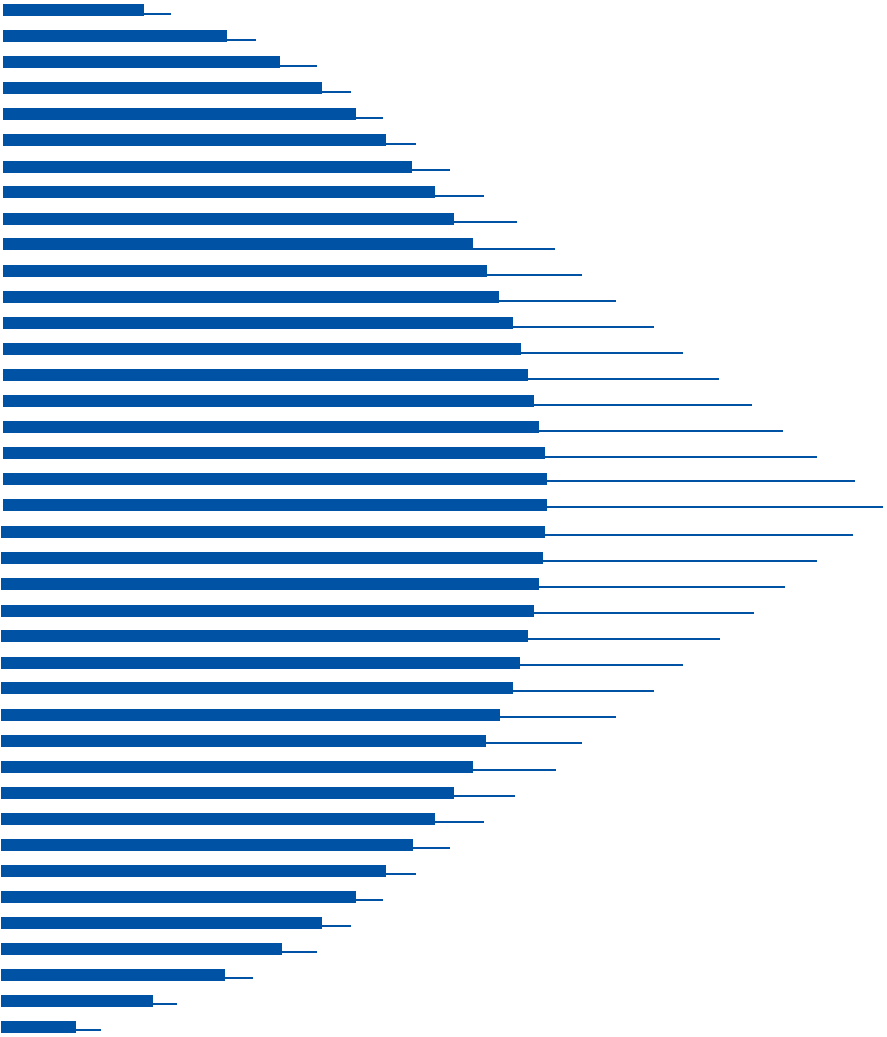


Polybutyleneterephthalate Resin

NOVADURAN®

Mitsubishi Engineering-Plastics Corporation

1 Introduction

Mitsubishi Engineering-Plastics' polybutyleneterephthalate **NOVADURAN**® (PBT) is a product of the polycondensation of dimethyl terephthalate and 1,4-butylene glycol.
PBT is easy to mold, resistant to abrasion, easy to color and has excellent electrical properties. Its applications are steadily expanding, particularly applications to electronic equipment and automobiles.
Mitsubishi Chemical Corporation, one of the parent companies of Mitsubishi Engineering-Plastics Corporation, is the only manufacturer in Japan producing the raw materials of PBT resin-dimethyl terephthalate and 1,4-butylene glycol (1,4-butanediol).
NOVADURAN® has many grades to meet a wide range of requirements. They are classified into four major groups, as shown below. Glass fiber (GF) is the most common filler but other fillers are also used. Alloy grades are also available. New grades such as soft PBT grades and hydrolytic-resistant grades offer new applications.

	Unfilled	**Filled**
Standard	5010R 5010CR2	5010G 5010F
Flame retardant	5010N5 5010N6	5010GN1 5010GN6

2 Characteristics of NOVADURAN®

Excellent mechanical properties
Excellent heat resistance
Excellent moldability and flowability
Low moisture absorption for high dimensional stability
Excellent surface gloss and color
Excellent oil and chemical resistance
Excellent electrical properties
Excellent friction and abrasion properties
Frame-retardant grades available

3 Other Properties of NOVADURAN®

Plastics are used under a wide range of conditions which affect their properties.
The temperature dependence of mechanical properties, thermal aging resistance and weathering characteristics of **NOVADURAN®** are presented in this section.

Temperature Dependence of Mechanical Properties

The temperature dependence of the tensile strength, flexural modulus and Izod impact strength of 5010R5, 5010G30 and 5010GN1-30AM are shown in Figs. 1 through 3.

Fig. 1 Temperature dependence of tensile strength

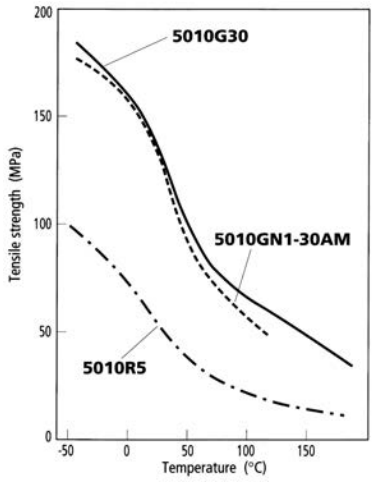


Fig. 2 Temperature dependence of flexural modulus

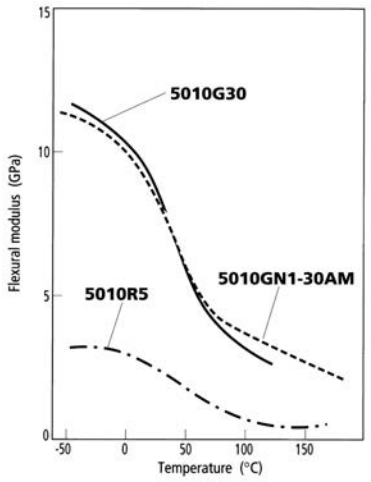
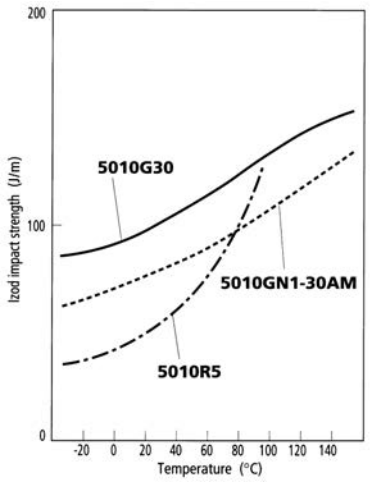


Fig. 3 Temperature dependence of Izod impact strength



Mitsubishi Engineering-Plastics Corporation

Thermal Aging Resistance

Results of a thermal aging resistance test on the tensile strength of 5010G30 and 5010R5 at 120℃ and 140℃ are shown in Figs. 4 and 5, respectively. These diagrams show the excellent heat resistance of **NOVADURAN**®.
An Arrhenius plot of the time required for a 50% drop in the tensile strength of 5010R5, 5010G30 and 5010GN1-30AM is shown in Fig. 6.

Fig. 4 Thermal aging resistance at 120℃

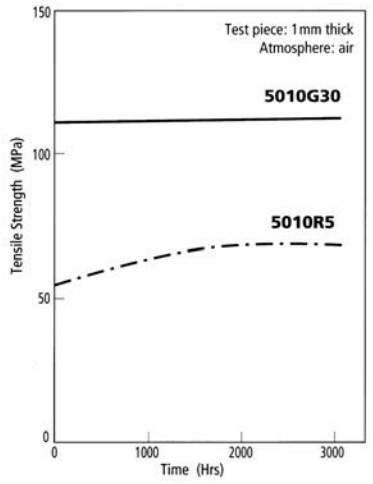


Fig. 5 Thermal aging resistance at 140℃

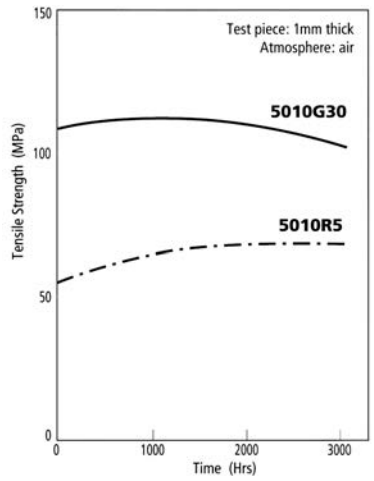
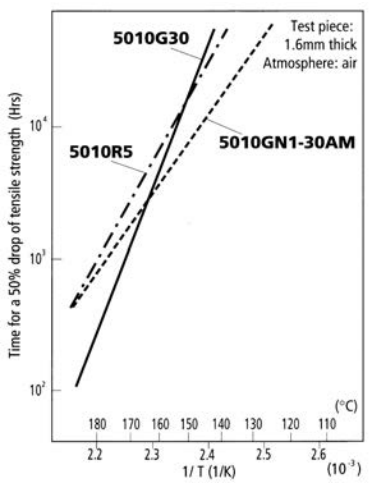


Fig. 6 Thermal aging resistance



Weathering

The weathering characteristics of plastics are important in many applications. The weathering characteristics are determined in two ways: using testing equipment by which the test can be accelerated and by exposing molded products to the weather.
The weathering characteristics of 5010R5, 5010G30 and 5010GN1-30AM, as determined using a Sunshine Weatherometer and by outdoor exposure (at Kyushu, Japan) are shown in Figs. 7 and 8. The results show that the unfilled grade, 5010R5, loses its strength slowly but loses its elongation ability quickly. Glass-fiber reinforced grades 5010G30 and 5010GN1-30AM maintain their tensile strength and elongation ability better than the unfilled grade.

Fig. 7 Sunshine Weatherometer test

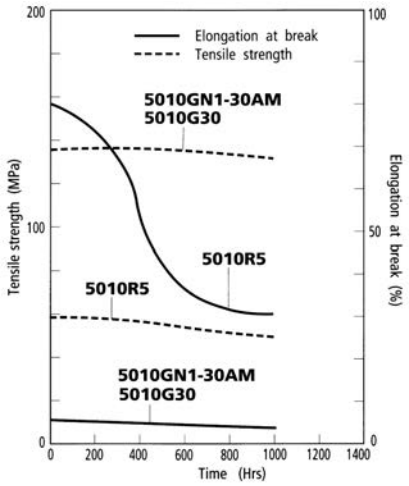
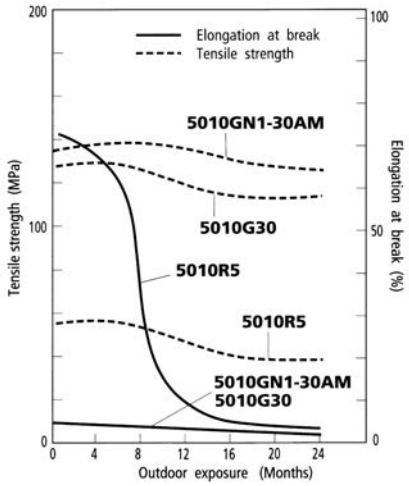


Fig. 8 Outdoor exposure weathering test



Electrical Properties

NOVADURAN® has excellent electrical properties. The temperature dependence of the electrical properties of 5010, 5010R5, 5010G30 and 5010GN1-30AM is shown in Figs. 9 and 10. The values specified by the UL Standard are shown in Table Ⅰ.

Fig. 9 Temperature dependence of dielectric strength

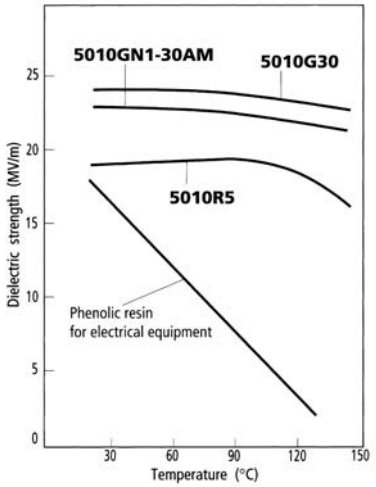


Fig. 10 Temperature dependence of volume resistivity

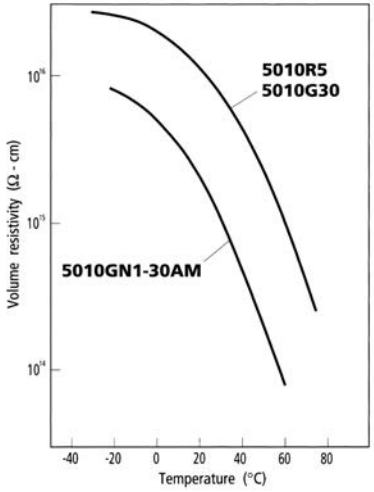


Table Ⅰ UL Standard Values

	Min Thk (mm)	UL94 Flame Class	RTI(℃) Elec	RTI(℃) Mech with Imp	RTI(℃) Mech w/o Imp	HWI (PLC)	HAI (PCL)	HVTR (PLC)	D495 (PLC)	CTI (PLC)
5010R5	0.83	94HB	130	75	140	4	1	0	-	-
	1.5	94HB	130	120	140	4	0	0	-	-
	3.0	94HB	130	120	140	3	0	0	5	0
	6.0	94HB	130	120	140	1	0	1	-	-
5010G30	0.81	94HB	140	120	140	2	3	1	-	-
	1.5	94HB	140	120	140	1	0	1	-	-
	3.0	94HB	140	120	140	1	0	1	5	1
	6.1	94HB	140	120	140	0	0	2	-	-
5010GN1-30	0.71	94V-0	130	120	130	3	0	-	-	-
	1.59	94V-0	130	120	140	2	0	-	-	-
	3.1	94V-0	130	130	140	1	0	4	6	3

Min Thk : Minimum Thickness
RTI : Relative Temperature Index
Elec : Elebtrical Properties
Mech with Imp : Mechanical Properties with Impact
Mech w/o Imp : Mechanical Properties without Impact

PLC : Performance Level Categories
HWI : Hot-wire Ignition
HAI : High Amp Arc Ignition
HVTR : High Voltage Arc Tracking Rate
D-495 : Arc Resistance
CTI : Comparative Tracking Index

** : Mean Number of Arcs to Cause Ignition

Relation between glass-fiber content and mechanical properties

PBT resin has excellent heat resistance, but this can be further improved by reinforcing the resin with Glass fiber (GF). The following figures show the effect of glass-fiber reinforcement on **NOVADURAN**®. The relation of the general grades' glass-fiber contents to tensile strength, Izod impact strength and an 18.6kg/cm^2-load DTUL is shown in Figs. 11 through 12. The relation of the flame-retardant grades glass-fiber content to tensile strength and Izod impact strength is shown in Figs. 13.

Fig. 11 DTUL dependence of 5010G on GF content

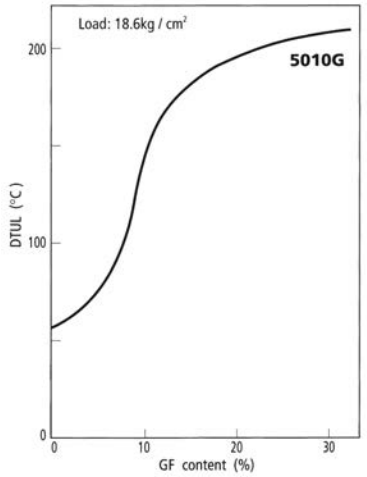


Fig. 12 Tensile strength dependence of 5010G on GF content

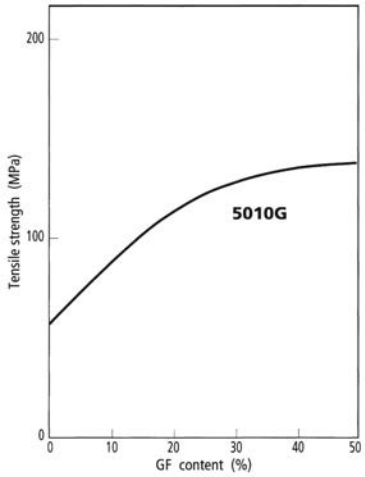
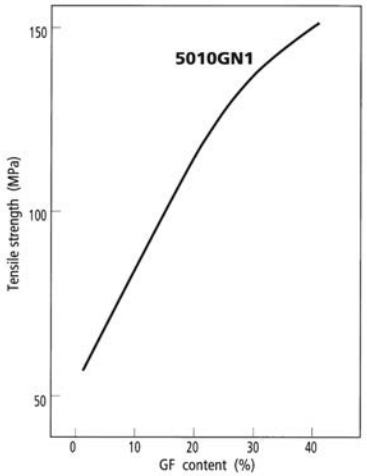


Fig. 13 Tensile strength dependence of 5010GN1 on GF content



Chemical Resistance

Chemical resistance can be an important factor in many applications. The chemical resistance of **NOVADURAN**® grades 5010R5, 5010G30 and 5010GN1-30AM in alkaline and acidic aqueous solutions is shown in Table Ⅱ.

Polyesters such as PBT show poor resistance in an alkaline solution due to their chemical structure. Our tests show the largest decrease of tensile strength occurs in a 10% aqueous solution of sodium hydride (NaOH). The decrease was more evident with glass-fiber reinforced grades.

Table Ⅱ Chemical resistance

Grade	Chemicals	Temp (℃)	Retention of tensile strength (%)		Weight increase (wt%)	
			after 7 days	after 30 days	after 7 days	after 30 days
5010GN1-30AM	5% aq-NH_3	23	96	94	0.1	0.2
	10% aq-NaOH	23	35	2	1.8	0.5
	10% aq-HCl	23	94	88	0.2	0.2
	36% aq-H_2SO_4	23	100	96	0.1	0.1
	36% aq-H_2SO_4	70	92	84	0.6	0.1
5010G30	5% aq-NH_3	23	97	95	0.1	0.2
	10% aq-NaOH	23	34	2	1.6	0.4
	10% aq-HCl	23	95	89	0.1	0.1
	36% aq-H_2SO_4	23	100	97	0.1	0.1
	36% aq-H_2SO_4	70	92	84	0.6	1.1
5010R5	5% aq-NH_3	23	97	95	0.1	0.2
	10% aq-NaOH	23	94	93	0.2	0.2
	10% aq-HCl	23	94	96	0.2	0.3
	36% aq-H_2SO_4	23	99	99	0.1	0.1
	36% aq-H_2SO_4	70	91	92	0.4	0.3

Table Ⅲ shows the oil resistance of **NOVADURAN**® grades 5010R5, 5010G30 and 5010GN1-30AM. Our PBT shows excellent oil resistance except in the case of 5010R5's decrease in tensile strength in brake fluid at 70℃.

Table Ⅲ Oil resistance

Grade	Oils	Temp (℃)	Retention of tensile strength (%)		Weight increase (wt%)	
			after 7 days	after 30 days	after 7 days	after 30 days
5010GN1-30AM	Gasoline	23	100	100	0.1	0.1
	Transmission fluid	23	100	100	0.0	0.1
		70	100	100	0.3	0.5
	Brake fluid	23	100	100	0.0	0.0
		70	100	100	0.2	0.4
	Silicone oil(Toray SH200)	23	100	100	0.1	0.0
		70	100	100	0.0	0.0
	Water-soluble cutting oil(Kyoseki Solcut W11)	23	100	100	0.1	0.2
		70	100	100	0.3	0.4
5010G30	Gasoline	23	100	100	0.1	0.1
	Transmission fluid	23	100	100	0.0	0.1
		70	100	100	0.3	0.5
	Brake fluid	23	100	100	0.0	0.0
		70	100	100	0.2	0.4
	Silicone oil(Toray SH200)	23	100	100	0.1	0.0
		70	100	100	0.0	0.0
	Water-soluble cutting oil(Kyoseki Solcut W11)	23	100	100	0.0	0.0
		70	100	100	0.1	0.2
5010R5	Gasoline	23	100	100	0.0	0.0
	Transmission fluid	23	100	100	0.0	0.0
		70	100	100	0.3	0.5
	Brake fluid	23	100	100	0.0	0.0
		70	92	87	0.3	0.6
	Silicone oil(Toray SH200)	23	100	100	0.1	0.1
		70	100	100	0.0	0.0
	Water-soluble cutting oil(Kyoseki Solcut W11)	23	100	100	0.0	0.0
		70	100	100	0.2	0.2

4 Molding of NOVADURAN®

Injection molding is the most common method of molding PBT. Optimum injection-molding conditions for our PBT are reported in this section.

Drying of feedstock resin

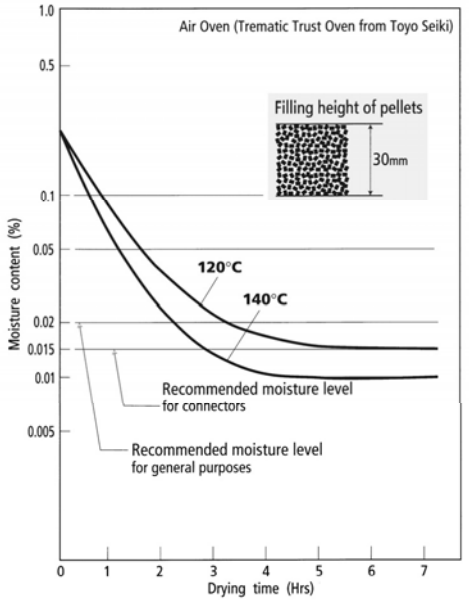
Our PBT suffers a loss in mechanical properties during processing with even a small amount of moisture in the feedstock resin. Removing moisture from the feedstock resin before use is critical. Typical drying conditions are as follows.

Hot air drying	at 140℃ --- 4 to 6 hours
	at 120℃ --- 5 to 8 hours

Drying temperature should be controlled not to exceed 140℃.

Figure 14 shows the effect of various drying rates. It should be noted that no drying effect can be expected with a drying temperature less than 100℃.

Fig. 14 Pellet drying rate of 5010R5



Effect of moisture on moldability and mechanical properties

The effect of moisture in feedstock resin on the mechanical properties of molded products of **NOVADURAN**® is shown in Fig. 15.
If the moisture in feedstock resin pellets exceeds 0.03%, abnormalities on the surface of the molded product and/or loss in mechanical properties might occur. Drying the feedstock resin thoroughly using the procedure described formerly is very important.
Thoroughly dried feedstock resin absorbs moisture easily. Figure 16 shows the moisture absorption of 5010R5. Molding feedstock resin left under ambient conditions for more than 30 minutes should be avoided.

Fig. 15 Moisture vs moldability and mechanical properties

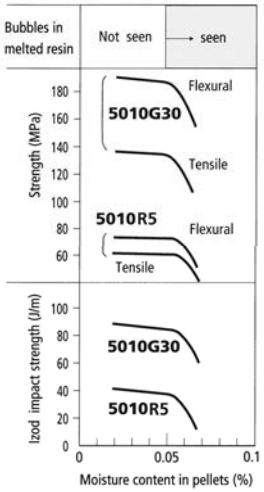
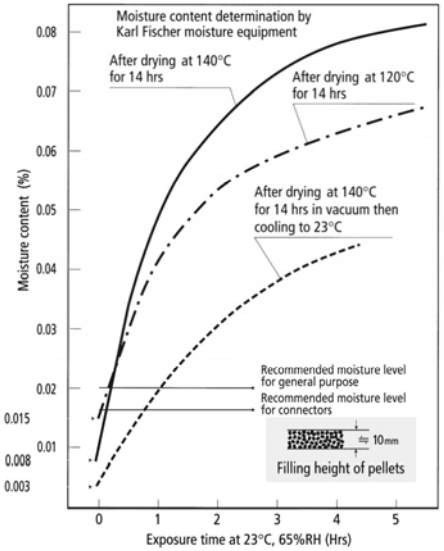


Fig. 16 Moisture absorption of 5010R5



Recommended molding machine

- For molding **NOVADURAN**®, a screw-in-line type injection-molding machine is generally used.
- Using an injection-molding machine whose injection volume capacity is 125 to 200% of the mold is recommended.
- An injection-molding machine with an open nozzle can be used if the nozzle temperature is properly controlled, but drooling might occur when molding some unreinforced low-viscosity grades. An injection-molding machine with a shut-off nozzle is useful in a such case.
- When molding grades reinforced with glass fiber or inorganic filler, attention should be paid to the wear of the screw and cylinder.

Molding conditions

Examples of recommended molding conditions are shown below.

Grade		5010R	5010F 5010G	5010N	5010GN
Cylinder temp(rear)	℃	235	240	235	235
Cylinder temp(center)	℃	240	245	240	240
Cylinder temp(front)	℃	240	245	240	240
Nozzle temp	℃	245	255	245	250
Mold temp	℃	80	80	80	80
Injection Pressure	MPa	30-40	50-70	30-40	40-50
Screw rotation	rpm	80	80	80	80
Injection speed	-	max	max	max	max

- The optimum resin temperature **NOVADURAN**® is 250-265℃.
  If the resin temperature exceeds 275℃, weakening of mechanical properties and/or burning may occur, even if the time the resin remains in the machine is relatively short.
- A mold temperature of 40-80℃ is usually adequate.
  It is necessary to control the mold temperature, depending on the surface required and the dimensions of the molded product. When molding a reinforced resin or where the temperature in which the molded products is expected to be used is high, a higher mold temperature is desirable.
- If the molding operation is suspended, it is important to purge all the resin remaining in the cylinder. To purge the resin in the cylinder, PE, PP or PS is used in the same manner as with other engineering plastics.

The mold

●Mold surface finish

For molding reinforced resin, it is necessary to make the mold sufficiently durable by quenching or plating its surface.

●Gate

We recommend using a side gate or pin gate. A rough guide to the gate dimensions is show below.

Profile	Thickness of product (mm)	Gate dimensions (mm)
Side gate	1	0.5 X 1.0
	3	1.5 – 2.0 X 2.5 – 3
	5	2.5 – 3.5 X 3.5 – 5
Pin gate	<3	0.8 – 1.0 (⌀)
	3 – 5	1 – 2 (⌀)

●Air purging

To avoid burning on the molded product, provide an air vent. A vent 0.02mm thick and 1-5mm wide is recommended.

Flowability

The flowability of **NOVADURAN**® is shown in Figs. 17 and 18.

Fig. 17 Flow length dependence on thickness

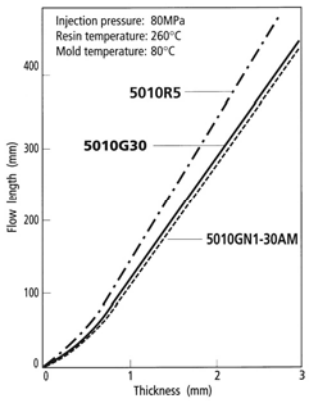
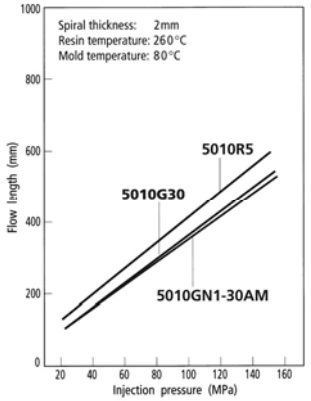


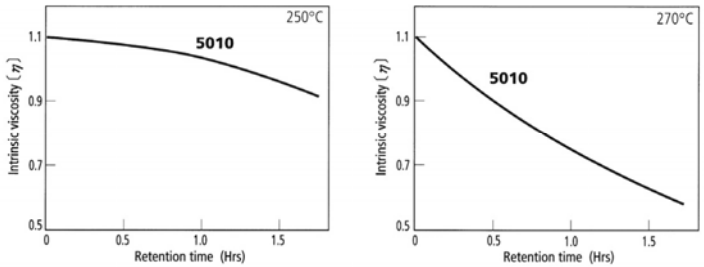
Fig. 18 Flow length dependence on injection pressure



Thermal stability at melt

The thermal stability of **NOVADURAN**® is shown in Fig. 19. As seen in Fig. 19, even if the resin is held in the molding machine for one hour at the normal molding temperature, the resin's intrinsic viscosity [η] is very stable, with a loss of only about 10%. At 270℃, however, even a 30-minute retention time causes the intrinsic viscosity [η] to deteriorate by about 20%, which suggests there will be a sharp deterioration under a high temperature.
For PBT, generally speaking, a long retention time is not desirable, but it should be noted that if the retention time is limited to 30 minutes at 250℃, there will be a minimum loss in mechanical properties. If PBT is held over 30 minutes, however, deterioration of the mechanical properties will gradually increase. If the molding operation is suspended for a relatively long period, lowering the cylinder temperature is recommended.

Fig. 19 Thermal stability of 5010, 5008 at 250℃ and 270℃



Mold shrinkage

The mold shrinkage of the most popular grades of **NOVADURAN**® is shown in Table Ⅳ.

Table Ⅳ Mold shrinkage of Mitsubishi Engineering-Plastics' PBT

Grade	1mmt (%)		3mmt (%)	
	// Direction	⊥Direction	// Direction	⊥Direction
5008	1.5	1.4	2.0	2.3
5010	1.4	1.4	1.9	2.2
5010R5	1.4	1.4	1.9	2.0
5010CR2	1.4	1.4	1.9	2.2
5010N6	1.4	1.4	2.0	2.2
5010G15	0.5	1.0	0.7	1.3
5010G20	0.2	0.9	0.3	1.4
5010G30	0.1	0.6	0.2	0.9
5010GN1-15AM	0.6	1.0	0.8	1.5
5010GN1-30AM	0.2	0.7	0.2	1.2

Mold size : length 80mm, width 80mm, thickness 1mm & 3mm
Gate : 0.55mm(film gate)
Molding Conditions : resin temperature 250-255℃, mold temperature 80℃

5 Applications of NOVADURAN®

With its many excellent properties, **NOVADURAN®** has a wide range of applications. Examples of current and possible future applications are shown below.

Electric and electronic applications	Connectors, switches, insulators, terminals, coil bobbins, fluorescent-lamp caps, push buttons of telephone receivers, parts of TV FBTs, nozzles of hair dryers, combs of hair curlers, parts of micro-switches, micromotor housings, terminal blocks, parts of timers, shaver circuits, and air outlets of air conditioners
Automobile applications	Electric connectors, distributor parts(body, cap, rotor), wiper gear cases, window-washer nozzles, door handles, couplers, ignition-system parts, gears, ABS unit housings, door-mirror parts, console boxes, G-sensor housings of air bags, valves of exhaust-gas treating systems, front skirts, air-inlet louvers, and bumpers
Other industrial applications	Cooling fans and fan housings of office equipment, paper guides for facsimile and photocopy machines, sheaths of optical fiber cables, sequencer housings, keyboard keys, parts of watches and clocks, camera parts, and pipe joints
Other applications	Textiles(panty hose and swimming suits), films, and blending material for polymer alloys

SI Conversion Table

Quantity	SI	Other Units	
	N	dyn	kgf
Force	1	1×10^{5}	1.01972×10^{-1}
	1×10^{-5}	1	1.01972×10^{-6}
	9.80665	9.80665×10^{5}	1

	Pa	kgf/cm²	atm	mmHg·Torr
Pressure	1	1.01972×10^{-5}	9.86923×10^{-6}	7.50062×10^{-3}
	9.80665×10^{4}	1	9.67841×10^{-1}	7.35559×10^{2}
	1.01325×10^{5}	1.03323	1	760
	1.33322×10^{1}	1.35951×10^{-3}	1.35951×10^{-3}	1

	Pa or N/m²	kgf/mm²	kgf/cm²
Stress	1	1.01972×10^{-7}	1.01972×10^{-5}
	9.80665×10^{6}	1	1×10^{2}
	9.80665×10^{4}	1×10^{-2}	1

	J	kW·h	erg	kgf·m	cal
Energy Work Calories	1	2.77778×10^{-7}	1×10^{7}	1.01972×10^{-1}	2.38889×10^{-4}
	3.600×10^{6}	1	3.600×10^{13}	3.67098×10^{5}	8.60421×10^{5}
	1×10^{-7}	2.7778×10^{-14}	1	1.01972×10^{-8}	2.38889×10^{-11}
	9.80655	2.72407×10^{-6}	9.80655×10^{7}	1	2.34385×10^{-6}
	4.18605	1.16222×10^{-6}	4.18605×10^{7}	4.26649×10^{-1}	1

Quantity	SI	Other Units	
	W	kgf·m/s	kcal/h
Power	1	1.01972×10^{-1}	8.5985×10^{-1}
	9.80665	1	8.43371
	1.16279	1.18572×10^{-1}	1

	Pa·s	cP	P
Viscosity	1	1×10^{3}	1×10
	1×10^{-3}	1	1×10^{-2}
	1×10^{-4}	1×10^{2}	1

	m²/s	cSt	St
Kinematic viscosity	1	1×10^{6}	1×10^{4}
	1×10^{-6}	1	1×10^{-2}
	1×10^{-4}	1×10^{2}	1

	W/(m·K)	kcal/(h·m·℃)	kcal/(s·m·℃)
Thermal conductivity	1	8.600×10^{-1}	2.3889×10^{-4}
	1.16279	1	2.7778×10^{-4}
	4.18604×10^{3}	3.600×10^{3}	1

	kJ/(kg·K)	kcal/(kg·℃)
Specific heat	1	2.38889×10^{-1}
	4.18605	1

Note

- The values described are typical values only.
- The usage examples indicated here do not guarantee results applicable to relevant uses of the products.
- It is the users' responsibility to investigate industrial property rights and the terms of use related to the uses and applications indicated here.
- For the handling (transport, storage, forming, disposal, etc.) of the products, it is advisable to refer to technical documents and the Safety Data Sheet (SDS) of the proper materials and grades. Please contact us for consultations when the products are used for the purpose of food containers and packaging, medical parts, safety equipment, and toys for children.
- In Japan, the colored products of each grade may contain chemicals subject to reporting requirements under the applicable law provided in Appendix 9 of Article 18-2 of the Enforcement Order, under Article 57-2 of the Industrial Safety and Health Act. For details, please contact us.
- For the export of our products and products incorporated with our products, please comply with the relevant laws and regulations, such as the Foreign Exchange and Foreign Trade Law.
- Please note that because of the chemical substance management systems in each country, the chemicals used in our products are subject to control, and separate applications might be required or are banned from imports and exports. It is advisable to inquire about the status of regulations in the relevant countries if you are exporting or importing our products.