446.326A CAD/CAM

Design for X (DFX)

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Sung-Hoon Ahn
School of Mechanical and Aerospace Engineering
Seoul National University

Introduction of DFX

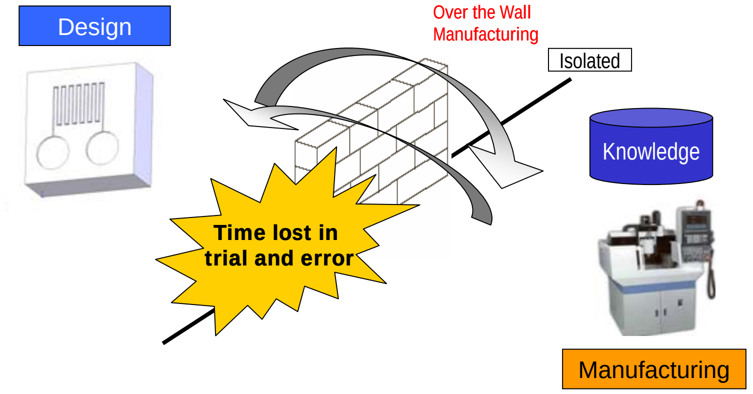
- Success in product manufacturing requires integration between the various phases of the product life cycle.
  – Ulrich and Eppinger, 1995

- 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)

⋮

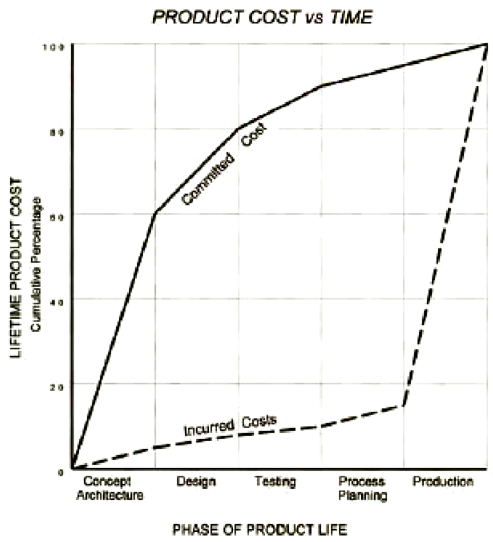
1. Design for Manufacturing (DFM)

- Traditional Design and Manufacturing Process



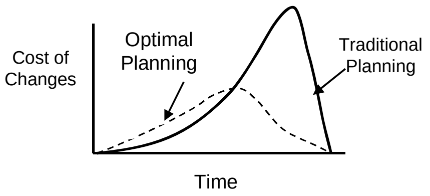
1. Design for Manufacturing (cont.)

- 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

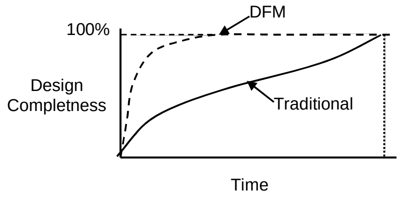


1. Design for Manufacturing (cont.)

- 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 >



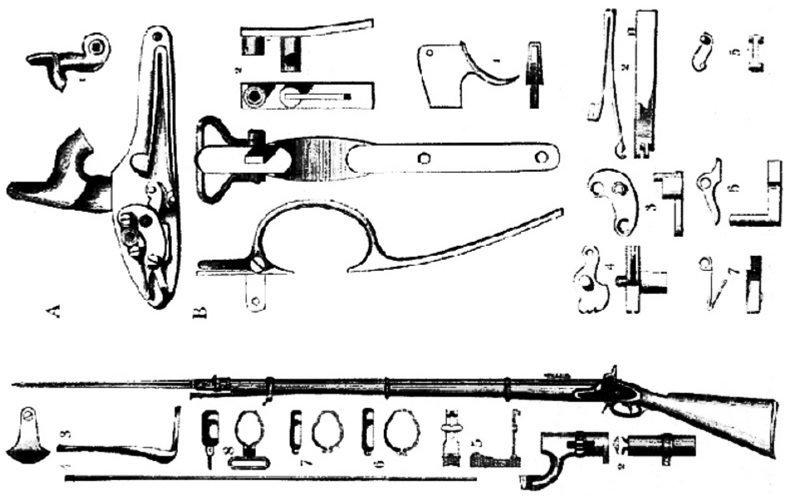
< Design completeness vs. time >

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

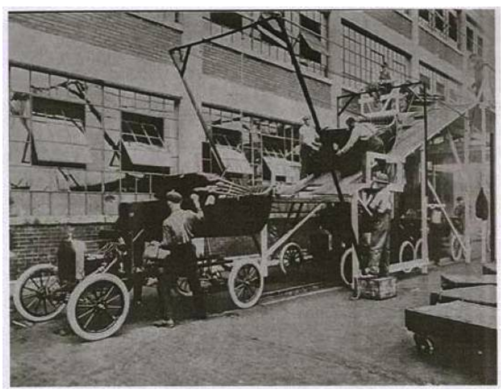
History of DFM I (cont.)

- 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

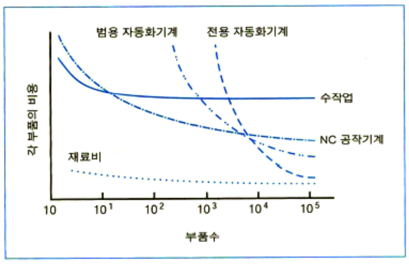
- General
- Process specific
- Product specific
- Design for Assembly (DFA)

General principles of DFM

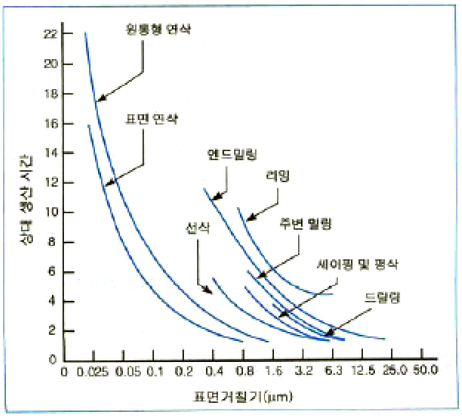
- Minimum number of parts
- Standard parts
- Modular design
- Multi-functional parts
- The same parts to various products
- Maximum surface roughness and tolerance
- Avoid secondary process
- Use materials easy to manufacture
- Consider number of parts to be manufactured
- Avoid many components
- Minimize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

General principles of DFM (cont.)

- Per part cost

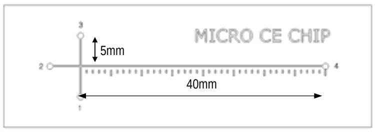


- Manufacturing Time vs. Surface Roughness



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



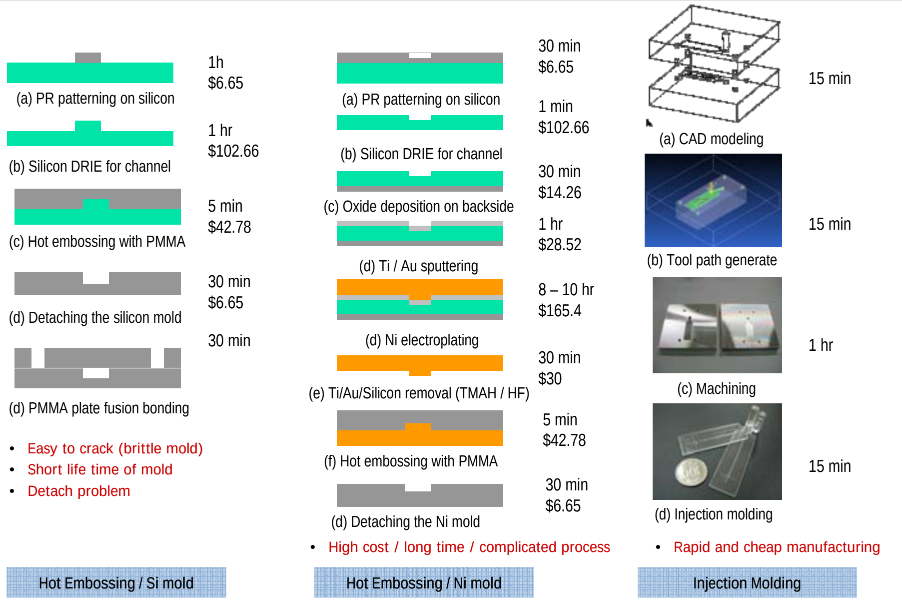
The 2-D Drawing of Microchip

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

- Fabrication via direct machining
  - Machining with ∅200 ㎛ 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

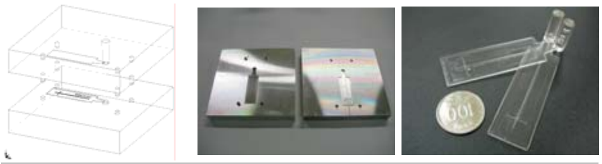
Microchip by direct machining

Comparison of processes



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)



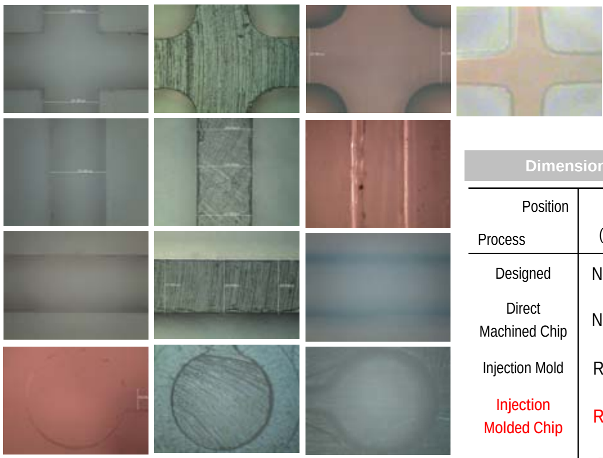
CAD Modeling of Injection Mold and Fabricated Microchip

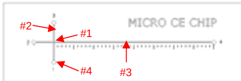
  - Injection molding machine
    - PMMA pellet : IF-850 (LG MMA)
    - Morgan press G-100T (Vertical type)
    - Nozzle and barrel temperature: 210 ℃
    - Clamping force: 14,000 lbf
    - Injection pressure: 6,000 psi (41MPa)

Fabrication of Microchip - III

- Dimensional tolerance of each microchips

	Direct Machined Chip	Injection Mold	Injection Molded chip	MEMS chip
#1 Inter-section				
#2 Vertical channel				
#3 Horizontal channel				
#4 Reservoir				





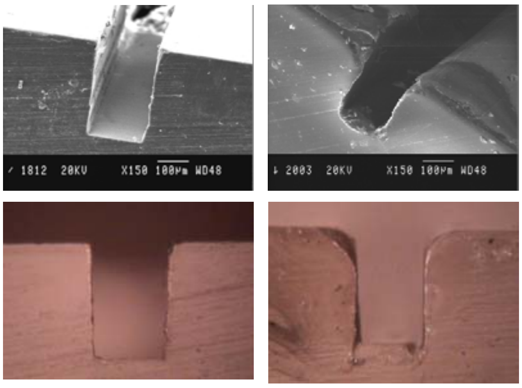
Dimensional Errors of Microchips

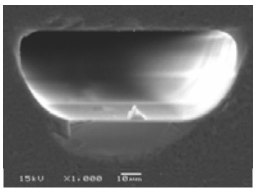
Position / Process	#1 (㎛)	#2 (㎛)	#3 (㎛)	#4 (㎛)
Designed	No R.	200	200	1000
Direct Machined Chip	No R.	1.5	2	3
Injection Mold	R100	2	2.5	5.5
Injection Molded Chip	R100	5.5	6	11
MEMS Chip	R50	3.5	4	5

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	Preparation Cost	Machining Cost	Tool Cost
C_w	C_p	C_m	C_t
$C_w = V\rho C_{um}$	$C_p = WT_p$	$C_m = T_m(W + B_m)$	$C_t = y\left(\frac{T_m}{T}\right)$

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

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

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

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

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

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

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

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

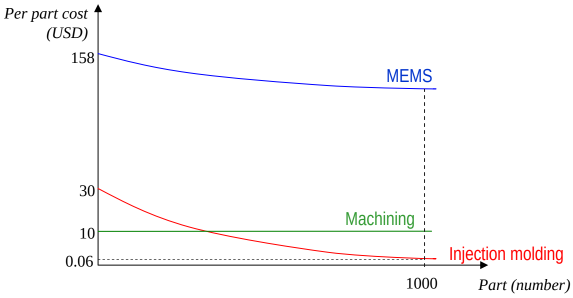
C, n: empirical constant
V: cutting speed

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

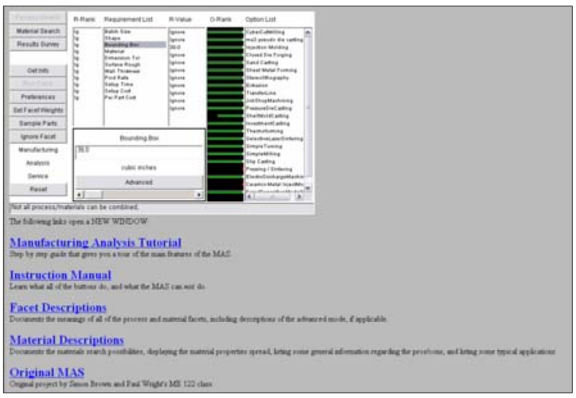
Evaluation of Cost - III

- Per part cost of mass production
- Cost of injection molding
  - Batch size: <u>1000 unit</u> 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
    - $C_{total,1000ea} = C_{total,1part} + 10.26 = 29.37 + (20 + 10.26) =$ <u>\$ 59.63</u>
    - Therefore, per part cost = <u>\$0.06</u>



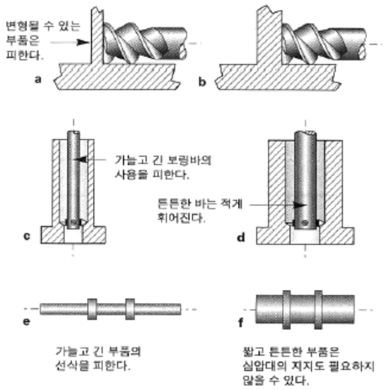
MAS

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

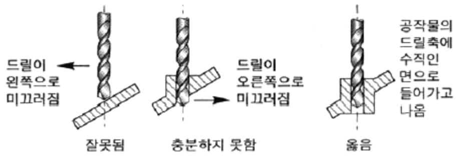


Process specific DFM

- Machining



- Drilling

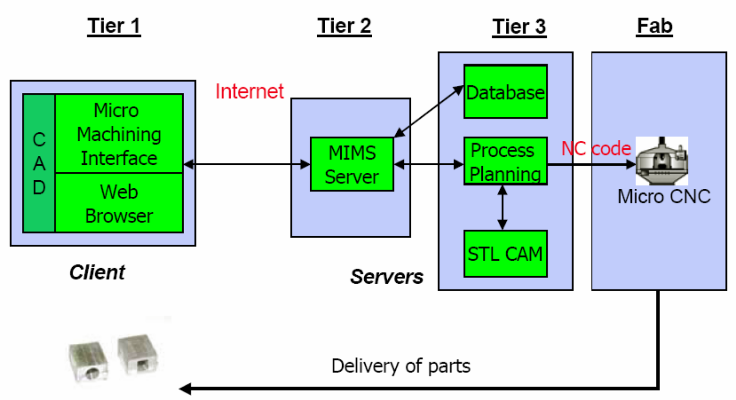


Web-based DFM systems - MIMS

- 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



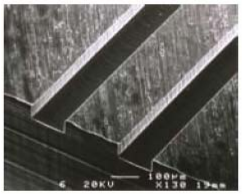
Web-based DFM systems - MIMS

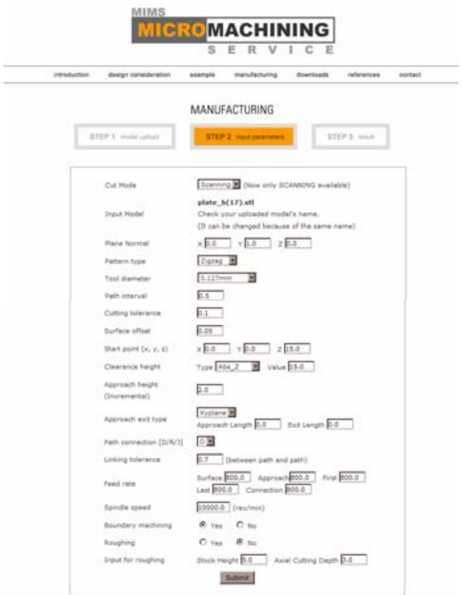
- DFM in machining: User Level
  - Expert mode:
    - 16 parameters
    - Max. control
  - Novice mode:
    - 2 parameters
      - Roughing
      - Tool diameter
    - Easy interface

	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

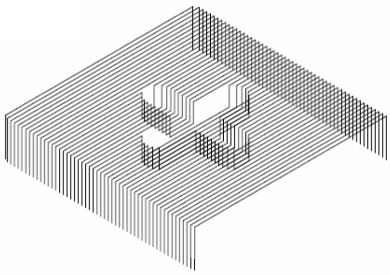
- DFM: Thin Client UI
  - HTML form
  - Tool database
  - Interpolation tolerance 1㎛



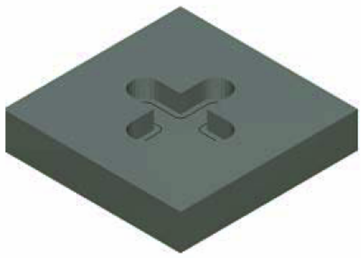


Web-based DFM systems - MIMS

- DFM: NC Code Simulation



Scanning

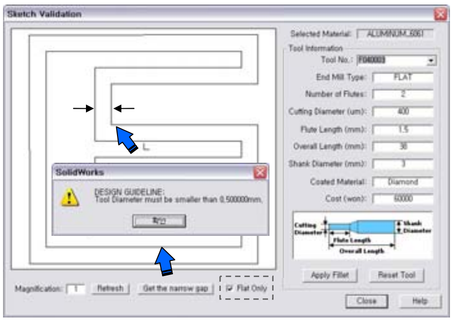


Pencil Cut

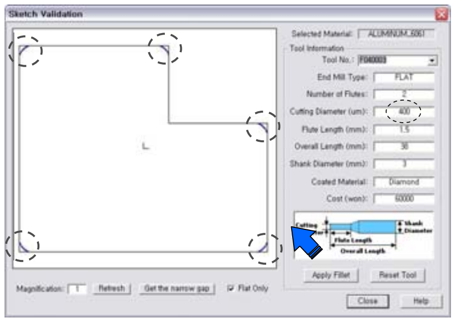
Issues in micro regime
- ✓ Run-out
- ✓ Tolerance of software

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



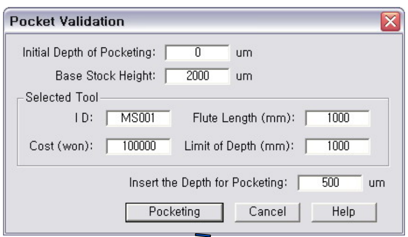
Check for minimum Gap



Check for fillet

Web-based DFM systems - SmartFab

- Pocket Validation



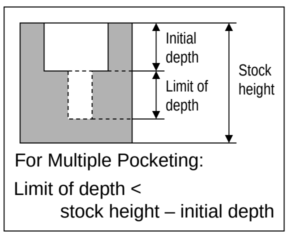
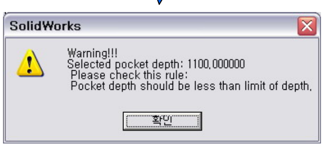
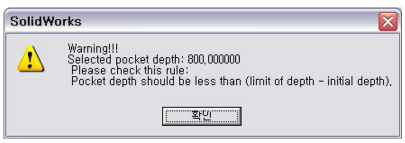


Fig 7. DFM in pocketing



Case I. Depth limit

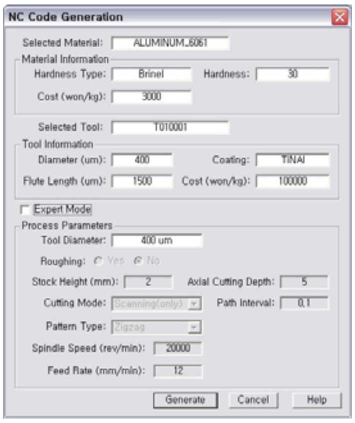


Case II. Depth limit and initial depth

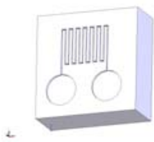
Examples of DFM in pocketing

Web-based DFM systems - SmartFab

- Convenience setting for NC code generation



Setting for NC generation



(a) STL model

(b) Machine setting

Results of DFM module

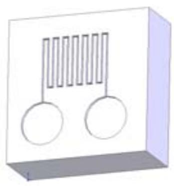
Upload form: model and setting

Web-based DFM systems - SmartFab

- For micro machining

Cost Estimation Service Calculate

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)

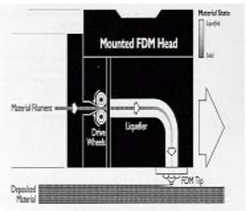
Ct: Tool usage cost
T: Tool life (4 hr)
y: tool cost (100,000)

DFM for RP

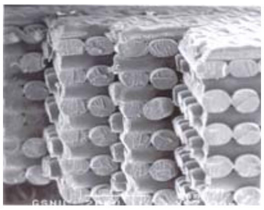
- Issues in FDM material (ABS)
- Porous & directional
- Build rule
- ...

Issues in FDM Material (ABS)

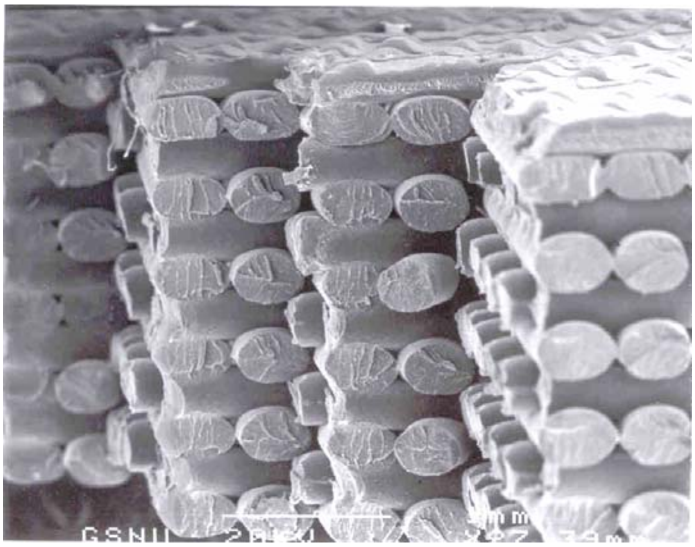
- Functional Properties
  - Strength
  - Nude style package
- Approach
  - Resin infiltration
  - Increase strength & transmissivity of light



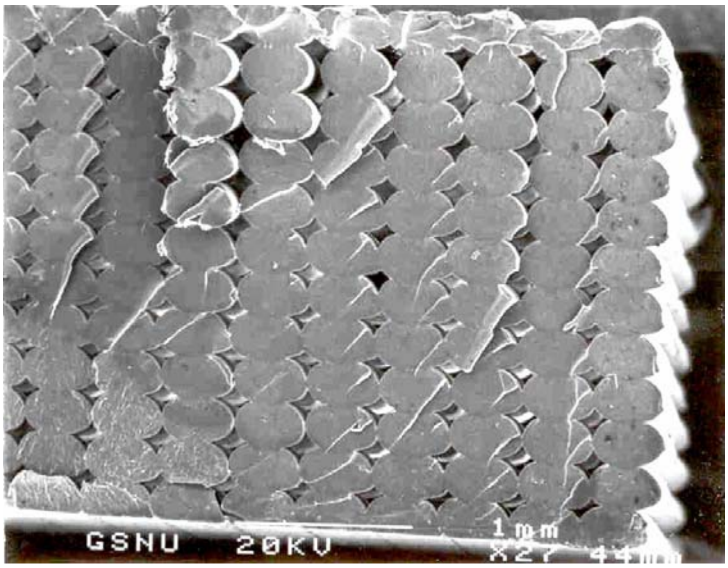
FDM process


Porous micro structure

Micro Structure of FDM Part

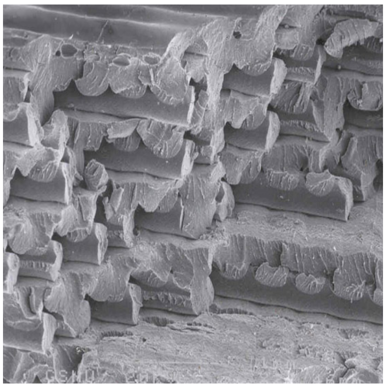


Porous & Directional

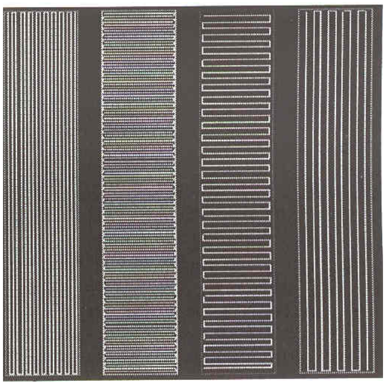


Anisotropy in FDM Parts

- “Raster Orientation” is the direction of deposition

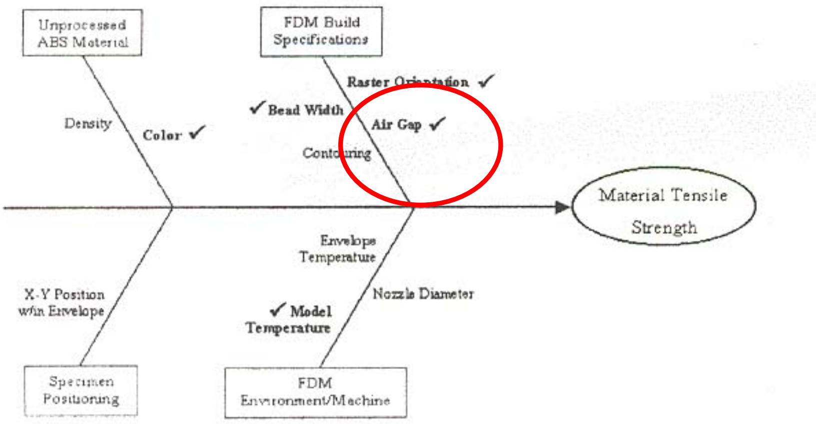


SEM picture of FDM specimen.

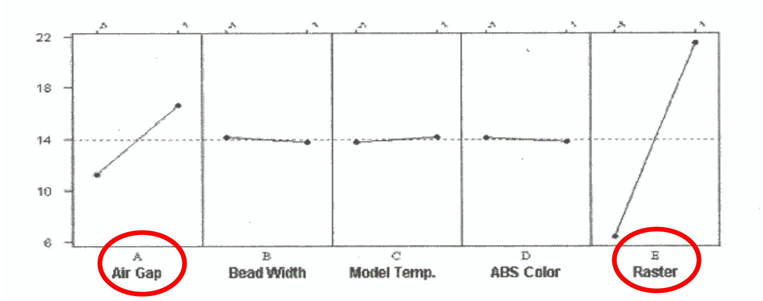


Quickslice SML file.

Design of Experiment (DOE)

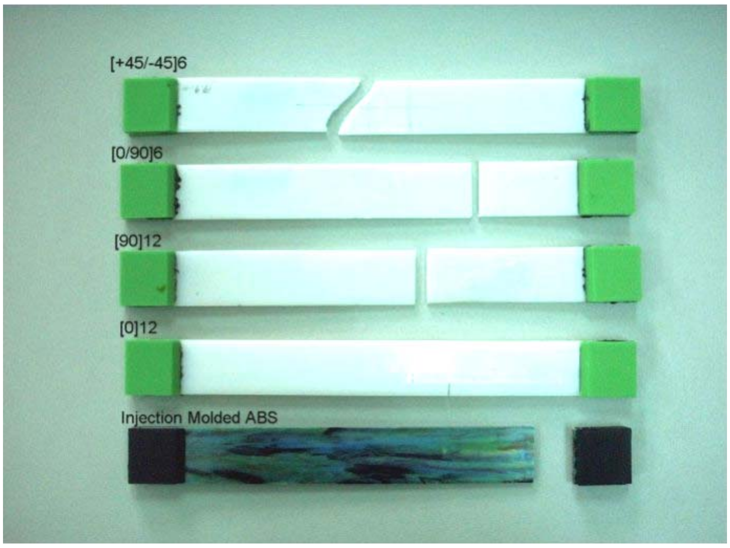


Results



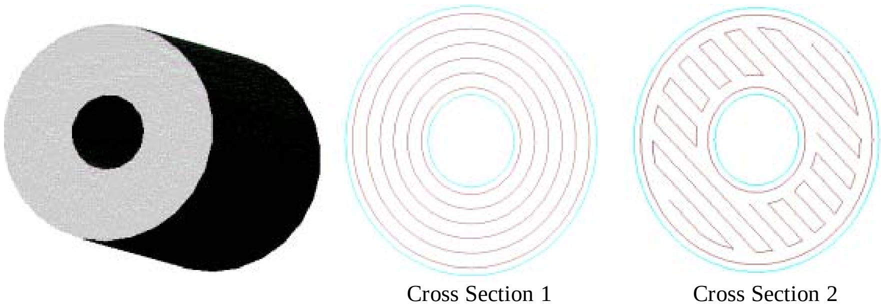
Variable	Symbol	Low(-)	High(+)
Air Gap (in.)	A	0.0000	-0.0020
Bead Width (in.)	B	0.0200	0.0396
Model Temperature(℃)	C	270	280
ABS Color	D	Blue	White
Orientation of Raster	E	Transverse	Axial

Failed Specimens



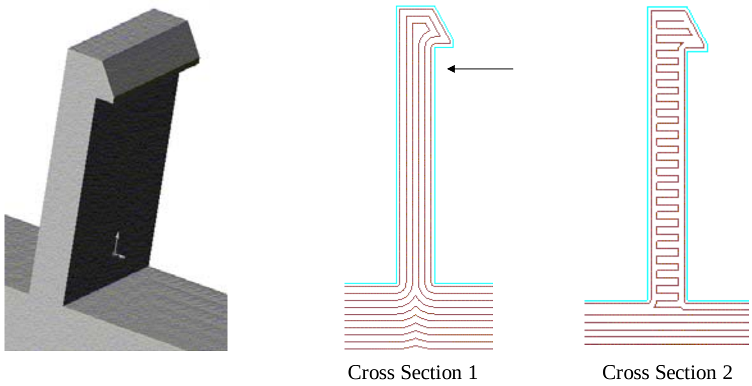
Build Rule #1

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



Two different road orientations for boss design.

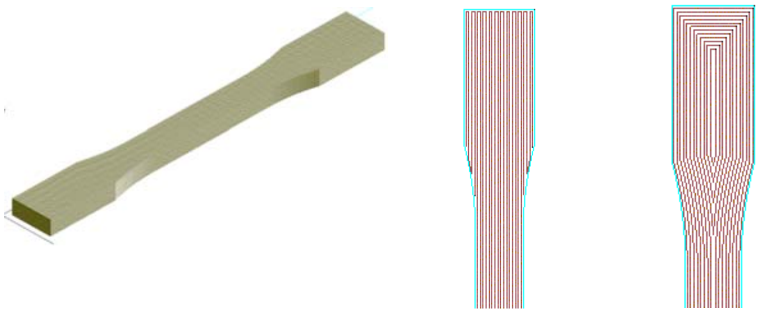
Build Rule #1 cont'd



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

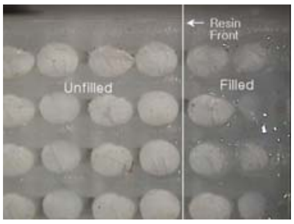
Two different road orientations for dog-bone design.

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

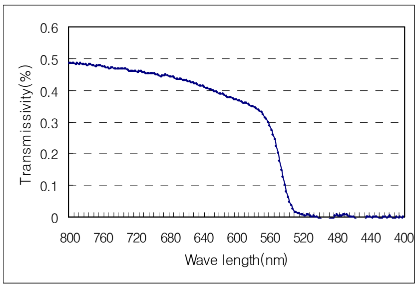
Resin Infiltration

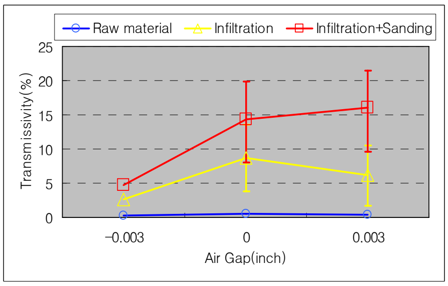
Raw FDM ABSi



During Infiltration

After Infiltration





Relative Transmissivity

(a) Raw Material
T=0.2%

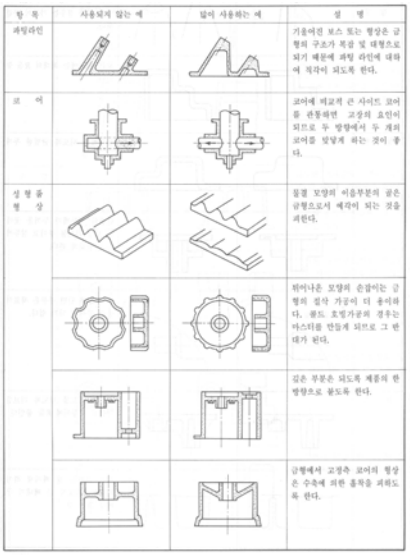
(b) Temperature(180℃)
T=8.4%

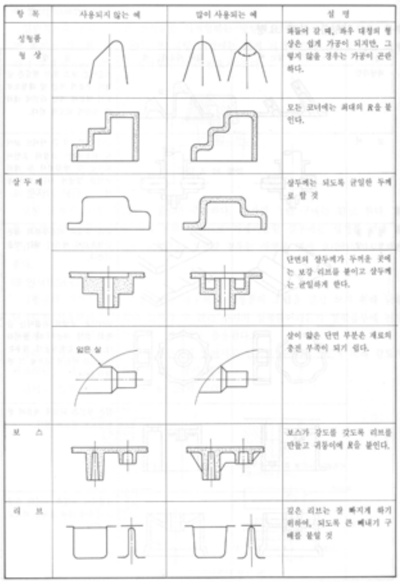
(C) Acryl
T=1.8%

(d) Acryl+Sanding
T=22.4%

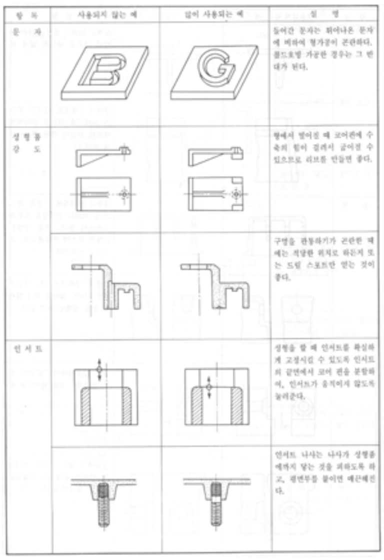
	ABSi	Acryl	Cyano Acrylate
Index of Refraction	1.57	1.69	1.51

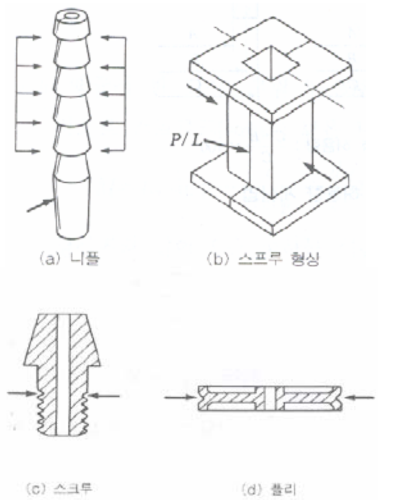
DFM in Injection Molding





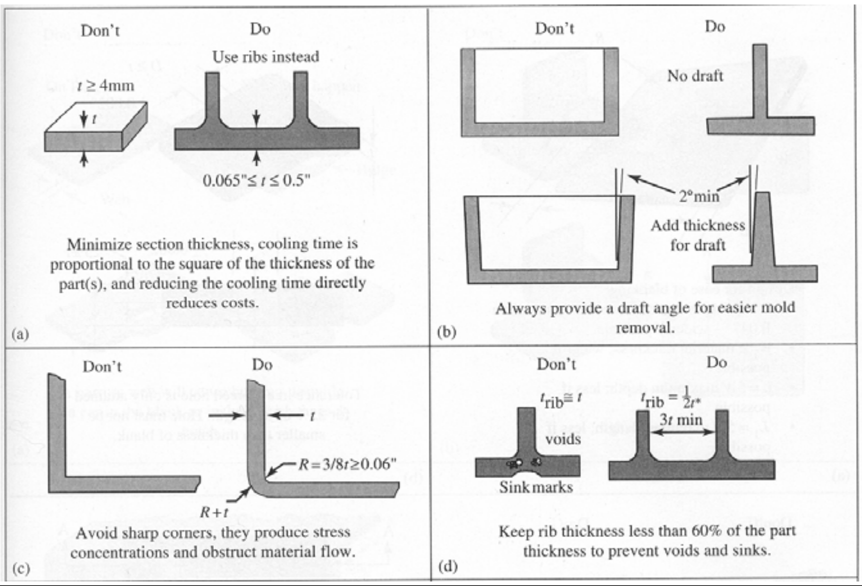
DFM in Injection Molding (cont.)





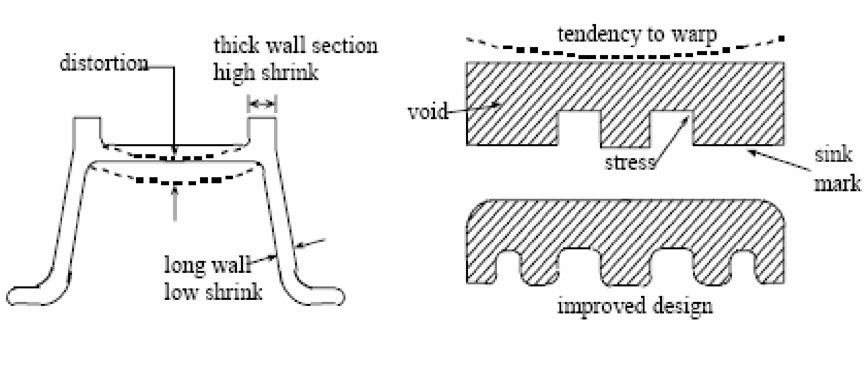
Prevent undercut

DFM in Injection Molding (cont.)



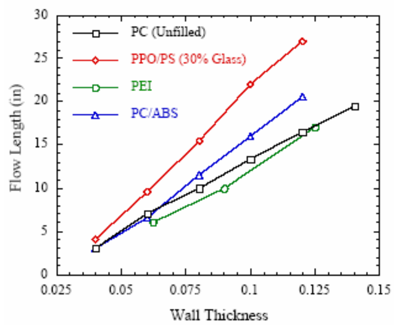
Warpage and sinkmarks

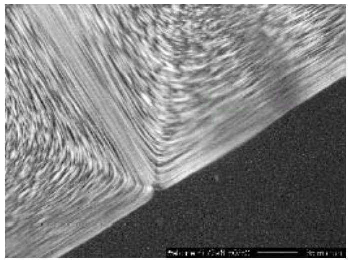
- Avoid thick "hot spots"



Injection and flow

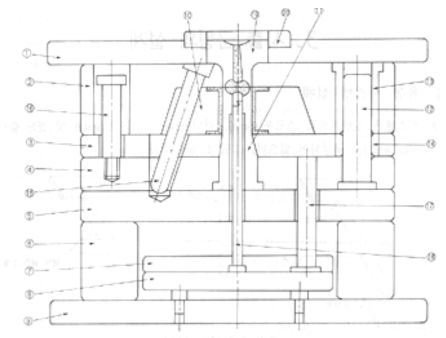
- Max length of flow
  - Part Thickness
  - Material
- Influences decision on
  - Part Geometry
  - Number of gates
  - Location of gates
    - Weldline

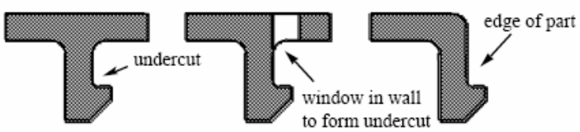


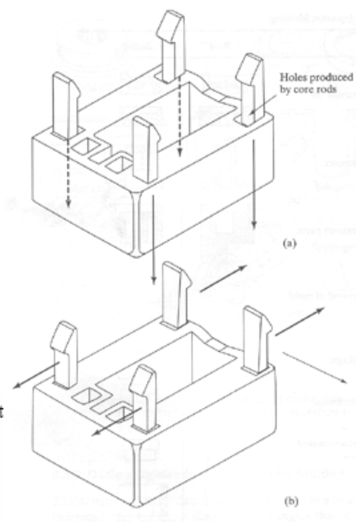


Avoid undercut

- Undercut requires cam pin, slider, or lifter







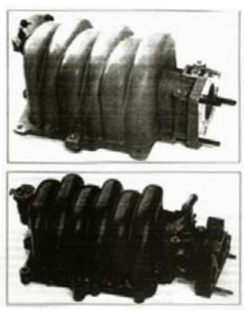
Key issues for each sub-process

- 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.)

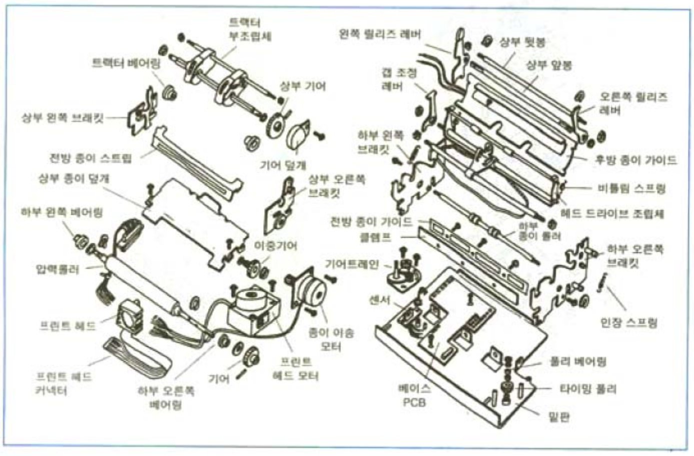


그림 13.21

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.)

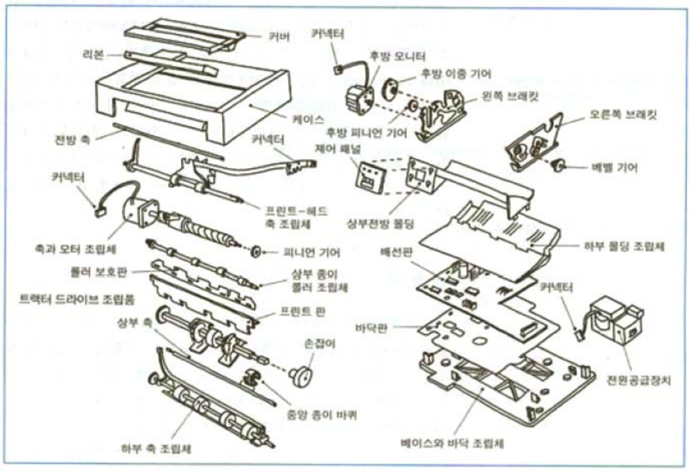


그림 13.22

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

부품 수: 32

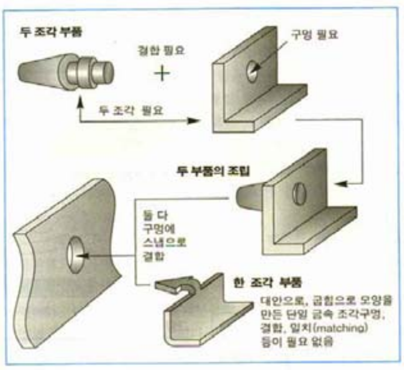
조립작업: 32회

조립시간: 170초

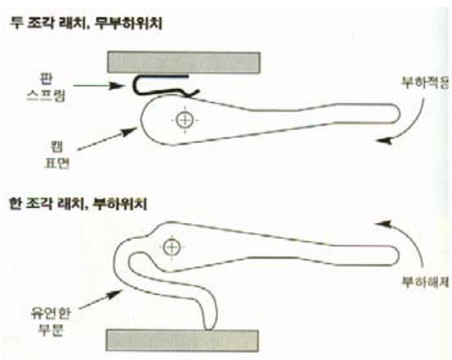
인건비: $1.18

Design for Assembly (cont.)

- Minimum number

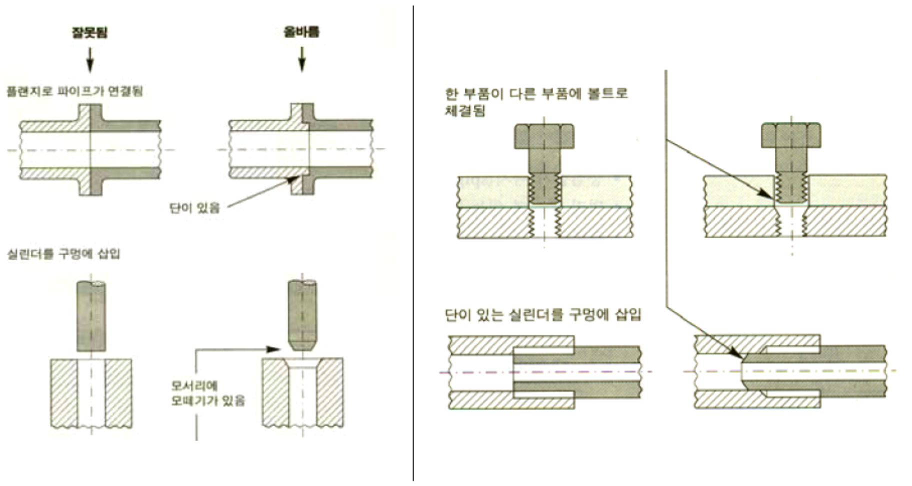


- Multi-functional Part
  - Compliant (flexible) part

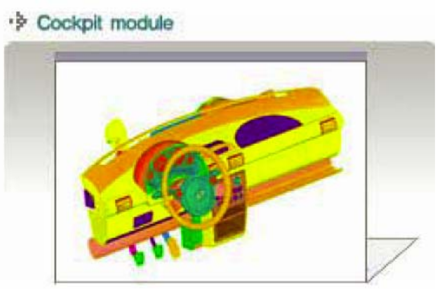


Design for Assembly (cont.)

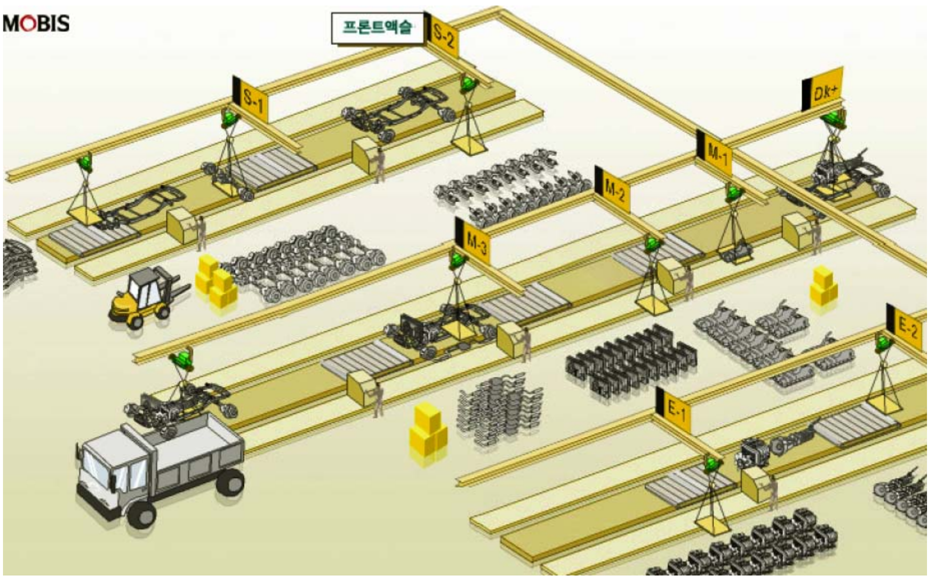
- Self Location



Design for Assembly (cont.)



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		
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)

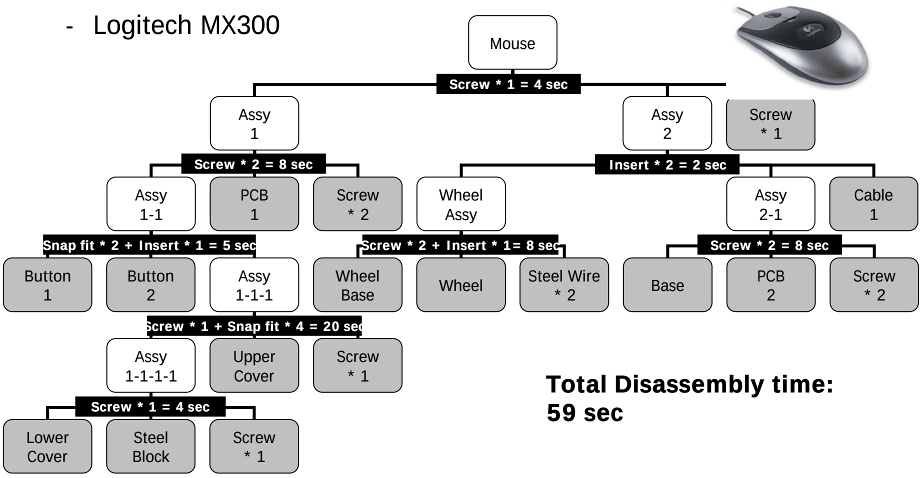
- Guidelines for joints III

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

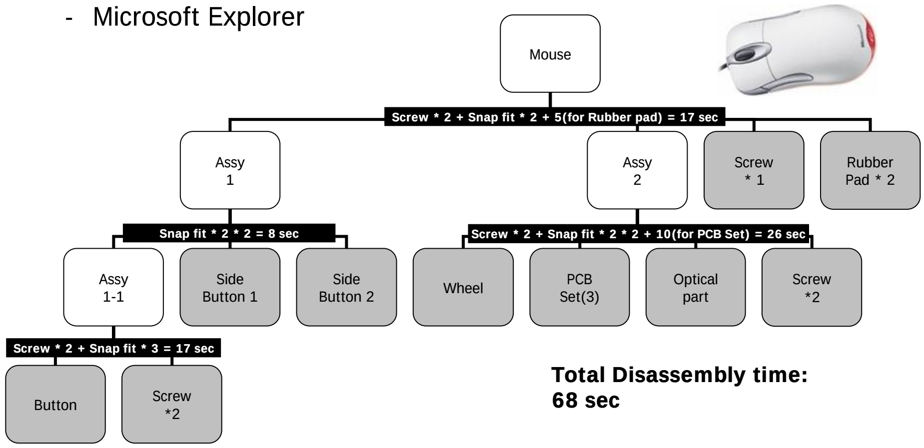


Total Disassembly time: 59 sec

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

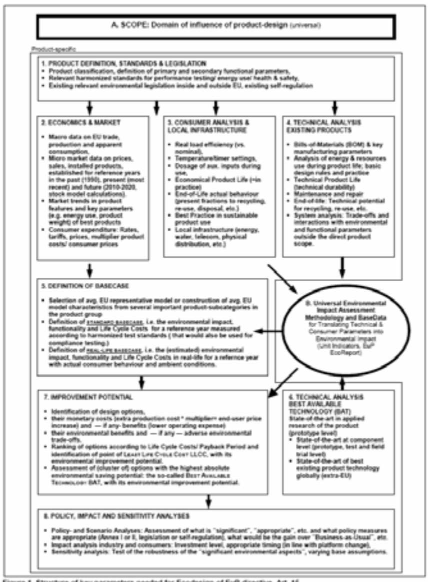


Figure 1. Structure of key parameters needed for Ecodesign of EuP directive, Art. 15.

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.

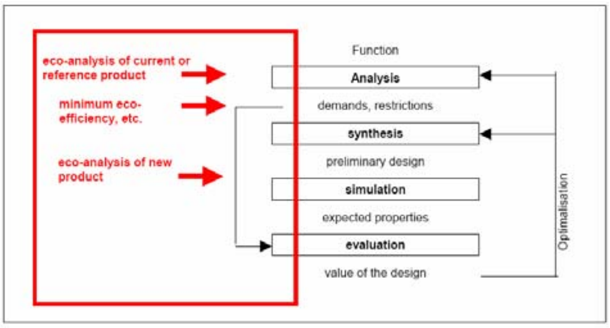


Figure 5 . Domain of Eco-design (in red) within the basis product design loop *[after Archer, Technological Innovation, 1973]*

Design for recycling

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

Plastic	1993		
	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).

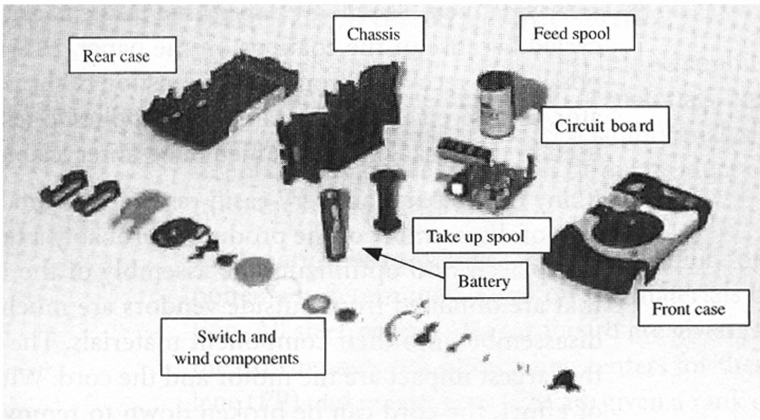
Rating	Description	Examples
1	Part is remanufacturable	Starter motor, alternator
2	Material in a part is recyclable with a clearly defined technology and infrastructure	Most metals, PETE, HDPE
3	Material is technically feasible to recycle—infrastructure to support recycling is not available	Most thermoplastics, 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

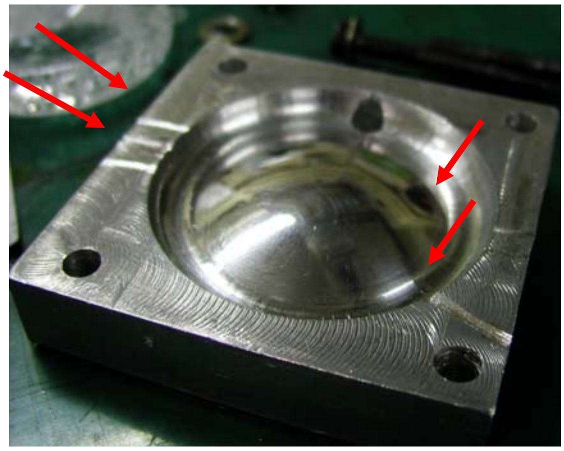
Source: Bras lecture notes, 1998.

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

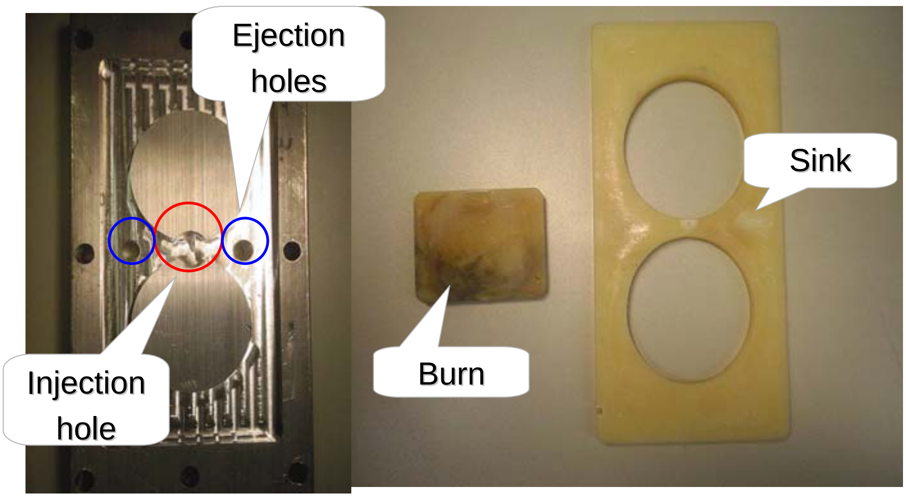
Case study #1

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



Case study #2

- Injection molding



Case study #3

- Re-design for injection molding