플라스틱 거푸집 패널의 성형특성에 관한 기초 연구

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1. 연구의 배경 및 내용

토목구조물의 플라스틱대체 기초성형기술개발

- 고분자 플라스틱 재료는 재활용이 가능한 친환경적인 소재임.
- 고분자 제품의 성형시 크기가 기존의 제품대비 상대적으로 커지게 되면 수축 및 수축편차로 인한 성형불량(휨 현상)이 더욱 크게 발생함.
- 제품의 휨에 영향을 주는 인자는 크게 Material, Part Design, Tooling & Processing Parameter 로 구분될 수 있음.
- **Material** 측면에서는 하중을 받는 부재 이므로, 강성 증가를 위한 **Fiber Filled** 수지가 사용됨.
- **Part Design** 측면에서는 구조설계 상 여러 가지 보강 현상이 존재 하지만 기본적인 구조는 사전에 결정되어 있음(1800x600x4mm, 1200x600x4mm).
- 따라서 본 연구에서는 변경이 가능한 **Tooling & Processing Parameter** 및 성형공법 자체의 변화를 통해 대형 직교 보강 플라스틱 평판의 성형특성에 관한 기초 연구를 수행하고자 함.

Air Trap

Overpacking

Hesitation

Thick/thin

Gating/Packing

Weld/Meld lines

Part Design

Tooling

Parameters

Short Shot
Sink Mark

Flash
Flow Mark
Silver Streak
Gloss badness
Cracking
Voids
Jetting
Strength, etc.

Gate Selection

Gate Sizing

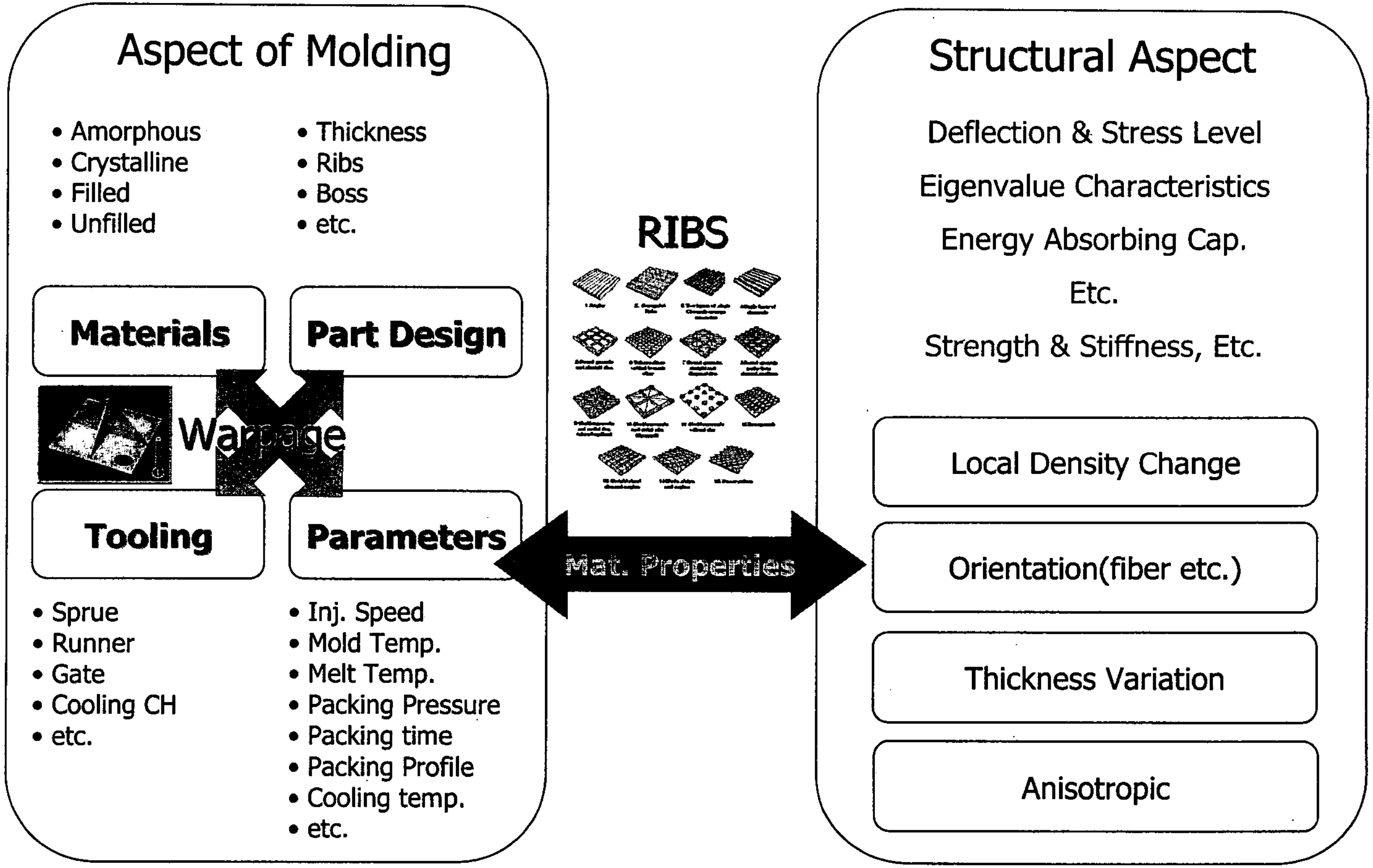
Weld Lines

Flow balance

Racetracking

Warpage

Home



Aspect of Molding

- Amorphous
- Crystalline
- Filled
- Unfilled

- Thickness
- Ribs
- Boss
- etc.

Materials

Part Design

Warpage

Tooling

Parameters

- Sprue
- Runner
- Gate
- Cooling CH
- etc.

- Inj. Speed
- Mold Temp.
- Melt Temp.
- Packing Pressure
- Packing time
- Packing Profile
- Cooling temp.
- etc.

RIBS

Mat. Properties

Structural Aspect

Deflection & Stress Level

Eigenvalue Characteristics

Energy Absorbing Cap.

Etc.

Strength & Stiffness, Etc.

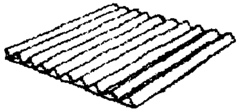
Local Density Change

Orientation(fiber etc.)

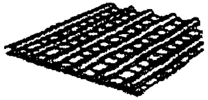
Thickness Variation

Anisotropic

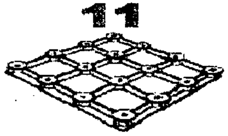
Home


1 Angles

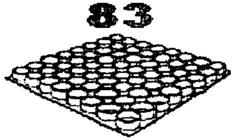

2. Corrugated Plate


3 Two layers of single Channels arrange crosswise

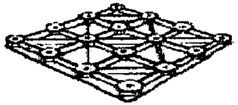

4 Single layer of channels



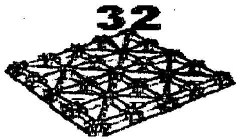
5 Round gussets and straight ribs



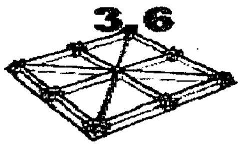
6 Tube sections welded to each other


7 Round gussets, straight and diagonal ribs

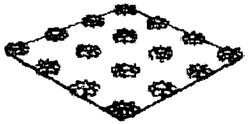
8 Round gussets made from channel sections



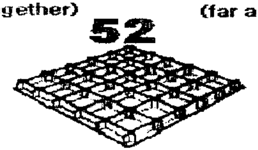
9 Starlike gussets and radial ribs (close together)



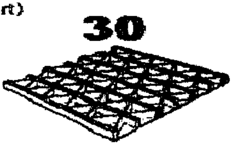
10 Starlike gussets and radial ribs (far apart)


11 Starlike gussets without ribs


12 Honeycomb



13 Straight sheet ribs and angles



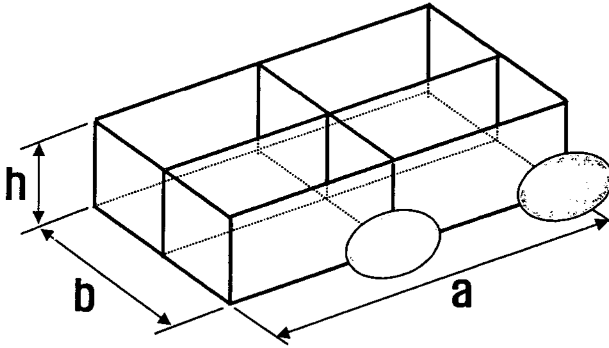
14 Studs, strips, and angles


15 Weave pattern

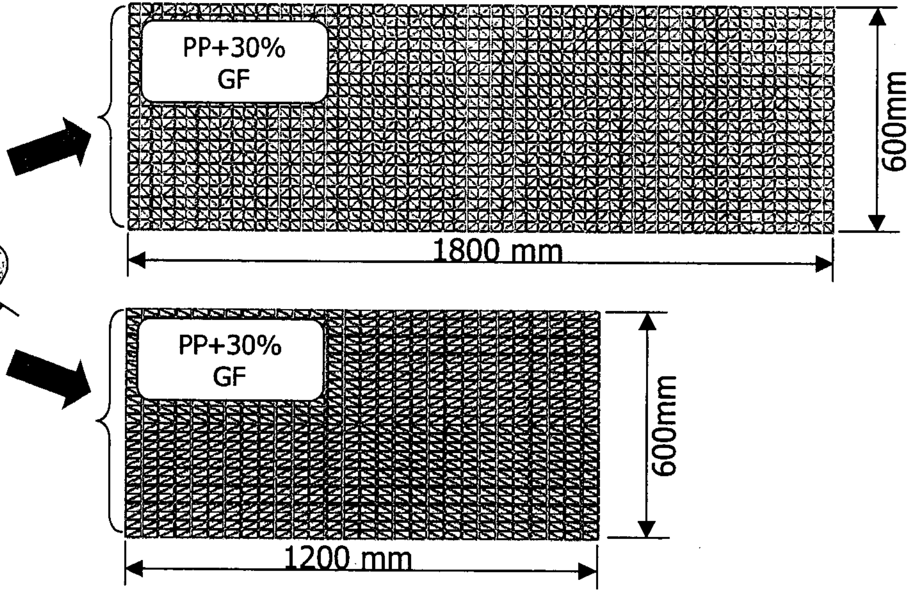
2. 플라스틱 거푸집 패널

일반사출성형모델
(CIM Model)
1800x600x4mm, thickness of rib=3mm

일반사출압축성형모델
(ICM Model)
1200x600x4mm, thickness of rib=3mm



<직교리브 평판구조>



3. 고분자 유동이론 개요

•Governing Equations

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho v_x)+\frac{\partial}{\partial y}(\rho v_y)=0 \quad (1)$$

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial v_x}{\partial z}\right)-\frac{\partial p}{\partial x}=0 \quad (2)$$

$$\frac{\partial}{\partial z}\left(\eta\frac{\partial v_y}{\partial z}\right)-\frac{\partial p}{\partial y}=0 \quad (3)$$

$$\rho C_p(T)\left(\frac{\partial T}{\partial t}+v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}\right) \quad (4)$$
$$=\frac{\partial}{\partial z}\left(\kappa(T)\frac{\partial T}{\partial t}\right)+\eta\dot{\gamma}^2$$

$$\frac{\partial}{\partial x}\left(S\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(S\frac{\partial p}{\partial y}\right)=G\frac{\partial p}{\partial t}+F \quad (5)$$

$$S=\int_0^b \rho\int_z^b \frac{z}{\eta}dz d\bar{z}$$

$$G=\int_0^\delta\left(\frac{\partial \rho_l}{\partial p}\right)_T dz+\int_\delta^b\left(\frac{\partial \rho_s}{\partial p}\right)_T dz \quad (6)$$

$$F=\int_0^b\left(\frac{\partial \rho_l}{\partial T}\right)_p \frac{\partial T}{\partial t}dz+\int_\delta^b\left(\frac{\partial \rho_s}{\partial T}\right)_p \frac{\partial T}{\partial t}dz \quad (7)$$
$$+(\rho_l-\rho_s)_{z=\delta}\frac{\partial \delta}{\partial t}$$

•Cross-WLF Viscosity Model

$$\eta(\dot{\gamma},T,P)=\frac{\eta_0(T,P)}{1+\left(\frac{\eta_0\dot{\gamma}}{\tau^*}\right)^{(1-n)}} \quad (8)$$

$$\eta_0=\begin{cases} D_1\exp\left[\frac{-A_1(T-T^*)}{A_2+(T-T^*)}\right] & T>T^* \\ \infty & T\le T^* \end{cases} \quad (9)$$

$T^*=D_2+D_3P,\quad A_2=\tilde{A}_2+D_3P$

$n,\ \tau^*,\ \mathrm{D}_1,\mathrm{D}_2,\mathrm{D}_3,\mathrm{A}_1,\tilde{\mathrm{A}}_2$: data fitted coefficients

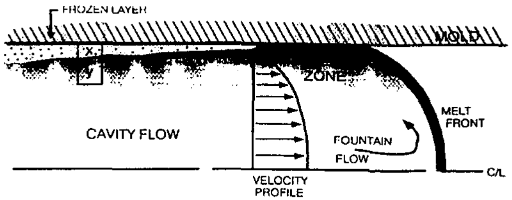
•Tait Formula (PVT)

$$v(P,T)$$
$$\begin{cases} (a_{0s}+a_{ls}(T-T_g))(1-0.0894\ln(1-\frac{P}{B_s})) & (T\le T_g) \\ (a_{0m}+a_{lm}(T-T_g))(1-0.0894\ln(1-\frac{P}{B_m})) & (T>T_g) \end{cases} \quad (10)$$

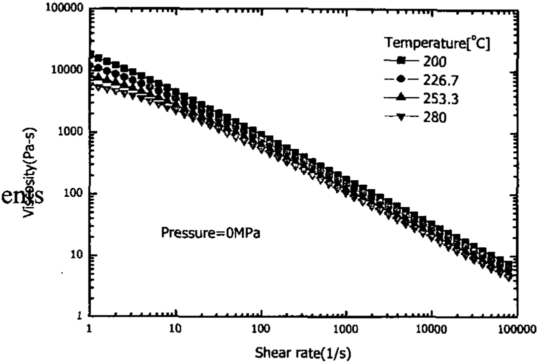
$$T_g=T_{g0}+B_2p$$
$$B_m=B_{0m}e^{-B_{lm}T} \quad (11)$$
$$B_s=B_{0s}e^{-B_{ls}T}$$

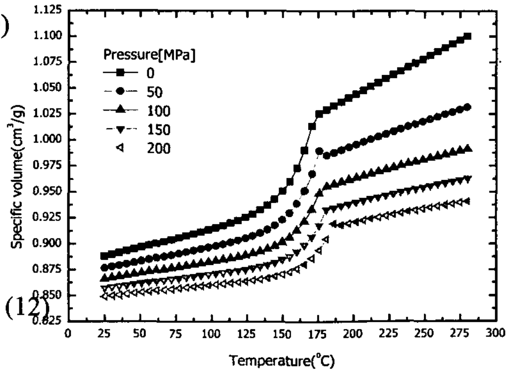
$$C_p(T)=C_1+C_2\overline{T}+C_3\tanh(C_4\overline{T}) \quad (12)$$
$$\overline{T}=T-C_5$$

C_1,C_2,C_3,C_4,C_5 : Specific Heat Parameters



PP+30%GF





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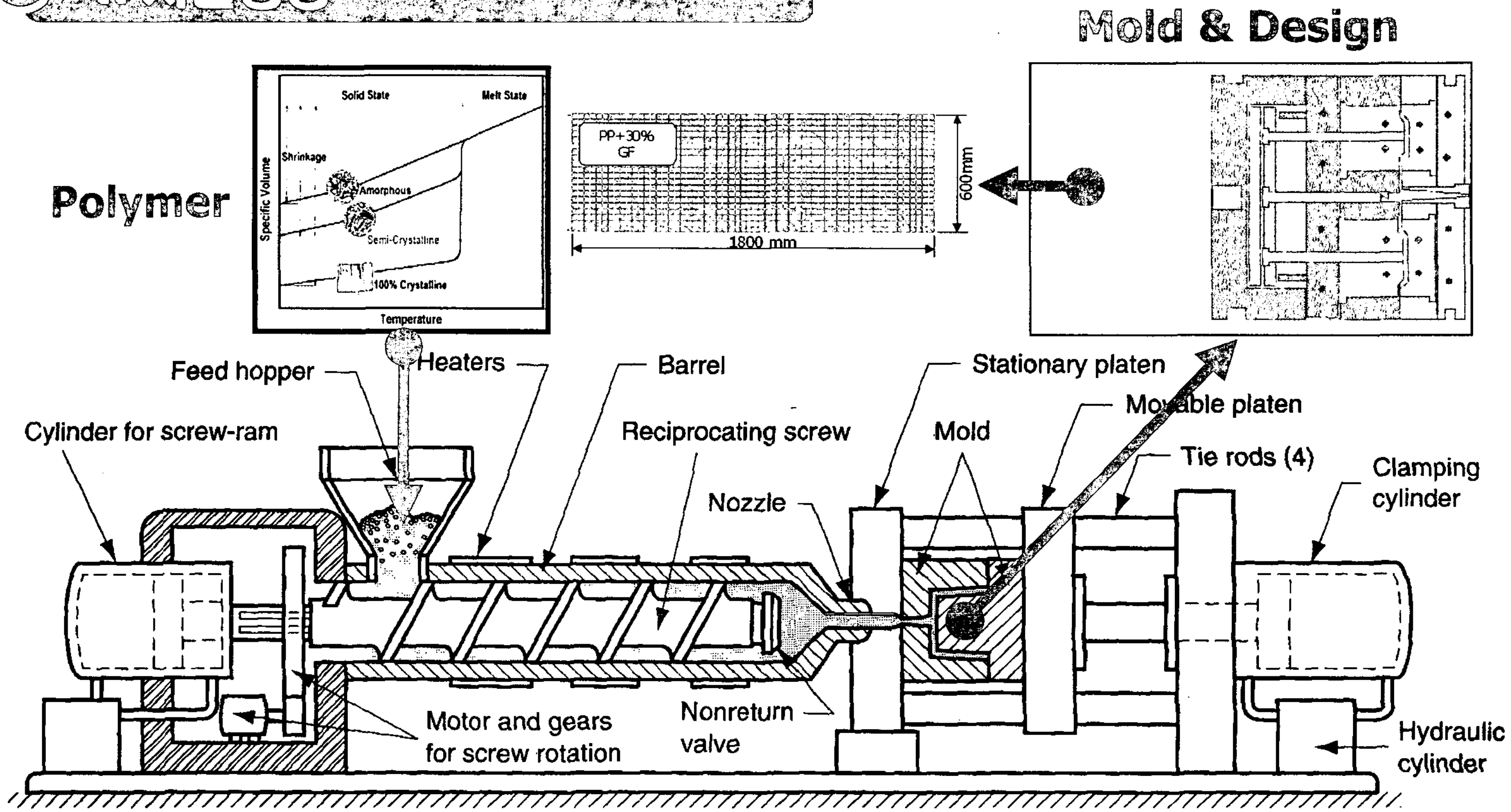
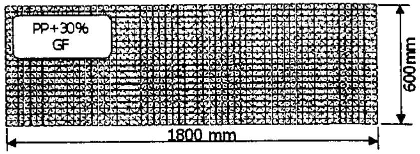
4. 사출성형


Mold & Design
Polymer
Solid State
Melt State
Shrinkage
Amorphous
Semi-Crystalline
100% Crystalline
Specific Volume
Temperature
PP+30% GF
600mm
1800 mm
Feed hopper
Heaters
Barrel
Stationary platen
Movable platen
Cylinder for screw-ram
Reciprocating screw
Mold
Tie rods (4)
Clamping cylinder
Nozzle
Motor and gears for screw rotation
Nonreturn valve
Hydraulic cylinder
Injection unit
Clamping unit

<Injection Machine>

4. 사출성형(계속)

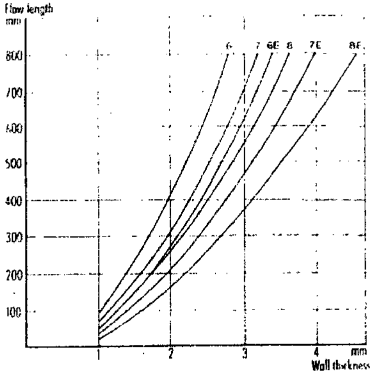


- **고분자 수지(Material) : PP+30%GF**
- **제품설계(Part Design) : CIM, ICM**
- **Tooling**
- **Processing Parameter**

Design of Delivery System

$$D = (w^{1/2} * L^{1/4})/3.7 \qquad d_{main} = d_{branch} * N^{1/3}$$

where D = runner diameter (mm)
W = part weight (g)
L = runner length (mm)

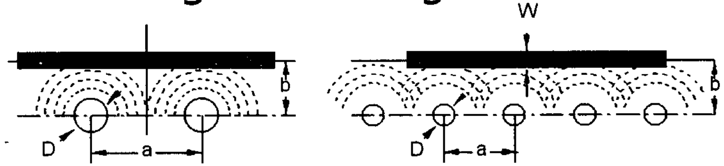


Relationship between wall thickness and flow length for a number of PMMA molding resins(Degussa Corporation) (There are two series of grades: Standard grades 6, 7 and 8, and E-grades with higher molecular weight)

Table 4-3 Approximate maximum flow-path-to-thickness ratio of thermoplastics

ABS	175 : 1
Acetal	140 : 1
Acrylic	130–150 : 1
Nylon	150 : 1
Polycarbonate	100 : 1
Polyethylene	
Low-density	275–300 : 1
High-density	225–250 : 1
Polypropylene	250–275 : 1
Polystyrene	200–250 : 1
Polyvinyl chloride, rigid	100 : 1

Design of Cooling Channel

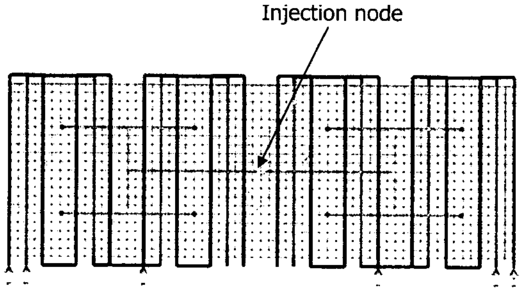


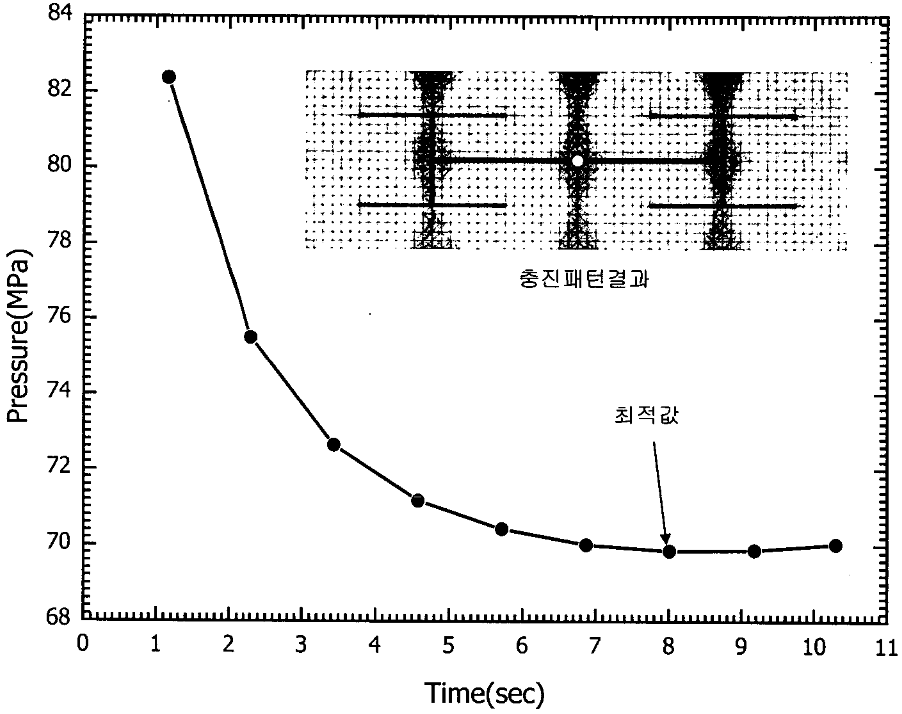
(a) Non-Uniform Heat Removal		(b) Largely Uniform Heat Removal
Design rules:	1. Part thickness W	Channel diameter D
	<2㎜	8~10㎜
	<4㎜	10~12㎜
	<6㎜	12~15㎜
	2. Spacing b	= 2~3×Channel diameter D
	3. Spacing a	= max3×Channel diameter D

4. 사출성형(계속)

Recommended processing parameters & operating conditions

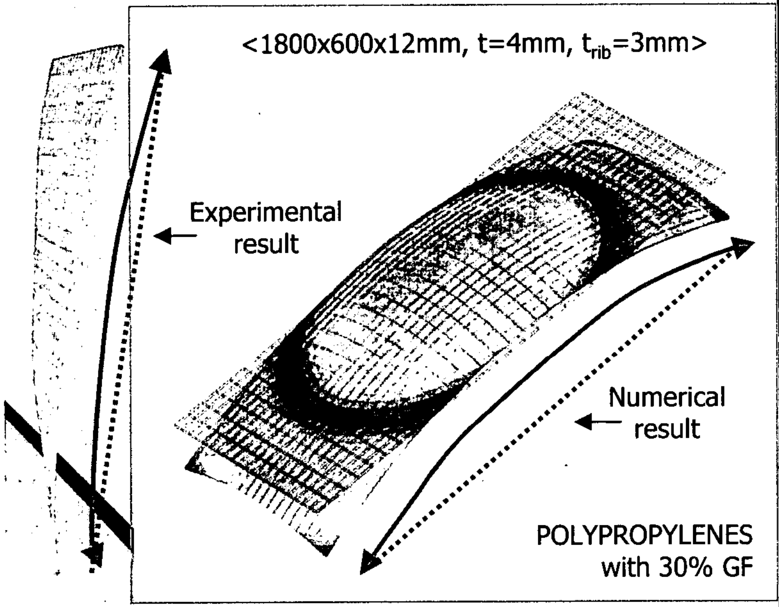
Recommended mold temperature range(℃)	20~80
Recommended melt temperature range(℃)	200~280
Absolute max melt temp(℃)	320
Ejecting temperature(℃)	93



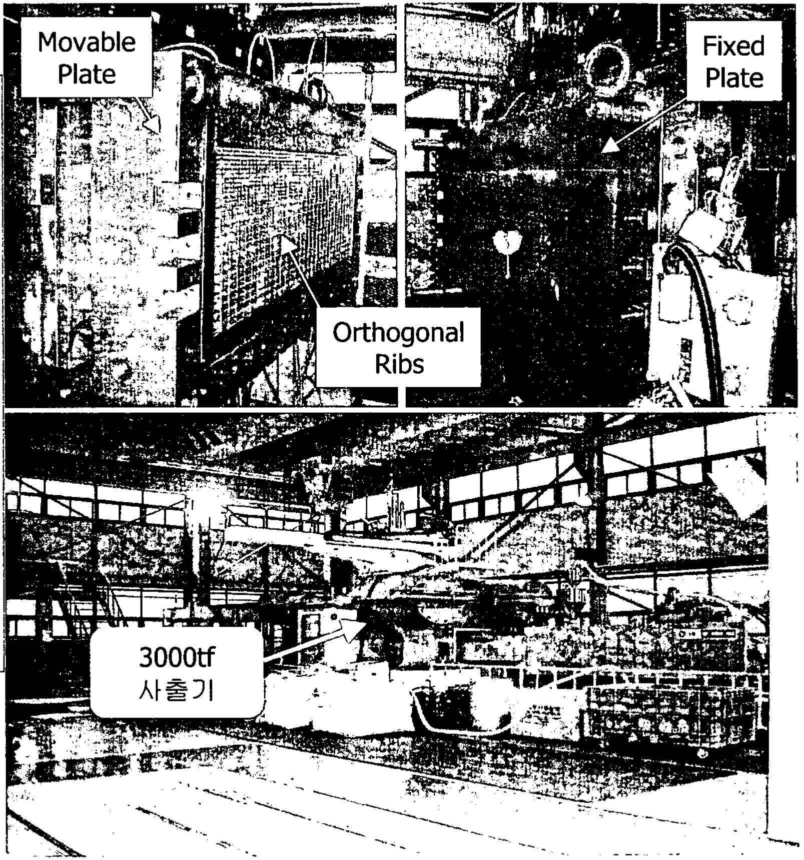


<사출시간의 최적화 결과>

4. 사출성형(계속)

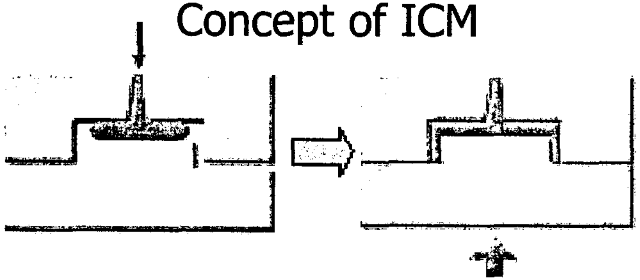


<사출성형해석결과와 실험 결과의 비교>

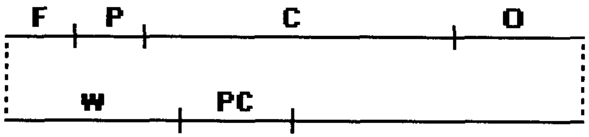


5. 사출압축성형

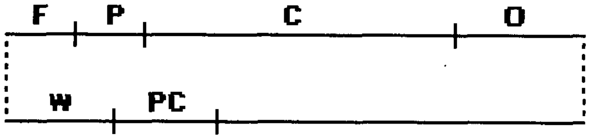
Concept of ICM



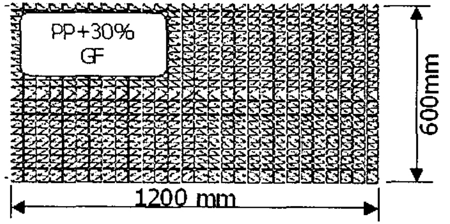
Sequential Injection Compression



Simultaneous Injection Compression



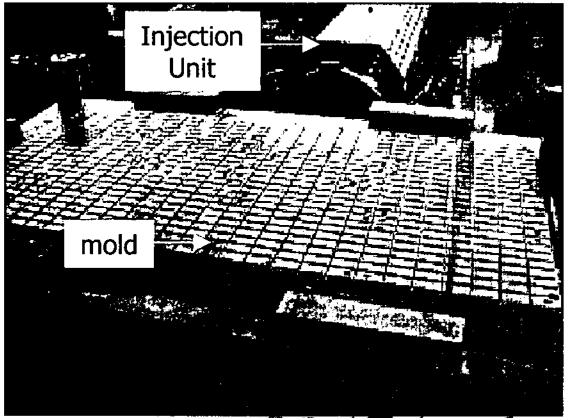
F: Fill Time, P: Pack Time, C: Cool Time, O: Mold Open Time
W: Press Waiting Time, PC: Press Compression Time

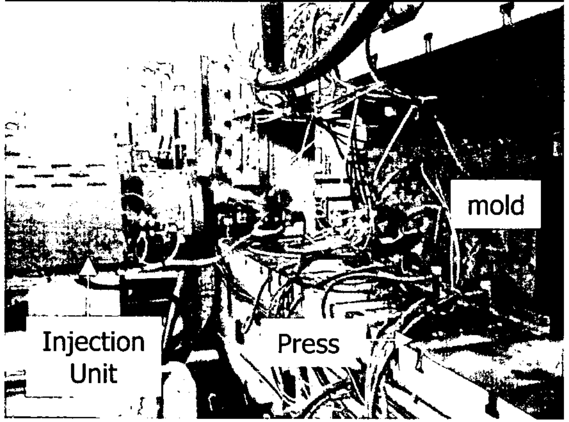


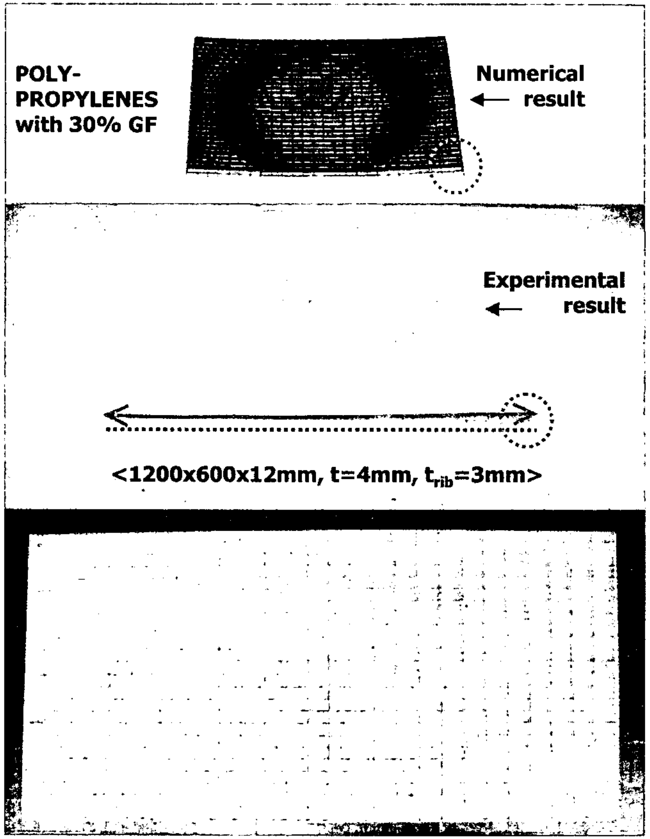
적용된 사출압축 성형조건

Mold Temperature	50	℃
Melt Temperature	240	℃
Injection Time	5	sec
Cooling Time	150	sec
Coolant	water	
Coolant Temperature	24	℃
Mold Open Distance	6	mm
Compression Delay Time	6	sec
Compression Time	20	sec
Compression Force	150-160	tonf

5. 사출압축성형(계속)





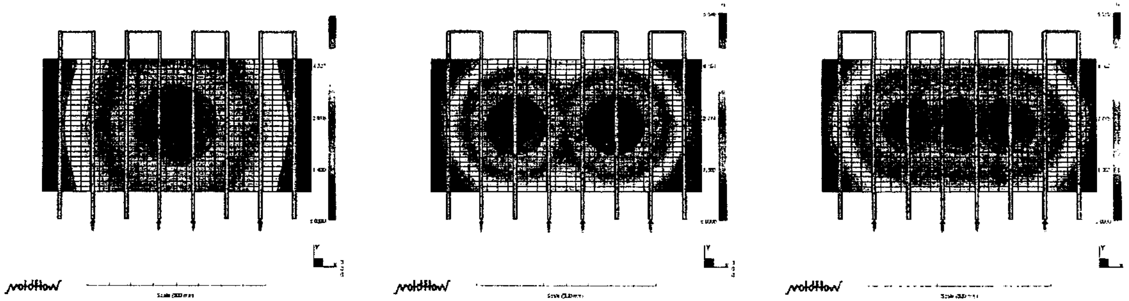


<1200x600x12mm, t=4mm, t_{rib}=3mm>

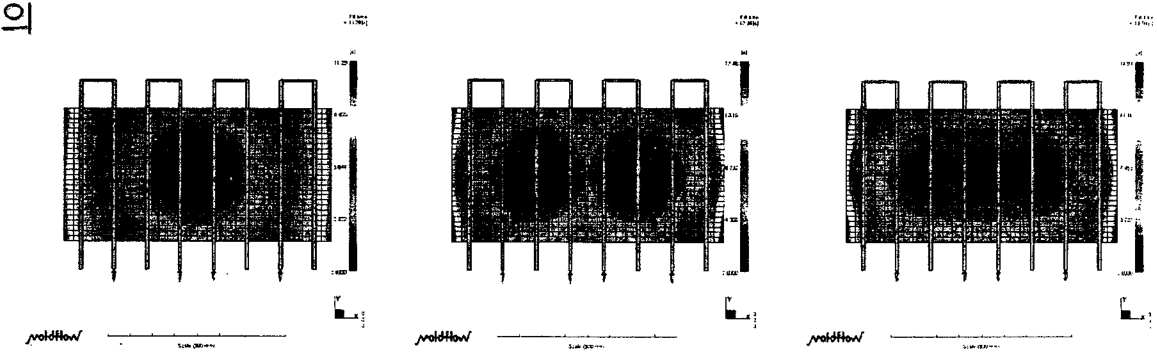
6. 비교 및 고찰(사례

<게이트 변화에 따른 사출성형(상)과 사출 압축 성형(하)의 충진패턴비교>

***동일모델(ICM)**

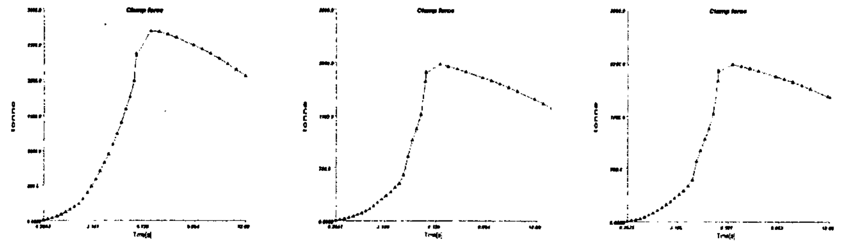


(a) One gate 사출 (b) Two gate 사출 (c) Three gate 사출

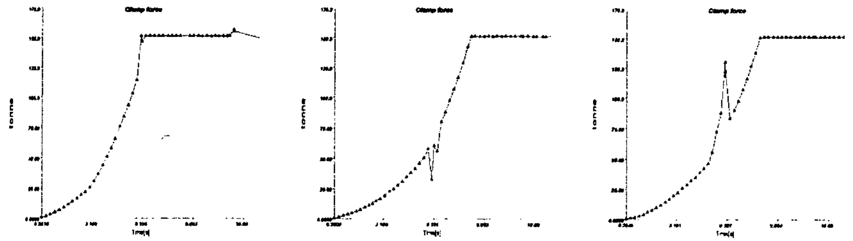


(d) One gate 사출/압축 (e) Two gate 사출/압축 (f) Three gate 사출/압축

6. 비교 및 고찰(계속)



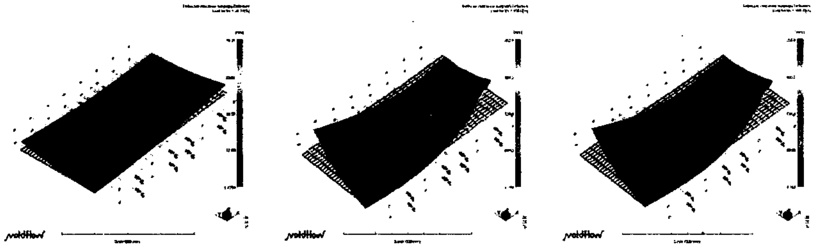
(a) One gate 사출 (b) Two gate 사출 (c) Three gate 사출



(d) One gate 사출/압축 (e) Two gate 사출/압축 (f) Three gate 사출/압축

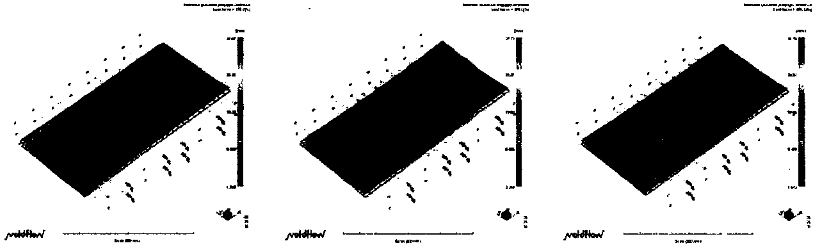
<게이트 변화에 따른 사출성형(상)과 사출압축성형(하)의 형체력 비교>
***동일모델(ICM)**

6. 비교 및 고찰(계속)


(a) One gate 사출
(70.31㎜)*

(b) Two gate 사출
(252.5㎜)*

(c) Three gate 사출
(255.0㎜)*


(d) One gate 사출/압축
(34.67㎜)*

(e) Two gate 사출/압축
(27.71㎜)

(f) Three gate 사출/압축
(31.75㎜)*

<게이트 변화에 따른 사출성형(상)과 사출압축성형(하)의 휨결과 비교>
***동일모델(ICM)**

7. 결론 및 향후과제

- 본 연구에서는 초대형 직교 보강 플라스틱의 성형을 위한 일반사출성형과 사출압축성형에 대한 기초 연구를 수행하였다.

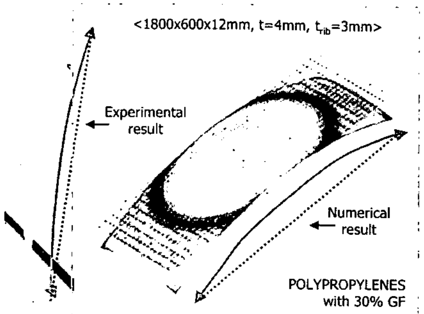
- 사출성형에서 휨 최소화 작업을 수행하였으나, 해석 및 실험적으로 만족스러운 결과를 도출하지 못하였다.

- 이러한 원인에는 제품의 초대형성으로 인한 다수개의 게이트 필요에 따른 용융 섬유 보강 수지의 성형시 배향성 효과에 기인한 것으로 판단된다.

- 한편 사출압축성형을 수행한 결과 사출성형대비 약 5%정도의 낮은 형체력으로도 모델의 최대길이 대비 약 1.5%의 양호한 변형(휨)결과를 얻을 수 있었다.

- 하지만 양산제품으로 발전시키기 위해서는 좀 더 조직적인 성형조건 최적화를 수행해야 된다고 사료된다.

CIM



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