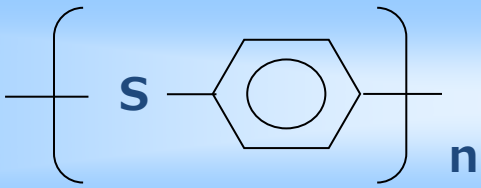




Introduction of Toray's materials for AM

What is PPS(Polyphenylene sulfide) resin?

Structure : 	<Main raw materials> p-Dichlorobenzene Sodium sulfide
Crystalline thermoplastic resin Melting point : 280 degree C Glass transition point : approx. 90 degree C 5% reduction weight temperature : approx. 480 degree C Water absorption (24hr in water) : 0.02%	
Features <ul style="list-style-type: none">• high strength, high rigidity, fatigue endurance, creep resistance• excellent long-term heat resistance (UL temperature index 200 - 240 degree C)• excellent chemical resistance (chemical resistance after fluorine resin)• UL 94 V-0 without blending the flame retardant• good electrical characteristics• good dimensional stability• excellent physical properties even under high temperature and high humidity	

Long-term durability

Flame retardance

High Strength

Chemical resistance

Solvent	PPS	PEEK	PA6	PA12
Caustic soda	✓	✓	✓	✓
Concentrated hydrochloric acid	✓	✓	✗	✗
Toluene	✓	✓	✓	✓
Acetone	✓	✓	✓✗	✓
NMP	✓	✓	✗	✗
Ethylene glycol	✓	✓	✓	✓
Gasoline, greases	✓	✓	✓	✓

※Chemical resistance under room temp. solvent

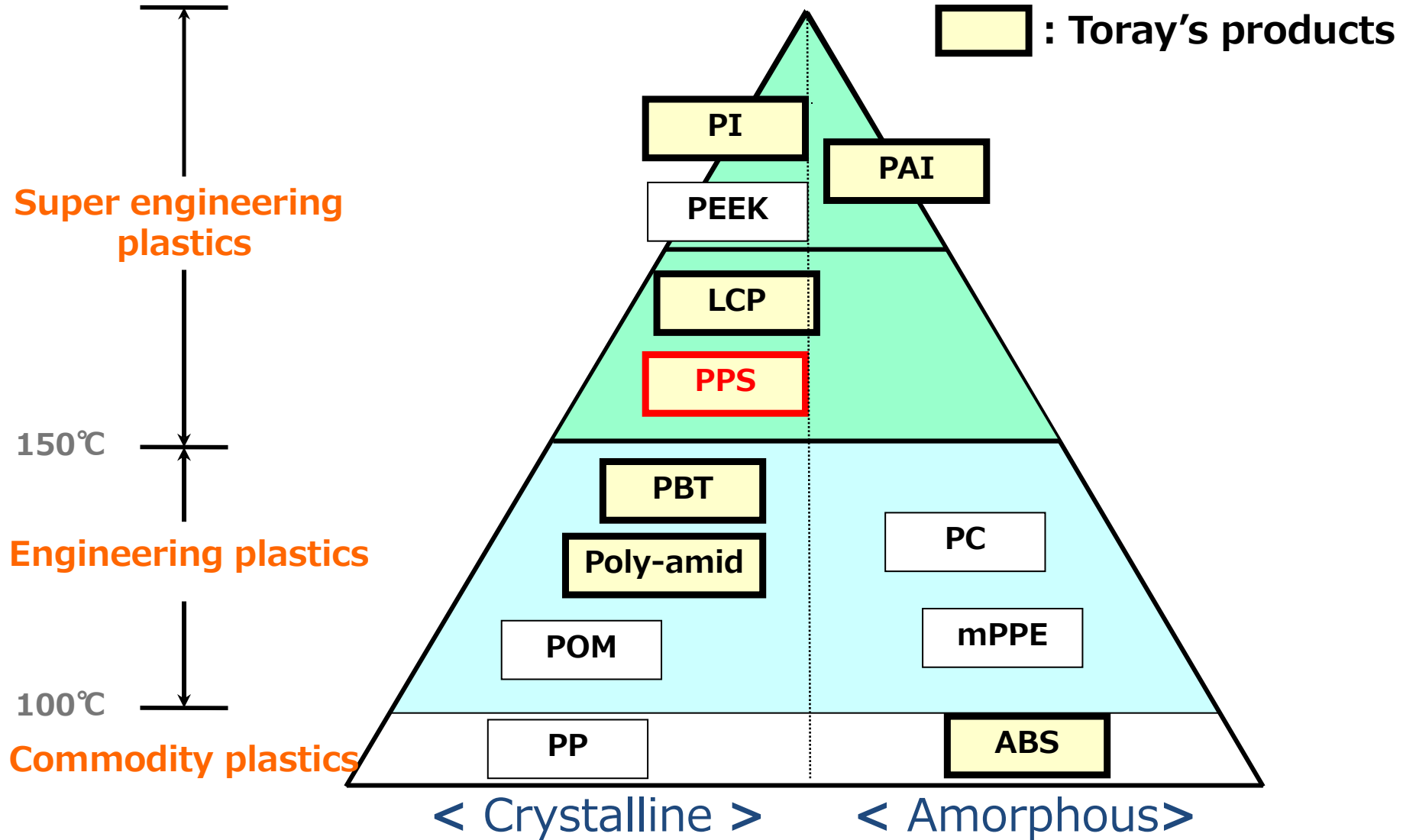
【Chemical resistance in bulk-molding material】

- ✓ : No change in shape
- ✓✗ : Shape retaining but partially deformed
- ✗ : Dissolved or deformed

※resource : Plastic encyclopedia, flonchemical chemical resistance data

Comparison of resin characteristics

Heat resistance



Toraymill™ PPS for 3D printer

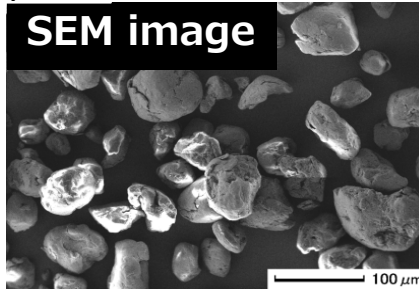
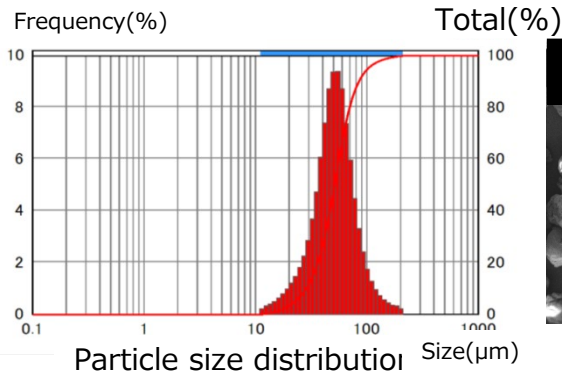
1. Toraymill™ PPS

Toraymill™ PPS has high-flow and polymer properties and is suitable for the Powder Bed Fusion process, which is the major 3D printing process.



2. Features

(1) Particle size distribution (D50 = Approx. 50 μm)



(2) High-flow powder



Current lineup and refresh rate

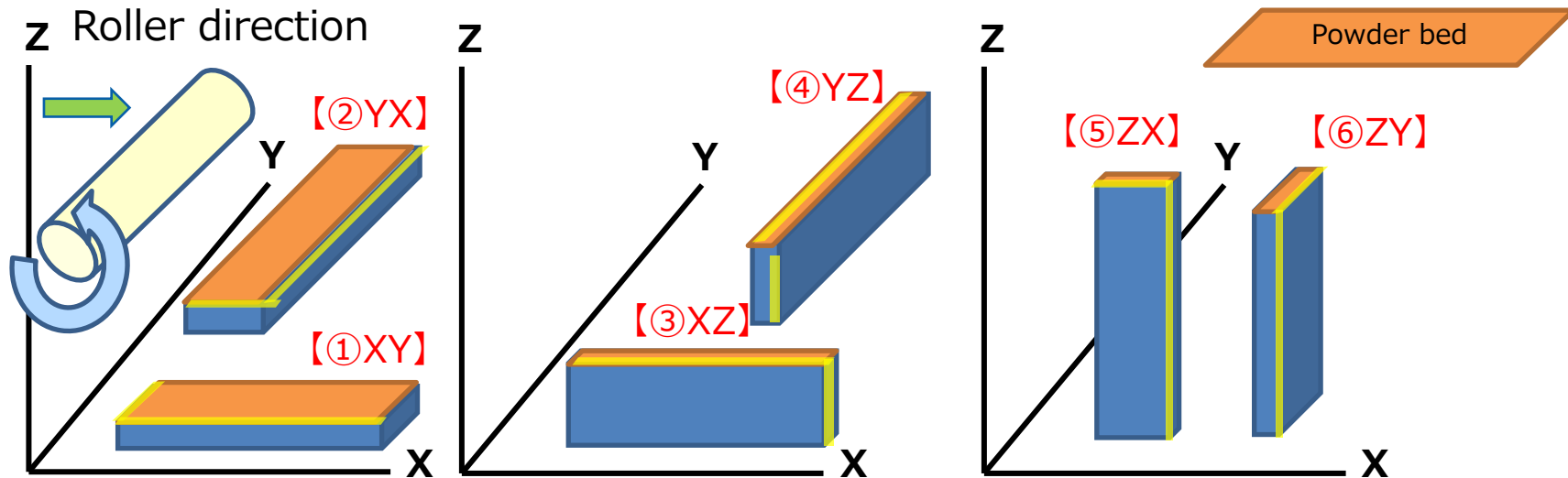
Line up	Refresh rate
(1) Unreinforced PPS	Refresh rate: 80% (recommended)
(2) Glass fiber reinforced PPS	Refresh rate: 70% (recommended)
(3) Carbon fiber reinforced PPS	Under development to improve refresh rate

Mechanical properties

Item(X-Y direction)		Unit	PPS			PA12
			Unreinforced	GF reinforced (25%)	CF reinforced (30%)	Unreinforced
Material for 3D printing		—	MIX	MIX	Virgin	MIX
Tensile	Strength	MPa	49	65	87	48
	Elongation	%	2.2	2.3	1.0	14.5
	Modulus	GPa	2.1	2.9	—	—
Flexural	Strength	MPa	63	104	123	61
	Modulus	GPa	3.3	3.8	8.6	1.4
	Strain	%	1.8	2.4	—	15.3
Charpy impact strength		%	—	—	2.5	—
Density		kJ/m2	1.22	—	1.38	0.99
Temp. of deflection under load [Flat wise1.82MPa]		℃	123	237	247	100
Linear expansion coefficient (-40~200℃)	X-Y	×10 ⁻⁵ /K	7.0	3.8	1.1	—
	Y-X	×10 ⁻⁵ /K	7.1	5.4	3.4	—
Melting point		℃	280			170
Crystallization temp.		℃	190			144
Flame retardance		UL	V-0			—

Above data is a representative example of the measurement values obtained under specific conditions.

Anisotropy



Material			PPS (Unreinforced) ※MIX					
Direction			①XY	②YX	③XZ	④YZ	⑤ZX	⑥ZY
Properties	Tensile strength	MPa	49	49	45	50	41	41
	Tensile Elongation	%	2.2	2.2	2.1	2.2	1.9	1.9
	Tensile Modulus	GPa	2.1	1.3	2.0	1.8	1.6	1.8
	Flexural Strength	MPa	63	66	77	74	65	64
	Flexural Modulus	GPa	3.3	3.1	3.6	3.6	3.4	3.4
	Flexural Strain	%	1.8	1.8	1.9	1.8	1.8	1.8

※MIX: Virgin: Recycle=2:8

Above data is a representative example of the measurement values obtained under specific conditions.

Anisotropy

Material			GF reinforced PPS(GF25%) ※MIX					
Direction			①XY	②YX	③XZ	④YZ	⑤ZX	⑥ZY
Properties	Tensile strength	MPa	65	52	-	-	-	30
	Tensile Elongation	%	2.3	1.9	-	-	-	1.2
	Tensile Modulus	GPa	2.9	2.6	-	-	-	2.3
	Flexural Strength	MPa	104	90	-	-	-	76
	Flexural Modulus	GPa	3.8	3.6	-	-	-	4.0
	Flexural Strain	%	2.4	2.4	-	-	-	1.9





※MIX: Virgin: Recycle=3:7

Material			CF reinforced (CF30%) PPS ※Virgin					
Direction			①XY	②YX	③XZ	④YZ	⑤ZX	⑥ZY
Property	Tensile strength	MPa	87	58	82	54	26	26
	Tensile elongation	%	1.0	1.2	1.0	1.3	0.9	0.9
	Flexural strength	MPa	123	88	111	76	33	36
	Flexural modulus	GPa	8.6	5.4	7.9	4.3	2.3	2.1
	Impact strength	kJ/m2	2.5	2.1	2.8	2.4	1.2	1.2

※Virgin: Virgin 100%

Above data is a representative example of the measurement values obtained under specific conditions.

Application example of PPS 3D printed parts

<p>Duct, Wind outlet, Bracket, Throttle body etc.</p>	<p>Turbo charger(Exhaust side)</p>
<p>GF reinforced PPS</p> 	<p>CF reinforced PPS</p> 
<p>Pump(Casing, Impeller)</p>	<p>Cooling pipe</p>
<p>GF reinforced PPS</p> 	<p>GF reinforced PPS</p>  <p>Post process by machining</p>

a)To make a complicated part at one time.

b)To reduce the weight compared with metal by 30 – 50%

(1) Aerospace and Train and automotive

<Method: UL94V>

Thickness(mm)	Result
0.49 t	V-0
0.68 t	V-0
0.95 t	V-0
1.75 t	V-0
2.26 t	V-0

Above data is a representative example of the measurement values obtained under specific conditions.

Application:
Duct, Wind outlet, Bracket,

Approval by Japan Railway Rolling Stock & Machinery Association



Suitable for small lots parts

(2) Impeller



For industry usage



For automotive usage

Fluid: Hot water (60 ° C, 80 ° C)
Lubricant etc.

Capable for evaluating functionality
in high-temperature fluids

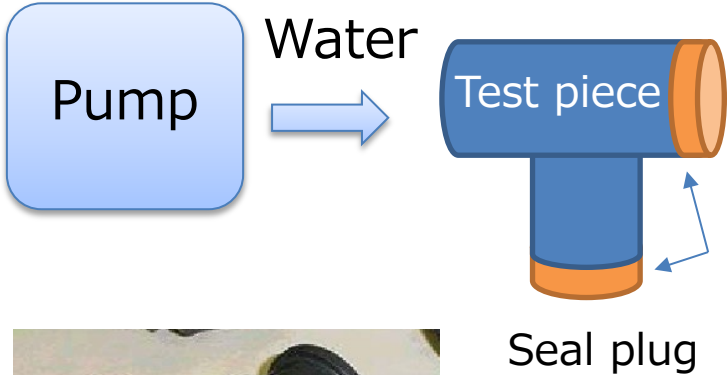
Application by features

High heat resistance for hot water
Chemical resistance

(3) Tube and pipe for parts in water

【Burst pressure test】

【Results】



Water fitting
Cheese
Elbow
Socket etc.

	Burst pressure (MPa)	T tube (Joint: polishing)	L tube (Joint: polishing)
3D printed parts	Unreinforced PPS	5.8MPa	5.4MPa
Injection	GF reinforced PPS	7.0MPa	-
Injection	GF+ Elastomer	12.0MPa	-

Above data is a representative example of the measurement values obtained under specific conditions.

Prototype: Available
Practical part (small lot products):
Can be used with shape optimization

Capable for evaluating functionality in high-temperature fluids

(4) Medical facility

※The biocompatibility of PPS resin is not confirmed. Toray assumes such application as devices not to contact directly with living bodies.

Features

Excellent heat resistance
(Temperature for long-term continuous usage: 200°C and higher, DTUL: 260°C and higher)

Excellent hydrolysis resistance (Resistance to steam and hot water)

Excellent chemical resistance
(no solvent to dissolve PPS below 200 °C)

Needs

Metal replacement
Lighter
Flexible for design

Durability against repeated autoclave sterilization
(gamma rays, electron rays)

Resistance for various chemicals

Application

Medical instruments
(pump, housing, Case etc.)

Sterilizer

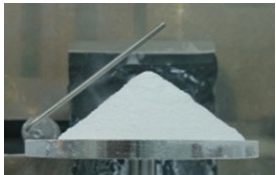
Chromatography parts
Resident Evil Countermeasure equipment / parts

Suitable for small lots parts

Toray's Total Solution for AM business

Toray Industries, Inc.

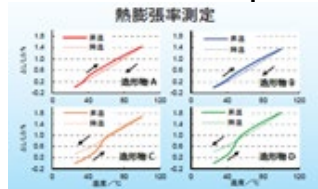
- PPS powder



Material

Toray Research Center Inc.

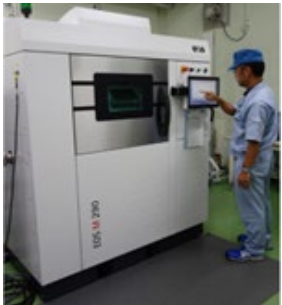
- Any analyses for materials and parts



Toray Precision Co., Ltd.

- Service for metal and second processing

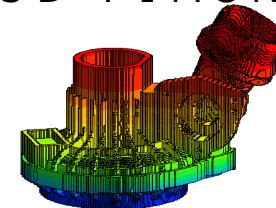
Product



Analysis

Toray Engineering Co., Ltd.

- Simulation (3 D-T I M O N)
- Equipment



Various detailed data

1. Strength

1) Temperature dependence(Unreinforced, x-y direction)

- ① Tensile strength
- ② Flexural strength
- ③ Flexural modulus

2. Heat resistance

3. Linear expansion coefficient

4. Flame retardance(Unreinforced PPS/UL)

5. Pressure resistance

6. Electrical property

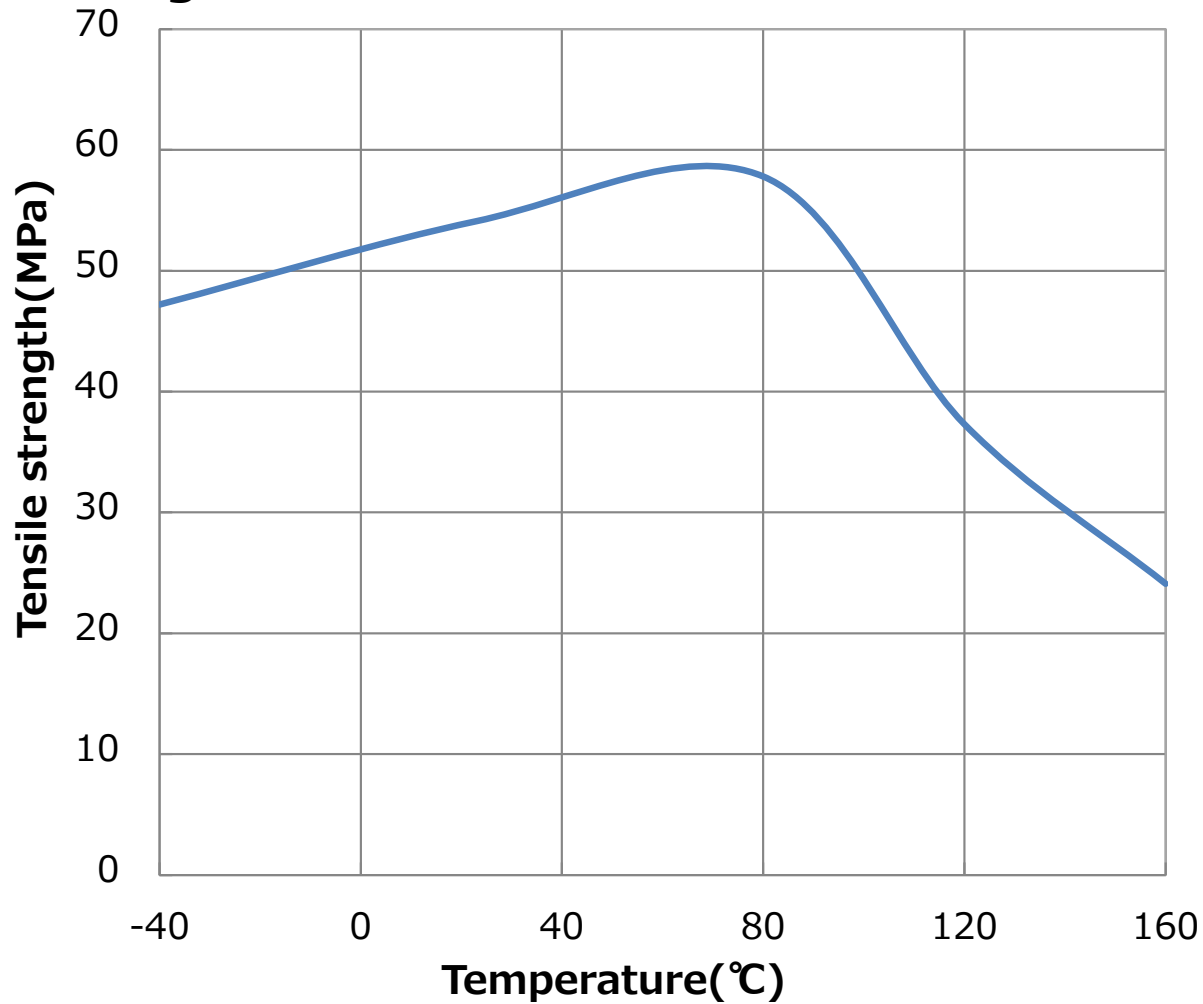
7. Heat Dissipation

8. Electromagnetic wave shield (Electric field)

9. Electromagnetic wave shield (Magnetic field)

1. 1) Temperature dependence(Unreinforced, x-y direction)

① Tensile strength

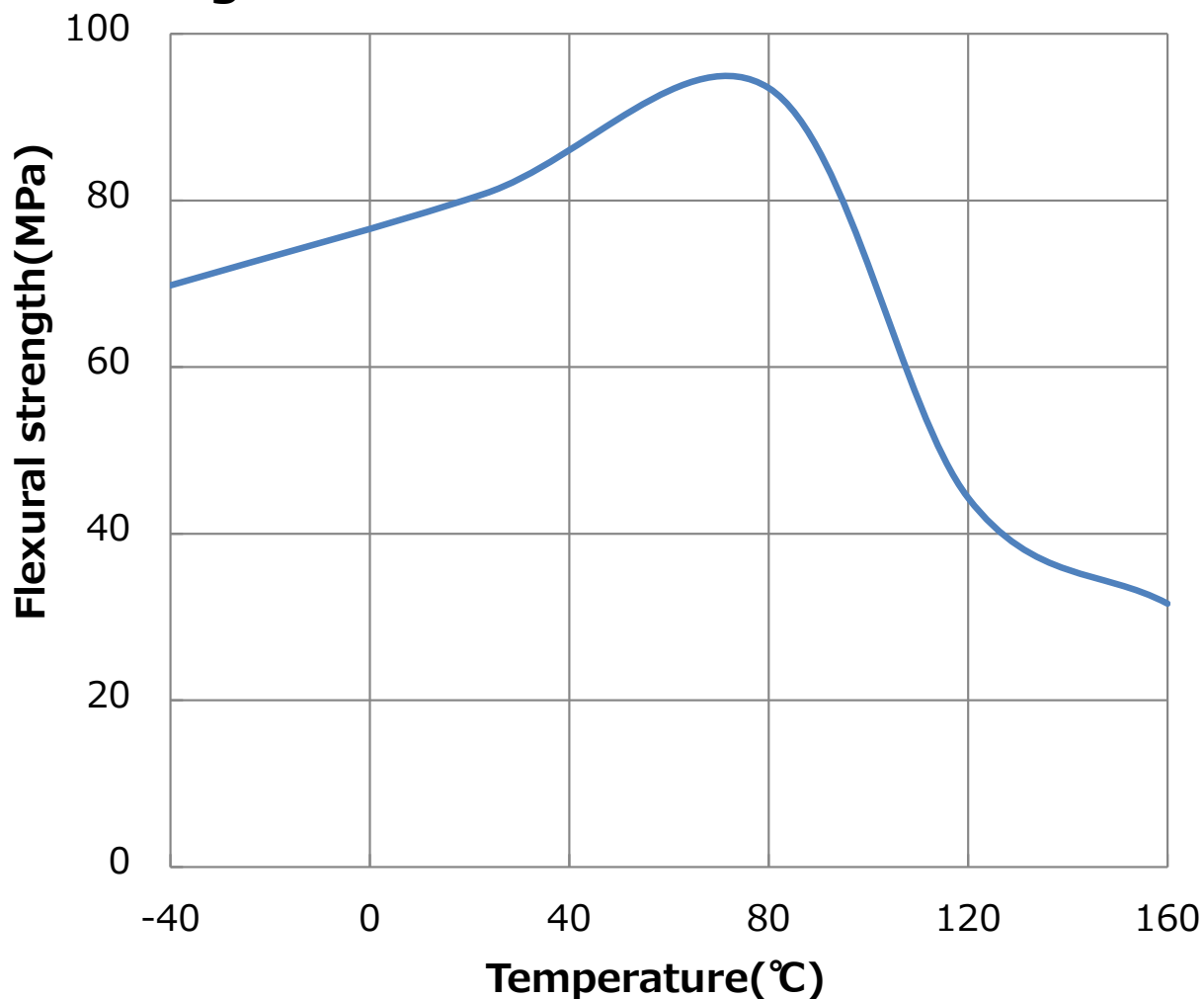


※The data for GF reinforced and CF reinforced is under acquisition.

Above data is a representative example of the measurement values obtained under specific conditions.

1. 1) Temperature dependence(Unreinforced, x-y direction)

② Flexural strength

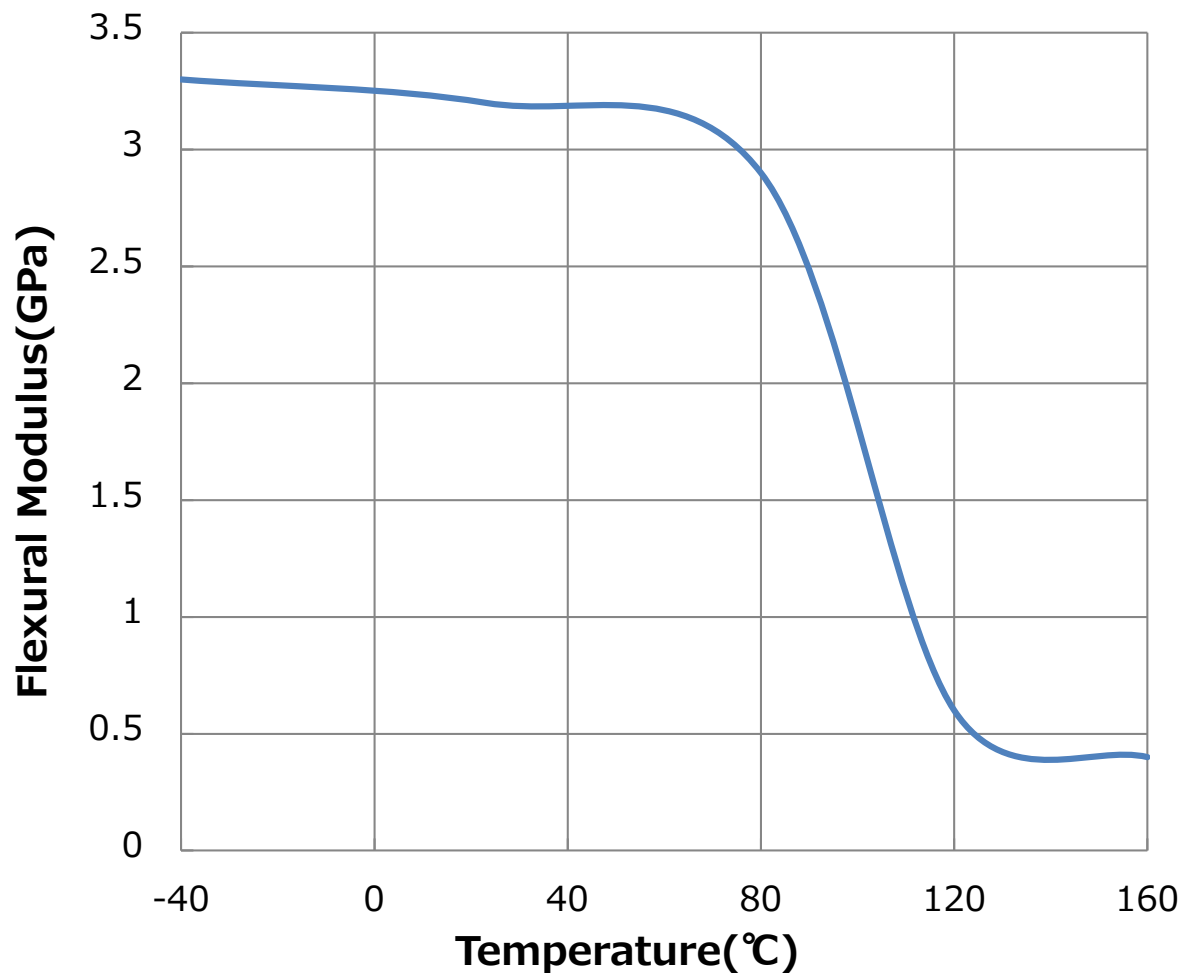


※The data for GF reinforced and CF reinforced is under acquisition.

Above data is a representative example of the measurement values obtained under specific conditions.

1. 1) Temperature dependence(Unreinforced, x-y direction)

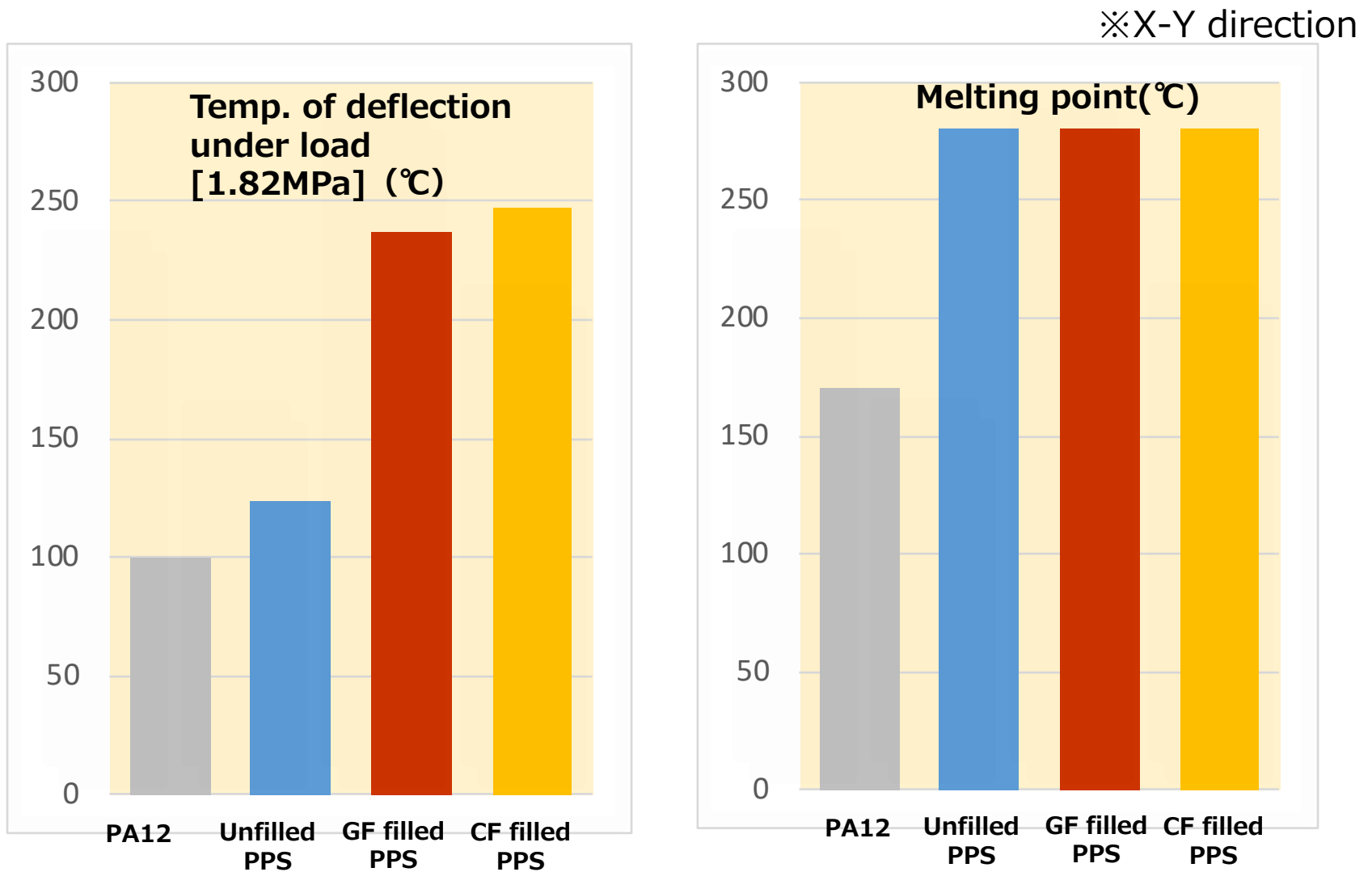
③ Flexural modulus



※The data for GF reinforced and CF reinforced is under acquisition.

Above data is a representative example of the measurement values obtained under specific conditions.

2. Heat resistance



Above data is a representative example of the measurement values obtained under specific conditions.

3. Linear expansion coefficient

【Conforming to ISO 11359

(measurement of linear thermal expansion coefficient and glass transition temperature)】

Item		Unit	Unreinforced PPS	Glass 25% reinforced PPS	CF 30% reinforced PPS	
Linear Expansion coefficient	X-Y direction	-40~80°C	$\times 10^{-5}$	5.5	3.2	1.0
		80~200°C	$\times 10^{-5}$	8.4	4.3	1.3
	Y-X direction	-40~80°C	$\times 10^{-5}$	5.5	3.9	2.7
		80~200°C	$\times 10^{-5}$	8.6	6.8	4.1
	Z-X direction	-40~80°C	$\times 10^{-5}$	5.6	5.0	2.7
		80~200°C	$\times 10^{-5}$	7.7	10.7	4.1

Above data is a representative example of the measurement values obtained under specific conditions.

4. Flame retardance (Unreinforced)

<Method: UL94V>

【20mm vertical combustion test (IEC60695-11-10 B method, ASTM D3801)】

Attach the test piece vertically to the clamp. Contact the test piece for 10 seconds twice with 20mm flame. Determine V-0, V-1, V-2 or Not by its combustion behavior.

Thickness(mm)	Result
0.49 t	V-0
0.68 t	V-0
0.95 t	V-0
1.75 t	V-0
2.26 t	V-0

※ UL standard (blue card): Not acquired yet

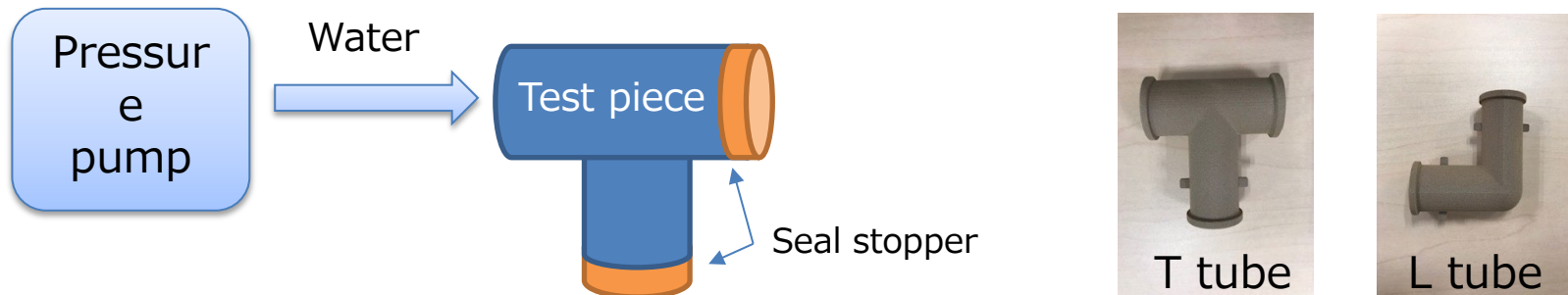
Criteria for determination	Classification		
	V-0	V-1	V-2
Combustion time of test piece	Less than 10 seconds	Less than 30 seconds	Less than 30 seconds
Total combustion time of 5 test piece	Less than 50 seconds	Less than 250 seconds	Less than 250 seconds
Combustion time of each test piece and glowing time	Less than 30 seconds	Less than 60 seconds	Less than 60 seconds
Combustion up to the clamp	Non	Non	non
Cotton ignition of dripping	Non	Non	Non

Above data is a representative example of the measurement values obtained under specific conditions.

5. Pressure resistance

【Pressure breaking test】

Apply pressure by water to the T-tube or L-tube test piece.
Measure the pressure at the point of breaking the test piece.



Breaking pressure (MPa)	T tube (Joint area polished)	L tube (Joint area polished)
Unreinforced PPS	5.8MPa	5.4MPa
GF reinforced PPS	Under acquisition	Under acquisition
CF reinforced PPS	Under acquisition	Under acquisition

※PPS+GF40%(Injection grade) : 7.0MPa

PPS+GF30% + Elastomer(Injection grade) : 12.0MPa

<Conditions>

- Manual test pump : Made by Kyowa T-300N (Maximum pressure: 30MPa)
- Test piece : 3D printed parts by PPS
- Wall thickness : 2.8mm(Peripheryφ21.7mm, Inner periphery φ16.1mm)

Above data is a representative example of the measurement values obtained under specific conditions.

6. Electrical Properties

Method : According to IEC 62631-2-1(Automatic balance bridge method)
 Sample size : 80×80×t3(mm)
 Frequency condition : 1 MHz
 Electrode size: Main Electrode diameter φ36mm
 Annular electrode inner diameterφ38 mm
 Electrode mat. : Conductive silver paint
 Condition control : 23 °C±2 °C, 50 %RH±5 %RH×24 h<
 Test environment : 23 °C±2 °C, 50 %RH±5 %RH
 Measuring device : Precision LCR meter E4980A
 (Made by Agilent Technologies Ltd.)

Item	Unit	Unreinforced PPS	GF reinforced PPS(25%)	CF reinforced PPS (30%)
Volume Resistivity	Ωcm	2.80×10 ¹⁷	—	1.30×10 ⁴
Dielectric Strength	kV/mm	18.5	—	5.7
Dielectric constant(εr)	—	3.86	3.86	—
Dielectric tangent(tanδ)	—	0.00124	0.00161	—

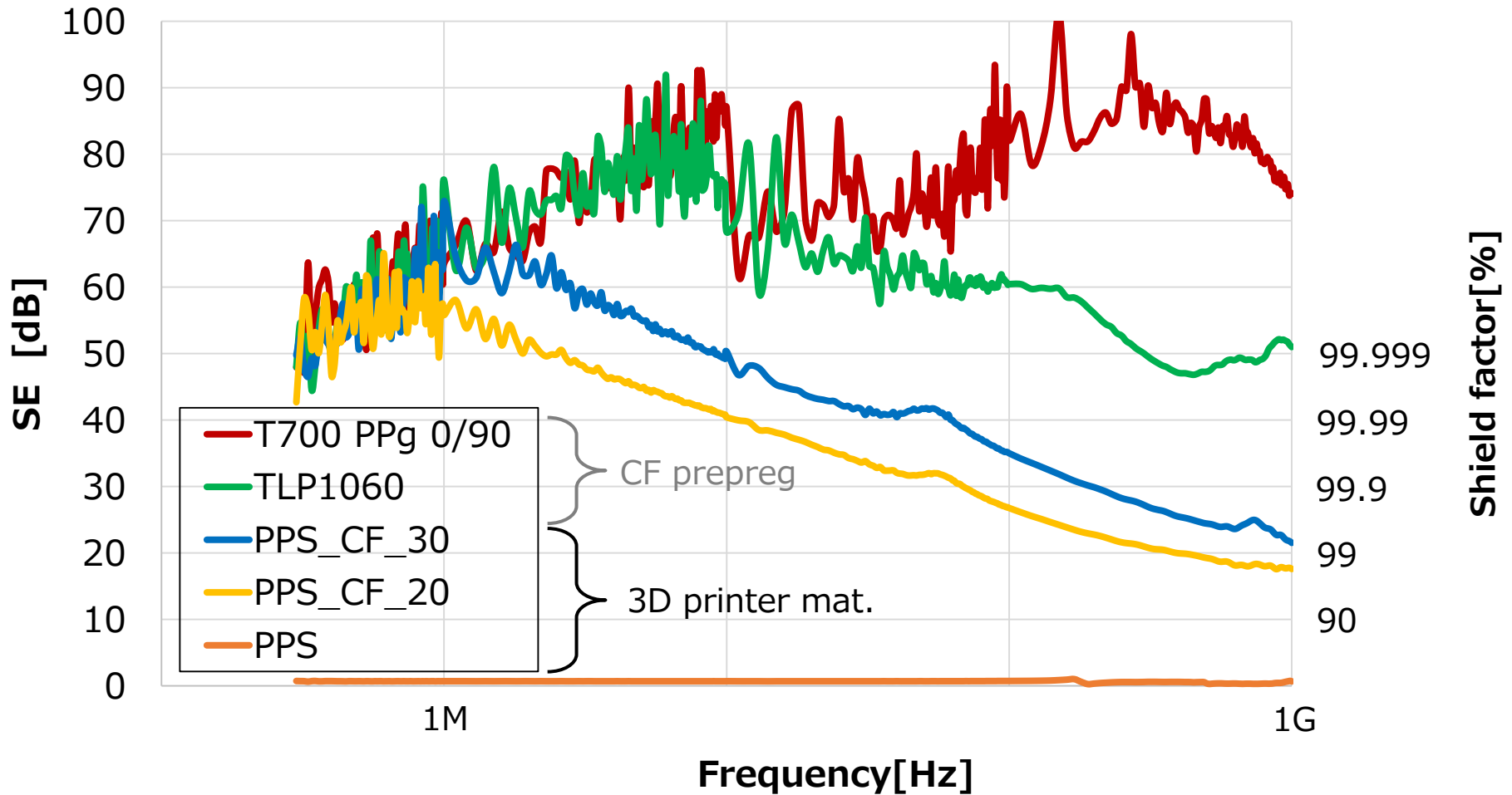
Above data is a representative example of the measurement values obtained under specific conditions.

7. Heat Dissipation

	Unit	3D printing mat.			Injection moldings mat.
		PPS+GF25	PPS+CF20	PPS+CF30	PPS+GF40 (A504X90)
Thermal conductivity (Hot disk method)	W/m·K	0.5	0.8	0.9	0.5

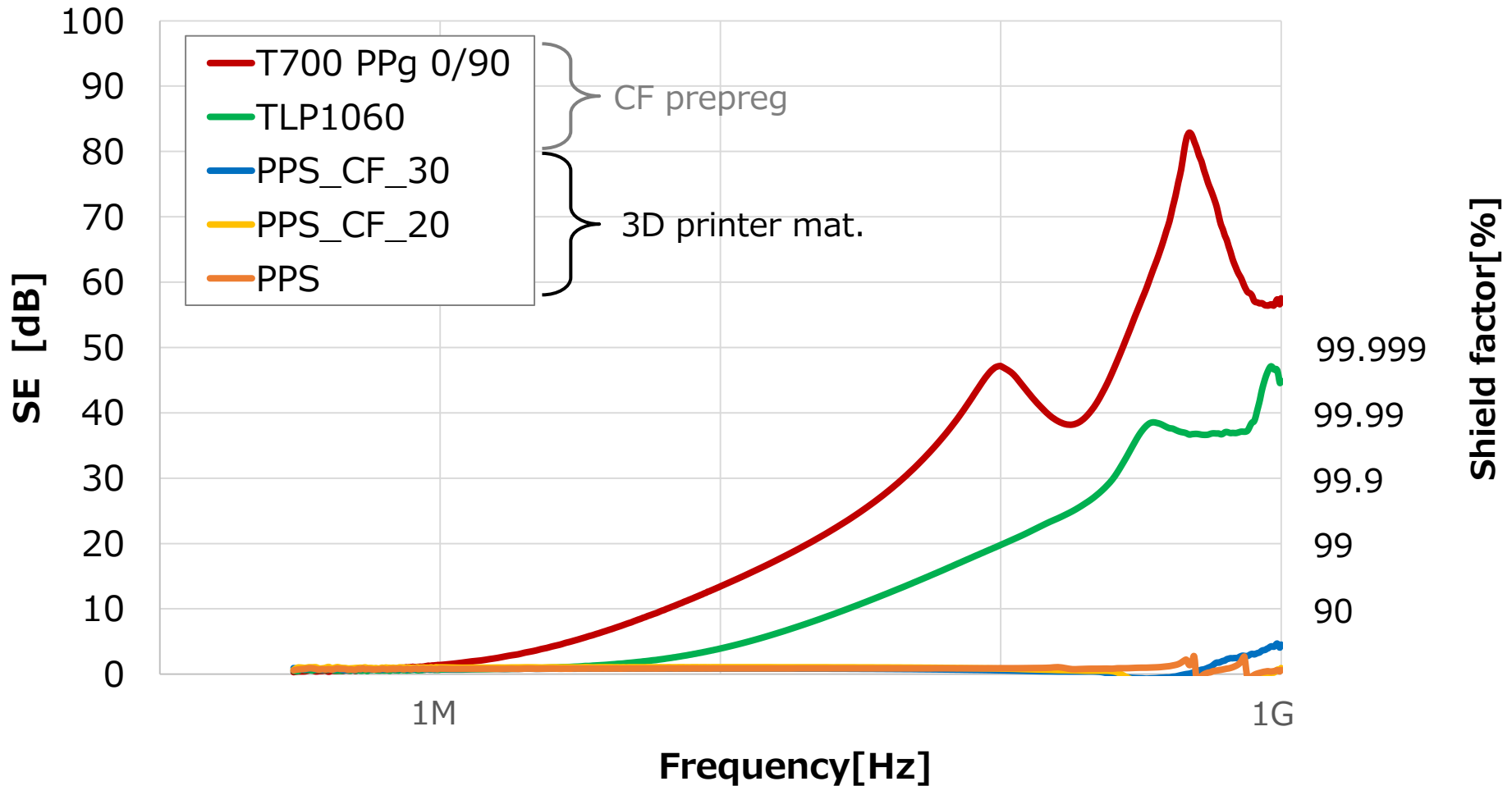
Above data is a representative example of the measurement values obtained under specific conditions.

8. EMI shield_Electric field_0.3k~1.0GHz



Above data is a representative example of the measurement values obtained under specific conditions.

9. EMI shield_Magnetic field_0.3k~1.0GHz



Above data is a representative example of the measurement values obtained under specific conditions.

Comparison with injection moldings

Item		Unit	3D printing mat. (X-Y direction)			Injection		
			Unreinforced (MIX)	GF reinforced (MIX)	CF reinforced (Virgin)	Un reinforced	GF reinforced	CF reinforced
Reinforced mat.		%	—	25	30	—	30	30
Tensile	Strength	MPa	49	65	87	85	155	235
	Elongation	%	2.2	2.3	1.0	8.0	1.7	1.4
	Modulus	MPa	2.8	2.9	—	—	—	—
Flexural	Strength	MPa	63	104	123	140	230	340
	Modulus	GPa	1.8	3.8	8.6	3.9	12.0	27.5
	Strain	%	3.3	2.4	—	—	—	—
Density		g/cm ³	1.22	—	1.38	1.34	1.57	1.46
Temp. of deflection under load [Flat wise 1.82MPa] (°C)		°C	123	237	247	105	>260	>260
Flame retardance		UL	V-0	V-0	V-0	V-0	V-0	V-0
Linear expansion coefficient		X -Y ×10 ⁻⁵ /K	7.0	3.8	1.1	6.2	3.0	1.1
		Y-X ×10 ⁻⁵ /K	7.1	5.4	3.4	6.6	3.4	1.9

Above data is a representative example of the measurement values obtained under specific conditions.

'TORAY'

Innovation by Chemistry