TECHNICAL NOTE

SUMITOMO CHEMICAL

High Heat Resistance Amorphous Polymer

SUMIKAEXCEL PES

Polyethersulfone

High heat Resistance Amorphous Polymer

Version 02 / Nov. 2019

SUMITOMO CHEMICAL COMPANY, LIMITED Advanced Polymers Division

SUMIKAEXCEL PES Technical Notes Index

Proper Use of SUMIKAEXCEL PES

The contents of this document have been compiled based on current documents, information, and data and may be revised when new information is available.

(1) Handling
The following items refer to essential points when handling SUMIKAEXCEL PES. Ensure that SUMIKAEXCEL PES is handled safely. Carefully read the Material Safety Data Sheet regarding the handling of SUMIKAEXCEL PES before use. Examine the safety of any additives for use with SUMIKAEXCEL PES.

· Safety and Health
Ensure that any gases emitted from drying or melting SUMIKAEXCEL PES do not come in contact with the eyes or skin or are inhaled. In addition, be careful not to touch the resin while it is still hot. Local ventilation equipment must be installed and proper protective gear (such as protective goggles and protective gloves) must be worn while drying or melting this product.

· Flammability
SUMIKAEXCEL PES is a flame-resistant material (classified as UL94 V-0), however, it should be handled and stored in places well away from sources of heat and flame. If the material catches fire, toxic gases may be released. Use water, foam, or chemical fire extinguishers to extinguish any flames.

· Disposal
SUMIKAEXCEL PES may be disposed by burial or incineration. Burial of the material should be conducted by certified industrial waste processors or by the local municipal authorities in accordance with the "Waste Management and Public Cleansing Law". Incineration should be conducted using a furnace which complies with the laws and regulations of the Air Pollution Control Law. Toxic gases may be released when this product is incinerated.

· Storage
Store SUMIKAEXCEL PES at room temperature away from direct sunlight, water, and humidity.

(2) Applicable Standards
SUMIKAEXCEL PES comes in a variety of grades which comply with standards specified by the American Underwriters Laboratories Inc., i.e. UL94 and UL746, and by the Electrical Appliance and Material Control Law, i.e. ball pressure temperature. Refer to this booklet or contact Sumitomo Chemical for further details. Contact Sumitomo Chemical for information regarding the use of this material in other special applications.

(3) Security Trade Control
The products of SUMIKAEXCEL series and SUMIPROY series are not on the control list of the Foreign Exchange and Foreign Trade Control Act of Japan but implemented in catch-all control.

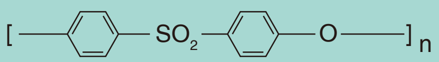
(4) Others
All the data given in this document are for reference only and are not intended as guarantees on product performance.
Be aware of intellectual property rights when using this product.

1. General Characteristic and Grade Lineup

1-1 Features

Introduction

SUMIKAEXCEL PES (Polyethersulphone) is a heat resistant amorphous resin that Sumitomo Chemical manufactures in Japan under license from Imperial Chemical Industries PLC. The molecular structure is shown in the figure below.



(Glass transition temperature Tg 225 deg C)

SUMIKAEXCEL PES is a transparent resin with a slightly amber color. It possesses a variety of useful properties, such as heat resistance, creep resistance, dimensional stability, flame resistance and hot water resistance. SUMIKAEXCEL PES is utilized as a molding material in many different applications, including : electronic components, such as relays and burn-in sockets ; IC trays ; printers; photocopier components; sterile medical and dental instruments ; and LCD substrate films for pagers and mobile phones.
In addition, SUMIKAEXCEL PES is also available in powder grades. Powder grades are utilized for a wide range of applications, including: impact modifier for epoxy-based composites used in aircraft ; heat resistant coatings; adhesives; flat films and hollow-fiber membranes used in the medical and food processing industries.

Features of SUMIKAEXCEL PES

Heat Resistance

The DTUL (Deflection Temperature Under Load) for SUMIKAEXCEL PES ranges from 200 - 220 deg C and the UL temperature index designates its continuous service temperature as 180 - 190 deg C.
Its flexural modulus is very stable at temperatures ranging from -100 to +200 deg C. In particular, at temperatures of 100 deg C or greater, SUMIKAEXCEL PES shows the highest flexural modulus among most thermoplastic resins (Figure 1-1). As well, due to its excellent thermal stability during the molding process, the amount of gas trapped within moldings is much lower than in other engineering plastics (Figure 1-2).

Figure 1-1 Temperature Dependency of Flexural Modulus

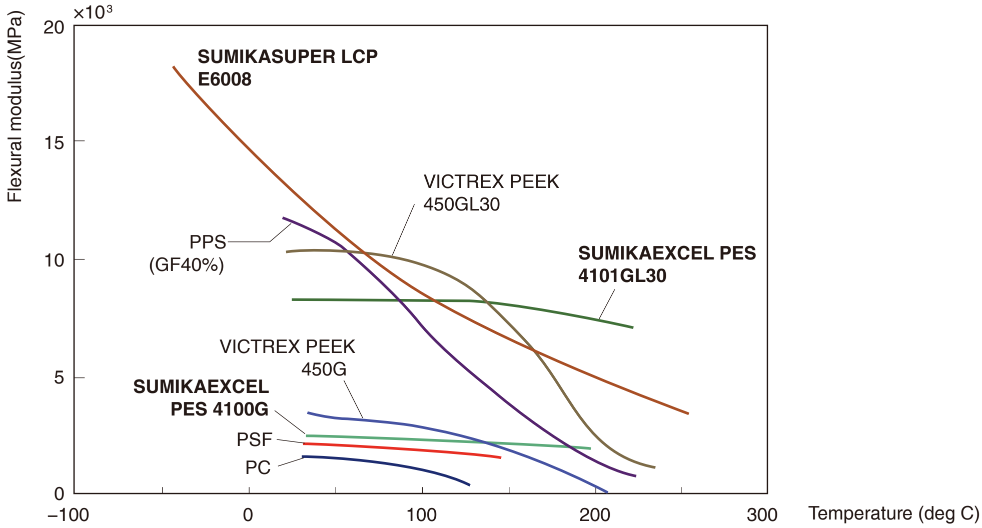
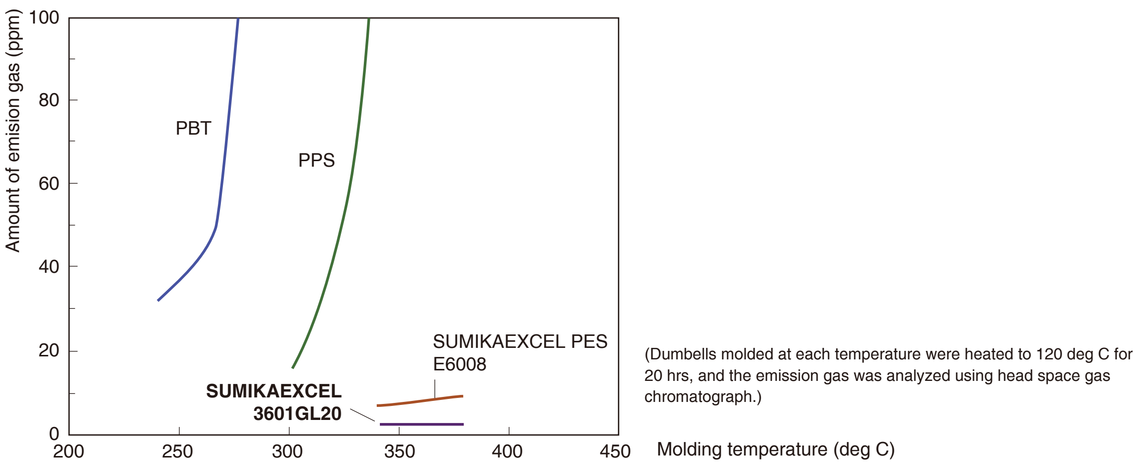


Figure 1-2 Molding Temperature and Emission Gas from Moldings



Impact Resistance

SUMIKAEXCEL PES possesses a good impact strength. Snap-fit products can be produced with natural grades, however, additional precautions must be observed, as SUMIKAEXCEL PES is susceptible to breakage at sharp notches.

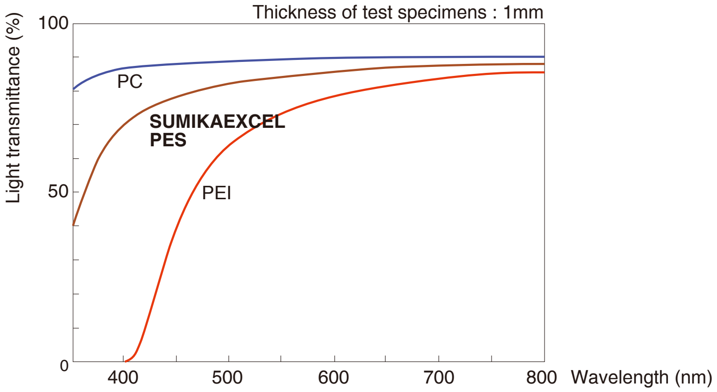
Creep Resistance

At temperatures ranging up to 180 deg C, SUMIKAEXCEL PES exhibits the highest creep resistance among all thermoplastic resins.

Light Transmittance

SUMIKAEXCEL PES possesses a high level of light transmittance, outstanding among most heat resistant engineering plastics.

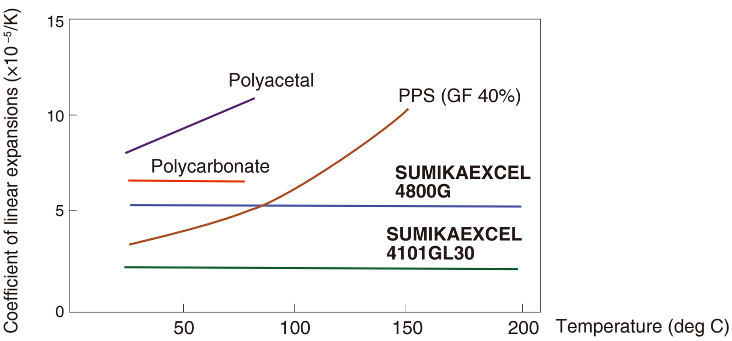
Figure 1-3 Light transmittance



Dimensional Stability

SUMIKAEXCEL PES exhibits both a low coefficient of linear expansion and a low temperature dependence. In particular, the coefficient of linear expansion of grades having high glass fiber content (4101GL30) is 2.3 10^{-5}/deg C. This value is similar to that of aluminum, and is maintained up to nearly 200 deg C.

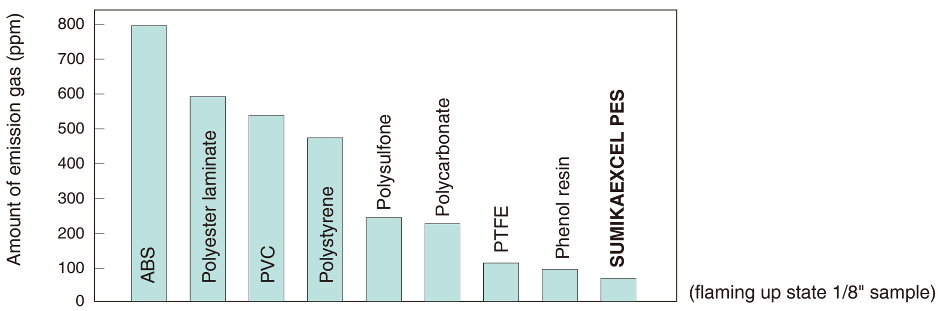
Figure 1-4 Temperature Dependency of Coefficient of Linear Expansion



Flame Resistance

SUMIKAEXCEL PES has been certified as UL94V-0 (0.43 mm) without any flame retardants. In addition, according to the results of testing conducted by the American National Bureau of Standards, it is commonly understood that, during combustion, PES generates the lowest amounts of smoke among all plastics.

Figure 1-5 Results of Smoke Chamber Tests of U.S. NBS



Hot water Resistance

SUMIKAEXCEL PES is not susceptible to hydrolysis, thus enabling its usage in hot water and steam having a high temperature of 160 deg C. However, attentions must be given to potential changes in its properties that may occur due to the absorption of water.

Chemical Resistance

SUMIKAEXCEL PES can withstand cleaning solvents, oil and grease, such as Chlorothene Freon, gasoline and engine oil. However,

SUMIKAEXCEL PES is affected by polar solvents such as acetone and chloroform. Therefore, additional precautions must be taken whenever these solvents are used. SUMIKAEXCEL PES possesses the highest resistance to stress cracking among most amorphous resins (Table 1-1).
SUMIKAEXCEL PES is also resistant to the effects of acid and alkali solutions, even at high temperatures. However, an assessment of effects should be conducted on actual moldings prior to usage.

Table 1-1 Chemical Resistance, Stress Cracking Resistance

	Immersion Test	Stress Cracking Resistance Test	
	4800G	**4800G**	Polysulfone
Ammonia	A	-	-
50% NaOH	A	-	-
Conc. hydrochloric acid	A	-	-
10% Nitric acid	A	-	-
Conc. nitric acid	C	-	-
Hydrogen peroxide	A	-	-
Benzene	A	a	c
Xylene	B	a	c
Acetone	C	c	c
Methyl ethyl ketone	C	c	c
Heptane	A	a	a
Cyclohexane	A	a	a
Glycerine	A	a	a
Ethylene glycol	A	a	a
Carbon tetrachloride	A	a	a
Gasoline	A	a	b
Ethyl acetate	C	b	c

A: No effect
a: Can be used, except under large loads.
B: Some effect
b: Can only be used when the load is small.
C: Unfit for use
c: Unfit for use.

Weather Resistance

PES does not possess good weather resistance. However, for certain applications, the addition of carbon black to a grade may render it adequate for outdoor usage.

Safety

SUMIKAEXCEL PES has been approved by the US FDA (Food and Drug Administration) (4100G, 4100P, 4800G, 4800P, 5200P, 5400P, 5900P, 5003P and 5003PS) and are compliant with Japanese Food and Sanitation Standards (Ministry of Health, Labour and Welfare, Notification No. 20).

§ Please be sure to inform in advance if you consider use for medical applications, food industry, container, and miscellaneou s-goods field.
Contact: Electronic Materials Division Phone : +81-3-5543-5845

1-2 Grade Lineup

Molding Grades

There are two grade categories for injection molding which are non-reinforced grades and glass fiber reinforced grades.

Table 1-2 Molding Grades

Grades		Filler	Applications
SUMIKAEXCEL PES General Purpose Grades	**3600G**	-	High-flow grade for injection molding
	4100G	-	Standard grade for injection
	4800G	-	and extrusion molding
	3601GL20	Grass fiber 20%	High molecular weight grade for injection and
	3601GL30	Grass fiber 30%	ectrusion molding
	4101GL20	Grass fiber 20%	High molecular weight grade especially used for
	4101GL30	Grass fiber 30%	extrusion molding

Powder Grades

A variety of grades are available as powder grades having different RV values (reduced viscosity), which is a guideline for molecular weight. The most appropriate grade may be selected to suit the particular application.
The following solvents can be used with PES : N-methylpyrrolidone (NMP), dimethylformamide (DMF) dimethyl acetamid, utyrolactone, and a 50 / 50 (weight %) mixture of dichloromethane and 1,1,2 trichloroethane.

Table 1-3 Powder Grades

Grades	Reduced Viscosity (RV)(*1)	Main Applications				
		Resin Compound	Coating	Impact modifier for Epoxy	Adhesive	Membrane
3600P	0.36	◎		-	-	-
4100P	0.41	○	○	-	○	-
4800P	0.48	-	○	-	○	○
5200P	0.52	-	-	-	-	◎
5003P (*2)	0.50	-	◎	◎	◎	-

(*1) Viscosity measured with 1(W/V)% PES dissolved in DMF.
(*2) Having many terminal hydroxyl groups. For example, 100 times of repeated polymerization and for 5003P, it is 0.6 - 1.4.

1-3 Physical Properties

Table 1-4 Physical and Mechanical Properties

				SUMIKAEXCEL PES		
		Test method	Unit	3600G 4100G 4800G	3601GL20 4101GL20	3601GL30 4101GL30
Filler		–	–	–	Chopped GF	Chopped GF
Filler quantity		–	–	–	20%	30%
Standard molding temperature		–	deg C	350/360	350/360	350/360
Specific gravity		ASTM D792	–	1.37	1.51	1.6
Water absorption		ASTM D570	%	0.43	0.36	0.3
Mold shrinkage	MD	Sumitomo method	%	0.6	0.3	0.2
	TD		%	0.6	0.4	0.4
Tensile strength		ASTM D638	MPa	84	124	140
Elongation at break		–	%	40 - 80	3	3
Flexural strength		ASTM D790	MPa	129	172	190
Flexural modulus		ASTM D790	MPa	2550	5990	8400
Izod impact strength	6.4mmt notched	ASTM D256	J/m	85	80	81
	6.4mmt unnotched		J/m	Not broken	431	539
Rockwell hardness		ASTM D785	R scale	120	134	134
DTUL (1.8MPa)		ASTM D648	deg C	203	210	216
Coefficient of linear expansion (50 - 150 deg C)	MD	Sumitomo method	x 10^{-5}/deg C	5.5	2.6	2.3
	TD		x 10^{-5}/deg C	5.7	4.8	4.3
Flame retardancy (Certified thickness)		UL94	mm	V-0 0.46	V-0 0.43	V-0 0.43
Volume resistivity		ASTM D257	Ωm	10^{15}	10^{14}	10^{14}
Electric arc resistance		ASTM D495	sec	70	120 - 180	120 - 180

2. Physical Properties

2-1 Heat Resistance

Table 2-1 indicates the thermal properties of PES that are required for the design of moldings.

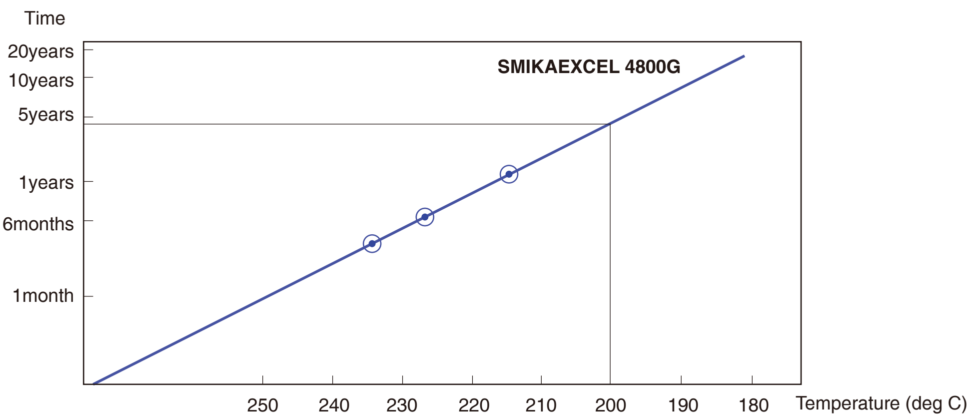
Test Properties	Test Method (ASTM)	Units	Non-reinforced	Glass Fiber Reinforced	
			4100G 4800G	**3601GL20 4101GL20**	**3601GL30 4101GL30**
DTUL) Deflection Temperature Under Load (0.45Ma)	D648	deg C	210	–	–
(DTUL) Deflection Temperature Under Load (1.82Ma)	D648	deg C	203	210	216
Vicat softening Point (1kg)	D1525	deg C	226	–	–
Vicat softening Point (5kg)	D1525	deg C	222	–	–
Coefficient of Linear Expansion (MD)	D696	x 10^{-5}/deg C	5.5	2.6	2.3
Coefficient of Linear Expansion (TD)	D696	x 10^{-5}/deg C	5.7	4.8	4.3
Heat Conductivity	C177	W/m·K	0.18	0.22	0.24
Specific Heat	–	J/deg C·kg	1,121	–	–
Temperature Index	UL746	deg C	180	180	190

For reference only

Continuous Service Temperature

The UL temperature index for long-term continuous service of PES is 180 - 190 deg C, which is the highest temperature value among most amorphous resins.
Figure 2-1 depicts the tensile strength half-life of PES. At a temperature of 180 deg C, PES will lose a half of its original tensile strength after 20 years. At a temperature of 200 deg C, this half-life is shortened to 5 years.

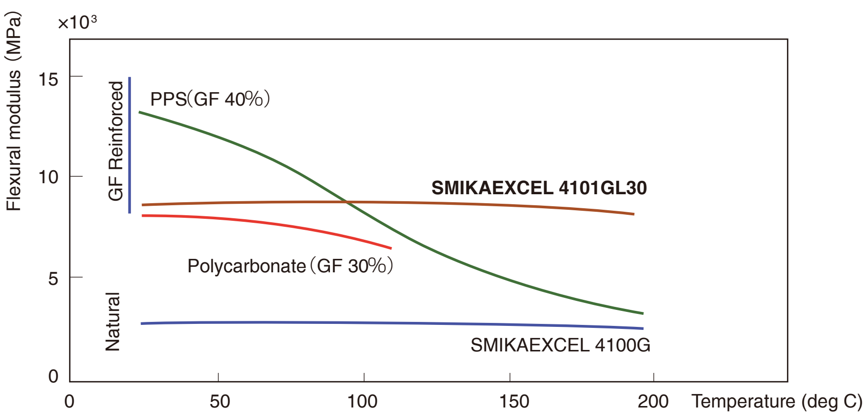
Figure 2-1 Temperature Dependence of Tensile Strength Half-Life



Temperature Dependence of Flexural Modulus

Figure 2-2 depicts the temperature dependence of the flexural modulus. The flexural modulus is very stable at the temperatures ranging from -100 to +200 deg C. In particular, SUMIKAEXCEL PES has far better temperature dependence characteristics than glass fiber reinforced materials, such as PBT and PPS crystalline resins, at temperatures greater than 100 deg C, thus SUMIKAEXCEL PES is ranked at the top of its class among most thermoplastic resins.

Figure 2-2 Temperature Dependence of Flexural modulus

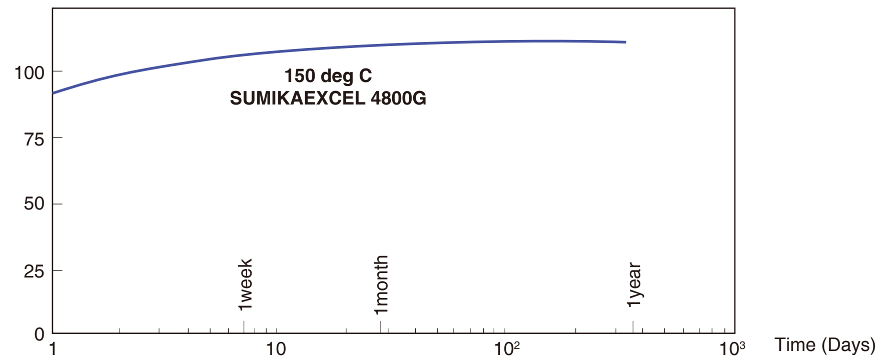


Aging Characteristics (in Air and in Hot Water)

Heat Aging Characteristics

PES has excellent long life heat stability. Even after PES is aged in air at a temperature of 150 deg C, its strength does not deteriorate.

Figure 2-3 Effects of Aging on Tensile Strength, in Air at a Temperature of 150 deg C



Hot Water Resistance

Changes in the tensile strength of PES are minimal (Figure 2-4) after aging in both water (23 deg C) and in hot water (100 deg C).
PES impact strength drops slightly upon initial exposure to hot water (100 deg C), however an adequate level of impact resistance (Figure 2-5) is maintained during subsequent exposure.

Figure 2-4 Aging Dependence in Hot Water for Tensile Strength

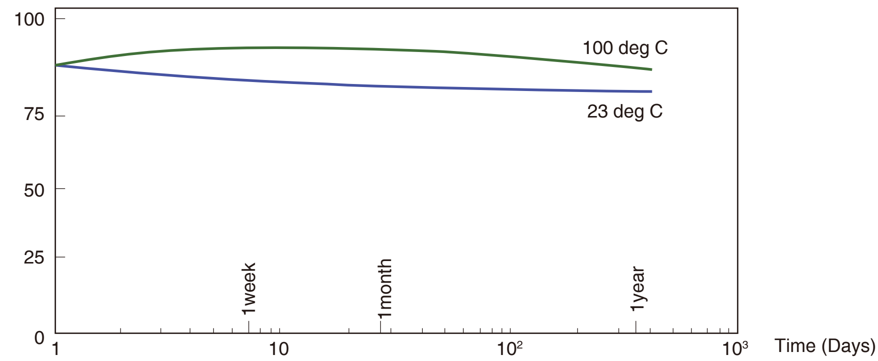
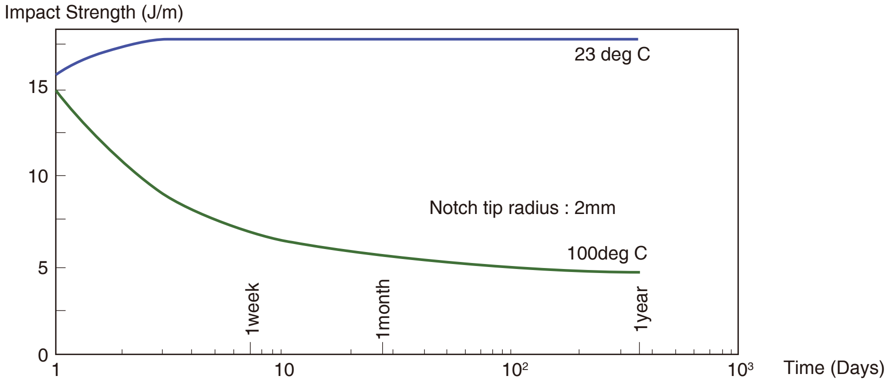


Figure 2-5 Aging Dependence in Hot Water for Impact Strength



Steam Resistance (Effects from Steam Sterilization Cycle)

No changes to impact strength were observed as a result of cyclical tests using a steam pressure of 3.2 atmospheres (143 deg C) ↔ vacuum dehydration (room temperature).
However, when PES is to be used at high temperatures or in hot water, testing should be performed prior to usage at actual operating temperatures, in accordance with the specified application.

2-2 Mechanical Properties

Long Term Deformation

Creep

When designing products of the appropriate strength required for actual usage, it is not adequate to rely solely upon the values derived from standard testing (i.e., ASTM) for mechanical strength and flexural modulus. In order to determine the most appropriate design values, all potential changes that may occur in the dimensions and mechanical strength of moldings must be considered under actual operating conditions, based upon creep properties and temperature-induced changes.

Figure 2-6 depicts the tensile creep properties of natural grade 4800G at temperatures of both 20 deg C and 150 deg C. As indicated in Figure 2-7, it can be seen that PES possesses excellent creep resistance. The natural grades of PES sustained a creep deformation of only 1% after 3 years, under a load of 20 MPa and at a temperature of 20 deg C. At a temperature of 150 deg C, the creep deformation after 3 years remained at only 1%, even though a load of 10 MPa had been applied.

Figure 2-6 Tensile Creep Properties of Natural PES (4800G)

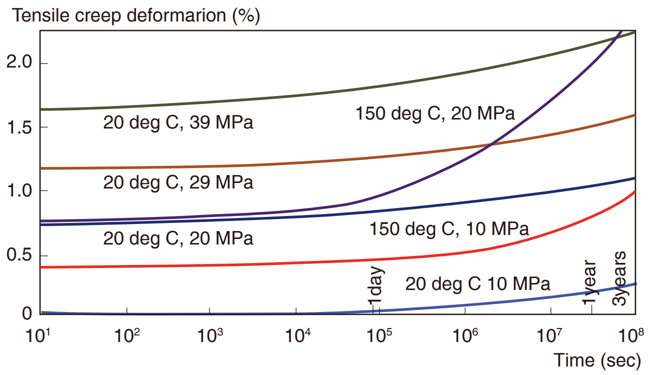
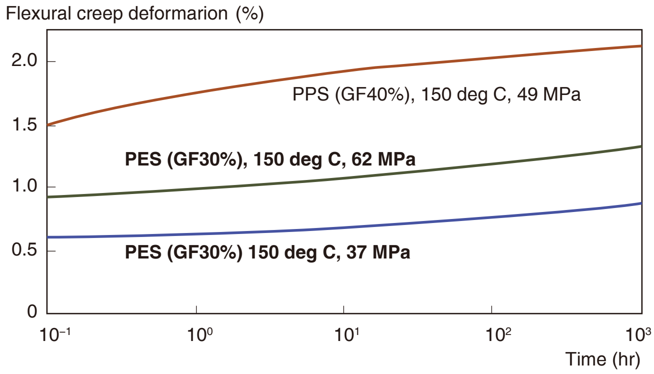


Figure 2-7 Fexural Creep Properties of Glass Fiber Reinforced PES (3601GL30 and 4101GL30)



Impact Strength

PES is tough resin that possesses outstanding impact resistance.Figure 2-8 depicts the comparison of the Izod impact strength with unnotched of PES with several high heat resistant plastics. It shows that natural grade of PES keeps higher impact property compared with glass fiber reinforced grade, which is very similar with other plastics. PES, however, is susceptible to notch shape. Figure 2-9 and 2-10 describe radius dependence of notch tip for Izod impact properties. The tooling design requires attention, if product by PES has sharp corners or screw threads. As well, cutting sprue and gates cleanly, and smoothing mold surfaces will prevent stress concentration, thus ensuring the original strength of PES.

Figure 2-8 Impact Resistance

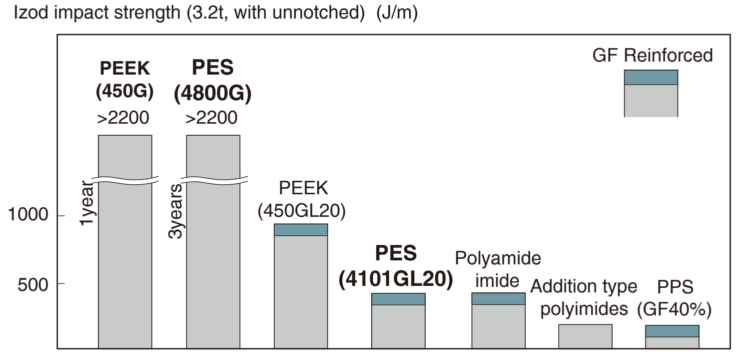


Figure 2-9 Notch Tip Radius Dependence of Impact Strength at a Temperature of 20 deg C (PES 4800G)

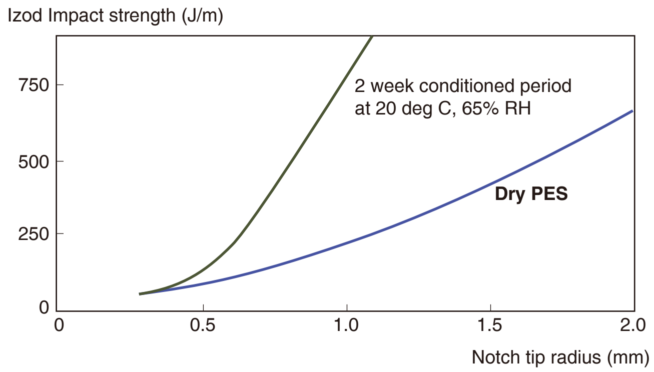
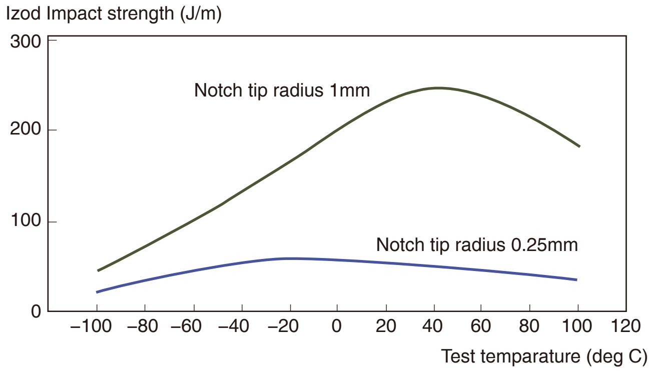


Figure 2-10 Temperature Dependence of Impact Strength (PES 4800G)



Weld Strength

General Feature

When injection molding is performed, the temperature of weld areas (resin junctions) will be lower than that of non-weld areas. The strength of weld areas of glass fiber reinforced grades decreases with the glass fiber content. Figure 2-11 depicts a comparison between the strengths of non-weld and weld areas. Table 2-2 shows the tensile strengths of weld areas for PES grades.

Figure 2-11 Flexural Strengths of Weld and Non-weld Areas

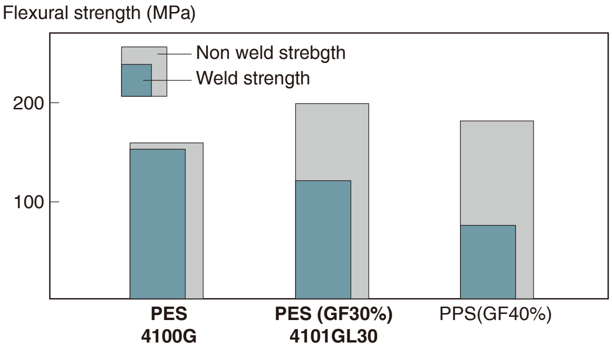


Table 2-2 Tensile Strength of Weld Areas

(Unit : MPa)

Grade	Non weld	Weld area
4100G	84	81
4800G	84	82
3601GL20	124	67
4101GL20	124	68
4101GL30	140	61

From the above figure and table, it is apparent that PES possesses far greater weld strength than that of other resins. In particular, natural grades experience only minimal degradation of weld strength and maintain similar strength to that of non-weld areas.

Weld Strength of 4100G

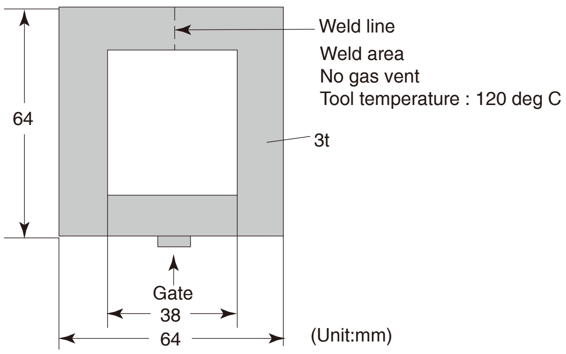


Table 2-3 Weld Strength

Resin		Flexural strength (MPa)		Izod impact strength (J/m)			
				Without notch		0.25OR notch	
		Non weld	Weld area	Non weld	Weld area	Non weld	Weld area
PES	4100G	140*	140*	>1960*	2156	68	49
	4101GL20	190	110	411	117	68	29
	4101GL30	180	110	362	98	68	29
PPS (GF40%)		170	70	166	29	49	19

Figure Marked with * = did not rupture

Note 1)

Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.

Injection Pressure : 130 MPa

Injection Speed : 60%

Cylinder Temperature : 340 deg C (4100G)

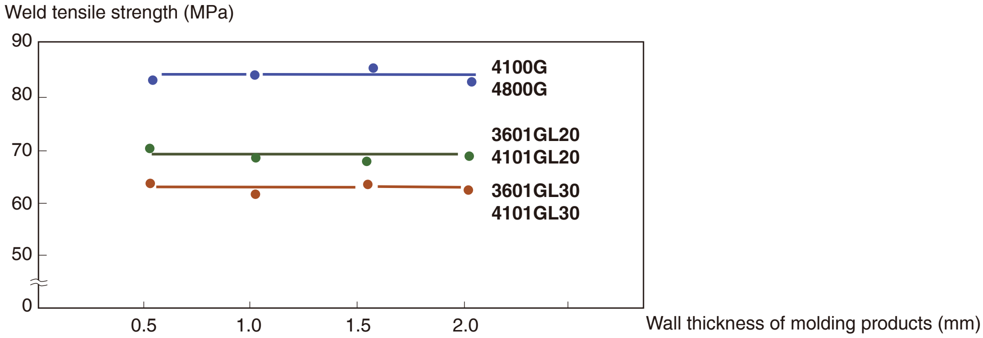
350 deg C (4101GL20·4104GL30)

Injection Time : 10 seconds

Cooling Time : 20 seconds

Weld Strength of Thin-walled Moldings

Figure 2-12 Relationship Between Wall Thicknesses of Moldings and Weld Area Tensile Strength



Improvement of Weld Strength

If the degradation of weld strength proves to be a problem during actual usage, weld strength can be improved through the methods introduced below.

• Improvement by Annealing

Weld areas of glass fiber reinforced grades can be improved by 15 - 20% through annealing treatment at a temperature range of 150 - 180 deg C. The appropriate annealing conditions are as follows: 150 deg C x 20 minutes for moldings having a wall thickness of 0.5 - 1.5 mmt ; and 180 deg C x 180 minutes for moldings having a wall thickness of 2 mmt.

Table 2-4 Improvement of Weld Tensile Strength in Glass Fiber Reinforced Grades Through Annealing

(Units: MPa)

Grade	Before Annielaing	50 deg C	180 deg C	
		20min	20min	180min
3601GL20 4101GL20	68	76(113%)	76(113%)	77(114%)
3601GL30 4101GL30	61	75(123%)	75(121%)	75(121%)

Percentage in parentheses indicates the comparison with the strength before annealing as 100%.

• Improvement Through Increased Tool Temperatures

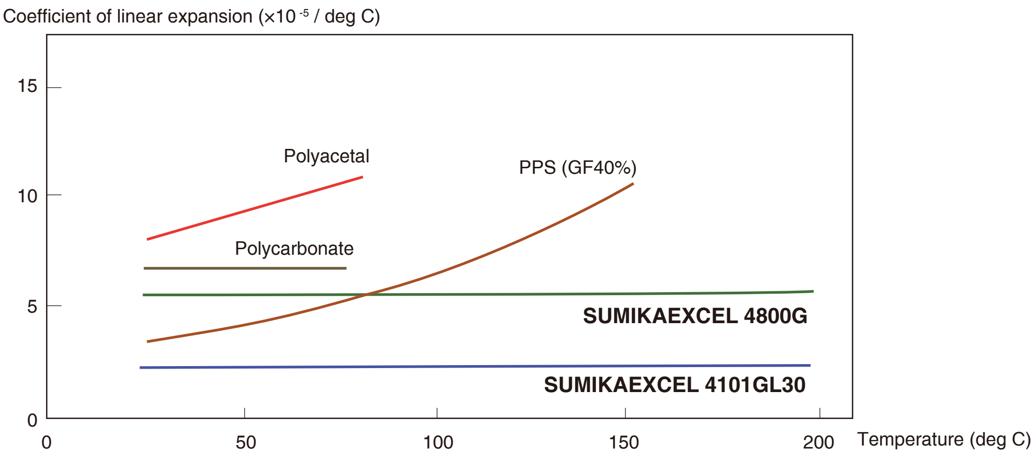
Greater weld strengths can be achieved if the tool temperature is increased during the molding process. Therefore, set the tool temperature to 160 - 180 deg C and then observe any strength changes.

2-3 Dimensional Stability

Coefficient of Linear Expansion

PES possesses the special properties of having both a low coefficient of linear expansion and a low temperature dependence. Figure 2-13 depicts the temperature dependence of the coefficient of linear expansion. The coefficient of linear expansion of crystalline PPS (40% GF) increases as the temperature rises. However, the coefficient of linear expansion of amorphous PES is not temperature-dependent and maintains a constant value up until a temperature of 200 deg C. Furthermore, 4101GL30, a glass fiber reinforced grade, possesses a coefficient of linear expansion as low as that of aluminum, which is 2.3×10^{-5} / deg C. For this reason, 4101GL30 is considered to be a suitable material for usage in precision molding applications.

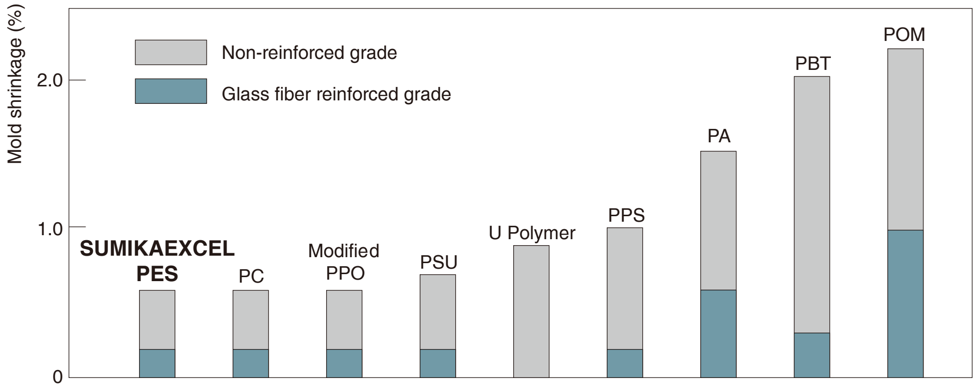
Figure 2-13 Temperature dependability of a coefficient of linear expansion



Mold Shrinkage

Non-reinforced grades of PES have low mold shrinkage (0.6%) and no anisotropy. However, glass fiber reinforced grades possess anisotropic shrinkage, at 0.2% for MD and 0.4% for TD due to the orientation of GF.

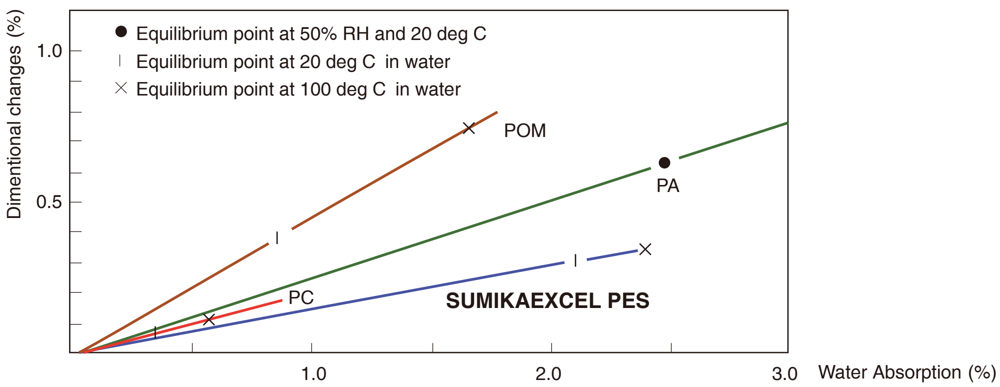
Figure 2-14 Mold Shrinkage Comparison



Dimensional Changes Due to Water Absorption

PES is susceptible to water absorption. From our experiences, however, it is at most 1.1% remain in wait change and 0.15% remain in dimensional change if the test piece is left in the air for long time (until saturated condition).

Figure 2-15 Water Absorption Dependence of Dimensional Changes



2-4 Flame Resistance

Figure 2-16 depicts the limiting oxygen index, in order to compare the flame resistance of PES to that of other resins.
Furthermore, it is commonly known that the combustion of PES produces extremely low amounts of smoke, thus PES is often utilized for aircraft interior components.
Figure 2-17 shows the results of testing conducted by the American National Bureau of Standards to determine the smoke production of PES and other resins, during combustion. PES also produces minimal amounts of corrosive gases during the molding process, and molded products have minimal outgassing.

Figure 2-16 Limiting Oxygen Index (ASTM D-2863)

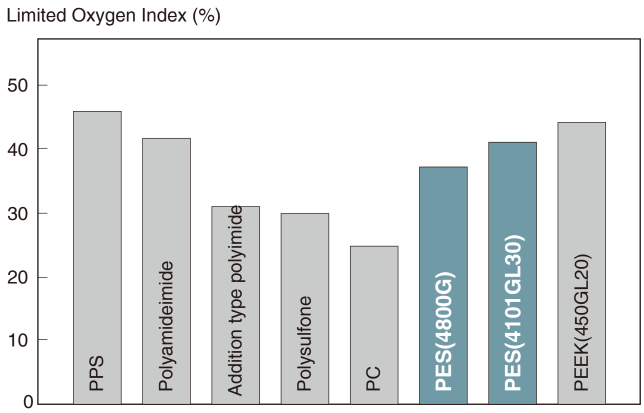
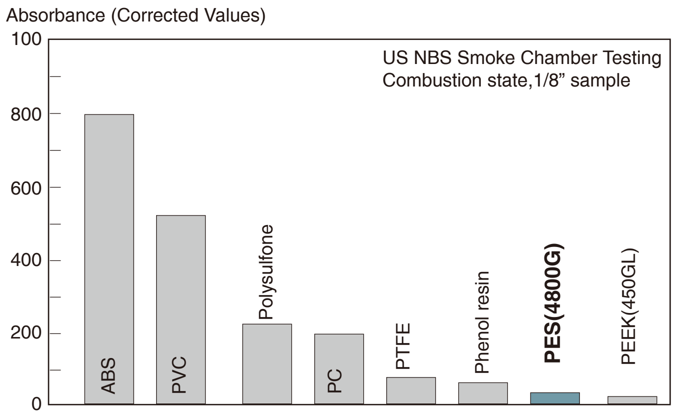


Figure 2-17 Amount of Smoke Produced



2-5 Chemical Stability

- PES is not susceptible to hydrolysis
- Please note that PES may be affected by strong acids
- PES has outstanding chemical resistances among most amorphous polymers. However, precautions must be observed in accordance with conditions of actual usage, as some organic chemicals such as ketones and esters may cause stress cracking. In addition, please note that PES does dissolve in highly polar solvents such as dimethylsulfoxide (DMSO), aromatic amines, nitrobenzene and some chlorinated hydrocarbons (i.e., dichloromethane, chloroform).
- PES possesses excellent resistances to aliphatic hydrocarbons, alcohols, certain types of chlorinated hydrocarbons, certain aromatic chemical agents, oil and grease. Furthermore, depending upon conditions of actual usage, PES is not usually affected by most bleaches and disinfectants.

However, chemical effects should be evaluated based on actual conditions prior to usage.

Hot water Resistance

PES is not susceptible to hydrolysis in either hot water, or in steam having a temperature of 160 deg C. However, attention must be paid to potential changes in its properties that may occur due to the absorption of water.

Table 2-5 Resistance to Hot Water Under Load (Hot Water at 90 deg C)

		Stress (MPa)				
		13	20	26	33	40
Polyethersulfone	**4100G(Non-reinforced)**	R56.5	R20.2	R15.3	R12.5	–
	4800G(Non-reinforced)	989.6	R65.5	R18.7	–	–
	4101GL30(GF30%)	–	–	987.3	732.5	R25.5
PPS(GF40%)		–	–	R130	R87	–

(Legend) R56.5: Ruptured after 56.5 hours [R = ruptured].
987.3: No problems up until 98.7 hours.

Table 2-6 Hot water Resistance at 140 deg C (4100G)

Period (Weeks)	Tensile Strength (MPa)	Rate of Change (%)	Charpy Impact Strength (J/m)	Rate of Change (%)
Control	81	100	382	100
2	88	108	176	46
7	93	114	137	35
14	92	113	137	34
29	81	100	137	37
42	84	104	147	39

- Steam Sterilization at 140 deg C
  The tensile strength of PES does not change at all, even after steam sterilization has been performed at 140 deg C 24 hours. A 1% increase in weight occurred during this time.

* 4800G, with high molecular weight, possesses greater resistance to severe hot water conditions than 4100G.

Inorganic Chemical Resistance

PES is resistant to the effects of acid and alkali compounds, even at high temperatures (Table 2-7).

Organic Chemical Resistance

PES can withstand greases; oils, such as gasoline and engine oils; and cleaning solvents, such as Chlorothene and Freon. However, PES is affected by polar solvents such as acetone and chloroform therefore additional precautions must be taken whenever these solvents are used. PES possesses the highest resistance to stress cracking among most amorphous resins (Table 2-8).

Stress Cracking Resistance

Constant loads were applied to tensile impact test specimens (thicknesses of 1.6 mm). The test specimens were then soaked in the chemicals for up to 20 minutes. The resulting condition of each test specimen is indicated in Table 2-8, in accordance with the legend.

Table 2-7 Changes of Weight and Tensile Strength in Inorganic

Chemical Name	Grade	Temperature (deg C)	Weight Change		Tensile Strength Change(%)					Remarks
			Immersion Time (Days)	Weight Change (wt%)	Immersion Time (Days) 14	30	90	180	360	
Water	**4100G**	Room Temperature	1	0.43	–	-17.7	-16.6	-21.1	–	–
Water	**4100G**	50	–	–	–	-13.5	-13.1	-17.7	–	–
Water	**4100G**	100	–	–	7.0	7.4	9.8	9.2	9.5	–
10% hydrochloric acid	**4100G**	Room Temperature	180	1.95	-15.6	-14.9	-17.8	-21.1	–	–
Concentrated hydrochloric acid	**4100G**	Room Temperature	180	2.19	–	-6.3	-12.2	-21.1	–	–
15% hydrochloric acid	**4100G**	90	–	–	–	–	-40.0	-49.0	-53.0	Significant crazing occurs
10% sulfuric acid	**4100G**	Room Temperature	180	1.82	–	-13.2	-17.7	-23.4	–	–
50% sulfuric acid	**4100G**	60	14	-0.39	6.3	–	–	–	–	–
50% sulfuric acid	**4101GL30**	60	14	-0.20	–	–	–	–	–	–
Concentrated sulfuric acid	**4100G**	Room Temperature	–	–	–	–	–	–	–	Dissolves
25% sulfuric acid	**4100G**	90	–	–	–	–	2.0	3.0	7.0	–
40% sulfuric acid 40% phosphoric acid	**4100G**	60	14	-0.55	–	–	–	–	–	–
40% sulfuric acid 40% phosphoric acid	**4101GL30**	60	14	-0.37	–	–	–	–	–	–
10% nitric acid	**4100G**	Room Temperature	180	2.27	–	–	–	–	–	–
Concentrated nitric acid	**4100G**	Room Temperature	–	–	–	–	–	–	–	Dissolves
5% nitric acid	**4100G**	90	–	–	–	–	0.0	-29.0	-24.0	Slight crazing occurs
10% caustic soda	**4100G**	Room Temperature	180	1.79	–	-13.9	-18.2	-22.3	–	–
Saturated caustic soda	**4100G**	Room Temperature	180	0.82	–	-4.8	-11.0	-14.2	–	–
5% caustic soda	**4100G**	90	–	–	–	–	3.0	2.0	6.1	–
Saturated potassium chloride	**4100G**	Room Temperature	120	1.46	–	–	–	–	–	–
Saturated sodium hypochlorite	**4100G**	Room Temperature	180	1.42	–	-9.8	-15.8	-19.6	–	–
25% saturated sodium hypochlorite	**4100G**	90	–	–	–	-10.0	-9.0	-6.0	–	–
10% ammonium hydroxide	**4100G**	Room Temperature	120	1.63	–	–	–	–	–	–
Aqueous hydrogen peroxide	**4100G**	Room Temperature	120	2.52	–	-9.8	–	–	–	–
Chlorinated bromine water (PH4)	**4100G**	90	30	0.33	–	-10.0	–	–	–	–
5% alum	**4100G**	90	–	–	–	–	-8.0	-11.0	-12.0	Slight crazing occurs
Sulfur dioxide	**4100G**	Room Temperature	180	8.49	–	-15.0	–	-34.0	–	–
Nitrogen dioxide	**4100G**	Room Temperature	180	1.19	–	-4.5	–	-4.5	–	–
Sulfur hexafluoride	**4100G**	Room Temperature	30	-0.11	–	2.4	–	–	–	–
Chlorine	**4100G**	Room Temperature	28	0.47	–	-62.8	–	–	–	Cracking occurs

Table 2-8 Stress Cracking Resistance

	Stress 10 MPa						Stress 19 MPa					
	Polyethersulfone			Poly sulfone	Poly carbonate	Modified PPO	Polyethersulfone			Poly sulfone	Poly carbonate	Modified PPO
	4100G	**4800G**	**4101GL30**	Non-reinforced	Non-reinforced	Non-reinforced	**4100G**	**4800G**	**4101GL30**	Non-reinforced	Non-reinforced	Non-reinforced
Acetone	R1S	R4S	○	R2S	R1S	○	R1S	R3S	○	R2S	R1S	○
Methyl ethyl ketone	R1S	R2S	○	R1S	○	R18	R1S	R1S	○	R1S	R5	R20S
Cyclohexanone	R1S	R19S	○	D	D	D	R1S	R5S	○	D	D	D
Benzene	C20	○	○	R1S	R4	D	R2	C20	○	R1S	R3	D
Toluene	○	○	○	R1S	R11	D	R6	C20	○	R1S	R3	D
Xylene	○	○	○	R4S	R15	D	○	○	○	R2S	R11	D
Trichloroethylene	C20	C20	○	D	○	D	R6	R11	○	D	R17	D
1,1,1-trichloroethane (Chlorothene)	○	○	○	R8S	R3	D	○	○	○	R3S	R1	D
Tetrachloromethane	○	○	○	SLC20	R6S	D	○	○	○	R3	R3S	D
1,2-dichloroethane	R1S	R1S	○	D	D	D	R1S	R1S	○	D	D	D
Perchloroethylene	○	○	○	C20	R1S	D	○	○	○	R8	R1S	D
Chloroform	R1S	R1S	○	D	D	D	R1S	R1S	○	D	D	D
Trichlorotrifluoroethane (Freon)	○	○	○	○	○	D	○	○	○	○	○	D
Methanol	○	○	○	○	○	○	○	○	○	○	○	○
Ethanol	○	○	○	○	○	○	○	○	○	○	○	○
n-butanol	○	○	○	○	○	○	○	○	○	C20	C20	○
Ethylene glycol	○	○	○	○	○	○	○	○	○	○	○	○
2-ethoxyethanol	C20	SLC20	○	C20	R17	○	C20	C20	○	C20	R10	○
Propane-1,2-diol	○	○	○	○	○	○	○	○	○	○	○	○
Heptane	○	○	○	○	○	○	○	○	○	○	SLC20	R19
Ethyl acetate	R31S	C20	○	R3S	○	○	R17S	R7	○	R1S	R4	○
Diethyl ether	C20	S1.C20	○	C20	R1	○	C20	C20	○	R7	R1	R15
Carbon disulfide	○	○	○	R8S	R1S	D	○	○	○	R5S	R1S	D
Gasoline	○	○	○	○	C20	○	○	○	○	C20	R3	R1
Light oil	○	○	○	○	○	○	○	○	○	○	○	○

(Legend)
○ : After 20 minutes of immersion, no changes at all were observed in the test specimen.
C20 : After 20 minutes of immersion, crazing occurred on the test specimen.
SLC20 : After 20 minutes of immersion, slight crazing occurred on the test specimen
R8 : After 8 minutes of immersion, the test specimen ruptured.
R2S : After 2 seconds of immersion, the test specimen ruptured.
D : The test specimen dissolved.

Solubility

PES is a polar polymer that dissolves in polar solvents. PES solubility is important for coating applications and for adhesion of solvents. Solvents for PES are as follows:
dimethylsulfoxide, N,N-dimethylformamide, N-methylpyrrolidone and dimethylacetamide.

Changes in Weight and Tensile Strength

Table 2-9 indicates the weight changes that occur when PES is immersed in a variety of different organic chemicals. Although the weight of PES will change over a range of -0.5% - 2% when immersed in non-solvent chemicals, depending upon the temperature and time of immersion, the dimensions themselves remain unchanged. When immersed in weak solvents, PES generally softens and swells, with its weight changing significantly.

Table 2-9 Changes in Weight and Tensile Strength When Immersed in Organic Chemicals (4100G)

Chemical Name	Grade	Temperature (deg C)	Weight Change		Tensile Strength Change					
			Immersion Time (Days)	Weight Change (wt%)	Immersion Time (Days)					
					7	30	90	180	360	
25% acetic acid	4100G	90	–	–	–	–	-3.00	-27.00	-42.00	Crazing occurs after 360 days
Glacial acetic acid		Room Temperature	30	0.31	–	–	–	–	–	–
5% phenol		Room Temperature	90	6.66	-29.70	-35.70	-45.80	–	–	–
Hydrazine anhydrous		Room Temperature	14	3.50	–	–	–	–	–	Softens
Benzene		Room Temperature	180	1.48	-3.20	-3.10	-8.60	-13.50	–	–
Xylene		Room Temperature	7	0.49	–	–	–	–	–	–
Heptane		Room Temperature	180	0.21	-0.80	-1.00	-5.80	-10.00	–	–
Cyclohexane		Room Temperature	120	0.12	–	–	–	–	–	–
Methanol		Room Temperature	14	2.09	–	–	–	–	–	–
Ethanol		Room Temperature	180	1.46	-2.20	-5.00	-13.60	-18.70	–	–
Ethylene Glycol		Room Temperature	120	0.53	–	–	–	–	–	–
Propylene Glycol		100	14	-0.36	–	–	–	–	–	–
Glycerin		150	14	0.06	–	–	–	–	–	Slight cracking
White spirits		130	7	-0.51	+21.09	–	–	–	–	–
Ethyl acetate		Room Temperature	60	10.7	–	–	–	–	–	Softens
Amyl acetate		Room Temperature	120	-0.08	–	–	–	–	–	–
Diethyl ether		Room Temperature	120	2.91	–	–	–	–	–	–
Tetrachloromethane		Room Temperature	180	0.44	-0.40	-0.30	-6.40	-11.30	–	–
1,1,1-trichloroethane (Chlorothene)		Room Temperature	120	1.01	-10.20	-19.20	-32.80	-51.60	–	–
Genklene		Room Temperature	120	1.13	–	–	–	–	–	–
Perchloroethylene		Room Temperature	120	0.78	–	–	–	–	–	–
North Sea Gas		Room Temperature	180	0.01	-0.90	-0.34	–	0.20	–	–
Ethylene oxide		Room Temperature	190	7.59	–	-14.00	–	-39.10	–	Cracking occurs at a stress of 140 kg/cm ²
Propylene gas		Room Temperature	180	0.21	-0.60	0.00	–	-0.110	–	–

Cleaning Solvents

When coating or bonding with PES, it is often necessary to remove grease, oil and parting agents from the surface of moldings. For this purpose, the usage of certain cleaning solvents, such as acetone and methyl ethyl ketone, should be avoided. Table 2-10 indicates the effects of cleaning solvents on 4100G.

Table 2-10 Effects of Cleaning Solvents (4100G)

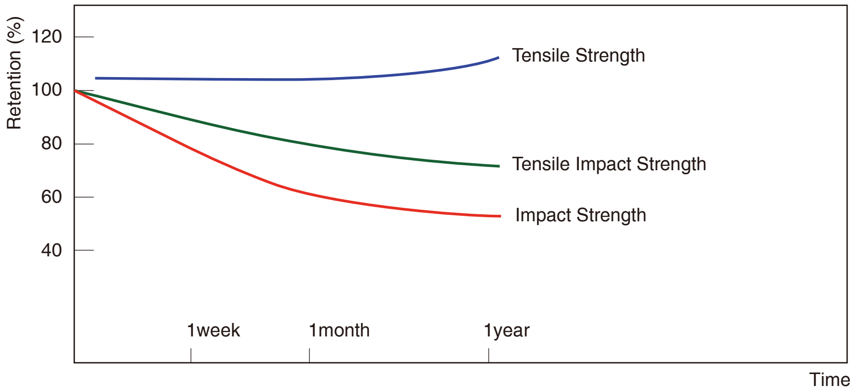
Cleaning Solvent (Under Reflux)	Time (Minutes)	Hardness (Initial Value = 98)	Weight Increase (%)
Arklone P	2	98	0
	10	98	0
	30	98	0
Arklone L	2	98	0
	10	98	0
	30	98	0
Genklene	2	98	0
	10	98	0
	30	98	0
Trinklone A	2	98	0
	10	98	1
	30	98	1
Trinklone N	2	98	1
	10	Surface cracking occurs	1
	30	Surface cracking occurs	2
Perchloroethylene	2	98	0
	10	98	0
	30	98	0
Dichloromethane	2	91	3
	10	Dissolves	–
	30	Dissolves	–

Oil , Gasoline and Transmission Fluid Resistance

Table 2-11 Weight Changes in Oils or Gasoline (4100G)

Environment	Immersion Time (Days)	Temperature (deg C)	Weight Change (%)
Linseed Oil	180	Room Temperature	0.63
Deep Frying Oil	2	180	-0.10
Silicon Oil (ICI 190)	180	Room Temperature	0.37
Veedol ATF 3433 (Transmission Fluid)	365	130	0.38
Castrol ATF	90	160	-0.55
Shell Diala Transmission Fluid	180	Room Temperature	0.30
Castrol ATF Solvent flushing Oil	90	Room Temperature	0.50
Duckhams 20/50 Oil	90	160	2.84
Gunk	90	Room Temperature	0.55
98 Octane Gasoline	180	Room Temperature	0.60
3 Star Gasoline	90	Room Temperature	0.20
ASTM·Oil	7	Room Temperature	0.00

Figure 2-18 Changes in Mechanical Properties in Transmission Fluid (4100G)



(Immersion Conditions)
Transmission Fluid : VEEDOL ATF
Temperature : 130 deg C

Table 2-12 Stress Cracking Resistance in Gasoline (at Room Temperature)

Grade	Environment	Stress (MPa)			
		9	19	28	37
4100G	Diesel Fuel	20	20	20	20
4100G	97 Octane Gasoline	20	20	SLC20	C20
4100G	100 Octane Gasoline	20	R270h	C20	R19
4100G	Paraffin	2110h	2110h	2110h	2110h
4101GL30	97 Octane Gasoline	20	20	20	20
4101GL30	100 Octane Gasoline	360h	360h	20	20

R : Cracking
C : Crazing occurs
SLC : Slight crazing occurs
h: Time - numbers with no units represent "minutes"
(Legend)
20 : no problems occurred during a period of 20 minutes
R270h : cracking occurred after 270 hours
2110h : no problems occurred during a period of 2110 hours

Table 2-13 Stress Cracking Resistance in Oil (Vactralite Oil) (100 deg C)

Grade	Notch Radius (mm) 5	Stress (MPa)					
		10	20	25	30	40	
4100G	0.01	2000h	R150h	-	-	-	-
4100G	0.25	2300h	R110h	-	-	-	-
4100G	0.50	-	1450h	R330h	-	-	-
4100G	1.00	-	2000h	2000h	-	3000h	R790h
4100G	2.50*	-	-	2300h	-	2000h	R700h
4101GL20	0.50	-	-	-	1632h	R460h	R160h

* Mold Notch
(Those not marked with an * have a machined notch.)
(Legend)
20 : no problems occurred during a period of 20 minutes
R270h : cracking occurred after 270 hours
2110h : no problems occurred during a period of 2110 hours

Table 2-14 Stress Cracking Resistance in Turbine Oil (160 deg C)

Grade	Oil	Notch Radius (mm)	Stress (MPa)			
			10	20	30	40
4800G	Aeroshell 555	2.5	3000h	R1h	-	-
4101GL20	Aeroshell 555	0.5*	250h	R3h	-	-
4101GL30	Aeroshell 555	2.5	-	3700h	-	-
4800G	Esso Turbo 2380	2.5	3200h	-	-	-
4101GL30	Esso Turbo 2380	2.5	-	-	1650h	R2h
4800G	Esso Turbo 2389	2.5	1400h	R20h	-	-

* Mold Notch
(Those not marked with an * have a machined notch.)
(Legend)
20 : no problems occurred during a period of 20 minutes
R270h : cracking occurred after 270 hours
2110h : no problems occurred during a period of 2110 hours

Table 2-15 Effects of Oil Immersion on Mechanical Properties (4800G)

Oil type		Temperature (deg C)	Immersion Time (Weeks)					
			2	4	6	16	32	52
Mineral Oil		100	+	+	+	+	+	+
		120	+	+	+	+	0	0
		140	+	0	0	0	0	
Synthetic Hydrocarbon Oil		100	+	+	+	+	0	0
		120	+	+	+	+	0	0
		140	0	0	0	0	–	
Silicon Oil	–Dimethyl	120	+	+	+	+	0	0
		160	+	0	0	0	0	0
	–Methylphenyl	120	+	+	+	+	+	+
		140	+	+	0	0	0	
		160	+	0	0	0	0	0
		180	+	0	–	–	–	–
	–Chlorophenyl	200	–	–	–	–	–	–
		160	0	0	0	0	0	0
		180	–	–	–	–	–	–
Ester Oil	–Diester	120	+	+	+	+	0	0
	–Polyester	120	+	+	0	0	–	–
		160	0	0	–	–	–	–
		180	0	–	–	–	–	–
Polyglycol Oil		100	+	+	+	+	+	+
		120	+	+	+	0	0	0
		140	0	0	0	0	0	
Fluorinated Alkylether Oil		180	0	0	0	–	–	–
		200	–	–	–	–	–	–
Water-soluble Oil Emulsion		80	0	0	0	0	–	–
Mineral-based Oils + Thickener								
a) Calcium soap		80	+	+	0	0	0	0
b) Lithium soap		120	+	0	0	–	–	–
c) Lithium-lead soap		120	0	0	0	0	–	–
d) Calcium complex soap		120	+	+	+	+	+	–
e) Synthetic sodium soap		120	0	0	0	–	–	–
f) Polyurea		120	0	0	0	0	–	–
Diester + Lithium Soap		120	+	+	+	+	0	0
Silicon-based Oil –Dimethyl + Modified amide –Methylphenyl + Lithium Soap		120	+	0	0	0	0	0
		120	+	+	+	+	0	0
		140	+	+	+	+		
		160	+	+	0	0		

+	Resistance	Excellent	Retention	75% or greater
0		Good		50% or greate
–		Fail		5 less than 50%

Table 2-16 Stress Cracking Resistance under Constant Strain in Turbine Oils (4800G)

Oil	Temperature			
	Room Temperature	150 deg C	160 deg C	
	Strain			
	3%	2%	1%	0%
Aeroshell 500	0.05	R5	0.15	15
Aeroshell 555	5	R5	15*	15
Aeroshell 750	5	R5	15	–
Castrol 580	5	R5	15	–
Esso Turbo 25	5	R5	25	–
Esso Turbo 274	5	R5	R25**	15
Esso Turbo 2380	5	R5	R25**	15
Esso Turbo 2389	5	R5	–	–

(Legend)
* Surface cracking occurred parallel to the resin flow direction .
** Cracking did not occur during a 15-minute exposure.

Bleaches and Liquid Disinfectant Resistance

PES is not affected by most bleaches and liquid disinfectants, unless they are in highly concentrated form. After being immersed in liquid disinfectant, molded PES products must be rinsed water. If further sterilization is required, steam or dry heat can be applied.

Table 2-17 Effects of Bleaches and Liquid Disinfectants (4100G)

Solution	Weight Change (%)	Tensile Strength Change (%)
10% Lissapol N	1.46	-11.6
2% Ivisol	1.35	-14.6
0.5% Gevisol	1.40	-14.8
2% Instrusan	1.42	-15.6
1% Bentenol	1.30	-13.6
1% Soilay 901-SD	1.36	-14.7
Household Bleach	1.27	–

Conditions: immersed for a period of 1 month at room temperature.

Annealing

Residual stresses in molded articles can be relived through annealing processes. Annealing is also effective in improving chemical resistance. This fact can easily be verified by immersing annealed PES in toluene or MEK.

2-6 Electrical Properties

PES is a heat resistant material that possesses electrical insulating properties. It maintains an outstanding dielectric constant and dielectric dissipation factor, as well as superb electrical resistance, up until temperatures exceeding 200 deg C.

Dielectric Dissipation Factor

PES has a constant, low dielectric dissipation factor of approximately 0.001 across a temperature range of 20 - 150 deg C (Figure 2-19). Even at frequencies of 10^9 Hz, the frequency dependence of the dielectric dissipation factor is only approximately 0.003 (Figure 2-20).

Figure 2-19 Temperature Dependence of Dielectric Dissipation Factor (60 Hz)

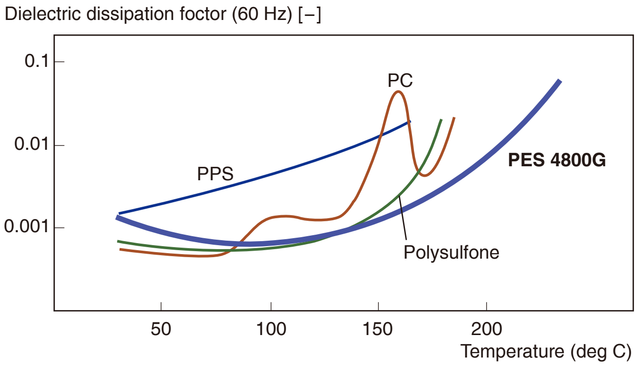
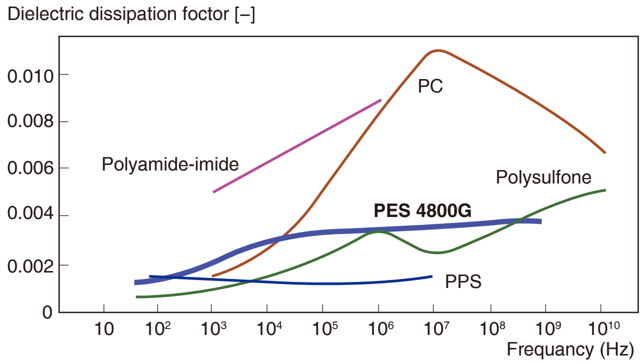


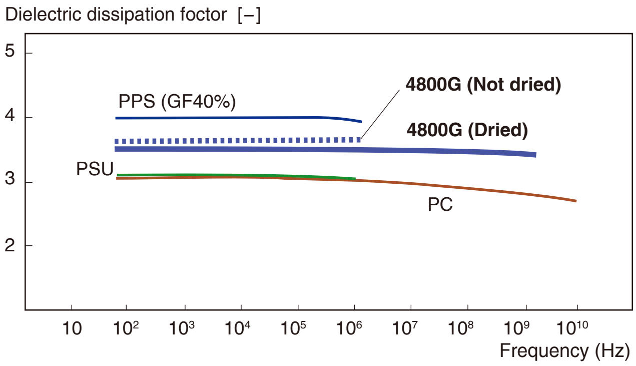
Figure 2-20 Frequency Dependence of Dielectric Dissipation Factor (Room Temperature)



Dielectric Constant

The dielectric constant of PES is consistent (3.5) from 60 Hz - 109 Hz. Even when a test specimen has absorbed water, the dielectric constant will only increase by a very small amount (Figure 2-21).

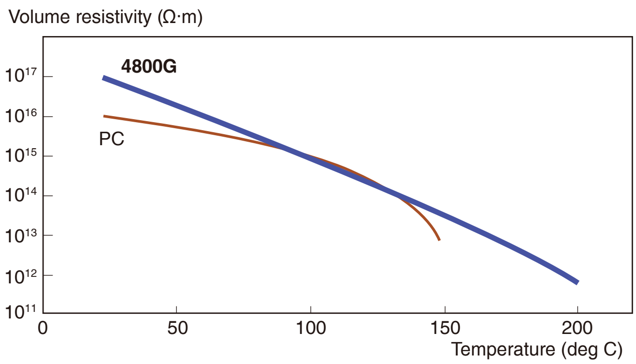
Figure 2-21 Frequency Dependence of Dielectric Constant



Volume Resistivity

PES possesses a high volume resistivity of 10^{11} Ω/m, even at 200 deg C (Figure 2-22).

Figure 2-22 Temperature Dependence of Volume Resistivity (Polarization Time: 1000 sec.)



3. Injection Molding / Fabricatinging

3-1 Moldability

General Feature

The moldability of PES improves tremendously with increaseing in the cylinder temperature, the injection pressure and the wall thickness of molding. The tool temperature does not significantly affect moldability. However, as PES has a high glass transition temperature of 225 deg C, it is recommended that the tool temperature is set to 160 deg C or higher. At low tool temperature, additional attention should be paid to avoid mold release defects. Especialy in glass fiber reinforced grade, low tool temperature is easy to be a cause of rough surface of the moling.

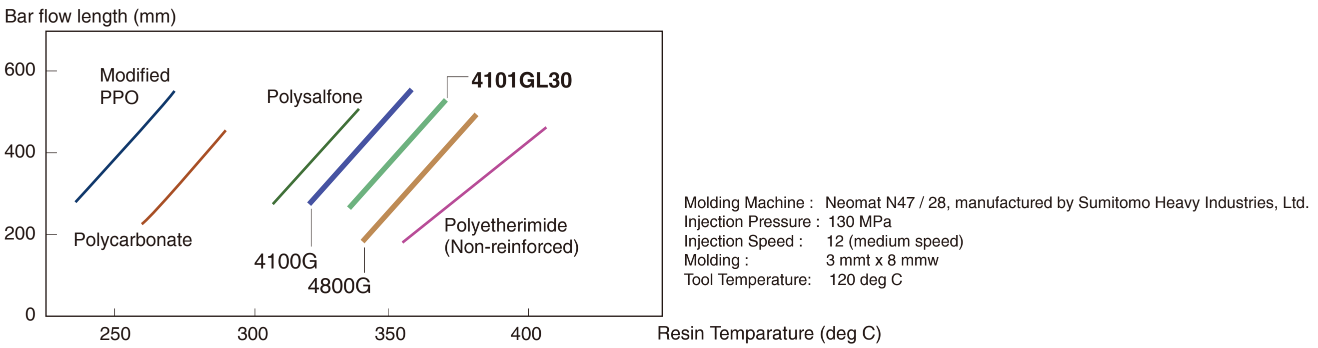
Standard Molding

This section describes the moldability characteristics of moldings of PES that have a wall thickness of 3 mm.

Effects of Cylinder Temperature

If the cylinder temperature is raised, the melt viscosity of the resin will decrease, and improved the moldability. Raising the cylinder temperature by 20 deg C will improve the bar flow length by 30 - 60%.

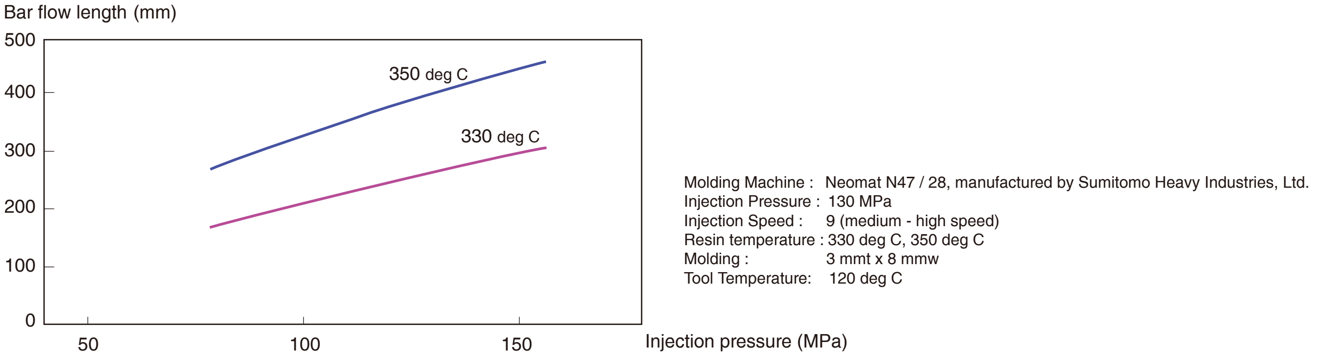
Figure 3-1 Temperature Dependence



Effects of Injection Pressure

Increasing the injection pressure 20 MPa will improve the bar flow length by 10 - 20%. In general, it is recommended that high-pressure molding be utilized. However, it is necessary to ensure that mold release defects do not occur due to overcharging, and careful attention must be taken to preventing the buildup of residual stresses. Furthermore, the secondary pressure must be set in order to ensure the selection of appropriate conditions.

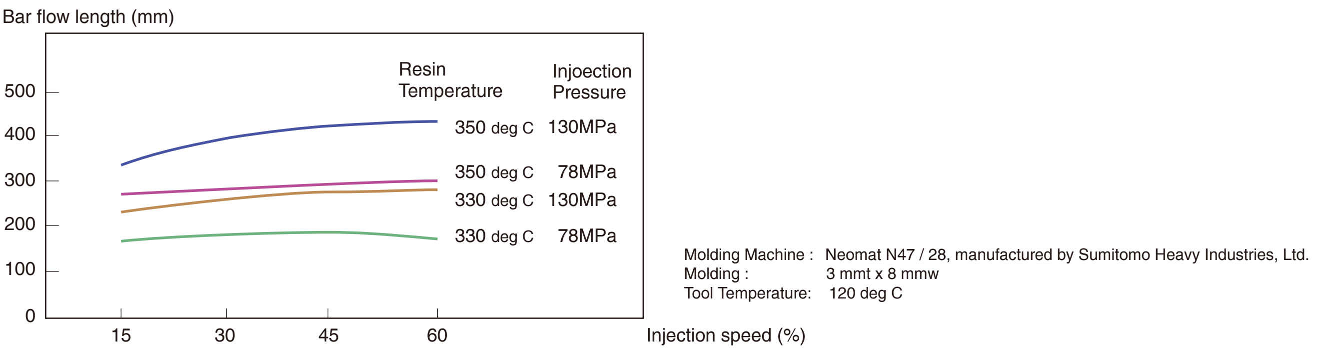
Figure 3-2 Injection Pressure Dependence (4100G)



Effects of Injection Speed

The injection speed does not affect the bar flow length.

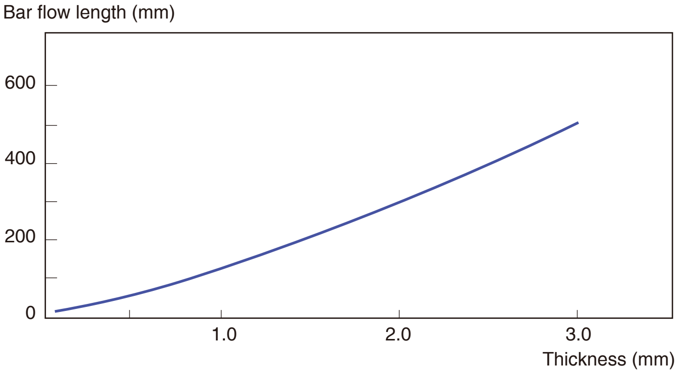
Figure 3-3 Injection Speed Dependence (4100G)



Effects of Product Wall Thickness

The flow length is rapidly improved by increasing of products wall thickness. In case of over 1.5mm thickness of wall, the moldability will be improved by 40 - 70% for each 0.5 mm increase in wall thickness.

Figure 3-4 Effects of Wall Thickness (4100G) on Moldability



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 60%
Resin temperature : 360 deg C
Molding : 8 mmw Bar Flow
Tool Temperature: 120 deg C

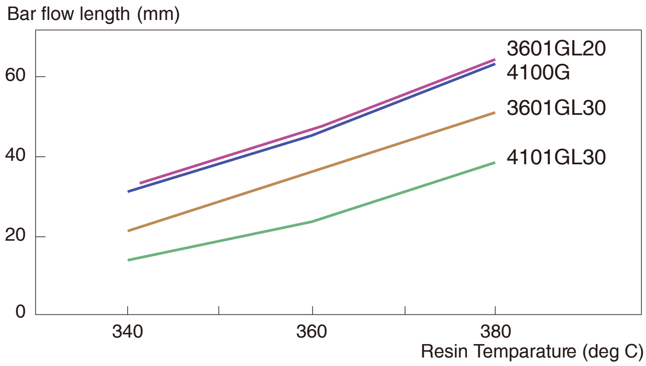
Thin Wall Molding

This section describes the characteristics of moldability of PES in very thin wall thickness (0.1-0.7 mm).

Effects of Cylinder Temperature

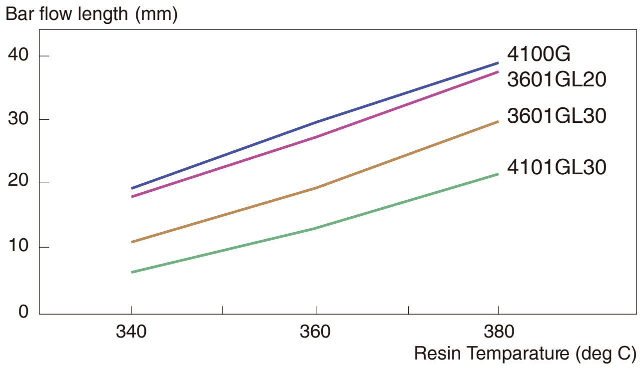
The moldability is improved with increasing the cylinder temperature. However, this effect is smaller for moldings having a wall thickness of 0.3 mm or less. In case of over 1.5mm thickness of wall, the moldability will be improved by 40 - 70%.

Figure 3-5 Cylinder Temperature Dependence of Bar Flow Length (0.7 mm)



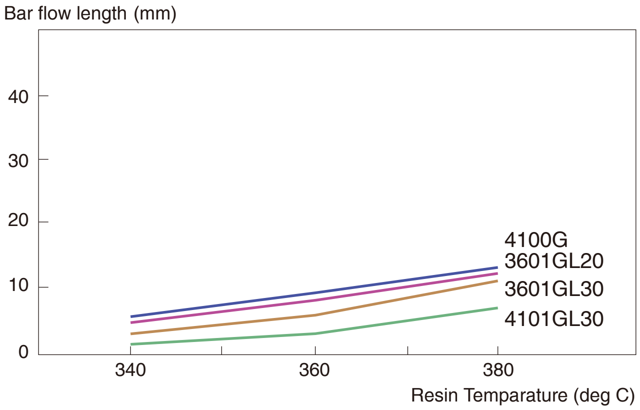
Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Molding : 0.7 mmt 8 mmw
Tool Temperature: 140 deg C

Figure 3-6 Cylinder Temperature Dependence of Bar Flow Length (0.5 mm)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Molding : 0.3 mmt 8mmw
Tool Temperature: 140 deg C

Figure 3-7 Cylinder Temperature Dependence of Bar Flow Length (0.3 mm)

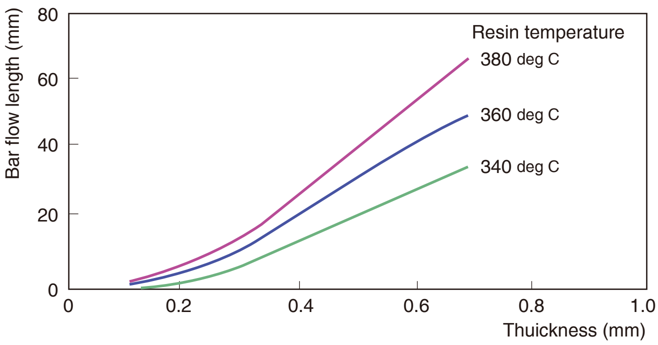


Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Molding : 0.3 mmt 8 mmw
Tool Temperature: 140 deg C

Effects of Wall Thickness of Moldings

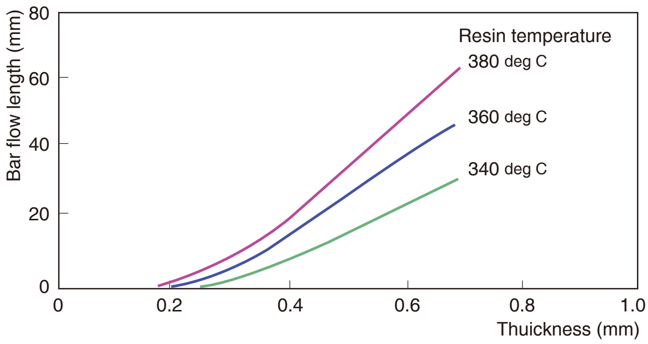
The moldability of PES depends upon the wall thickness of the molding.

Figure 3-8 Wall Thickness Dependence (4100G)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Molding : Xmmt 8 mmw
Tool Temperature: 140 deg C

Figure 3-9 Wall Thickness Dependence (3601GL20)

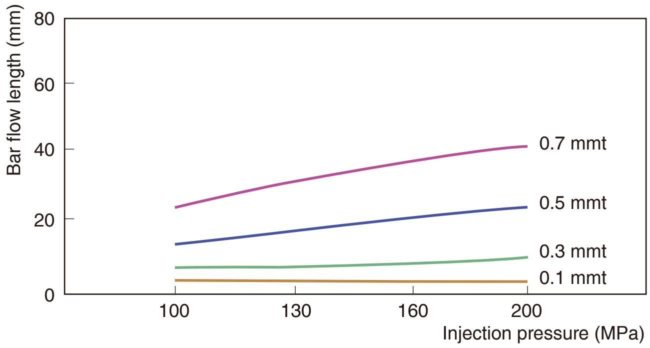


Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Molding : Xmmt 8 mmw
Tool Temperature: 140 deg C

Effects of Injection Pressure

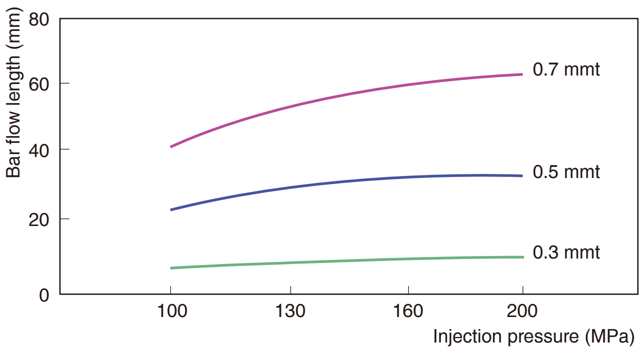
The injection pressure has a relatively large effect on the moldability of thin-walled PES products. The injection pressure of 130 MPa or greater is recommended. As well, the appropriate pressure must be selected with due consideration for product appearance and the prevention of residual stresses.

Figure 3-10 Injection Pressure Dependence (4100G)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Resin temperature : 340 deg C
Molding : xmmt 8 mmw
Tool Temperature: 140 deg C

Figure 3-11 Injection Pressure Dependence (3601GL20)

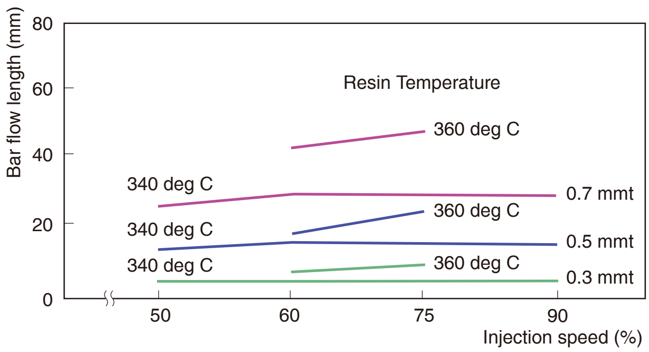


Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Resin temperature : 340 deg C
Molding : xmmt 8 mmw
Tool Temperature: 140 deg C

Effects of Injection Speed

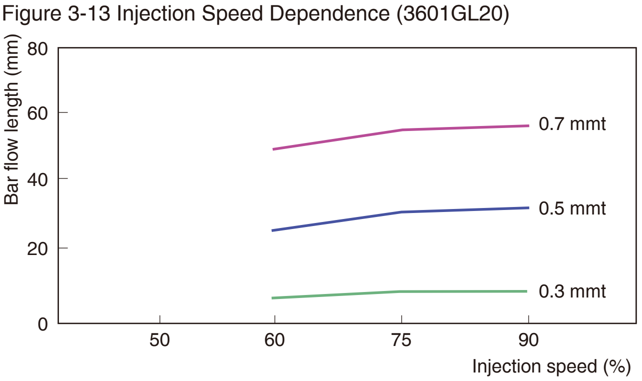
The injection speed has only minimal effects on the moldability of thin-walled PES products. If the injection speed is excessively high, defects such as "burning" may occur.

Figure 3-12 Injection Speed Dependence (4100G)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Molding : xmmt 8 mmw
Tool Temperature: 120 deg C

Figure 3-13 Injection Speed Dependence (3601GL20)

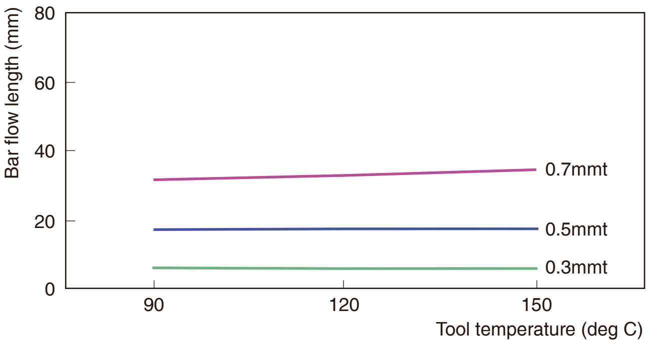


Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Resin temperature : 360 deg C
Molding : xmmt 8 mmw
Tool Temperature: 140 deg C

Effects of Tool Temperature

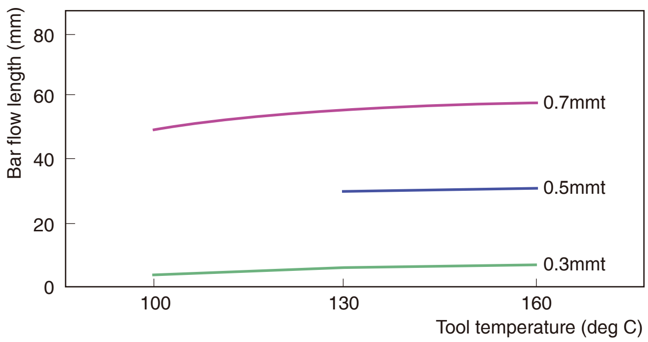
The tool temperature has only minimal effects on the moldability of thin-walled PES products.
However, as PES has a high glass transition temperature of 225 deg C, it is recommended that the tool temperature be set to 160 deg C or higher. When the tool temperature is low, additional precautions must be taken to prevent the occurrence of mold release defects. When glass fiber reinforced grades are molded, low tool temperatures may cause low weld strength or surface roughness of products.

Figure 3-14 Tool Temperature Dependence (4100G)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Resin temperature : 340 deg C
Molding : χmmt 8 mmw

Figure 3-15 Tool Temperature Dependence (3601GL20)



Molding Machine : Neomat N47 / 28, manufactured by Sumitomo Heavy Industries, Ltd.
Injection Pressure : 130 MPa
Injection Speed : 75%
Resin temperature : 360 deg C
Molding : χmmt 8 mmw

Viscosity Characteristics

The apparent melt viscosities are as follows:

Figure 3-16 Resin Temperature Dependence of Apparent Melt Viscosity

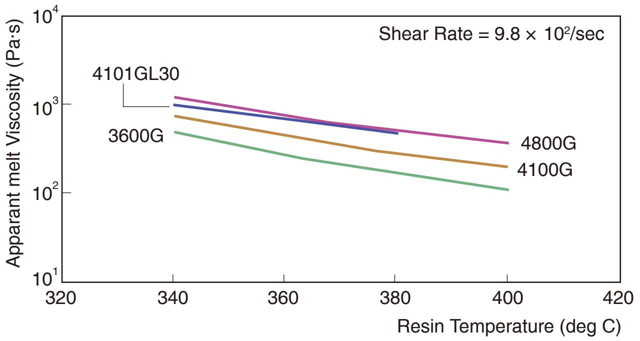
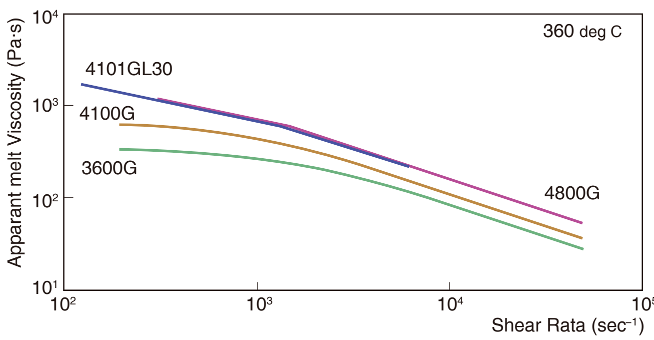


Figure 3-17 Shear Rate Dependence of Apparent Melt Viscosity



3-2 Injection Molding Conditions

Selection of Injection Molding Machine

SUMIKAEXCEL PES can be molded by standard inline type and plunger type (ram fed) injection molding machines.

Screws and Cylinders

- As filler reinforced grades of SUMIKAEXCEL PES contain glass fiber and other materials as filler, it is preferable that materials with good abrasion resistance be utilized.
- Standard full flight screws are preferable for their low shear heating. Sub-fight screws and high mixing screws are not recommended for avoiding degradation of resin due to high shear heating.

Typical screw designs are as follows:

- L/D: screw length (L) / screw diameter (D) = a value of approximately 20 is preferable.
- Compression ratio: compression ratio = a value of 2 - 2.2 is preferable.
- Zone length ratio
  e.g.) Feeding zone: approximately 55%
  Compression zone: approximately 25%
  Metering zone: approximately 20%
- Screw heads with check valve are recommended.

Nozzles

- Nozzle materials must be suited to the particular screw and cylinder utilized.
- Open nozzles should always be used. Shut-off nozzles should not be used, as they have excessive dead space that can trap and retain resin.
- The nozzle heaters used must have independent temperature control employing the PID control method. The PID control method provides good controllability.
- When extension nozzles are used, they should be designed with consideration for consistent temperature distribution.

Injection Unit and Control System

- As SUMIKAEXCEL PES possesses high melt viscosity, it is preferable to utilize molding machinery that is capable of supplying an injection pressure of 200 MPa or greater.
- As SUMIKAEXCEL PES possesses high melt viscosity, large amounts of torque are produced within the metering zone. Therefore, it is recommended that a high power injection unit is used.

Molding Machine Capacity

- Although capacity depends upon the size of the moldings, the best results are obtained from a combination of cylinder diameter and mold clamp pressure that allows for continuous metering of 1/3 - 3/4 of the total injection capacity. If there is inadequate continuous metering capability, then any excess residual resin may result in a variety of molding defects.

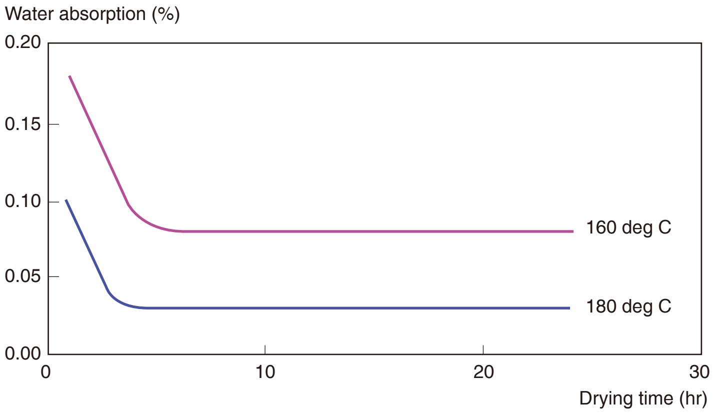
Pre-drying

As SUMIKAEXCEL PES is susceptible to water absorption, it must be dried thoroughly prior to usage. PES resin should be dried at temperatures ranging from 160 - 180 deg C for 5 - 24 hours, using a hot air circulation oven or a dehumidifying dryer. When drying using oven trays, PES resin should be spread on the trays to a thickness of 50 mm or less. In particular, for molding large sized moldings, it is recommended that PES resin is dried at a temperature of 180 deg C.

In addition, the use of a dehumidifying dryer is recommended for non-reinforced grades and for large sized moldings. If a hopper dryer is used, it is important to ensure that it contains both adequate resin capacity and large heat capacity. If sufficient pre-drying does not occur, then silver streaking may appear on the surface of the molding. If this kind of phenomena occurs, then further drying of the resin is necessary.

As SUMIKAEXCEL PES is not susceptible to hydrolysis, it will not deteriorate during the drying process, if dried in accordance with the abovementioned conditions.

Figure 3-18 Relation of Drying Temperature / Time and Water absorption



Molding Conditions

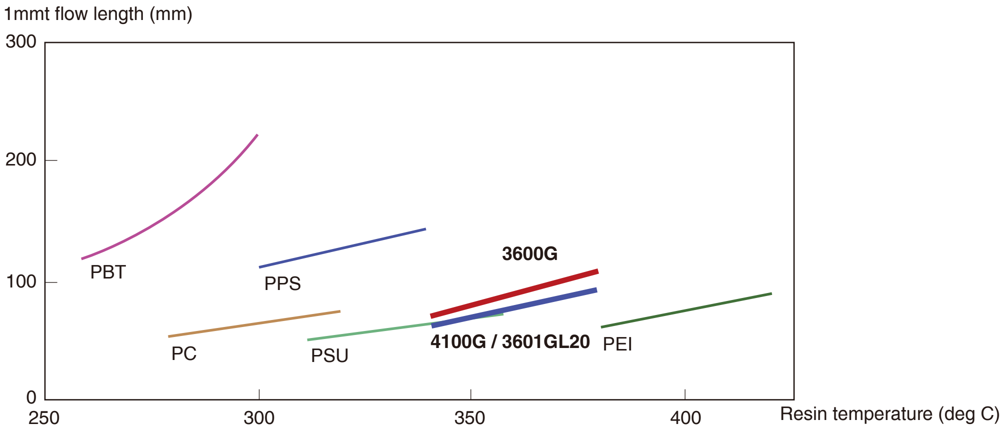
Standard molding conditions for SUMIKAEXCEL PES are as follows:

Grade		3600G 4100G	4800G	Glass Fiber Reinforced Grades
Drying Conditions		160 - 180 deg C X 5 - 24 hr	160 - 180 deg C X 5 - 24 hr	160 - 180 deg C X 5 - 24 hr
Cylinder Temperature (deg C)	Rear	300 - 340	320 - 340	300 - 340
	Center	320 - 370	330 - 370	320 - 370
	Front	330 - 380	340 - 390	330 - 380
	Nozzle	330 - 380	340 - 390	330 - 380
Tool Temperature	(deg C)	120 - 180	120 - 180	120 - 180
Injection Pressure	(MPa)	100 - 200	120 - 200	100 - 200
Holding Pressure	(MPa)	50 - 100	80 - 150	50 - 100
Injection Speed		Low speed - medium speed	Low speed - medium speed	Low speed - medium speed
Screw Rotation Speed	(rpm)	50 - 100	50 - 100	50 - 100
Back Pressure	(MPa)	5 - 10	5 - 20	5 - 10

Resin Temperature

A resin temperature of 330 - 380 deg C is recommended. As SUMIKAEXCEL PES possesses high melt viscosity, the resin temperature tends to increase to a value somewhat higher than the cylinder temperature setting, thus may result in a temperature difference of more than 40 deg C. The resin temperature must be carefully monitored while molding operations are performed.

Figure 3-19 Flow Lengths of PES



Tool Temperature

The tool temperature should be set in a manner such that the surface temperature will be between 120 - 180 deg C. Also, ensure that the surface of the mold has a uniform temperature distribution.
If the tool temperature is excessively low, moldings may warp and crack (rupture) due to residual stresses. Residual stresses may also cause glass fibers to be visible on the surface of moldings using glass fiber grades. Moldings having low residual stresses can be obtained by using a high tool temperature. However, if the tool temperature is excessively high, deformation may occur during mold release.
With respect to the methods used for tool heating, both heaters and oil temperature control are recommended. However, for the following tools, oil temperature control should be implemented in order to ensure the most uniform tool temperature distribution: tools that have complex shapes; deep tools; and tools that have slide cores.
In particular, when molding large sized products and when using non-reinforced grades, additional precautions must be taken to ensure that proper tool temperatures are maintained.

Injection Pressure and Maintained Pressure

In general, the molding of SUMIKAEXCEL PES requires a high injection pressure. Over 150 MPa of injection pressure is required for the molding of thin-walled products; the use of glass fiber reinforced grades; and for moldings that have long flow lengths.
It is recommended that the maintained pressure is set to 1/2 - 1/3 of the injection pressure. Lower maintained pressures will result in moldings that have less residual stress.

Injection Speed

In general, SUMIKAEXCEL PES should be molded at low - medium injection speeds. However, the optimum injection speed will vary depending upon the shape of the molding.
As SUMIKAEXCEL PES has a high melt viscosity, an excessively high injection speed will result in burning and silver streaking, due to the heat produced from shearing and adiabatic air compression. However, high injection speeds are required for the molding of both thin-walled products (1 mmt or less) and products having long flow distances.
In general, lower injection speeds result in moldings that have less residual stress.

Screw Rotation Speed and Back Pressure

It is recommended that screw rotation speed is between 50 - 100 rpm in order to prevent increases in resin temperature due to shear heat.
The application of the appropriate back pressure allows for consistent melting of resin. The recommended back pressure is 5 - 10 MPa.
When using PES grades that have high molecular weights, ensure that a greater back pressure is applied. However, if back pressure becomes excessively high, the resin may overheat and overcharging may occur.

Purging

The following materials are suitable for usage in purging : polyethylene that has a high molecular weight of approximately MFR 0.05; polycarbonate; or more preferably, these same materials yet containing glass fiber.
After shooting out any resin remaining within the cylinder, set the cylinder temperature to 280 - 300 deg C. Once the temperature has dropped to 340 deg C or less, feed in high molecular weight polyethylene, then continue the purging operation until the preset temperature has been reached.
If molding is operated with PES after purging, shoot out all purging agent that remains within the cylinder, then set the initial cylinder temperature to a relatively low temperature (300 - 320 deg C) and feed in the PES. After the purging agent has been completely displaced with PES at this temperature, raise the cylinder temperature to the molding temperature. If PES has been fed in after the temperature of the cylinder has already risen to the molding temperature, then some purging agent may tend to remain inside the cylinder. This may lead to thermal deterioration of the purging agent, possibly resulting in molding defects.
Whenever the molding process is paused for a short period of time, set the cylinder temperature to 250 - 260 deg C, in order to prevent thermal deterioration of the resin. If the resin decreases to a temperature lower than 250 deg C, the screw surfaces and internal walls of the cylinder may be damaged and lumps of hardened resin may be formed after the molding process has resumed. When the molding process is to be paused for a long period of time, reduce the cylinder temperature only after the inside of the cylinder has been purged with purging agent.

Purging Method

The purging method for SUMIKAEXCEL PES is explained here.
Recommended purging agents : Polyethylene that has a high molecular weight of approximately MFR 0.05 ; polycarbonate; or more preferably, these same materials yet containing glass fiber.

· As SUMIKAEXCEL PES requires high processing temperatures, generating smoke, gas emission and resin scattering may occur during the purging process.
· Ensure that none of the purging agent is left within the cylinder.

1 End of molding	Shoot out all preceding resin (from within both hopper and cylinder). Set the cylinder temperature to 280 - 300 deg C.
2 Feeding of purging agent	Once the temperature has decreased to 340 deg C or less, feed in the purging agent, then continue the purging operation until the preset temperature is reached. As soon as all purging agent has been shot out, if polycarbonate is being used, feed in the polyethylene to displace the polycarbonate in the cylinder.
3 End of operation	Turn OFF the power. (It is OK to power down while the temperature is decreasing.)

Replacement with SUMIKAEXCEL PES

1 End of molding	Shoot out all preceding resin (from within both hopper and cylinder).
2 Raising of cylinder temperature	Set the cylinder temperature to the molding temperature for SUMIKAEXCEL PES.
3 Displacement of resin	After completely displacing the resin with SUMIKAEXCEL PES, resume the molding process.

3-3 Recycling

When mixing recycled pellets into virgin pellets, it is necessary to adjust the mixing ratio in accordance with the grade and the application. Possible recycled pellet mixing ratios for each grade are shown in Table 3-18.

Table 3-18 Recommended Mixing Ratios for Recycled Pellets

Grade	Mixing Ratio for Recycled Pellets (%)
4100G,4800G	30 or less
3601GL20,4101GL20	20 or less
3601GL30,4101GL30	10 or less

In non-reinforced grades, the use of excessive amounts of recycled pellets will cause stronger coloration of molding and will tend to make molding crumble more easily. As well, in glass fiber reinforced grades, the recycling process shortens the lengths of the glass fibers, resulting in molding with somewhat degraded mechanical strength. Therefore, the percentage of recycled resin must be limited. Table 3-19 indicates the recycling repetitions (number of times recycled) and subsequent changes to the tensile properties.

Table 3-19 Recycling Repetitions and Tensile Properties of Non-reinforced Grades and Glass Fiber Reinforced Grades

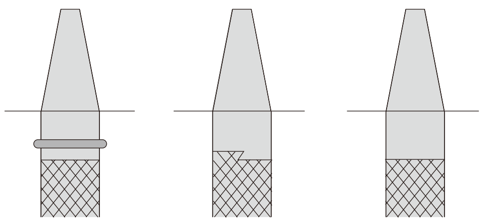
Grade		**4100G / 4800G**				**3601GL20 / 4101GL20**			
Recycled Pellets Ratio		30		100		30		100	
Physical Properties		Tensile Strength (MPa)	Rupture Status	Tensile Strength (MPa)	Rupture Status	Tensile Strength (MPa)	Rupture Status	Tensile Strength (MPa)	Rupture Status
Number of Recycling Repetitions	Virgin	86	Ductile	86	Ductile	126	Ductile	126	Ductile
	1	87	Ductile	87	Ductile	126	Ductile	121	Ductile
	2	89	Ductile	87	Ductile	125	Ductile	116	Ductile
	3	88	Ductile	87	Brittle	126	Ductile	109	Ductile
	4	88	Ductile	88	Brittle	124	Ductile	102	Ductile
	5	89	Ductile	87	Brittle	122	Ductile	98	Ductile

3-4 Tool Design

As PES has high melt viscosity and low mold shrinkage, the following factors must be taken into account when designing tools.

Sprue

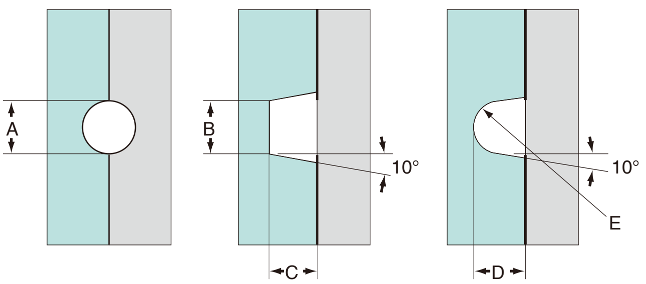
- The length of the sprue should be designed as short as possible. It is preferable to have as large as possible a taper (- 5°).
- A sprue lock should be installed in order to provide better sprue removal, as shown in the accompanying figure.



Under-cut　Z-pin sprue lock　Taper

Runners

- Runners must be thick and short. The thickness and length should be determined with consideration for moldability.
- Runners should have a circular or trapezoidal cross-sectional shape.
- The gates must be properly balanced.



Circular　Trapezoidal　Semi-circular

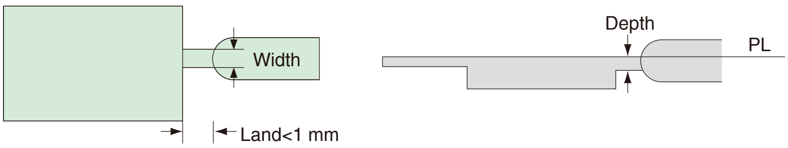
Examples of Runner Cross-sectional Sizes (mm)

A	B	C	D	E
>4	>3	>3	>4	D/2

Gate System

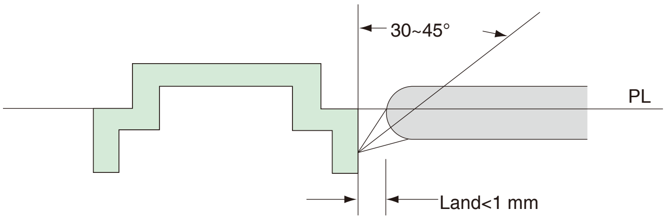
Side Gates

• For rectangular gates, it is most efficient to use deep lands with short lengths. The gate depth should be about 70% of parts wall thickness.The preferred land length is 1mm or less.



Pinpoint / Submarine Gates

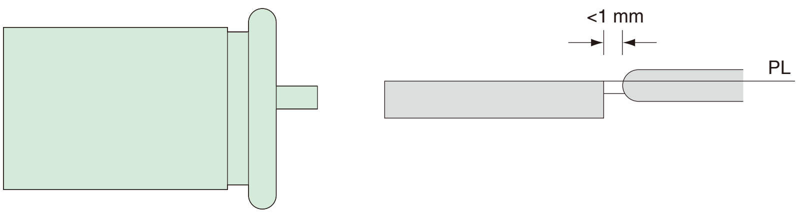
• The gate diameter should be between 0.8 - 1.2 mmφ, with gate land lengths of 1 mm or less. If flow distances are long, it is preferable to have multiple points rather than enlarging the gate diameter.



(Submarine gate example)

Film Gates

• The preferred gate thickness used should be equivalent to the wall thickness of the molding x 0.5. The land length should be 1mm or less.



Extraction Taper

• As PES has low mold shrinkage, it is recommended that an extraction taper with an angle of at least 1° (1/60) - 2° (1/30) be used, even for products molded with shallow molds. If the product uses a deep mold, the extraction taper should have a larger angle.
• As thin-walled moldings tend to be susceptible to overcharging, a larger extraction taper angle than usual is recommended. As well, a larger extraction taper angle should also be utilized with glass fiber reinforced grades.
• If an adequate extraction taper angle cannot be utilized due to the shape of the molding, then creative use must be made of slide cores and mold ejection methods.

Air Venting (Gas Drainage)

• As SUMIKAEXCEL PES has high melt viscosity, flash does not easily occur, even if air venting of only 1/100 - 5/100 (mm) has been installed.
• Air venting should be installed for the molding of thin-walled products.

Mold Material

• Molds used for making prototypes and for small production lots can be composed of carbon alloy steel for machine structural use (S55C). However, these molds should be hardened by quenching if they are to incorporate sliding core parts.
• When mass production and high dimensional precision are required, it is recommended that steels having greater rigidity be used, such as chrome molybdenum steels (SCM3 and 4) and alloy tool steels (SKD11 and 61).

3-5 Secandary Processing

Adhesives

Commercial off-the-shelf adhesives can be utilized for SUMIKAEXCEL PES (see Table 1).

Table 3-20 Adhesion

		Type of Adhesive	Adhesive Name	Manufacturer
Epoxy-based	2-component	Araldite Eco-	AW136 / AV138 104 / 144B 316	Chiba-Geigy Japan Emerson & Cumming Japan Grace Japan
	1-component	Sumimac Araldite Technodyne	ECR9000 Series XN1244 AH-3063R	Sumitomo Bakelite Chiba-Geigy Japan Taoka Chemical
Rubber-based		Hamatite	PL605-50	Yokohama Rubber
Polyimide		Thermoket	CS-170	Toray

Table 3-21 Bond Strength of Each Adhesive (Units : MPa)

Adhesive	Curing Conditions	4100G	4101GL30
Araldite AW136 / AV138	120 deg C x 1 hr	3.0	–
Eco-bond 104	180 deg C x 1 hr	5.4	8.8
Eco-bond 144B	150 deg C x 1 hr	2.0	3.5
Amicon 316	150 deg C x 1 hr	3.2	7.4
Sumimac ECR9000 Series	100 deg C x 1 hr	4.6	6.7
Hamatite PL605-50	250 - 300 deg C x 5 min	13.0	–
Thermoket CS-170	70 deg C x 1 hr ~ 180 deg C x 3 hr	4.1	8.1

Ultrasonic Welding

As SUMIKAEXCEL PES is an amorphous resin, an ultrasonic welding is relatively easy to perform if both pieces to be bonded are made of SUMIKAEXCEL PES. Three welding combinations are possible:

1. Both pieces are natural grades.
2. A natural grade is to be bonded to a fiber reinforced grade.
3. Both pieces are fiber-reinforced grades.

Case 1 is the easiest to accomplish and results in the greatest weld strength. However, cases 2 and 3 have adequate weld strengths and have better weld characteristics than crystalline resins (i.e.: PPS).

The conditions for ultrasonic welding will vary, depending upon the output of the welding horn, the product shape, weld area and grade. The standard conditions are as follows:

Table 3-22 Standard Conditions for Ultrasonic Welding

Pressure (MPa)	30 - 60
Amplitude (μm)	50 - 80
Welding Time (sec.)	0.1 - 2.0

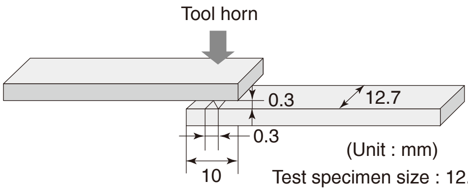
Measurements of PES shear strength after ultrasonic welding are shown below. The test method and test specimens used, are as follows:

Ultrasonic Welder

SONOPET-1200B (Seidensha Electronics Co., Ltd.)

Nominal Rating : 1200W
Oscillation Frequency : 19.5kHz
Welding Force : 18N
Amplitude : 34μm

Figure 3-20 Test Specimen for Measuring the Shear Strength of Welded Areas



Test specimen size : 12.7 mm × 78 mm × 1.6 mmt

Table 3-23 Shear Strength of Welded Areas (Unit : N)

	Oscillation Time (sec.)		
	0.1	0.2	0.3
3600G	680	700	Rupture occurred in area other than the welded area.
3601GL20	660	850	Rupture occurred in area other than the welded area.
3601GL30	740	830	Rupture occurred in area other than the welded area.

4. Applications

4-1 Molding Grades

Electrical / Electronics Applications

The range of applications for PES now encompasses the following products, which take advantage of its special characteristics, such as low outgassing, dimensional stability, creep resistance, low flash properties and resistance to cleaning solvents:
Relay bases, coil bobbins, movable plates (armature blocks), switch bases, burn-in sockets, connectors, fuse cases, cases and covers for various sensors, IC trays and printed circuit boards.

Hot water Applications

The range of applications for PES now encompasses the following products, which take advantage of its resistance to hot water conditions and hot steam (160 deg C), its dimensional stability and its creep resistance:
Valve joints for use within hot water and steam environments, insulating materials for corrosion-prevention electrodes, temperature sensor cells, components for both hot water pumps and ultrafiltration devices.

Automotive and Machinery Applications

The range of applications for PES now encompasses the following products, which take advantage of its outstanding rigidity throughout a wide range of temperatures (-100 to +180 deg C), its dimensional stability, its resistance to creep at high temperatures, its resistance to gasoline / gasohol / engine oil
Gearbox bearing retainers, brake shaft bushings, carburetor coil bobbins, thrust washers and lamp reflectors.

OA / AV Equipment Applications

The range of applications for PES now encompasses the following products, which take advantage of its outstanding dimensional stability, excellent creep resistance:
Various guides, gears and lubricant-free bearings for photocopiers & printers; and optical pickup components.

Applications for LCD Substrate Films

Films created by extrusion process have superior transparency (total light transmittance of 89%), heat resistance and dimensional stability. PES products that incorporate a thin film of vapor-deposited ITO (indium-tin oxide) are utilized as LCD substrates in the following applications:
Card-type electronic calculators, pagers, mobile phones and electronic organizers.

§ Please be sure to inform in advance if you consider use for medical applications, food industry, container, and miscellaneou s-goods field.
Contact: Electronic Materials Division Phone: +81-3-5543-5845

4-2 Powder Grades

Introduction

SUMIKAEXCEL PES powder grades are suitable for usage in the following applications:
• Adhesives and paint / coating compounds in solvent solutions
• Hollow-fiber membranes and cast films (flat films) in solvent solutions
• Compounds and epoxy reinforcing applications
Table 4-1 shows PES powder grades and their applications.

Table 4-1 PES Powder Grades

Powder Grades	RV (Reduced Viscosity)	Main Applications
3600P	0.36	Compounds
4100P	0.41	Paint / coating compounds, adhesives
4800P	0.48	Flat films and hollow-fiber membranes, adhesives
5003P	0.50	Paint / coating compounds, adhesives, impact modifier for epoxy compounds
5200P	0.52	Flat films and hollow-fiber membranes

Physical Properties of SUMIKAEXCEL Powder Grades

Characteristics of 3600P, 4100P, 4800P and 5200P

To obtain the physical properties for the following grades: 3600P, 4100P, 4800P, please refer to the physical properties for pellet-type grades: 3600G, 4100G, 4800G (Table 4-2).

Table 4-2 Physical Properties of 3600G, 4100G, 4800G

		Test Method (ASTM)	Units	3600G 4100G 4800G
Physical Properties	Specific gravity	D792	–	1.37
	Mold shrinkage MD	D955	%	0.6
	Mold shrinkage TD	D955	%	0.6
	Water absorption (23 deg C, 24 hr)	D570	%	0.43
	Refractive index	–	–	1.65
Mechanical Properties	Tensile strength (23 deg C)	D638	MPa	85
	Elongation at break	D638	%	40–80
	Flexural strength	D790	MPa	130
	Flexural modulus (23 deg C)	D790	MPa	2,600
	Compressive strength	D695	MPa	109
	Compressive modulus	D695	MPa	1,625
	Izod impact strength (6.4 mm. notched)	D256	J/m	85
	Izod impact strength (6.4 mm. without notch)	–	J/m	Did not break
	Rockwell hardness	D785	–	M88
		–	–	R120
	Taber abrasion (Load of 1 kg, CS17 Wheel)	D1044	mg/1000rev	20
Thermal Properties	Deflection temperature under load (0.46 MPa)	D648	deg C	210
	Deflection temperature under load (1.82 MPa)	D648	deg C	203
	Vicat softening point (1 kg)	D1525	deg C	226
	Vicat softening point (5 kg)	D1525	deg C	222
	Coefficient of linear expansion MD	D696	x 10^{-5}/deg C	5.5
	Coefficient of linear expansion TD	D696	x 10^{-5}/deg C	5.7
	Thermal conductivity	C177	x 10^{-4} cal/sec · cm · deg C	4.3
	Specific heat	–	cal/deg C · g	0.26
	Temperature index	UL746	deg C	180
Electrical Properties	Dielectric constant (23 deg C, 60 Hz)	D150	–	3.5
	Dielectric constant (23 deg C, 106 Hz)	D150	–	3.5
	Dielectric constant (23 deg C, 2.5 x 109 Hz)	D150	–	3.4
	Dielectric dissipation factor (23 deg C, 60 Hz)	D150	–	0.001
	Dielectric dissipation factor (23 deg C, 106 Hz)	D150	–	0.0035
	Dielectric dissipation factor (23 deg C, 2.5 x 109 Hz)	D150	–	0.004
	Volume resistivity	D257	Ω · cm	10^{17}–10^{18}
	Dielectric breakdown voltage	D149	kV/mm	16
	Track resistance	DIN53480	V	150
	Arc resistance (tungsten electrode)	D495	sec	70
	High voltage arc ignition	UL746	sec	300
	High current arc ignition	UL746	sec	200
Flammability	Flame resistance (0.46 mm)	UL94	–	V-0
	Limiting oxygen index (1.6 mm)	D286	–	38
	Hot wire ignition	UL746	sec	80

Characteristics of SUMIKAEXCEL 5003P

- SUMIKAEXCEL 5003P is an amorphous resin that has a glass transition temperature of 225 deg C.
- It possesses excellent adhesive properties due to the large number of terminal hydroxyl groups, which range from 0.6 - 1.4 per 100 polymer repeating units.
- Its other physical properties are similar to those of other grades.

Paint / Coating Applications

SUMIKAEXCEL 4100P and 5003P grades are utilized as paints and as coating compounds. The following characteristics have been specially enhanced in the 5003P grade: hardness after heating, chemical resistance and adhesion toward metals.
This section describes the paints and coating compounds that utilize 5003P.

Features of Paints and Coating Compounds of SUMIKAEXCEL 5003P

- Stable even after long periods of usage in air at a temperature of 250 deg C, and when used under conditions of repetitive heating and cooling cycles (0 deg C - 250 deg C).
- Adhesive Properties and Bonding : Demonstrates outstanding adhesion to glass, ceramic, iron, stainless steel, aluminum and aluminum alloys.
- Solvent Resistance : Demonstrates the highest solvent resistance among most amorphous resins.
- Resistance to Hydrolysis : Polyethersulfone resin itself has outstanding hydrolysis resistance, yet 5003P possesses even greater resistance to hydrolysis.
- Film Formation Properties : Has superior film formation properties and provides effective protection against base materials.
- Flame Resistance : Has high flame resistance without utilizing any flame retardant components.
- Transparency : Has excellent transparency and does not change the appearance of the base material, even after application.
- Hygienic Properties : Does not contain additives, such as plasticizers, thus making it highly hygienic.

Coating Procedures for SUMIKAEXCEL 5003P (Example of Solution Method)

- Remove all oil and grease from the base material. If necessary, sandblast or etch the surface.
- Dissolve 5003P in a solution of solvent.
- Apply this solution to the base material, using any of the following methods: immersion; brush application or spraying. Allow to air dry.
- Heat-treat the material in hot air at a temperature of 350 - 400 deg C for 30 minutes.

Heat Resistance of SUMIKAEXCEL 5003P Coating on Aluminum Plate (Example)

Table 4-3 Heat Resistance Under Continuous Service (in air at a temperature of 250 deg C)

Item Evaluated	Time (Hr)		
	0	115	235
Change in Appearance	–	No change	No change
Cross-cut Adhesion Test (*1)	100/100	100/100	100/100
Corrosion Resistance Test (*2)	No corrosion	No corrosion	No corrosion

Table 4-4 Repetitive Heating and Cooling Cycle Test (2 minutes in ice water at 0 deg C ↔ 2 minutes in oven at 250 deg C)

Item Evaluated	Number of Cycles (Repetitions)		
	0	25	50
Change in Appearance	–	Minimal changes	Slight occurrence of foam around edges
Cross-cut Adhesion Test (*1)	100/100	100/100	100/100
Corrosion Resistance Test (*2)	No corrosion	No corrosion	No corrosion

(*1) The test procedure for cross-cut adhesion is as follows: Using a safety razor, create a mesh of intersecting cuts (the shape of lines on a Checker board) into a base material that has been coated with SUMIKAEXCEL 5003P. The cuts must be deep enough to reach the base material and should be spaced 1 mm apart, to form a series of 1 mm x 1 mm squares, over an area of 100 mm^2. Place adhesive tape over the area of the cuts and apply pressure, then remove the tape. Check the squares to determine the number of squares that still contain the PES coating.
(*2) The test procedure for corrosion resistance is as follows: Place several drops of a solution containing 15% (vol) nitric acid onto the test surface that has been coated with SUMIKAEXCEL 5003P. Cover the surface with a glass plate and let it stand for 24 hours. Observe any changes in the surface appearance.

Applications as Impact Modifier for Epoxy based systems

SUMIKAEXCEL 5003P is utilized in the creation of epoxy-based composite materials. The advantages of adding SUMIKAEXCEL 5003P to epoxy-based composites are as follows:
- Improves the toughness of epoxy.
- Has an extremely high Tg (230 deg C).
- Possesses outstanding mechanical properties.

Enhancing the Plasticity of Epoxy Resins

SUMIKAEXCEL 5003P is essentially plastic in behavior, thus has both a high Tg and flexural modulus. Therefore, it has the ability to add plasticity to epoxy resins without degrading the overall performance of the composite itself.

Table 4-5 Effects when Blended with TGDDM / 4, 4'-DDS

Concentration of 5003P (%)	Flexural modulus (GPa)	Tg (deg C)	G_{1C} (KJ/m^2)
0	3.34	205	0.28
10	3.21	205	0.41
15	3.07	200	0.47

(Note)
1) G_{1C} values were measured under flat surface distortion conditions at -65 deg C.
2) Tg values were measured using torsion DMA.

The table above indicates a large increase in fracture toughness (G_{1C}). It is also apparent that Tg does not decrease as significantly.

Table 4-6 Comparison of 5003P and PEI

Results of Comparing Epoxy Resin and As4CF at a Polymer Concentration of 30% (wt)

		PEI	**5003P**
CAI(Compressive strength after impact)	MPa	194	223
Compressive Strength	MPa		
(Room Temp.)		1697	1731
(82 deg C)		1434	1648
(82 deg C)/Wet		N/A	1076
88 deg C Viscosity (Cps)	(Pa·s)	130	100

N /A: no data available

5003P for Aircraft and Sporting Equipment Applications

Epoxy thermosetting resins are utilized as the resin matrix in CFRPs (Carbon Fiber Reinforced Polymers). Although epoxy resins possess excellent mechanical and thermal properties, it is more susceptible to fracture than thermoplastic resins. For applications in the area of aircraft and sporting equipment, it is mandatory that its fracture toughness (residual compressive strength : CAI = Compressive Strength After Impact) is improved. If 5003P is added to epoxy resin, a reaction occurs, which increases the resin's plasticity, toughening it against impact fractures that may cause delamination within the resin matrix.

- Procedures for SUMIKAEXCEL 5003P

  The 5003P is dissolved directly in the epoxy base resin and mixed until a homogeneous solution is obtained. Next, the hardener is mixed into the solution. As the epoxy mixture hardens, it reacts with the hydroxyl radicals in the 5003P, forming a special morphology that contains an "ocean and islands structure" (matrix and discontinuous phase), thus providing improved impact resistance. Either of the two following procedures can be utilized in order to obtain a homogeneous solution of 5003P in epoxy base resin: the 5003P can be ground finely and dissolved directly in the epoxy base resin in an N2 atmosphere at a temperature of approximately 150 deg C. Alternately, the 5003P can first be dissolved uniformly in a solvent, then the solvent is later removed. The epoxy base resin is then mixed into this remaining compound to obtain a homogeneous solution.
- Amounts of 5003P for Usage in Composites (Example)
- Per unit of matrix range

  Epoxy base resin (100 phr) : hardening agent (30 - 40 phr) : 5003P (30 phr)
- Per unit of prepreg

  -10% (wt)
- Usage in Aircraft Structural Composites

  In order to utilize 5003P in structural composites for aircraft, precisely-sized fine particles of 5003P (tough balls), are sprinkled onto the surface of CF prepreg, which has been produced according to the above section entitled "Procedures for Using SUMIKAEXCEL 5003P". Next, several dozen of these CF prepreg layers are laminated together. This process improves the impact resistance, due to the PES particles that are located on the boundaries of each surface. Furthermore, a variety of creative laminating methods have also been invented thus far.

(Example : structural composite standards for Boeing aircraft)

- CAI (Compression After Impact) value must be 310 MPa or greater.
- CS (Compressive Strength under hot / wet conditions) value must be 1,100 MPa (at 82 deg C) or greater.

Adhesive Applications

PES can be utilized as a heat resistant adhesive. It possesses particularly outstanding adhesive strength toward metals.

Features

- Bonded surfaces possess high tensile adhesive shear strength and T-peel adhesive strength. Its characteristics are well balanced, as it also possesses both rigidity and flexibility.
- PES possesses the highest heat resistance of most commercial thermoplastic resin adhesives. It possesses an extremely high, tensile fracture adhesion strength of 20 MPa, even at a temperature of 200 deg C. As well, for short periods of time, it can be utilized repeatedly at temperatures of up to 250 deg C.
- PES has outstanding chemical resistant and heat resistant properties.
- PES does not contain any solvents or volatile components and demonstrates excellent adhesion toward a variety of materials, including unprimed metals such as aluminum, stainless steel, steel and brass.

Bonding Methods

- Hot Melt Bonding Using PES Film
- Cut the film to the size of the objects being bonded (adherends).
- Roughen the adherend surfaces using sandpaper or a disc sander, then clean the surfaces with acetone or toluene.
- Sandwich the film between the adherends, apply a small amount of pressure using a jig, then heat the joint for 10 - 30 minutes at a temperature of 300 - 360 deg C. An adequate level of pressure will be achieved if the melted resin just begins to ooze out from between the adherends, as flash.
- A strong bond will be obtained if the joint is left to stand in cold conditions.
- Bonding With Adhesive Solutions

5003P Solvent Solutions

5003P is unstable when dissolved in a single solvent, resulting in some deposition of the PES. Therefore, a solution of mixed solvents (examples shown in Table 4-7) is usually utilized. (Solution stability is low in a single solvent, thus causing gelation.)

Table 4-7 Examples of Mixed Solvent Solutions for SUMIKAEXCEL 5003P

Solvent Solution	Solvent	Mixing ratio (volumetric ratio)
A	1,1,2-trichloroethane Dichloromethane	1 1 (by weight)
B	Dimethylformamide Cychlohexanone Methyl ethyl ketone	20 80 25
C	N-methyl-2-pyrrolidone Toluene or xylene	2 1
D	N-methyl-2-pyrrolidone Dichloromethane	1 1
E	N-methyl-2-pyrrolidone Toluene or xylene Silicone flow modifier Methyl ethyl ketone	60 30 0.5–1 35

• Bonding Method

As the strength of PES adhesives will vary depending upon the thermal treatment conditions, it is necessary to determine the appropriate conditions in accordance with each particular application.

(Condition Example 1) : Dry for 2 hours at a temperature of 130 deg C

(Condition Example 2) : Dry for 1 hour at a temperature of 100 deg C, then continue drying for 15 minutes at a temperature of 350 deg C

Characteristics of SUMIKAEXCEL 5003P Adhesives

SUMIKAEXCEL 5003P has outstanding adhesive strength at high temperatures. For example, when bonding chrome/nickel stainless steel (18/8 W/W) using 5003P adhesive, changes to the adhesive strength as the temperature rises to 220 deg C are shown in Table 4-8. As well, the adhesive retention of bonded materials during aging at a temperature of 150 deg C is shown in Table 4-9.

Table 4-8 The Effects of Temperature on Peel Strength

Temperature (deg C)	Peel Strength (MPa)
23	37
150	26
220	14

Peel strength was measured at a peel rate of 12.5 mm/min.

Table 4-9 The Effects of High Temperatures on Retention Time and Peel Strength

Retention Time at 150 deg C (hours)	Peel Strength at 150 deg C (MPa)
No retention	26
1000	21

Even after a temperature of 150 deg C has been maintained for 1,000 hours, 81% of initial adhesive strength was retained.

Applications for Membranes

High molecular weight grades of PES 4800P, 5200P, 5400P and 5900P are utilized mainly for applications as membranes. The remarkable features of polyethersulfone membranes include: excellent heat and chemical resistance, and compatibility with the majority of sterilization methods.

The features and applications of PES are described below, using examples.

Example 1. Polyethersulfone UF Membranes

Features

- Polyethersulfone UF membranes are suitable for repetitive heat sterilization, as is required in order to maintain stringent sanitary conditions for applications within the food and pharmaceutical industries, and for fermentation processes.
- Polyethersulfone UF membranes can be utilized over a wide range of pH values, from pH 1 - 14. They also have excellent resistance to chemicals and can withstand strong cleaning agents, thus facilitating easy recovery of membrane performance.

Applications

<u>Manufacturing Processes for Medicinal Preparations</u>

- Manufacture of biogen-free water and sterile water
- Concentration and desalination of protein and enzyme preparations

<u>Fermentation and Brewing Processes</u>

- Concentration and recovery of yeasts and fermentation microbes
- Refining of fermented products
- Sedimentation prevention for fermented and brewed products

<u>Food Manufacturing Processes</u>

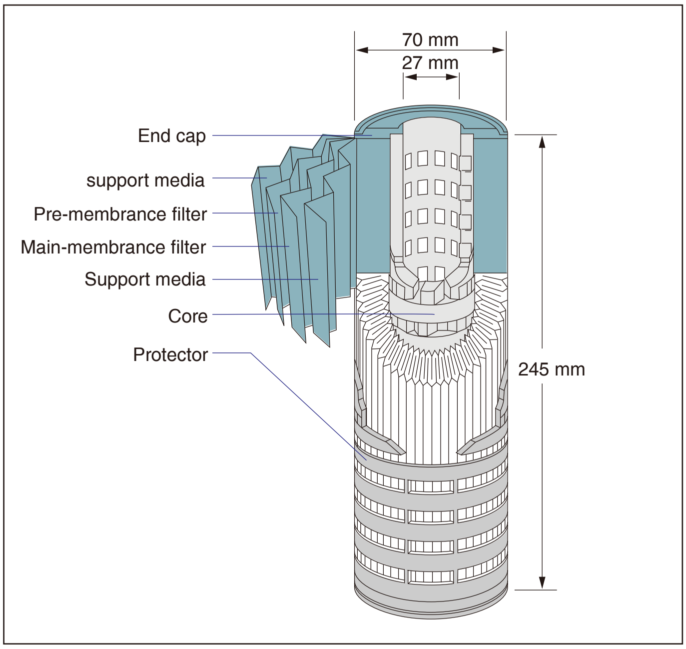
- Recovery and refining of usable substances
- Separation and refining of usable products

Example 2. Cartridge Filters Utilizing PES Membranes (Courtesy of Toyo Roshi)

This cartridge filter is composed of a polyethersulfone (PES) membrane filter and polypropylene. It possesses superior resistance to both heat and chemicals.

Features

- Minimal amounts of eluted substances are produced, thus minimizing the amount of cartridge cleaning required as a pretreatment process.
- As it utilizes asymmetric media and incorporates a pre-membrane filter having a different aperture size, it possesses high filtration efficiency and a high flow rate, thus has a long filtration life.
- Both autoclave sterilization and in-line steam sterilization can be performed.
- As the media itself is inert, sample constituent absorption is very minimal.



Applications

- Precision filtration of ultrapure water in the electronics industry
- Particle removal and disinfecting of process gases and vented air

Please be sure to inform in advance if you consider use for medical applications, food industry, container, and miscellaneous-g oods field.
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