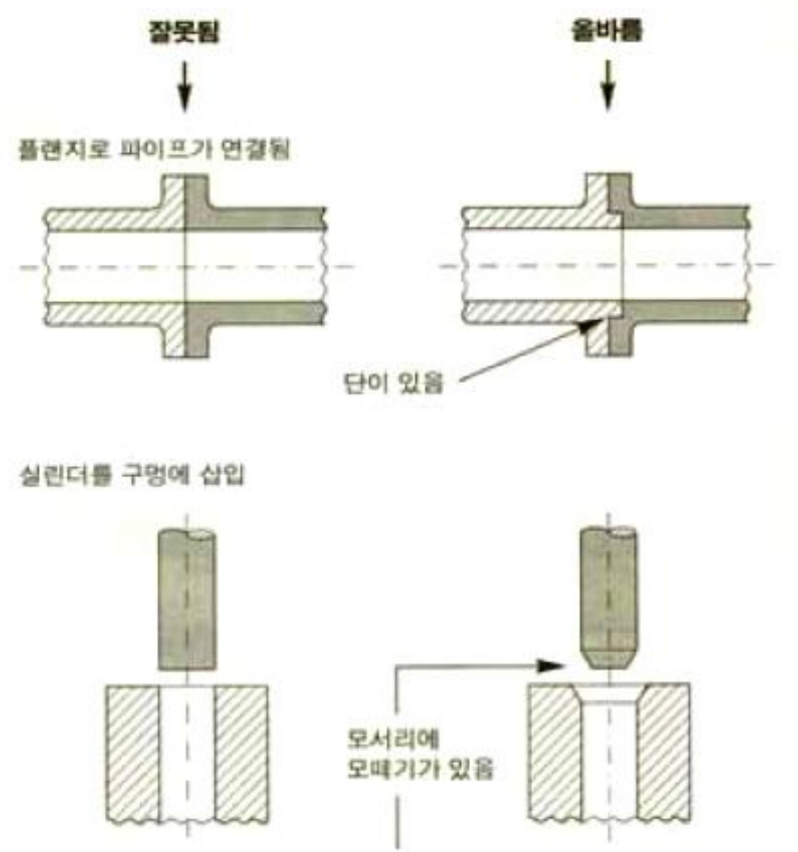


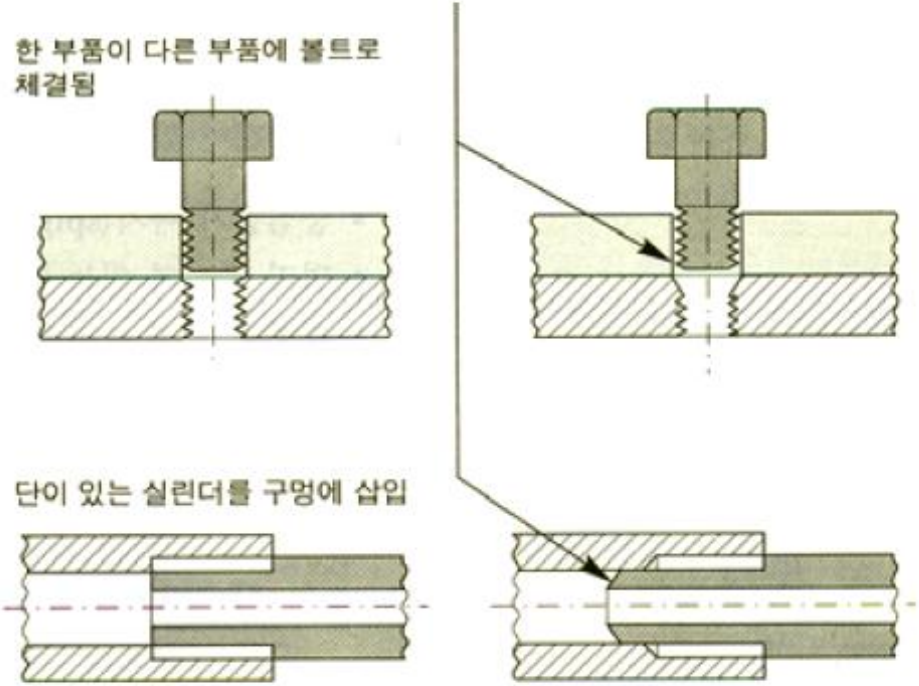
- Multi-functional Part
  - Compliant (flexible) part



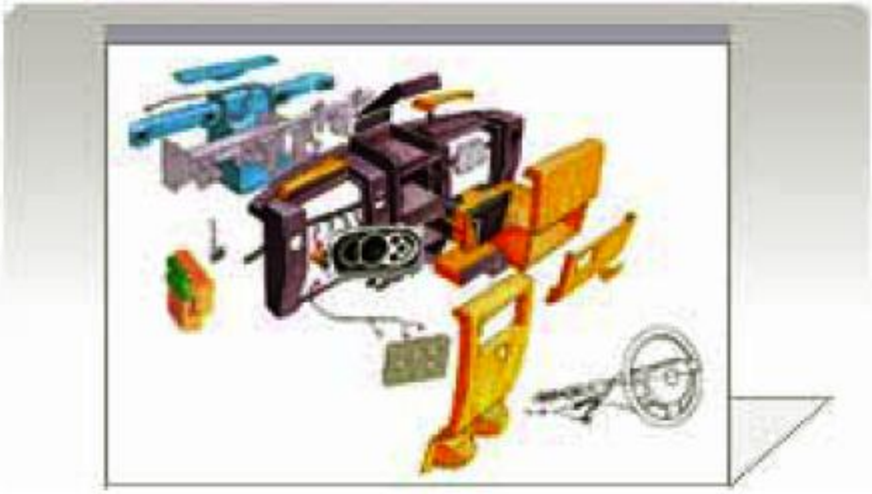
Design for Assembly (cont.)

- Self Location

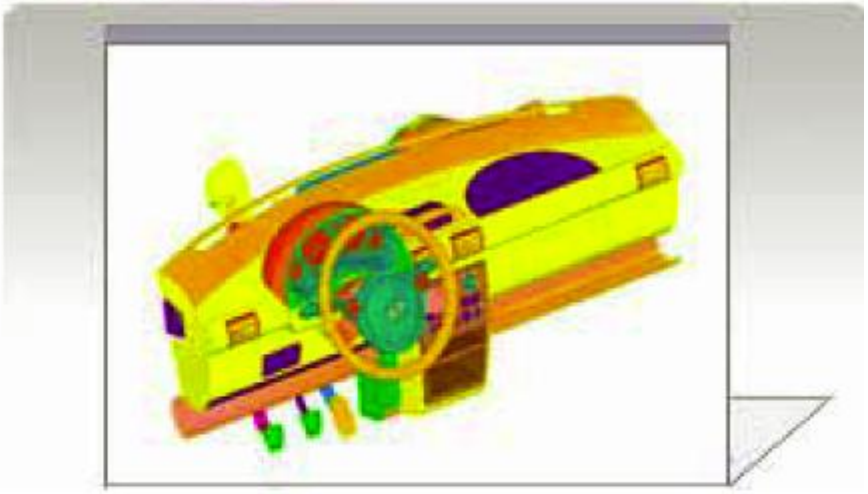




Design for Assembly (cont.)

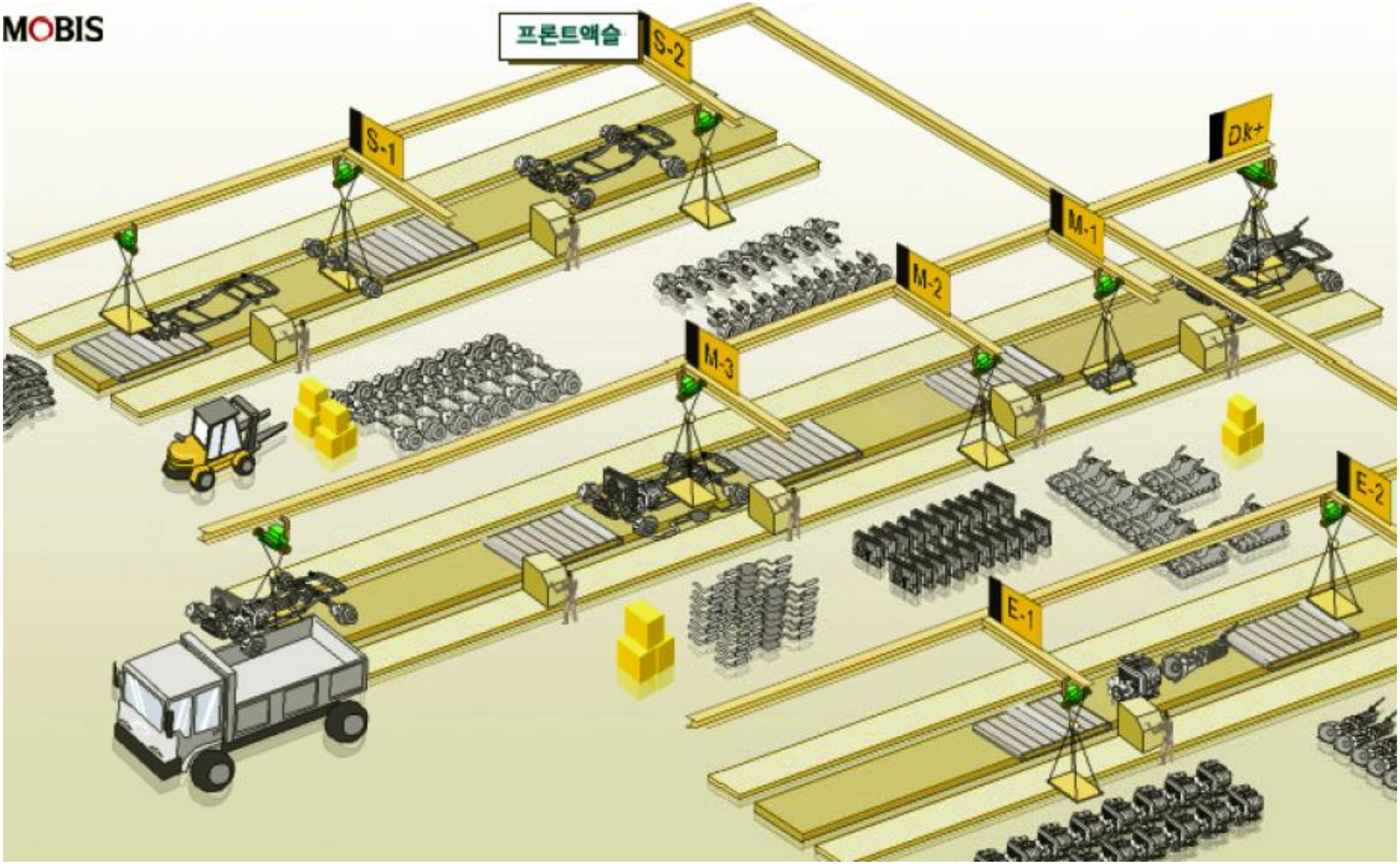


기존방식



Cockpit module

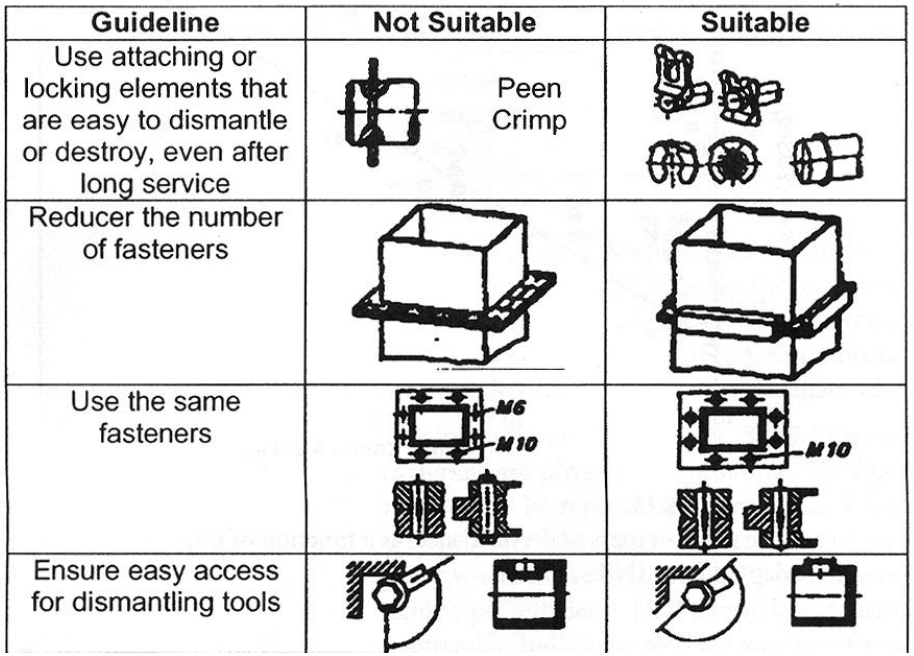
Design for Assembly (cont.)



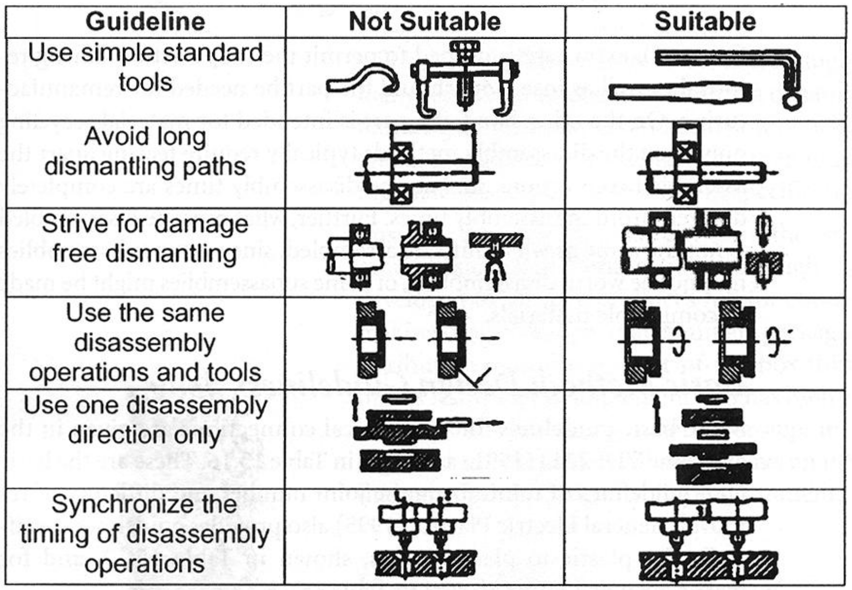
Design for Disassembly (DFDA)

- Guidelines for joints I

TABLE 15.16. MECHANICAL JOINTS SUITABLE FOR DISASSEMBLY



Guideline	Not Suitable	Suitable
Use attaching or locking elements that are easy to dismantle or destroy, even after long service	Peen Crimp	
Reducer the number of fasteners		
Use the same fasteners	M6 M10	M10
Ensure easy access for dismantling tools		

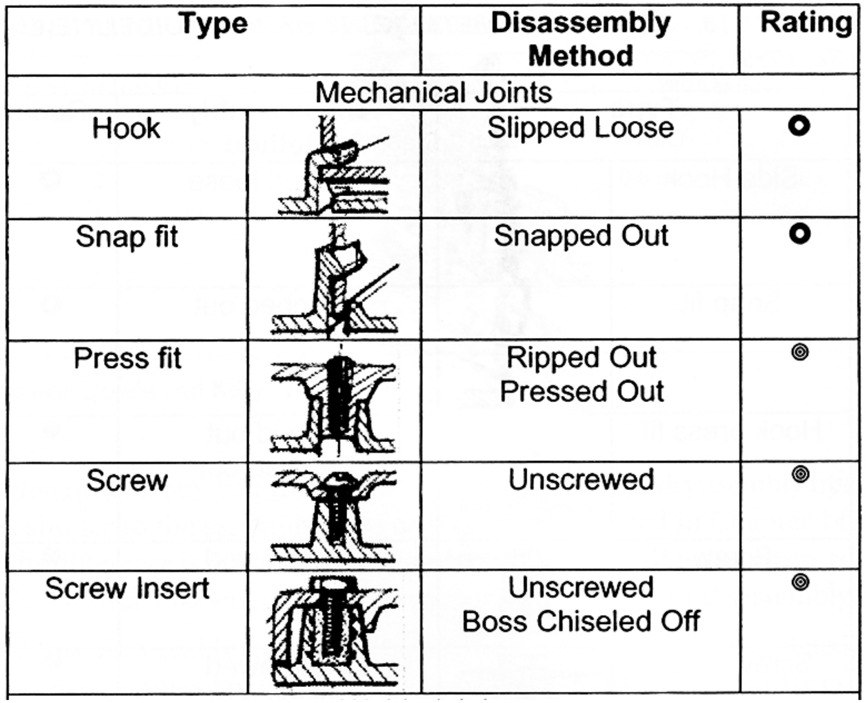


Guideline	Not Suitable	Suitable
Use simple standard tools		
Avoid long dismantling paths		
Strive for damage free dismantling		
Use the same disassembly operations and tools		
Use one disassembly direction only		
Synchronize the timing of disassembly operations		

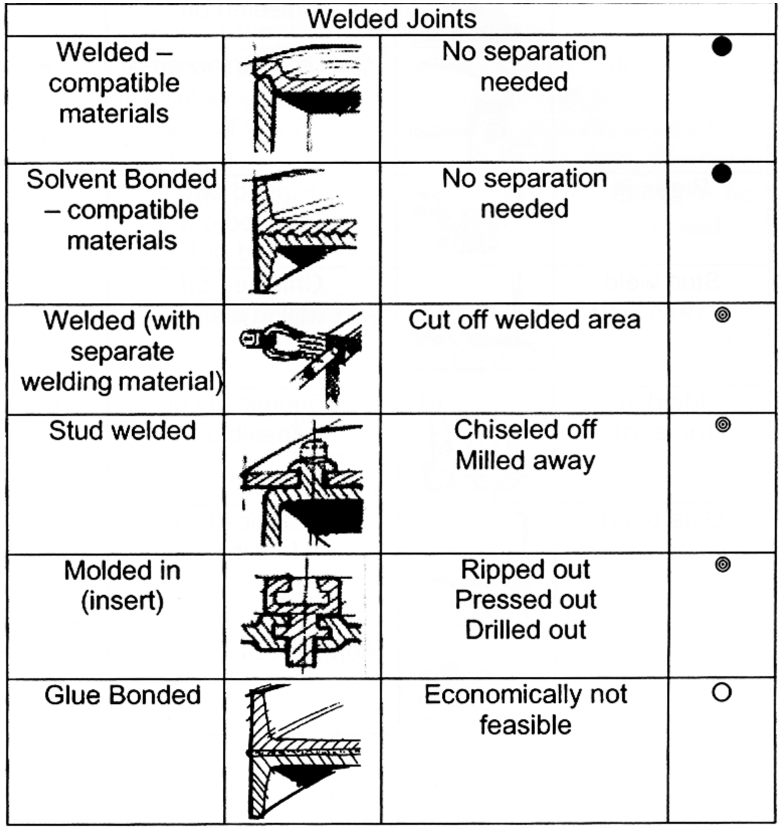
Design for Disassembly (DFDA)

- Guidelines for joints II

TABLE 15.17. PLASTIC-TO-PLASTIC JOINT DESIGN GUIDELINE (GE, 1995).



Type		Disassembly Method	Rating
Mechanical Joints			
Hook		Slipped Loose	○
Snap fit		Snapped Out	○
Press fit		Ripped Out Pressed Out	◎
Screw		Unscrewed	◎
Screw Insert		Unscrewed Boss Chiseled Off	◎



Welded Joints			
Welded – compatible materials		No separation needed	●
Solvent Bonded – compatible materials		No separation needed	●
Welded (with separate welding material)		Cut off welded area	◎
Stud welded		Chiseled off Milled away	◎
Molded in (insert)		Ripped out Pressed out Drilled out	◎
Glue Bonded		Economically not feasible	○

Design for Disassembly (DFDA)

- Guidelines for joints III

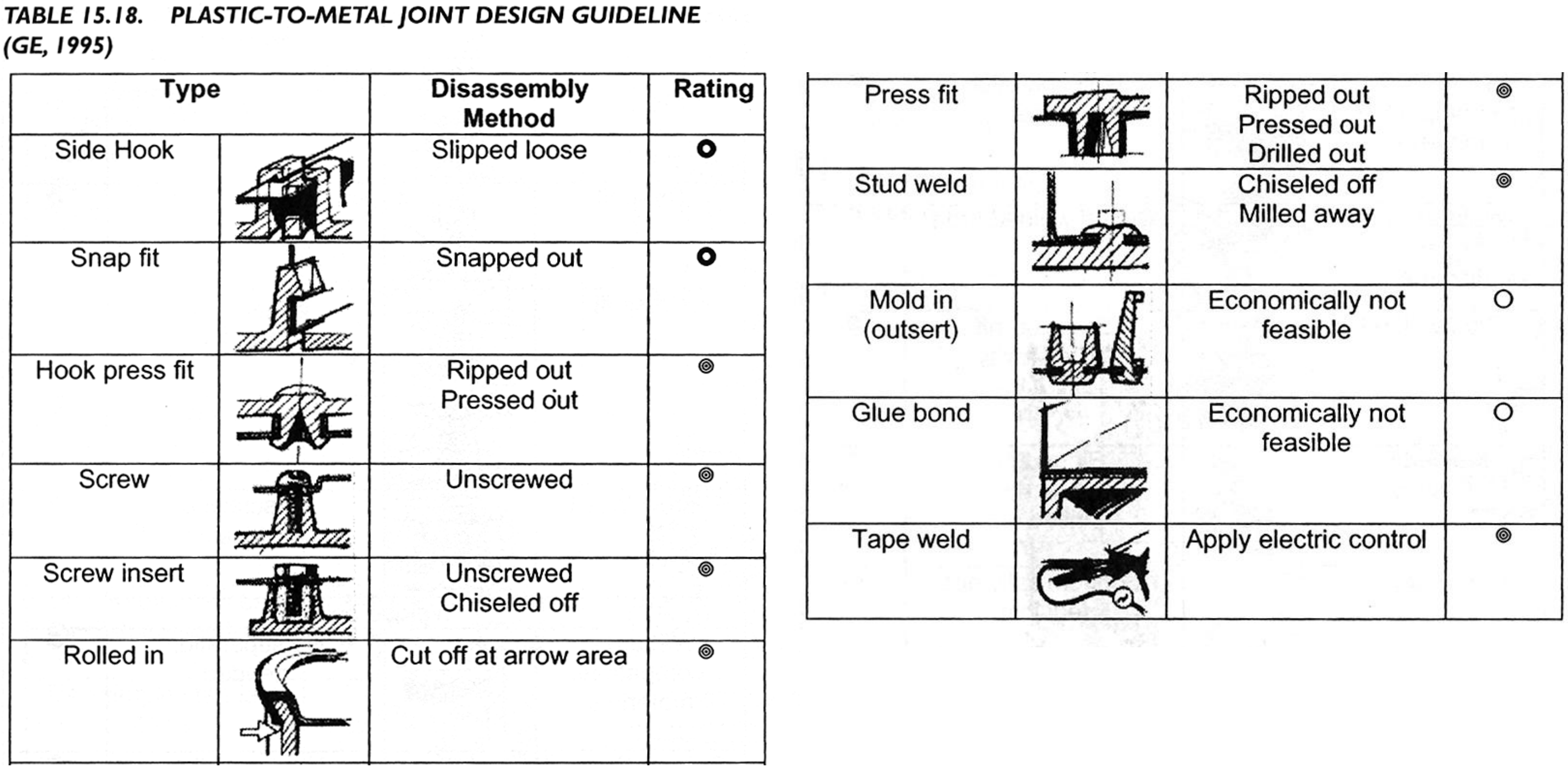
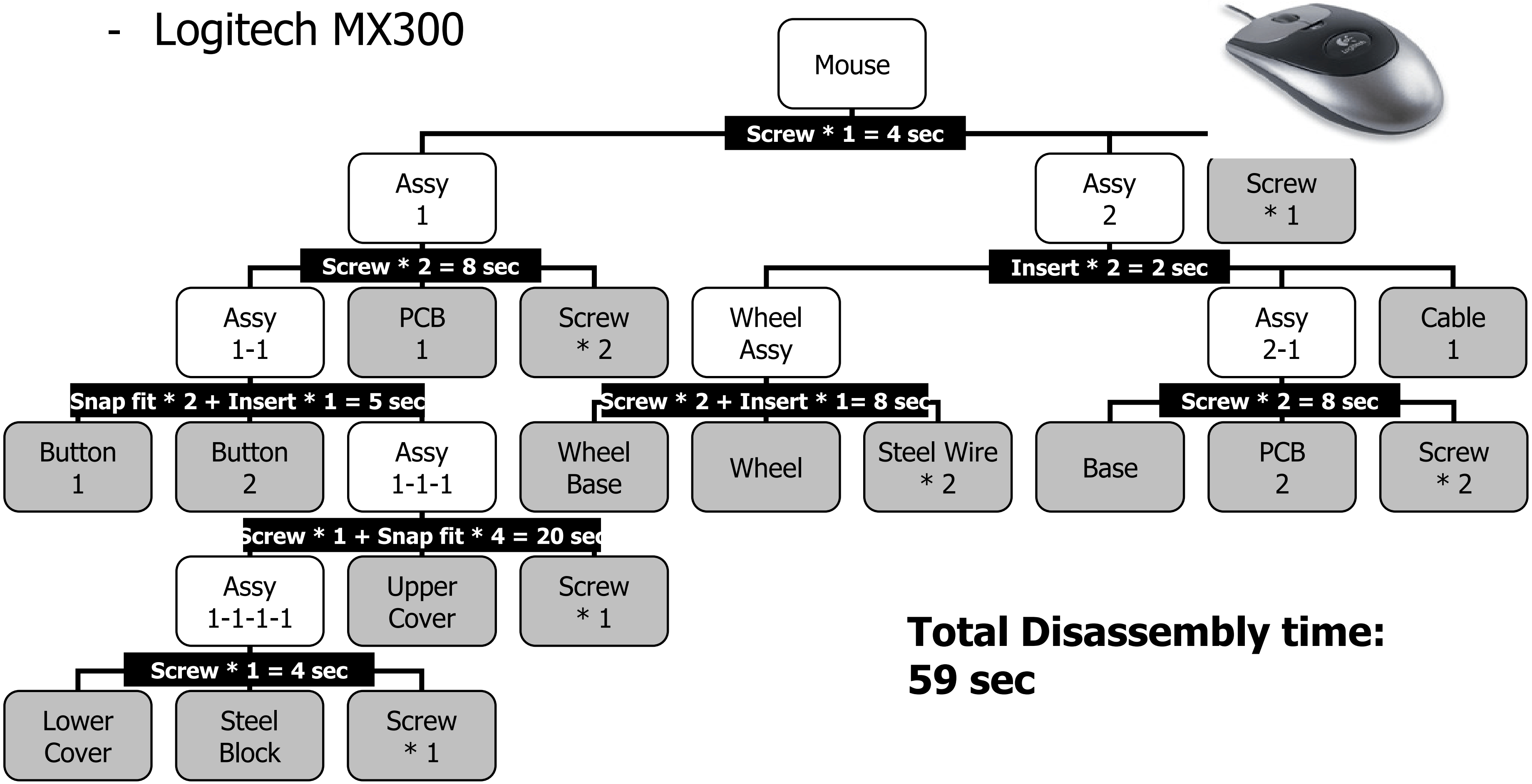


TABLE 15.18. PLASTIC-TO-METAL JOINT DESIGN GUIDELINE (GE, 1995)

Type		Disassembly Method	Rating
Side Hook		Slipped loose	◉
Snap fit		Snapped out	◉
Hook press fit		Ripped out Pressed out	◎
Screw		Unscrewed	◎
Screw insert		Unscrewed Chiseled off	◎
Rolled in		Cut off at arrow area	◎
Press fit		Ripped out Pressed out Drilled out	◎
Stud weld		Chiseled off Milled away	◎
Mold in (outsert)		Economically not feasible	○
Glue bond		Economically not feasible	○
Tape weld		Apply electric control	◎

Design for Disassembly (DFDA)

- Time issue
  - Logitech MX300



Mouse

Screw * 1 = 4 sec

Assy 1

Assy 2

Screw * 1

Screw * 2 = 8 sec

Insert * 2 = 2 sec

Assy 1-1

PCB 1

Screw * 2

Wheel Assy

Assy 2-1

Cable 1

Snap fit * 2 + Insert * 1 = 5 sec

Screw * 2 + Insert * 1= 8 sec

Screw * 2 = 8 sec

Button 1

Button 2

Assy 1-1-1

Wheel Base

Wheel

Steel Wire * 2

Base

PCB 2

Screw * 2

Screw * 1 + Snap fit * 4 = 20 sec

Assy 1-1-1-1

Upper Cover

Screw * 1

Screw * 1 = 4 sec

Lower Cover

Steel Block

Screw * 1

Total Disassembly time:
59 sec

Insert: x sec

Snap fit: x^2 sec

Screw: 4x sec

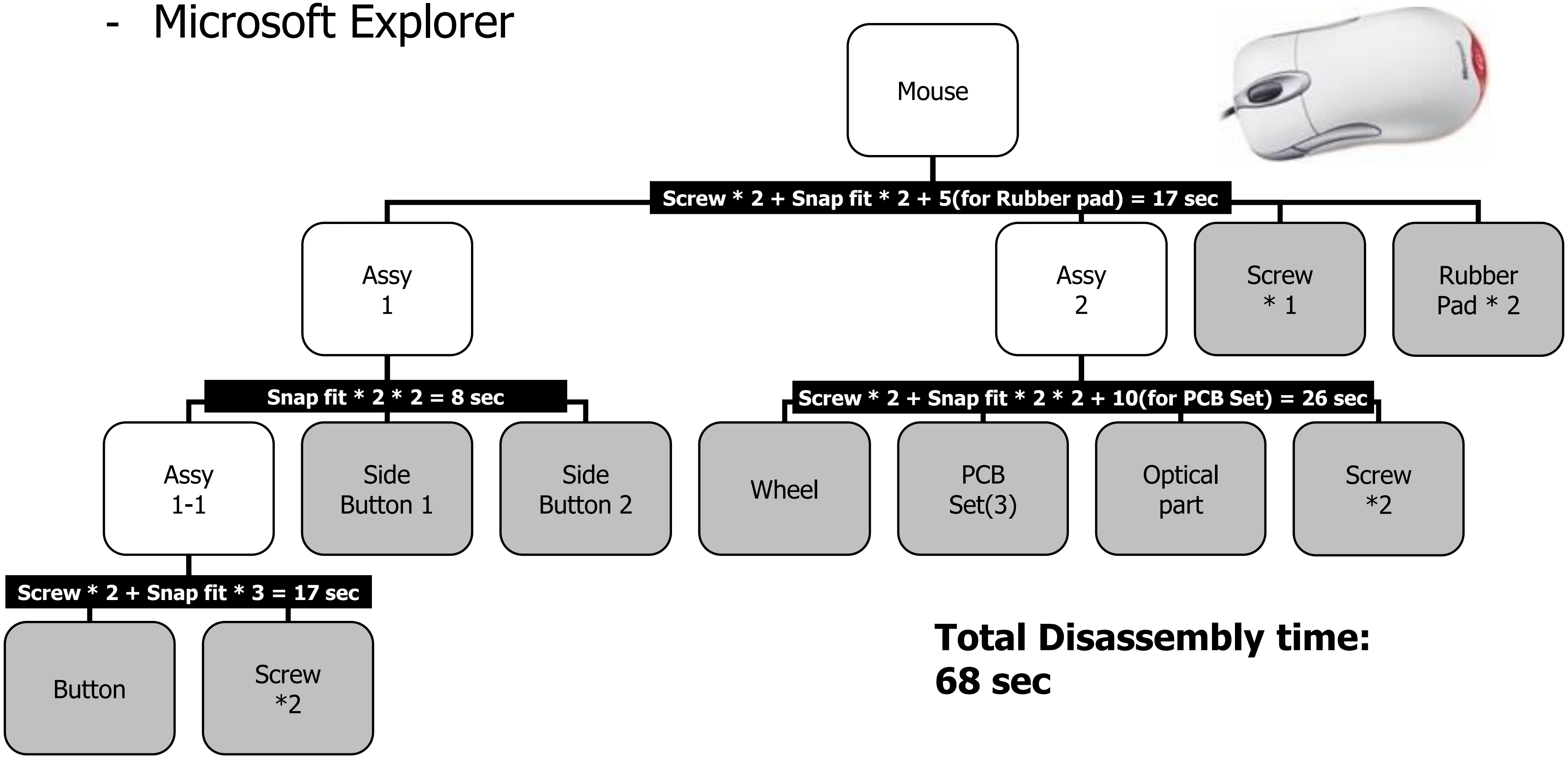
x: # of items

Assembly

Single part

Design for Disassembly (DFDA)

- Time issue
  - Microsoft Explorer



Total Disassembly time: 68 sec

Insert: x sec   Snap fit: x^2 sec   Screw: 4x sec   x: # of items

Assembly   Single part

Design for Environment (DFE)

- Benefit of DFE
  - Reduced health, safety, and ecological risks
  - Increased efficiency and customer acceptance
  - Improved worker morale and productivity
  - Reduced regulatory burden
  - Improved channels of communication, cooperation, and collaboration among stakeholder organizations
  - Expanded business and market opportunities

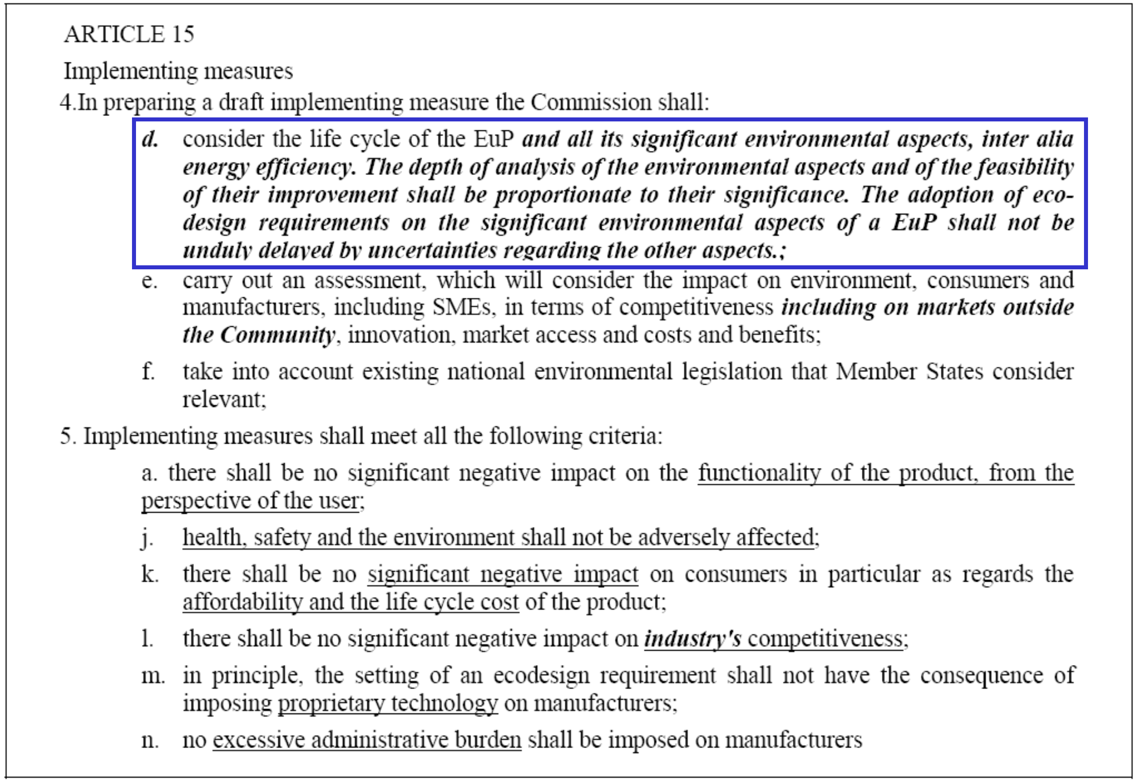
- from U.S. Envrionmental Protection Agency (EPA),
http://www.epa.gov/oppt/dfe

  - DFE includes
    - Design for Recycling
    - Design for remanufacturing
    - Design for energy efficiency

⋮

DFE as a real regulation

- Eco Design(DFE) of EuP Directive 2005/32/EC
    - EuP : Energy using Products which use any forms of energy
    - All EU countries must legislate for this EuP Directive until 11th August, 2007.



ARTICLE 15

Implementing measures

4.In preparing a draft implementing measure the Commission shall:

d. consider the life cycle of the EuP ***and all its significant environmental aspects, inter alia energy efficiency. The depth of analysis of the environmental aspects and of the feasibility of their improvement shall be proportionate to their significance. The adoption of eco-design requirements on the significant environmental aspects of a EuP shall not be unduly delayed by uncertainties regarding the other aspects.;***

e. carry out an assessment, which will consider the impact on environment, consumers and manufacturers, including SMEs, in terms of competitiveness ***including on markets outside the Community***, innovation, market access and costs and benefits;

f. take into account existing national environmental legislation that Member States consider relevant;

5. Implementing measures shall meet all the following criteria:

a. there shall be no significant negative impact on the functionality of the product, from the perspective of the user;

j. health, safety and the environment shall not be adversely affected;

k. there shall be no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product;

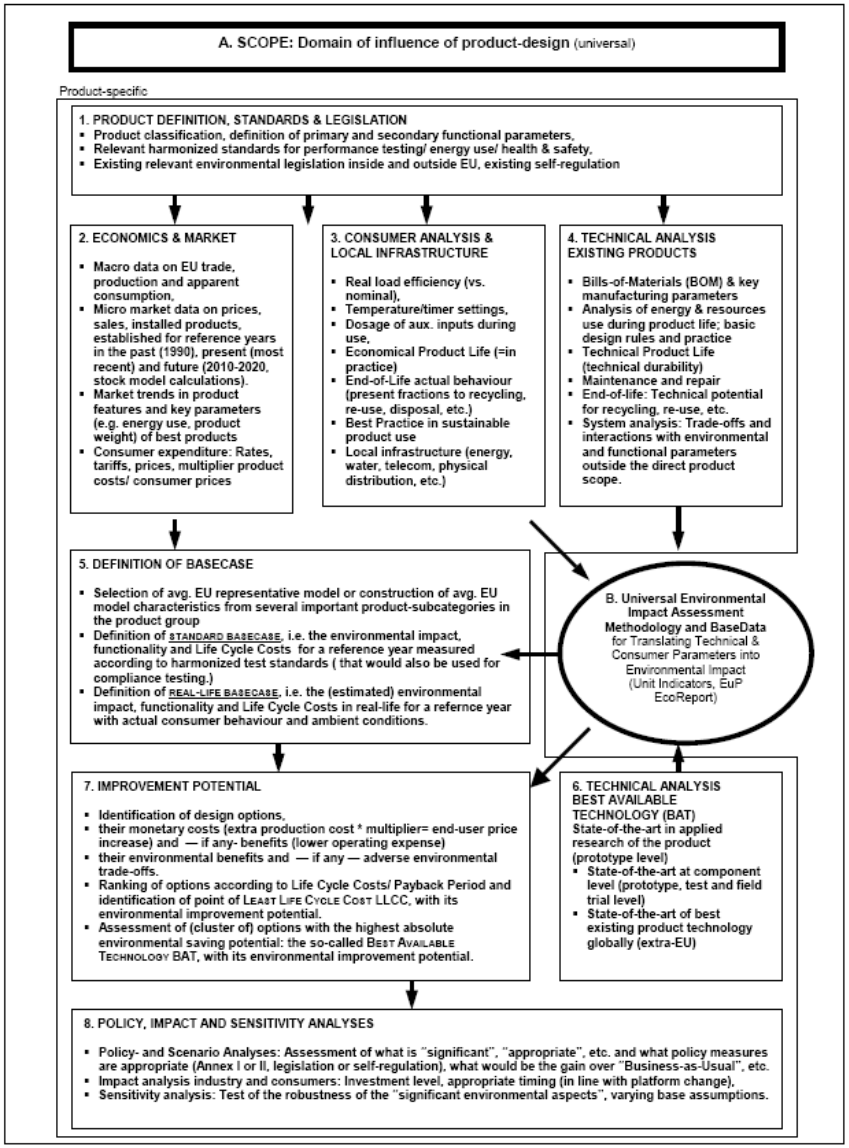
l. there shall be no significant negative impact on ***industry's*** competitiveness;

m. in principle, the setting of an ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers;

n. no excessive administrative burden shall be imposed on manufacturers

< A Part of Direcrive 2005/32/EC Article 15 >

DFE as a real regulation



A. SCOPE: Domain of influence of product-design (universal)

Product-specific

1. PRODUCT DEFINITION, STANDARDS & LEGISLATION
- Product classification, definition of primary and secondary functional parameters,
- Relevant harmonized standards for performance testing/ energy use/ health & safety,
- Existing relevant environmental legislation inside and outside EU, existing self-regulation

2. ECONOMICS & MARKET
- Macro data on EU trade, production and apparent consumption,
- Micro market data on prices, sales, installed products, established for reference years in the past (1990), present (most recent) and future (2010-2020, stock model calculations).
- Market trends in product features and key parameters (e.g. energy use, product weight) of best products
- Consumer expenditure: Rates, tariffs, prices, multiplier product costs/ consumer prices

3. CONSUMER ANALYSIS & LOCAL INFRASTRUCTURE
- Real load efficiency (vs. nominal),
- Temperature/timer settings,
- Dosage of aux. inputs during use,
- Economical Product Life (=in practice)
- End-of-Life actual behaviour (present fractions to recycling, re-use, disposal, etc.)
- Best Practice in sustainable product use
- Local infrastructure (energy, water, telecom, physical distribution, etc.)

4. TECHNICAL ANALYSIS EXISTING PRODUCTS
- Bills-of-Materials (BOM) & key manufacturing parameters
- Analysis of energy & resources use during product life; basic design rules and practice
- Technical Product Life (technical durability)
- Maintenance and repair
- End-of-life: Technical potential for recycling, re-use, etc.
- System analysis: Trade-offs and interactions with environmental and functional parameters outside the direct product scope.

5. DEFINITION OF BASECASE
- Selection of avg. EU representative model or construction of avg. EU model characteristics from several important product-subcategories in the product group
- Definition of STANDARD BASECASE, i.e. the environmental impact, functionality and Life Cycle Costs for a reference year measured according to harmonized test standards (that would also be used for compliance testing.)
- Definition of REAL-LIFE BASECASE, i.e. the (estimated) environmental impact, functionality and Life Cycle Costs in real-life for a refernce year with actual consumer behaviour and ambient conditions.

B. Universal Environmental Impact Assessment Methodology and BaseData for Translating Technical & Consumer Parameters into Environmental Impact (Unit Indicators, EuP EcoReport)

7. IMPROVEMENT POTENTIAL
- Identification of design options,
- their monetary costs (extra production cost * multiplier= end-user price increase) and — if any- benefits (lower operating expense)
- their environmental benefits and — if any — adverse environmental trade-offs.
- Ranking of options according to Life Cycle Costs/ Payback Period and identification of point of LEAST LIFE CYCLE COST LLCC, with its environmental improvement potential.
- Assessment of (cluster of) options with the highest absolute environmental saving potential: the so-called BEST AVAILABLE TECHNOLOGY BAT, with its environmental improvement potential.

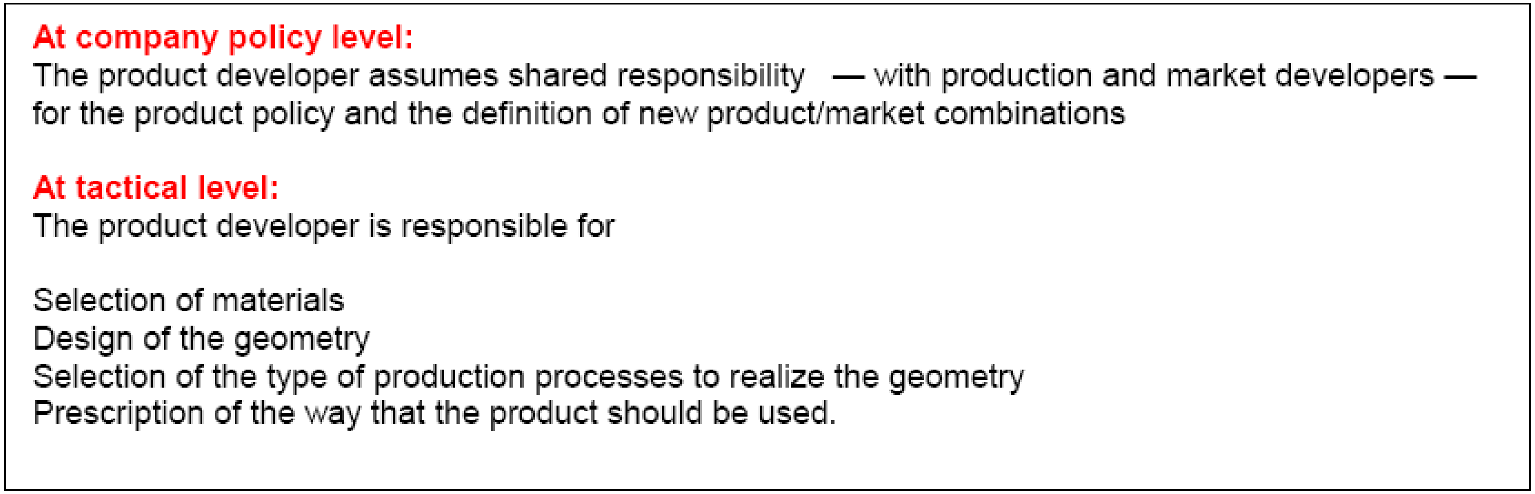
6. TECHNICAL ANALYSIS BEST AVAILABLE TECHNOLOGY (BAT)
State-of-the-art in applied research of the product (prototype level)
- State-of-the-art at component level (prototype, test and field trial level)
- State-of-the-art of best existing product technology globally (extra-EU)

8. POLICY, IMPACT AND SENSITIVITY ANALYSES
- Policy- and Scenario Analyses: Assessment of what is "significant", "appropriate", etc. and what policy measures are appropriate (Annex I or II, legislation or self-regulation), what would be the gain over "Business-as-Usual", etc.
- Impact analysis industry and consumers: Investment level, appropriate timing (in line with platform change),
- Sensitivity analysis: Test of the robustness of the "significant environmental aspects", varying base assumptions.

Figure 1. Structure of key parameters needed for Ecodesign of EuP directive, Art. 15.

DFE as a real regulation

- DFE affects the decisions listed hereafter



At company policy level:
The product developer assumes shared responsibility — with production and market developers — for the product policy and the definition of new product/market combinations

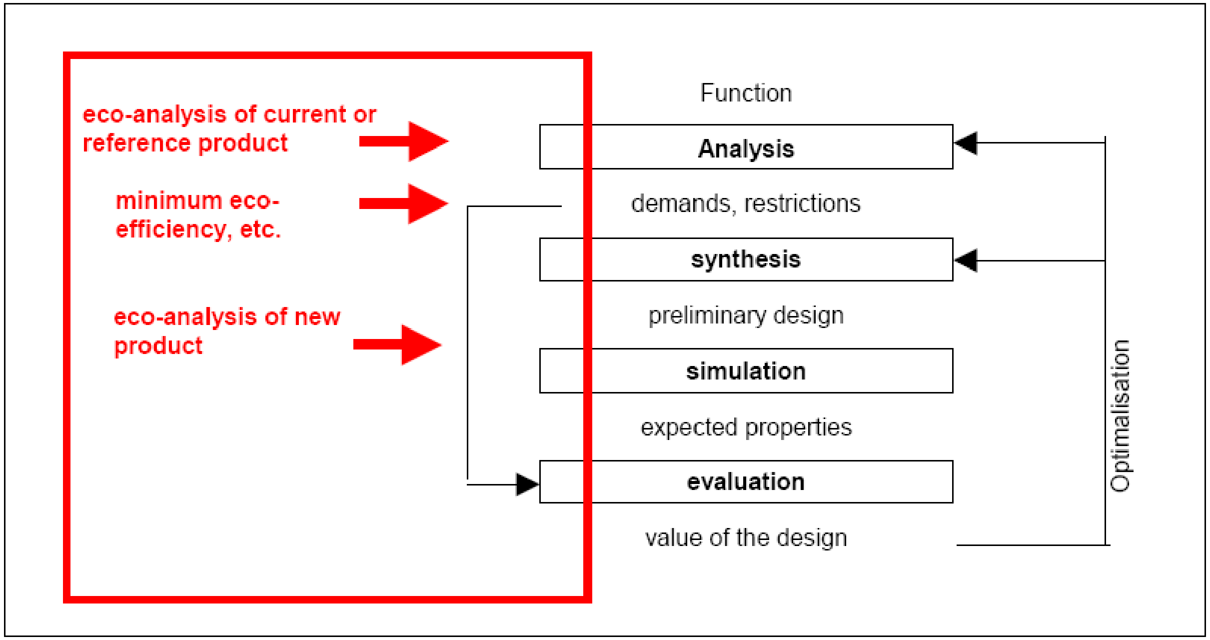
At tactical level:
The product developer is responsible for

Selection of materials
Design of the geometry
Selection of the type of production processes to realize the geometry
Prescription of the way that the product should be used.

- Integrated Product Policy
  - At the strategic level of generating ideas for new products, the notion of eco-analysis of current products, the environmental goals one is trying to reach and the notion of how new products would be an improvement can be qualitative and abstract.

DFE as a real regulation

- Integrated Product Policy
  - At such level, a company may decide for instance that all-in-one imaging center is more environmentally friendly than a single product. The DFE dimension, as one of the many factors that are taken into consideration, can be an inspiration and guidance.



eco-analysis of current or reference product

minimum eco-efficiency, etc.

eco-analysis of new product

Function

Analysis

demands, restrictions

synthesis

preliminary design

simulation

expected properties

evaluation

value of the design

Optimalisation

Figure 5 . Domain of Eco-design (in red) within the basis product design loop *[after Archer, Technological Innovation, 1973]*

Design for recycling

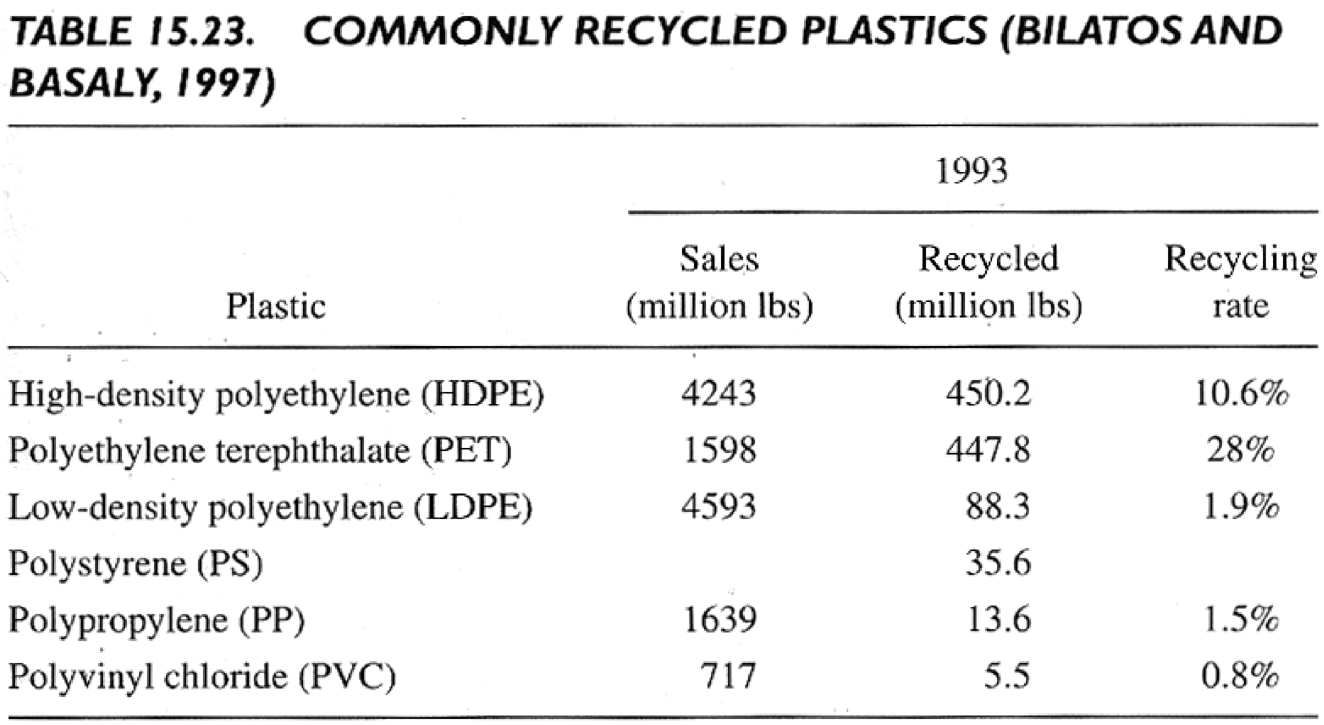


TABLE 15.23. COMMONLY RECYCLED PLASTICS (BILATOS AND BASALY, 1997)

	1993		
Plastic	Sales (million lbs)	Recycled (million lbs)	Recycling rate
High-density polyethylene (HDPE)	4243	450.2	10.6%
Polyethylene terephthalate (PET)	1598	447.8	28%
Low-density polyethylene (LDPE)	4593	88.3	1.9%
Polystyrene (PS)		35.6	
Polypropylene (PP)	1639	13.6	1.5%
Polyvinyl chloride (PVC)	717	5.5	0.8%

Design for recycling (cont.)

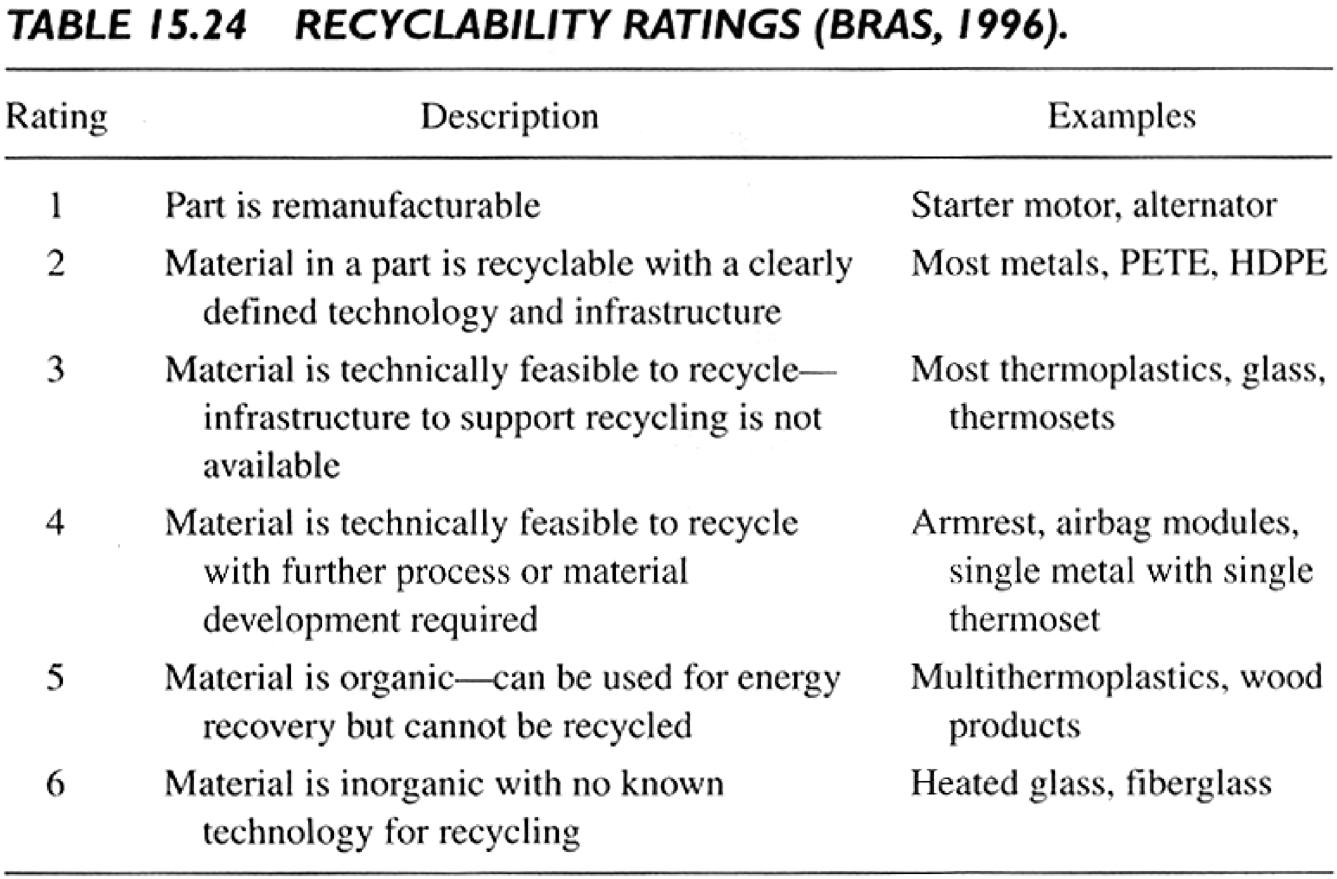


TABLE 15.24 RECYCLABILITY RATINGS (BRAS, 1996).

Rating	Description	Examples
1	Part is remanufacturable	Starter motor, alternator
2	Material in a part is recyclable with a clearly defined technology and infrastructure	Most metals, PETE, HDPE
3	Material is technically feasible to recycle—infrastructure to support recycling is not available	Most thermoplastics, glass, thermosets
4	Material is technically feasible to recycle with further process or material development required	Armrest, airbag modules, single metal with single thermoset
5	Material is organic—can be used for energy recovery but cannot be recycled	Multithermoplastics, wood products
6	Material is inorganic with no known technology for recycling	Heated glass, fiberglass

Design for recycling (cont.)

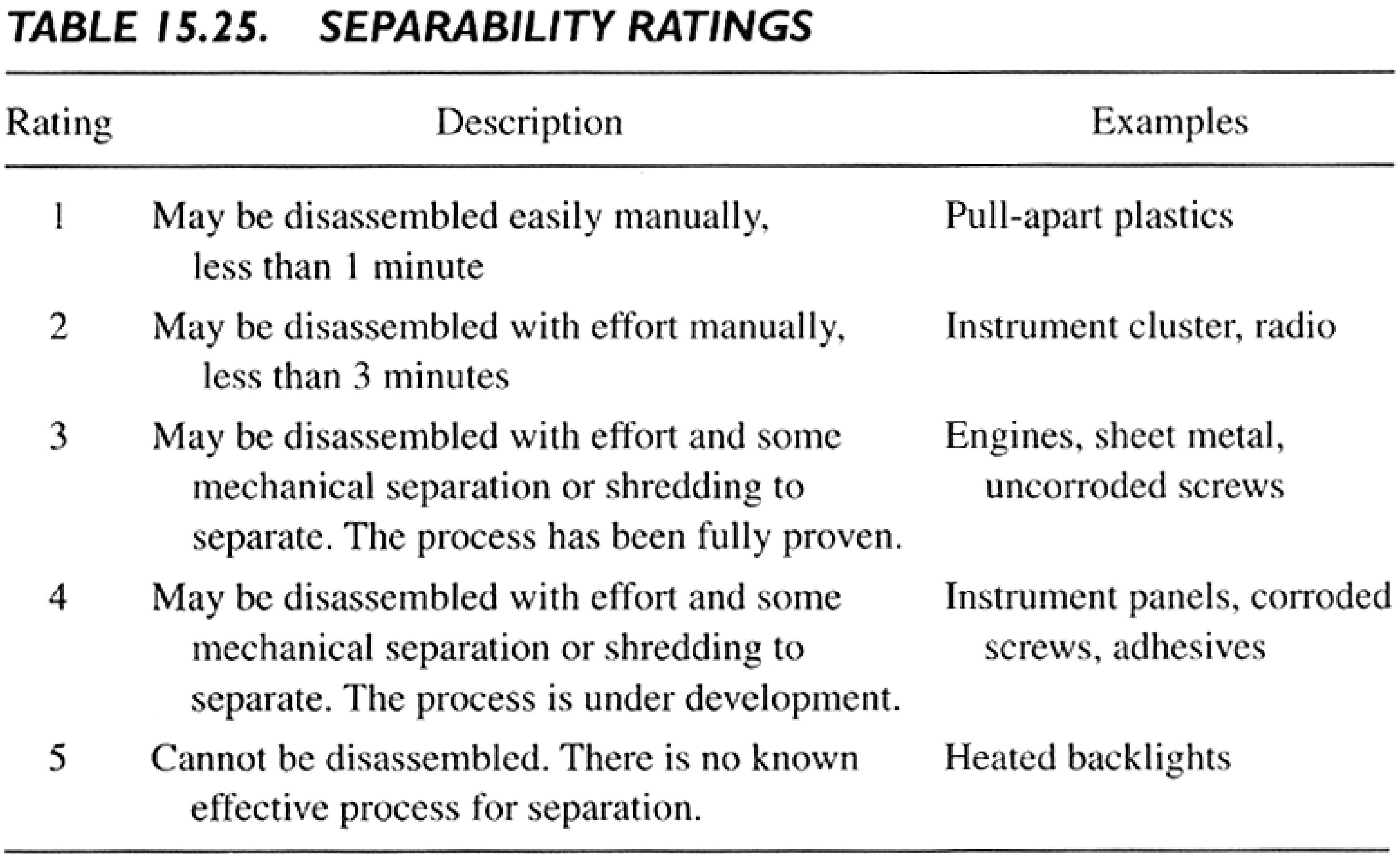
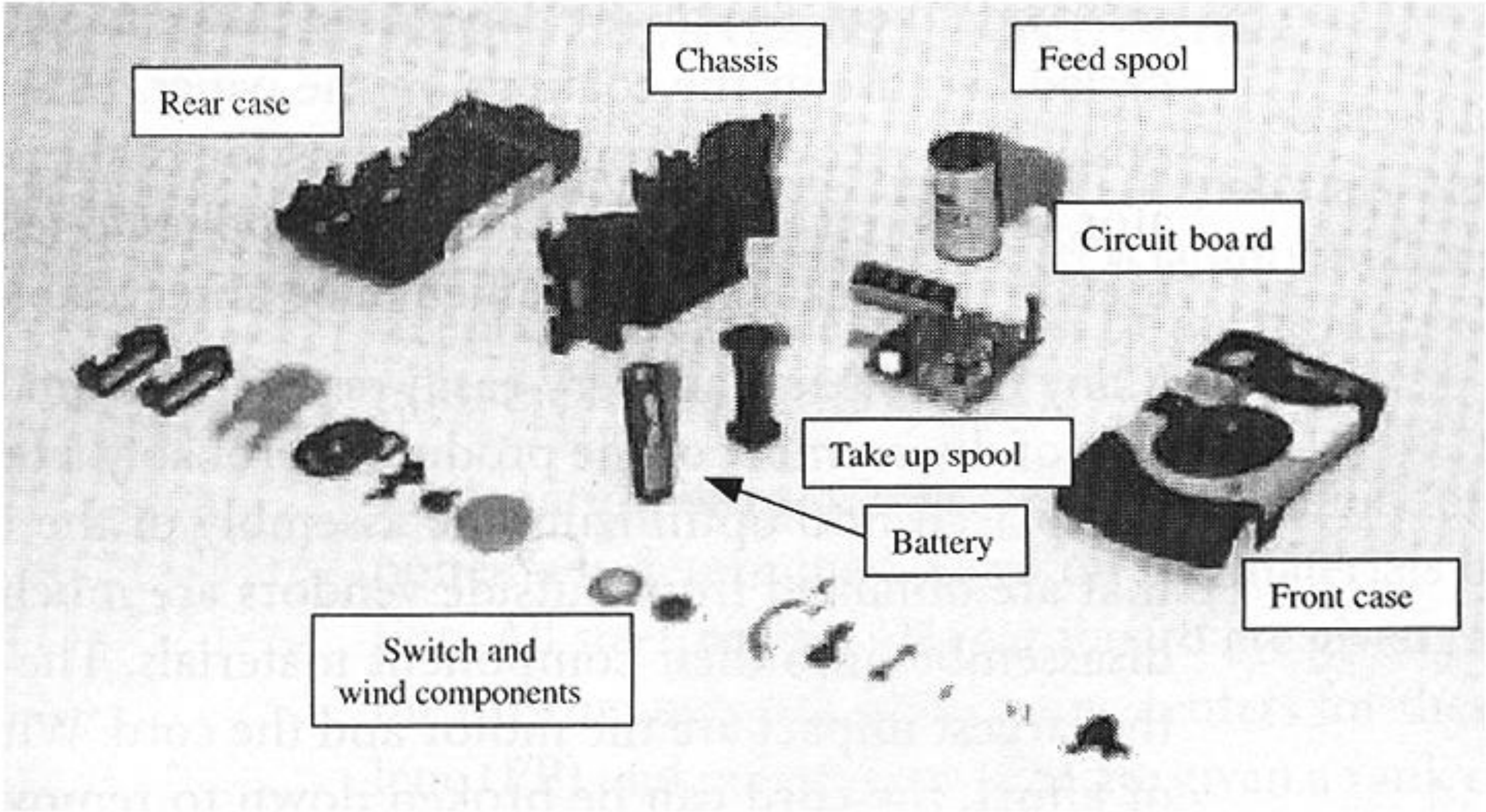


TABLE 15.25. SEPARABILITY RATINGS

Rating	Description	Examples
1	May be disassembled easily manually, less than 1 minute	Pull-apart plastics
2	May be disassembled with effort manually, less than 3 minutes	Instrument cluster, radio
3	May be disassembled with effort and some mechanical separation or shredding to separate. The process has been fully proven.	Engines, sheet metal, uncorroded screws
4	May be disassembled with effort and some mechanical separation or shredding to separate. The process is under development.	Instrument panels, corroded screws, adhesives
5	Cannot be disassembled. There is no known effective process for separation.	Heated backlights

Design for remanufacture



Parts of the Kodak Funsaver Single-use camera area remanufactured. Parts must be removed, cleaned, inspected, and returned to the factory for reuse.

Design for high-impact material reduction

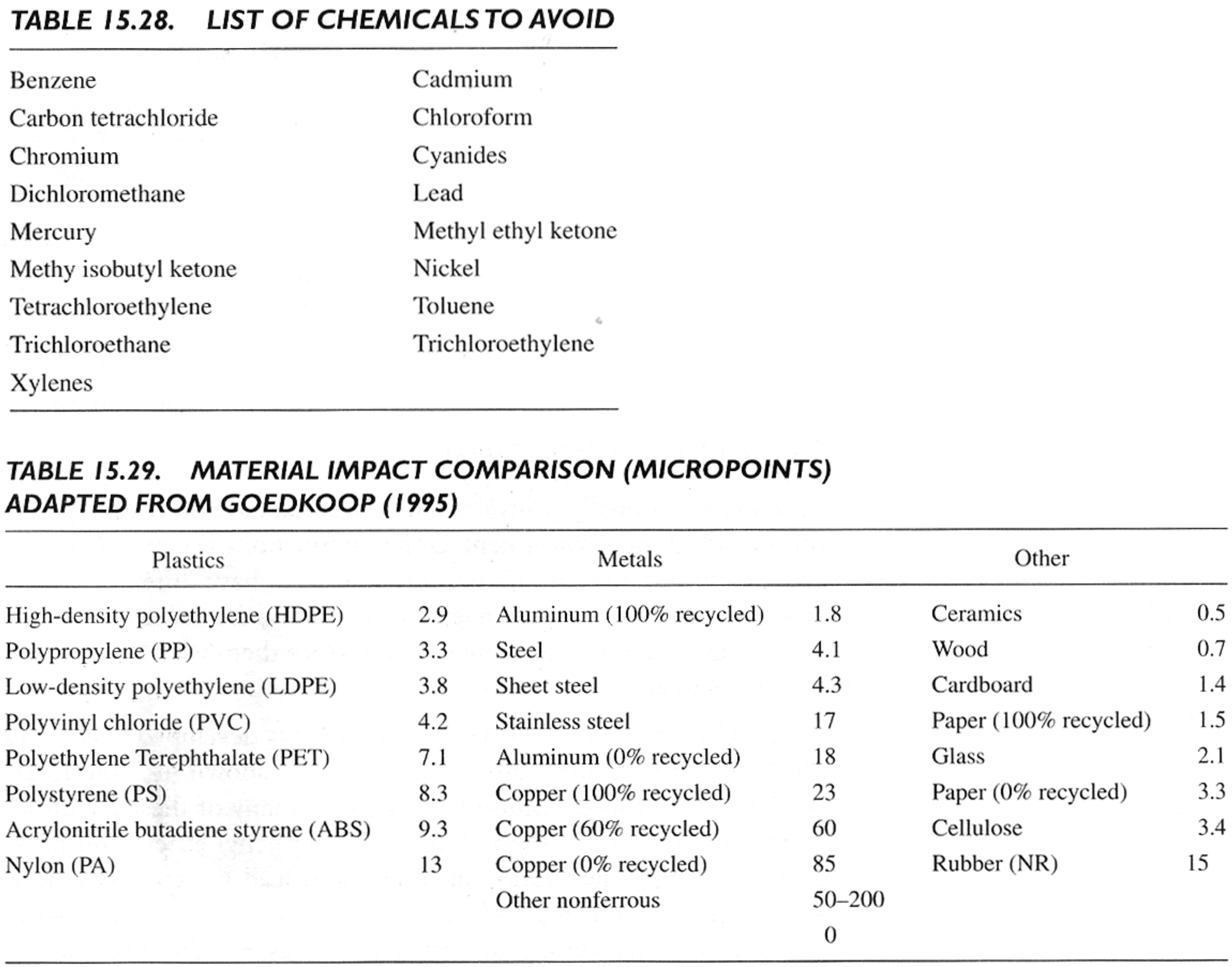


TABLE 15.28. LIST OF CHEMICALS TO AVOID

Benzene
Cadmium
Carbon tetrachloride
Chloroform
Chromium
Cyanides
Dichloromethane
Lead
Mercury
Methyl ethyl ketone
Methy isobutyl ketone
Nickel
Tetrachloroethylene
Toluene
Trichloroethane
Trichloroethylene
Xylenes

TABLE 15.29. MATERIAL IMPACT COMPARISON (MICROPOINTS) ADAPTED FROM GOEDKOOP (1995)

Plastics		Metals		Other	
High-density polyethylene (HDPE)	2.9	Aluminum (100% recycled)	1.8	Ceramics	0.5
Polypropylene (PP)	3.3	Steel	4.1	Wood	0.7
Low-density polyethylene (LDPE)	3.8	Sheet steel	4.3	Cardboard	1.4
Polyvinyl chloride (PVC)	4.2	Stainless steel	17	Paper (100% recycled)	1.5
Polyethylene Terephthalate (PET)	7.1	Aluminum (0% recycled)	18	Glass	2.1
Polystyrene (PS)	8.3	Copper (100% recycled)	23	Paper (0% recycled)	3.3
Acrylonitrile butadiene styrene (ABS)	9.3	Copper (60% recycled)	60	Cellulose	3.4
Nylon (PA)	13	Copper (0% recycled)	85	Rubber (NR)	15
		Other nonferrous	50–200 0		

Design for energy efficiency

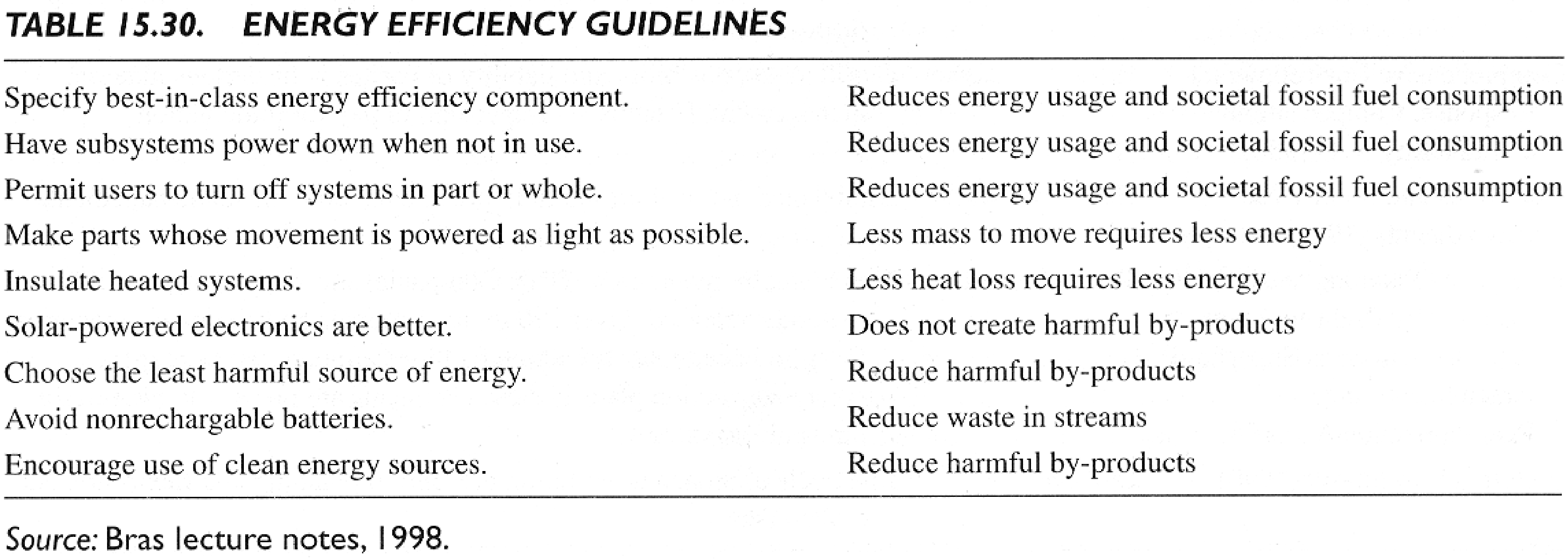


TABLE 15.30. ENERGY EFFICIENCY GUIDELINES

Specify best-in-class energy efficiency component.	Reduces energy usage and societal fossil fuel consumption
Have subsystems power down when not in use.	Reduces energy usage and societal fossil fuel consumption
Permit users to turn off systems in part or whole.	Reduces energy usage and societal fossil fuel consumption
Make parts whose movement is powered as light as possible.	Less mass to move requires less energy
Insulate heated systems.	Less heat loss requires less energy
Solar-powered electronics are better.	Does not create harmful by-products
Choose the least harmful source of energy.	Reduce harmful by-products
Avoid nonrechargable batteries.	Reduce waste in streams
Encourage use of clean energy sources.	Reduce harmful by-products

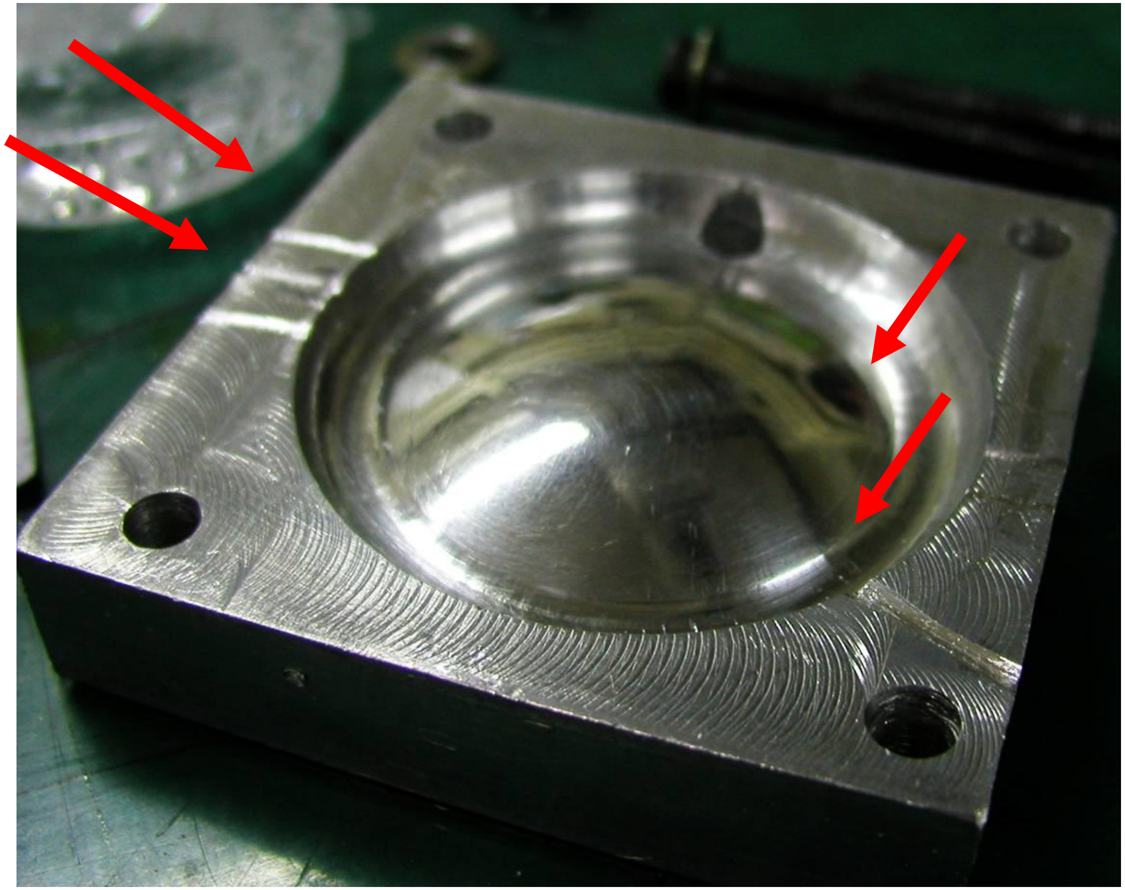
Source: Bras lecture notes, 1998.

Design for class project

- Minimum part size
- Minimum thickness
- Maximum part size
- Manufacturing cost
- Machining
  - No undercut for 3 axis milling and turning
  - Fixturing-vise, vacuum chuck
- RP
  - Surface roughness and post process
  - Strength
- Injection molding
  - Draft angle
  - No undercut, or undercut with slider mechanism

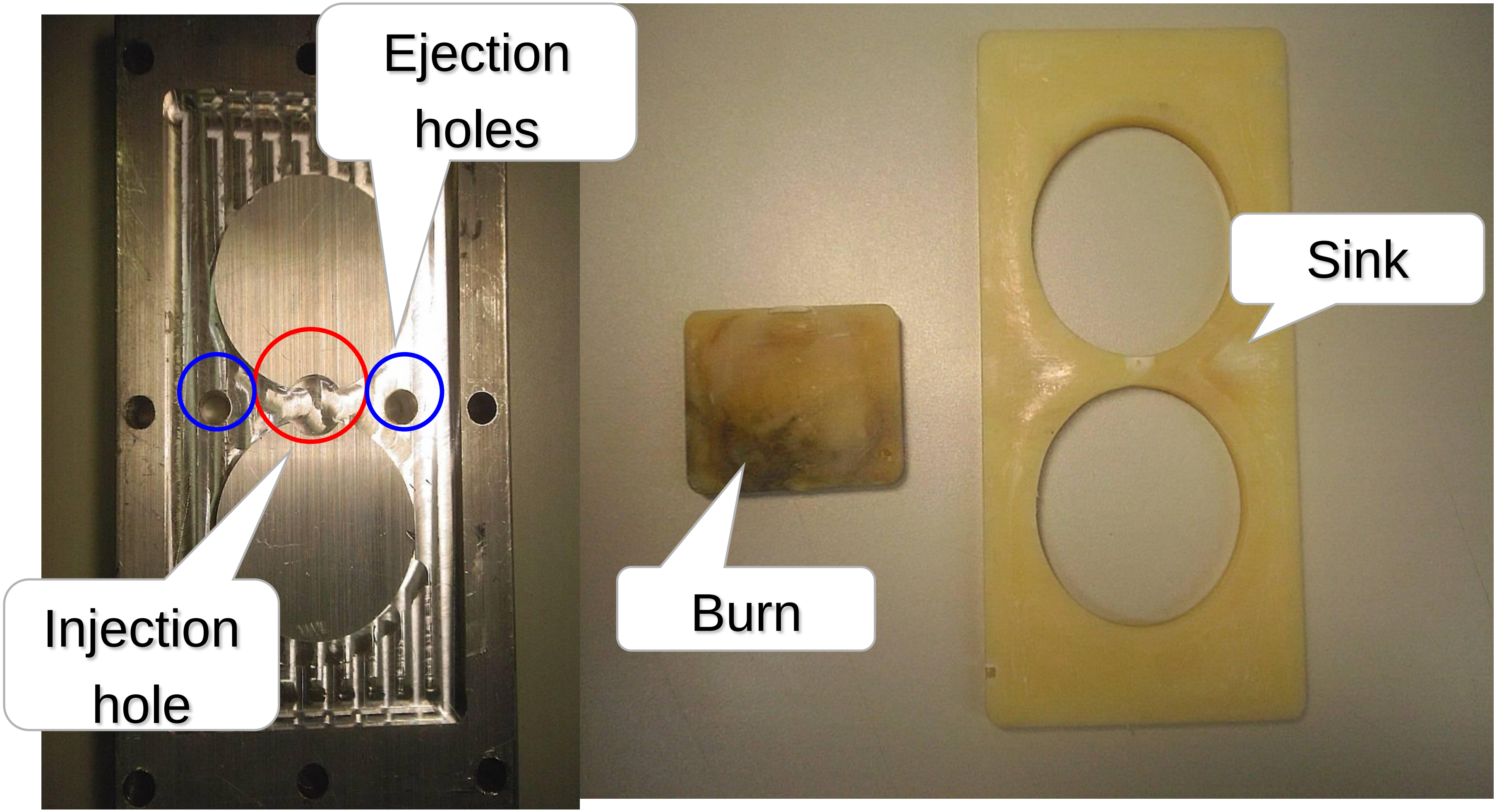
Case study #1

- Mold making
  - CNC, milling, turning
  - sanding
  - Channels for air escape



Case study #2

- Injection molding



Case study #3

- Re-design for injection molding