4. Thermal Properties

4 • 1 Transition Point

4 • 1 • 1 Glass Transition Point (Secondary Transition Point)

The glass transition point of polycarbonate obtained from the inflection point of refractive index is $141 \sim 149^{\circ}$ C, as shown in Fig. 4 • 1 • 1 – 1. In addition, the glass transition point obtained by the measurement of expansion coefficient, specific heat, differential thermal analysis, and viscoelasticity, etc. is in the range of $130 \sim 155^{\circ}$ C.

When the glass transition point is studied in further detail, it differs in accordance with the molecular weight, as shown in Fig. $4 \cdot 1 \cdot 1 - 2$ (Tg was obtained by the differential thermal analysis).

Also, the glass transition point is known to have the pressure dependence and as for polycarbonate, it is as follows:

$$\delta T_g / \partial p = 0.044$$
°C/atm

A comparison with other resins is shown in Table $4 \cdot 1 \cdot 1 - 1$.



Fig. 4 • 1 • 1 – 1 Temperature characteristics of refractive index of polycarbonate



Fig. 4 • 1 • 1-2 Relation between Tg (glass transition point) and M (molecular weight)

		Tg		Dispe	Dispersion temperature				
Name	T _m melting point	glass transition point (°C)	Crystalline dispersion	Primary dispersion	Secondary dispersion	Secondary dispersion	Secondary dispersion		
Polyethylene	107—138	-5323	60 72	—18 — 8 23	—126 —111 — 65				
Polypropylene	168—170	—35	82	— 2 22	— 83 — 40	—215 —173			
Polyvinyl chloride (PVC)	217	77		91 117 127	— 38 12				
Polyvinylidene chloride	190	-18	77	33	- 23				
Polytetrafluoroethylene	327	-7363	127 150	-33	- 93 - 66 - 31				
Polystyrol	230	80—90		117 131 148	40	—153 — 53 87			
Polymethyl methacrylate (PMMA)		82—102		127 143 167	27 103	115 69 17	183 143 53		
Polyvinyl acetate		7—27		30 90	— 47	—113 —17			
Polyethylene • terephthalate (PETP)	265	63—83		57 127	—10 7				
Polyoxymethylene	177	-4060	127	—13 45 127	— 73 — 58 — 33				
Nylon 6	223	33—53		57 82	- 61 - 23 32	-128 -105 30			
Nylon 66	275	33—53		67 82	— 53 — 23				

Table $4 \cdot 1 \cdot 1 - 1$ T_m, T_g and dispersion temperature of other resins

Note: The upper, middle and lower dispersion temperatures are the measuring results at 1, 10³ and 10⁶Hz., respectively.

4 • 1 • 2 Melting Point

The melting point of Iupilon / NoVAREX pellet is $220 \sim 230$ °C. The melting point of crystallized polycarbonate is about $230 \sim 260$ °C (Refer to Fig. 4 · 5 · 2-2). The melting heat of the crystalline is 134J/g (32cal/g). The melting point of other resins is shown in Table 4 · 1 · 1-1.

4 • 1 • 3 Dispersion temperature

As for the thermoplastic resin, it is known that there are the primary dispersion zone where the macro-Brownian motion of molecular chain occurs, and the secondary dispersion zone where the local thermal motion (for example, thermal motion of methyl group of a part of main chain or side chain) occurs. Polycarbonate is not exception, too and its exixtence is recognized in many literatures. The dispersion temperature of polycarbonate is summarized in Table $4 \cdot 1 \cdot 3 - 1$.

Table $4 \cdot 1 \cdot 3 - 1$ Dispersion temperature of polycarbonate

Disportion type	Primary disporsion	Secondary dispersion	Secondary dispersion	Secondary dispersion
Dispersion type	rinnary dispersion	Secondary dispersion	Secondary dispersion	secondary dispersion
	α	β	γ	δ
	157 (1)		—100 (1)	$-200 \sim -100$
Dispersion temperature	175 (10 ³)	0-100	-80 (10 ³)	
(°C)	195 (105)		-3 (10 ⁶)	
			Free rotation motion of	
	Macro-Brownian		the C=0 group which	Free rotation motion of
Thermal motion type	motion of main		accompanies the	the Me group
	chain		restricted motion of the	(by MMR)
			phenyl group	

The results of these dispersions are shown in Fig. $4 \cdot 1 \cdot 3 - 1$, 2, 3 and 4. The primary dispersion, the γ dispersion and the δ dispersion are shown in Fig. $4 \cdot 1 \cdot 3 - 1$, $4 \cdot 1 \cdot 3 - 2$, $4 \cdot 1 \cdot 3 - 3$, respectively. As for the β dispersion, its existence is recognized in many literatures but there is not definite one. Fig. $4 \cdot 1 \cdot 3 - 4$ is an example. Refer to Table $4 \cdot 1 \cdot 1 - 1$ for other resins.



Fig. 4 • 1 • 3-1 Change in tan δ at primary dispersion zone



Fig. 4 • 1 • 3-2 Change in tan δ at low temperature zone



Fig. 4 • 1 • 3–3 NMR of polycarbonate Change in temperature of Line width $(1Gs=10^{-4}T)$



Fig. $4 \cdot 1 \cdot 3 - 4$ Change in tan δ at low temperature zone

4 • 2 Thermal Conductivity and Specific Heat

As shown in Fig. $4 \cdot 2 - 1$, the specific heat of polycarbonate changes with temperature but it can be considered that this is $1.09 \sim 1.17 \text{ J/(g.k)}$ ($0.26 \sim 0.28 \text{ cal/g.°C}$) for the practical temperature range. This value does not differ very much from the common synthetic resins and corresponds to about 3 times of iron and copper etc.

The thermal conductivity of polycarbonate is

 $0.19W/(m.k)(4.6x10^{-4}cal/cm.sec^{\circ}C)$

This value does not differ very much from the common synthetic resins and is very small when compared with those of metals as it is 1/400 of iron, 1/1000 of aluminum and 1/2000 of copper.



Fig. $4 \cdot 2 - 1$ Specific heat – temperature characteristic of polycarbonate

The thermal conductivity and specific heat of other resins are shown in Table $4 \cdot 2-1$ Table $4 \cdot 2-1$ Comparison of thermal properties

	Thermal	Specific	Linear		Deflection t	temperature
	conductivity	heat	expansion	Brittle	under loa	d (°C)
Name	W∕ (m k)	kJ∕ (kg•k)	coefficient	temperature	1820kpa	455kpa
	(cal/cm. sec°C)	(cal∕g•°C)	10 ⁻⁵ 1 ⁻¹	⊃°	(18.6kgf/	(4.6kgf/
	X 10 ⁻⁴		10 ° • K		cm ²)	cm ²)
Low density polyethylene	0. 33	2. 3	16-18	-8555	32-41	38-49
	(8)	(0. 55)				
High donsity polyothylono	0. 46—0. 52	2. 3	11-13	-140	43—54	60-88
right defisity polyeurylene	(11—12. 4)	(0. 55)				
Polypropylene	0. 14	1. 9	6—10	-1035	57—63	93—110
	(3. 3)	(0. 46)				
	0 17-0 25	15	5-9	90	70—100	74-110
Acrylate (PMMA)	(4-6)	(0, 35)	0 0		/0 100	74 110
	0. 10-0. 14	1. 4	6—8		80—90	
Polystyrene	(2. 4–3. 3)	(0. 33)				
D-1	0. 13—0. 17	1. 0	5-6	81	54-79	57—82
Polyvinyl chloride	(3-4)	(0. 24)				
Polyvinylidene chloride	0. 13	1. 3	19	030	55-65	
	(3)	(0. 32)				
Polytetrafluoroethylene	0. 25	1. 0	10			121
	(6)	(0. 25)				
Polyvinyl acetate	0. 16	1. 6	8.6		38	
	(3. 8)	(0. 39)				
Acryl nitrile •	0. 12	1.4	6		88—102	
Styrene (AS)	(2.9)	(0. 33)				
66 Nylon	0. 22—0. 24	1. 7	10—15		66	
	(5. 2–5. 8)	(0. 40)	0 10	05 00		150
6 Nylon	0. 21	1. 6	8—13	-85-60	62	150
D - 1 4 - 1	(5. 0)	(0. 38)	77			
torophthalata (DETD)			21			
Polyothar	0 23	15	8 2	-76-120	110	170
roiyeulei	0. 23 (5 5)	(0.35)	0. 2	70 120	110	170
Triacetyl cellulose	0 17-0 33	15	8-16		44—91	49—98
Thacetyr centhose	(4-8)	(0 35)				
Modified PPF	0. 22	1. 3	5. 6	<-40	117	128
	(5. 2)	(0. 32)				
Polysulfone	· · · · ·	1. 3	5. 6		174	181
		(0. 3)				
Polycarbonate	0. 19	1. 1	6	—135	130-136	136-142
	(4. 6)	(0. 27)				

4 • 3 Coefficient of Thermal Expansion

The coefficient of linear expansion of Iupilon / NOVAREX at 20~120 $^{\circ}\text{C}$ is $6{\sim}7 \ x \ 10^{-5}/K$

The coefficient of volume expansion of Iupilon / NOVAREX at $30\sim130$ °C is $(20\pm5) \ge 10^{-5}/K$

The change in length and volume weight ratio is shown in Fig. $4 \cdot 3 - 1$ and 2, respectively. The relation between temperature and volume expansion coefficient is shown in Fig. $4 \cdot 3 - 3$. The coefficient of linear expansion has the refraction point near the room temperature and becomes small in the low temperature region.





Fig. 4 • 3-1 Coefficient of linear expansion of Iupilon / NOVAREX

Fig. $4 \cdot 3 - 2$ Relation between temperature and volume weight ratio



Fig. 4 \cdot 3–3 Relation between temperature and volume expansion coefficient

4.4 Deflection Temperature

The deflection temperature (ASTM-D648-56) of Iupilon / NOVAREX is

Stress	1.82MPa	(18.6kgf/cm^2)	132 ~ 138°C
Stress	0.45MPa	(4.6kgf/cm^2)	138~144°C

The deflection temperature changes in accordance with the added load and is shown in Fig. $4 \cdot 4 - 1$ in case of Iupilon / NOVAREX. Also, the deflection temperature is influenced by the molecular weight in the same way as Tg (glass transition point) as shown in Fig. $4 \cdot 4 - 2$.

When Iupilon / NOVAREX is heat-treated, as indicated in other physical properties, the heat hardening is shown and the deflection temperature changes rapidly as shown in Fig. $4 \cdot 4-3$.

A comparison with other resins is shown in Table $4 \cdot 2 - 1$ and Fig. $4 \cdot 4 - 4$.





Fig. $4 \cdot 4 - 1$ Change in deflection temperature by load molecular

Fig. $4 \cdot 4 - 2$ Relation between weight and deflection temperature (Stress 1.82MPa)



Fig. $4 \cdot 4 - 3$ Change in deflection temperature by heat-treatment (Stress 1.82MPa) $(M_V = 2.8 \times 10^4)$



Fig. $4 \cdot 4 - 4$ Deflection temperature of other resins (Stress 1.82MPa)

4 • 5 Thermal Stability and Pyrolysis

It is possible to know the excellent heat resistance as shown in Fig. $4 \cdot 5 \cdot 2 - 2$ where the differential thermal analysis result of Iupilon / NOVAREX is indicated. However, when examining it more in detail, the different aspect of every change in various temperature regions (practical temperature region, processing temperature region, decomposition combustion region), in the environment (in oxygen, in air, in nitrogen, in vacuum, in steam) is recognized.

4 • 5 • 1 Low temperature region

When Iupilon / NOVAREX is heat-treated at the temperature below Tg, the fact that the change in physical properties occurs due to the hardening phenomenon has already been known and there are a lot of researches to look for the cause in the change of the solid structure. However, when heating it in air at this temperature region for long time, it is observed that the chemical changes (oxidation, decomposition), discoloration, decrease in molecular weight etc. take place.

The result of arranging the yellowed degree of this temperature region is shown in Fig. $4 \cdot 5 \cdot 1 - 1$. Curve (1) shows the influence of temperature on the yellowed speed, but the aspect of change is different at the up-and-down region of Tg. This might be due to the difference of the thermal effect of the molecular chain, that is, the difference of oxygen diffusion speed. Curve (2) shows the relation between temperature and treated time that the yellowed degree becomes equivalent.

Fig. $4 \cdot 5 \cdot 1 - 2$ shows the CO₂ generation speed at this temperature region and the breakage of carbon bond, namely the decrease in molecular weight.

Fig. $4 \cdot 5 \cdot 1 - 3$ and 4 show the comparison of the oxidation with other resins and the antioxidative property of polycarbonate.



Fig. $4 \cdot 5 \cdot 1 - 3$ Oxygen absorption speed at 200°C



4.5.2 High temperature region

The heat stability of Iupilon/NOVAREX is excellent. As shown in Fig. $4 \cdot 5 \cdot 2 - 1$, the change in heat stability is observed at the temperature above 450° C, and the influence of atmosphere, impurities, and additives is large in such a high temperature region. especially oxygen and moisture promote the heat degradation considerably.



The pyrolysis of Iupilon/NOVAREX, consists of one exothermic region and two endothermic regions as shown from the result of the differential thermal analysis in Fig. $4 \cdot 5 \cdot 2 - 2$. The exothermic region is the first stage of pyrolysis, the oxidation reaction is observed as an exothermic peak that starts at about 340°C and is highest at about 470°C. The first endothermic region is based on the depolymerization and peaks at 500°C. The second one is the region where the bond energy becomes equivalent to thermal energy, and dissociation of all molecular bonds takes place. The exothermic peak based on thermal oxidation and endothermic peak also decrease considerably in nitrogen and show that the influence of oxygen is remarkable.

The decomposition gases generated by pyrolysis change by atmosphere as shown in Table $4 \cdot 5 \cdot 2 - 1$, but CO, CO₂ by the decomposition of carbonic acid group, CH₄ by the dissociation of methyl group, and various phenols by the decomposition of BPA (bisphenol A) are main decomposition

products. The generation of CO₂, CH₄, and various phenols are shown in Fig. $4 \cdot 5 \cdot 2 - 3$, 4 and 5. The generation becomes active at around 300°C in air, but shifts to high temperature side about 50°C in nitrogen atmosphere.

The decrease in molecular weight of Iupilon when heated for 2 hours in nitrogen and in air is shown in Fig. $4 \cdot 5 \cdot 2 - 6$ and 7.

Also, the result of heating for a long time in the sealed tube in vacuum was shown in Fig. $4 \cdot 5 \cdot 2-8$. The relation between temperature and pyrolysis kinetics is shown in Fig. $4 \cdot 5 \cdot 2-9$, 10, and the influence of oxygen and moisture is extremely big.



Fig. $4 \cdot 5 \cdot 2 - 2$ Result of differential thermal analysis of Iupilon / NOVAREX

								(+)	: generated
Decomposition products	In oxygen	In air	In vacuum sealed	In vacuum continuous	Decomposition products	In oxygen	In air	In vacuum sealed	In vacuum continuous
CO_2	+	+	+	+	Benzene	+	+		
СО	+	+	+	+	Toluene	+	+		
CH ₄	+	+	+	+	Ethyl benzene	+	+		
H_2	+				Phenol	+	+	+	+
H_2O	+	+	+		Cresol	+	+	+	+
НСНО	+				Ethyl phenol		+	+	+
CH₃CHO	+								
Acetone Methanol Diphenyl	+	+			Isopropyl phenol Isopropenyl phenol		+ +	++	+ +
			+	+	Bisphenol A	+	+	+	+

Table $4 \cdot 5 \cdot 2 - 1$ Decomposition products of polycarbonate









Fig. $4 \cdot 5 \cdot 2 - 5$ Relation between temperature and generated amount of phenol derivatives by decomposition when heated in air



Fig. 4 \cdot 5 \cdot 2–6 Decrease in molecular weight of Iupilon / NOVAREX by meltin (Completely dry, melted in nitrogen stream)



Fig. $4 \cdot 5 \cdot 2 - 7$ Decrease in molecular weight of Iupilon / NOVAREX by melting (Undried, melted in air)



Fig. $4 \cdot 5 \cdot 2 - 9$ Decreased quantity rate of Iupilon / NOVAREX by heating



Fig. $4 \cdot 5 \cdot 2 - 8$ Decrease in molecular weight (Mv) of sealed tube in vacuum



Fig. $4 \cdot 5 \cdot 2 - 10$ CO₂ generating rate of Iupilon / NOVAREX

When the inorganic filling agent is added to Iupilon / NOVAREX, the influence on the pyrolysis is big. For ezample, decreased quantity rate in case of adding an iorganic filling agent in Fig. $4 \cdot 5 \cdot 2 - 11$ and CO₂ generated amount in Fig. $4 \cdot 5 \cdot 2 - 12$ indicate the value which is bigger than the material in any case. Also, the influence of metal salts is shown in Table $4 \cdot 5 \cdot 2 - 2$. The influence of carbonates is extremely big, and the others also have influence to some degree.



Fig. 4 \cdot 5 \cdot 2–11 Influence on decreased quantity rate of the pigment (pigment additive amount: 1.0%)



Fig. 4.5.2–12 Influence on CO2 generation of the pigment

			Molecular weig	ght $Mv \ge 10^4$	Start
Metal oxides	Chemical Composition	рН	0%	1%	temperature of decreased
	•				quantity (°C)
Stannic oxide	SnO ₂	4. 2	2. 8	2. 4	340
Lead sulfate	PbSO ₄	4. 5	2. 8	2. 6	320
Lead chromate	PbCr ₂ 0 ₃	5. 4	2. 8	2. 4	306
Lead oxide	Pb ₃ 0 ₄	7.8	2. 8	2. 2	210
Lead monoxide	PbO	10. 2	2. 8	2. 5	363
Zinc sulfide	ZnS	2. 4	2. 8	2. 4	250
Zinc oxide	ZnO	7. 2	2. 8	2. 7	352
Zinc carbonate	ZnCO ₃	7.1	2. 8	1. 9	315
Cadmium sulfate	CdSO ₄	6. 3	2. 8	2. 7	335
Cadmium sulfite	CdS	6. 3	2. 8	2. 4	340
Cadmium oxide	CdO	9.4	2. 8	2. 6	315
Cadmium carbonate	CdCO ₃	7. 0	2. 8	2. 0	280
Aluminum oxide	A1 ₂ CO ₃	9. 0	2. 8	2. 7	320
Cobalt oxide	CoO	8. 2	2. 8	2. 7	330
Barium sulfate	$BaSO_4$	7. 2	2. 8	2. 7	340
Titanic oxide	TiO ₂	6. 8	2. 8	2. 7	343
Copper oxide	CuO	6.9	2. 8	2. 5	340
Manganese dioxide	MnO_2	6. 6	2. 8	2. 6	350
Ferric oxide	Fe ₂ 0 ₃	6. 4	2. 8	2. 7	320
Chromic oxide	Cr_2O_3	5. 5	2. 8	2. 7	358
Cadmium selenide	CdSe	6. 0	2. 8	2. 8	345

Table $4 \cdot 5 \cdot 2 - 2$ Influence of metal oxides on heat stability of Iupilon / NOVAREX

As for the molecular weight, the sample melted in nitrogen for 1 hour is used for measurement

As for the start temperature of decreased quantity, the sample added with 1% of the pigment is used for measurement in air.

When adding an organic additive (for example, ultraviolet absorber, stabilizer, antistatic agent, blowing agent, and plasticizer, etc.) to Iupilon / NOVAREX, the one that causes the chemical reaction with polycarbonate can not be used. Also, it is necessary to consider sufficiently not only the reactivity but also the heat stability of the additive to be used because the processing temperature of polycarbonate is high, close to the decomposition temperature of the organic substances at the temperature range above 300°C. When polycarbonate is heated in vacuum system, it is known that if the decomposition product is removed continuously, the peculiar phenomenon to cause rapidly the gel generation is observed.

The state of gel generation, and the change of soluble part $[\eta]$ of methyl chloride are shown in Fig. $4 \cdot 5 \cdot 2 - 13$ and Fig. $4 \cdot 5 \cdot 2 - 14$, respectively. The generation rate of the decomposition product in this system is indicated in Fig. $4 \cdot 5 \cdot 2 - 15$.

It is known that this gel phenomenon is recognized not only in polycarbonate but also in polysulfone, PPE (polyphenylene ether) etc. as shown in Fig. $4 \cdot 5 \cdot 2 - 16$.



Fig. $4 \cdot 5 \cdot 2 - 13$ Gel generation by heating in continuous vacuum system



Fig. 4 • 5 • 2–14 Change in [η] by heating in vacuum system



Fig. $4 \cdot 5 \cdot 2 - 15$ Generation rate of decomposed gas in continuous vacuum system

Fig. $4 \cdot 5 \cdot 2 - 16$ Gel generation of other resins

The generation of decomposed gas when heating polycarbonate at 700-1200°C is shown in Fig. $4 \cdot 5 \cdot 2 - 17$. CO₂ and CH₄ generation show a constant value regardless of temperature.



Fig. $4 \cdot 5 \cdot 2 - 17$ Generation of decomposed gas at high temperature

4 • 6 Hot Water Resisting Property

As the bond of the main chain of Iupilon / NOVAREX is an ester bond, hydrolysis takes place gradually and molecular weight decreases when it comes in contact with hot water and steam. At the same time, cracks form with the decrease in mechanical strength after a long time.

The decrease in molecular weight of Iupilon / NOVAREX by treating with hot water is shown in Fig. 4 • 6–1. The decrease in molecular weight occurs rapidly by treating at high temperature. Also, the decrease in case of only one surface of the molding contacts with hot water is gentle than the case of the immersion, for example, at 75°C, the treated time when the molecular weight becomes 2.0×10^4 is 3-4 times.





Fig. $4 \cdot 6-2$ Change in tensile yield or breaking strength by treating with hot water



Fig. $4 \cdot 6-3$ Tensile breaking elongation rate by treating with hot water

The tensile properties of Iupilon / NOVAREX treated with hot water show the deterioration by crack generation with decrease in molecular weight as indicated in Fig. $4 \cdot 6-2$ and 3.

The time when ductile breaking moves to brittle breaking is as follows : $100 \sim 200$ hours at 120° C (in steam of 98kPa, 1kgf/cm²), 1000~2000 hours at 100° C and 75° C, 2000~3000 hours at 60° C, 20000 hours at 75° C one surface, above 20000 hours at 40° C. Although the decrease in molecular weight at 75° C and 60° C is small but the tensile property is deteriorated. This is due to crack generation.

The deterioration of Izod impact strength is shown in Fig. 4 \cdot 6-4. The deterioration rate becomes fast compared with the case of dry-heat treatment. For example, as for dry-heat treatment at 100°C, 1000 hours is needed, but only 30~50 hours in case of treating with hot water.



Fig. 4 \cdot 6-4 Change in Izod impact strength by treating with hot water

4 • 7 Flammability

A comparison with other resins is shown in Table 4 \cdot 7–1.

Delawara	Combustion	Heat value	Generated	Flammability	Ovugen indev
Polymers	kJ∕g (cal∕g)	kJ∕g (cal∕g)	wt%	(in/min)	(%)
Polyethylene	45.9 (10965)	42. 8 (10225)	126. 6	2. 5 (1. 0)	17. 4
Polypropylene	44. 0 (10506)	41. 1 (9828)	115.9	2. 5 (1. 0)	17. 4
Polyvinyl chloride	18. 1 (4315)	16. 8 (4015)	51. 3	self-extinguishing	47. 0
Tetrafluoro ethylene	4. 2 (1004)			nonflammable	95. 0
Polymethylmethacrylate (PMMA)	26. 2 (6265)	24. 6 (5869)	67. 8	2.8 (1.1)	17. 3
Polystyrene	40. 2 (9604)	38. 4 (9182)	72. 1	2. 5-5. 1 (1. 0-2. 0)	18. 3
Acrylnitryl • stylene (AS) ABS	35. 3	33. 8	61. 2	2. 5 (1. 0) 3. 3	18. 1
Polyether	(8424) 16. 9 (4046) 22. 7	(8066) 15. 9 (3790)	43. 7	(1. 3) 2. 8 (1. 1) 2. 0-2. 6	16. 2
Ethylcellulose	(5659)			(0. 8–1. 4)	
Polyamide (nylon)	30. 9 (7371)	28. 7 (6863)	86. 8	self-extinguishing	28. 0
Polyphenylether (PPE) Polysulphone Polycarbonate	30. 5 (7294)	29. 4 (7020)	46. 8	self-extinguishing self-extinguishing self-extinguishing	30. 2 30. 4 25. 0
Copolymerization Polycarbonate (Iupilon N-3)					31. 0

Table 4 • 7-1Comparison of flammability with other resins

The problem should be considered when making plastic flame-resistant does not include only the improvement of its flammability but also the composition, quantity and fuming property of generated gas. In case of Iupilon / NOVAREX, because the composition element is $C \cdot H \cdot O$, the generation of toxic gas such as HCI (PVC, Polyvinylidene chloride etc.), NH₃, cyanide (polyamide, ABS, AS etc.), SO₂ (polysulfone etc.) does not occur (Refer to Fig. $4 \cdot 5 \cdot 2 - 17$). Also, as for the fuming property, results of various resins are shown in Table $4 \cdot 7 - 2$. Polycarbonate has a moderate fuming property in case of ignition combustion, but shows a characteristic with extremely low fuming property in case of burning combustion.

Diagting	Thickness	Ignition combustion		Burning combustion			
Flasues	mm	Dm	Rm	T16 (min)	Dm	Rm	T16 (min)
Polyvinyl chloride Polyvinylidene chloride Polydifluoride vinyl chloride Polyfluoro vinyl Polystyrol	6. 4 2. 8 0. 04 0. 05 6. 4	660 125 0 4 660	134 243	0. 8 1. 3	300 322	12 24	3. 9 7. 3
ABS Polymethyl methacrylate(PMMA) Cellulose acetate butyrate	1.2 5.6 6.4	660 660 49	400 23 12	0. 6 2. 6 5. 0	71 156 434	4 60 45	4. 8 9. 2 2. 7
Polycarbonate Polyphenylene ether (PPE) Polysulphone Nylon fiber	3.2 2.0 1.5 7.6	174 183 40 269	43	2. 1	12 320	1	2.0
Acryl fiber Polypropylene fiber Oak	7. 6 4. 6 6 4	159 110 155	29 50 18	0. 6	319 456 350	49 60 34	1. 5 2. 3 4. 8

Table 4 • 7-2 Fuming property of plastics

Dm : fuming quantity per unit area

Rm : fuming rate

 T_{16} : time when Dm becomes 16

4 • 8 Other Thermal Properties

4 • 8 • 1 Brittleness Temperature

The brittleness temperature of Iupilon / NOVAREX is -135°C.

A comparison with other resins is shown in Table 4 \cdot 2–1. The low temperature resisting property of Iupilon / NOVAREX is the best among plastics.

4 • 8 • 2 Heat Schrinkage

The change of heat schrinkage of Iupilon / NOVAREX when treated in hot air atmosphere is shown in Fig. $4 \cdot 8 \cdot 2 - 1$. The heat schrinkage takes place even at low temperature and shows a 0.1~0.2% change. However, such a heat schrinkage also changes in accordance with the molding conditions etc. (Refer to Fig. $4 \cdot 8 \cdot 2 - 2$).

The frozen orientation strain is released by macro-Brownian motion of the molecular chain in an atmosphere over 150° C and the schrinkage becomes 5~10%.



Fig. $4 \cdot 8 \cdot 2 - 2$ Relation between injection molding conditions and heat schrinkage