Appendix 01

Uses and substitutions of Specialist Equipment

This document is the appendix 01 of the general comment to the Restriction report on Per- and polyfluoroalkyl substances (PFAS) from Japan Inspection Instruments Manufacturers' Association (JIMA) submitted on 14. September 2023

Table of content

The characteristics and functions of PFAS

Summary

PFASs have many functions. The characteristics and functions of PFAS which are mainly used in Specialist equipment are described in this section.

PFAS has excellent properties such as, chemical resistance, electric insulation, heat resistance, repellency from water and oil, non-adhesion, weatherability, and others. PFASs are used where multiple of these properties are required simultaneously. We recognize that the ability to provide these various properties in a single material is the most important property of PFAS, and at present we do not have information on any other substance with this function other than PFAS.

Chemical resistance

Fluoropolymers compared to other general-purpose resins

	ETFE	FEP/TFE/FPA	FLPE	FLPP	HDPE	LDPE	PC	PETG	PP	PVC	TPE***
Acids, Dilute or Weak	E	E	E	E	E	E	E	G	E	E	G
Acids, **Strong/Concentrated	E	E	G	G	G	G	G	N	G	G	F
Alcohols, Aliphatic	E	E	E	E	E	E	G	G	E	G	E
Aldehydes	E	E	G	G	G	G	G	G	G	G	G
Bases/Alkali	E	E	F	E	E	E	N	N	E	E	F
Esters	G	E	G	G	G	G	N	G	G	N	N
Hydrocarbons, Aliphatic	E	E	E	G	G	F	G	G	G	G	E
Hydrocarbons, Aromatic	G	E	E	N	N	N	N	N	N	N	N
Hydrocarbons, Halogenated	G	E	G	F	N	N	N	N	N	N	F
Ketones, Aromatic	G	E	G	G	N	N	N	N	N	F	N
Oxidizing Agents, Strong	E	E	F	F	F	F	F	F	F	G	N

*Not for tubing chemical resistance (except PVC) **Except for oxidizing acids (See oxidizing agents, strong) ***TPE gaskets

Table1 **Classes of Substances at 20° C, Chemical Compatibility Chart - LDPE, HDPE, PP, Teflon Resistance (calpaclab.com)**[1]

* Not for tubing chemical resistance (except PVC) ** Except for oxidizing acids (See oxidizing agents, strong) *** TPE gaskets

Excellent: 30 days of constant exposure causes no damage. Plastic may tolerate for 30 years.
Good: Little or no damage after 30 days of constant exposure for the regent
Fair: Some effect after 7 days of constant exposure to the reagent. The effect may be crazing, cracking, loss of strength or discoloration.
Not recommended: Immediate damage may occur. Depending on the plastic, the effect may be severe crazing, cracking, loss of strength or dis coloration, deformation, dissolution or permeation loss.

[1] https://www.esaknowledgebase.com/wp-content/uploads/2022/06/PFAS-Article-Valve-World-May-2022.pdf last accessed on 14 July 2023

Type / Properties	Fluoroelastomer	Silicon rubber	Acrylic rubber	Nitrile rubber	Ethylene propylene rubber
	FKM	MQ, VMQ	ACM	NBR	EPDM
Specific gravity	1.8～2.0	1.0	1.0	1.0	0.9
Heat resistance	◎	◎	○	△	○
Low temperature resistance	△	◎	○	◎	◎
Electrical properties	○	○	△	△	◎
Solvent resistance	◎	◎	○	△	○
Flame resistance	◎	○	▲	▲	▲
Ozone resistance	◎	◎	◎	×	◎
Steam resistance	◎	○	×	△	○
Acid resistance	◎	○	△	○	◎
Alkaline resistance	◎	◎	△	○	◎
Oil resistance	◎	△	○	○	×
Permeability resistance	◎	▲	○	○	△

Table 1 Property Comparison of Fluoroelastomers (FKM) with Other Rubbers [2]

◎ : Excellent ○ : Good △ : Fair ▲ : Marginal × : Poor

"Cleanliness" is defined as the fact that fluoropolymers are not easily eluted by acids, alkalis, or solvents (chemical resistance), do not contain other materials such as plasticizers in the molding process, and do not contain products that would thermally decompose during the material molding process.

Ozone resistance

Ozone is known to degrade plastic materials in two ways:

A: Substances with double bonds (C=C) in their structures (such as natural rubber, chloroprene rubber, butadiene rubber, etc.) undergo decomposition in which ozone reacts with the double bonds to produce ketones, when they come into contact with ozone.

B: When ozone exists in water, peroxy radicals are generated. Non-fluorine materials (eg polyethylene, polypropylene, etc.) deteriorate even if they do not have double bonds.

Fluoropolymers does not have decomposition pathways such as A and B even if it comes into contact with ozone, so it can be used for a long time without deterioration.

[2] https://www.daikinchemicals.com/library/pb_common/pdf/catalog/RC-1L.pdf translated from the document in Japanese. Last accessed on 14 July, 2023

Thermoplastic resin		Ozon Resistance
Soft vinyl chloride	PVC	○
Rigid vinyl chloride	PVC	○
Vinylidene chloride resin	PVdC	◎
ABS	ABS	△
Polyethylene	PE	△
Nylon	N	×
Acrylic resin	PMMA	△
Fluoropolymer resin	PTFE	◎
Phenolic resin	PF	△
Melamine resin	PVC	○
Furan resin	FF	○
Epoxy resin	EP	△
Unsaturated polyester resin	UP	×

Table 2 Comparison of ozone resistance properties of plastics [3]

[3] https://www.kk-kunii.co.jp/dcms_media/other/%E8%80%90%E6%B2%B9%E6%80%A7%E3%83%BB%E8%80%90%E6%BA%B6%E5%89%A4%E6%80%A7%E3%83%BB%E8%80%90%E8%96%AC%E5%93%81%E6%80%A7%E3%83%87%E3%83%BC%E3%82%BF.pdf Last accessed on 20 July, 2023

Repellency from water and oil / non-adhesion

Since the fluoropolymers have a small polarizability, the intermolecular force is small. Because of its characteristics, fluoropolymers have repellency and non-adhere properties on the surface. In general, the repellency from various liquids is evaluated by the contact angle, and the larger the contact angle, the higher the repellency.

Contact angle θ

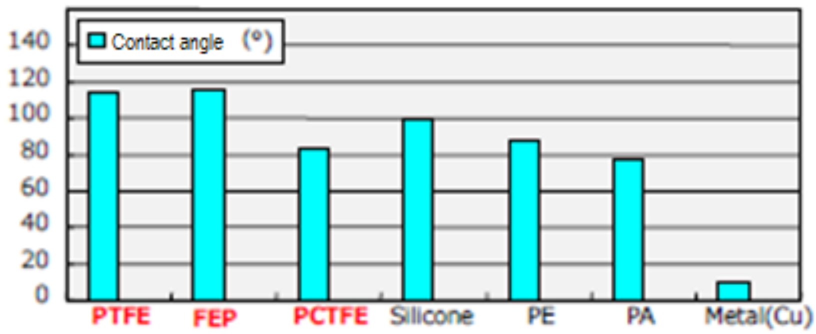


Figure 2 Contact angles with water

Adhesion energy refers to the amount of work required to pull a liquid contacting a solid away from the solid. The larger the contact angle, the smaller the adhesion energy. It means that a liquid in contact with a small adhesion energy solid easy to separate from the solid.[4]

Material name	Contact angle with water (°)	Adhesion energy (dyn/cm)
PTFE	114	43.1
FEP	115	42.0
Silicone resin	90~110	47.8~72.7
Paraffin	105~106	52.7~53.8
PE	88	75.2
PCTFE	83	-
PA	77	97.7
Phenolic resin	60	109.0
Copper(electropolishing)	9.6	144.2
Aluminium(electropolishing)	4.6	145.0

Table 3 Surface properties of various plastics and metals

[4] Japan Fluoropolymers Industry Association(2020), ふっ素樹脂ハンドブック, 14th edition. Page 34 Translated from Japanese.

This characteristic is sometimes called "mold releasability". It can also be expressed as antifouling because it does not easy to adhere.

Heat resistance

Fluoropolymers have high heat resistance as follows. They have higher heat resistance compared to other general-use resins

	Fluoropolymers						Other general-use resins	
Heat resistance : maximum operating temperature (C)	PTFE	PFA	FEP	ETFE	PCTFA	PVdF	PP	PVC
	260	260	205	150	120	120	100	60

Table 4 The heat resistance of Fluoropolymer [5]

Electric insulation

When the dielectric constant is low, the insulation in electrical components can be made thinner, leading to downsizing and weight reduction of the equipment. In applications where downsizing and weight reduction are necessary, it is an essential feature

	Fluoropolymer				Fluorine rubber	
	PTFE	FEP	PFA	ETFE	FKM	FEPM
Dielectric constant	◎ 2.1			○ 2.3～2.8	△ 3～4	△～○ 2.5～3.5
	Non-fluoropolymer				Non-fluorine rubber	
	PVC	PEEK	TPI (Thermoplastic Polyimide)	Polyolefin	Silicone rubber	EPDM
Dielectric constant	△ 4～6	△ 3.2～4.5	△ 2.8～3.2	△～○ 2.3～4	△ 3.2～10	△ 2.5～3.5

Table 5 The dielectric constants of various resins

Low friction, self lubrication

Friction coefficient of fluorine resin is lower than that of other resins. It is because polarizability (Mobility of electrons in an electric field) of C-F bonding is low (0.68) and the intermolecular force is weak. (Reference: polarizability of C-Cl bonding is 2.59) [6]

Types of plastic	Plastic / Plastic	Plastic / Steel	Steel / Plastic
PTFE	0.04	0.04	0.10
PE	0.10	0.15	0.20
PS	0.50 *)	0.30	0.35
PMMA	0.80 *)	0.50 *)	0.45 *)

*) indicates occurrence of stick-slip motion.

Measurement condition: Bowden-Laden type measurement equipment, load: 9.8-39.2N, sliding speed: 0.01cm/s

[5] DAIKIN INDUSTRIES, LTD. (2009) ダイキン フッ素樹脂ハンドブック, Page 4

[6] Japan Fluoropolymers Industry Association(2020), ふっ素樹脂ハンドブック, 14th edition. Page 9 Translated from Japanese.

Plastic/Steel indicates sample material/pin material
PE: polyethylene PS: polystyrene PMMA: polymethylmethacrylate

Table 6 Comparison of friction coefficient among PTFE and other materials[7]

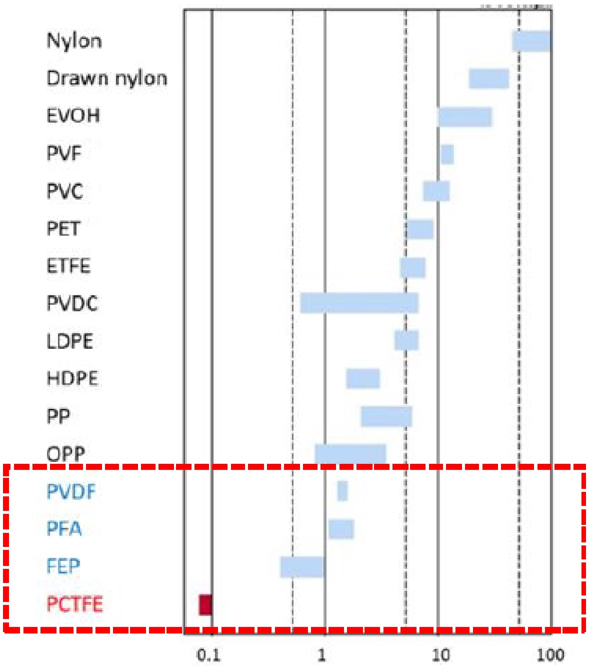
As an example of low friction, Table8 shows friction coefficient of PTFE.

Type	ASTM test method	Measurement condition		Unit	PFA	PTEF	FEP
Coefficient of static friction	-	Against polished steel		-	0.05	0.02	0.05

Table 7 Comparison of static friction coefficient among PFA, PTFE and FEP[8]

One of the characteristics related to friction is "self lubrication". The molecules of PTFE separate from molding of PTFE due to friction. The molecules in crystals of PTFE separate easily because intermolecular forces are weak. PTFE moves and attaches to the friction mating surface and generates friction between them. It lowers friction coefficient. [9]

Gas barrier properties/Gas permeation properties
Fluoropolymer film are less steam permeability.



steam permeability (g/m^2/d)

[7] Japan Fluoropolymers Industry Association(2020), ふっ素樹脂ハンドブック, 14th edition. Page 24 Translated from Japanese.
[8] DAIKIN INDUSTRIES, LTD. (2009) ダイキン フッ素樹脂ハンドブック, Page 53
[9] Japan Fluoropolymers Industry Association(2020), ふっ素樹脂ハンドブック, 14th edition. Page 24 Translated from Japanese.

Figure 3 The degree of steam permeability [10]

Fluorine elastomers are less atmospheric (nitrogen, oxygen) permeability.

Material	Temperature degree Celsius	He	H_2	O_2	N_2	CO_2	CH_4	C_2H_2	C_3H_8
Vinyl methyl silicone rubber (VMQ)	25	N/A	400	400	200	1600	N/A	N/A	10000 or more
	50		570	500	280	1550			
Ethylene propylene rubber (EPDM)	25	N/A	N/A	16.5	5.90	79.2	N/A	N/A	91.2
	50			46.6	13.7	183			246
Perfluoro-elastomer (FFKM)	25	10.3	8.25	2.5	8.1	28.7	3.3	N/A	N/A
Styrene butadiene rubber (SBR)	25	17.5	30.5	13	4.8	94	N/A	N/A	N/A
	50	42	74	34.5	14.5	195			
Vinylidene fluoride fluoro rubber (binary FKM)	25	2.95	4.6	1.0	0.8	3.9	0.6	N/A	N/A
Vinylidene fluoride fluoro rubber (Ternary FKM)	25	2.64	4.13	1.7	0.7	1.6	0.4	N/A	N/A
Chloroprene Rubber (CR)	25	N/A	10.3	3.0	0.89	19.5	2.5	N/A	N/A
	50		28.5	10.1	3.55	56.5	9.8		
nitril-butadiene rubber (Mid-high NBR)	25	9.32	12.1	2.94	0.81	23.5	N/A	18.9	26.9
	50	23.4	33.7	10.5	3.58	67.9		68.3	78.3
nitril-butadiene rubber (High NBR)	25	5.2	5.42	0.73	0.18	5.67	N/A	8.25	11.2
	50	14.2	17.0	3.5	1.08	22.4		19.8	33.1
butyl rubber (IIR)	25	6.4	5.5	0.99	0.25	3.94	0.6	1.28	N/A
	50	17.3	17.2	4.03	1.27	14.3	3.2	5.82	

(×10^{-8} cc, cm/cm^2,sec,atm)

Table 8 Comparison of gas permeability of elastomer[11]

[10] DAIKIN INDUSTRIES, LTD. (2009) Daikin Fluoropolymers Handbook, Page 109

[11] DAIKIN INDUSTRIES, LTD. (2009) Daikin Fluoropolymers Handbook, Page 78

Property of Gas Permeability

Property			Standard Test method	Unit	FEP film
Gas Permeability	Gas permeability coefficient	N_2	ASTM D1434	cm³・cm/cm²・s・atm	120×10^{-10}
		O_2			370×10^{-10}
		H_2			$1,080\times10^{-10}$
		CO_2			970×10^{-10}
		CH_4			66×10^{-10}
		C_2H_4			44×10^{-10}
	Water-vapor permeability		JIS Z0208	g/m²・24h	1.6
	Water Absorption		ASTM D570	%・24h	<0.01

Table 9 Gas Permeability of FEP film[12]

Fluoropolymers permeate small molecular gases, such as oxygen and nitrogen, conversely, large molecular gases do not permeate. Fluoropolymer properties are used in permeate membranes for measurement and analysis.

Gas	Gas Permeability		
	FEP	PTFE	Low Density Polyethylene
N_2	1.2×10^{-8}	1.1×10^{-8}	0.74×10^{-8}
O_2	3.7×10^{-8}	3.2×10^{-8}	2.2×10^{-8}
CO_2	9.7×10^{-8}	8.9×10^{-8}	9.6×10^{-8}
CH_4	0.66×10^{-8}	—	2.2×10^{-8}
CH_3	0.66×10^{-8}	—	5.2×10^{-8}
C_3H_8	0.11×10^{-8}	—	7.2×10^{-8}
C_2H_4	0.48×10^{-8}	—	—

Temperature: 25 degree Celsius(77°F) Units: cm^3 (ST P) cm/cm^2・atm

Table 10 Comparison of gas permeability of various materials[13]

[12] DAIKIN INDUSTRIES, LTD. (2009) Daikin Fluoropolymers Handbook, Page 78

[13] DAIKIN INDUSTRIES, LTD. (2009) Daikin Fluoropolymers Handbook, Page 80

Low refractive index

Amorphous fluoropolymer resin has high transmittance. This is utilized for optical components and optical fibers.

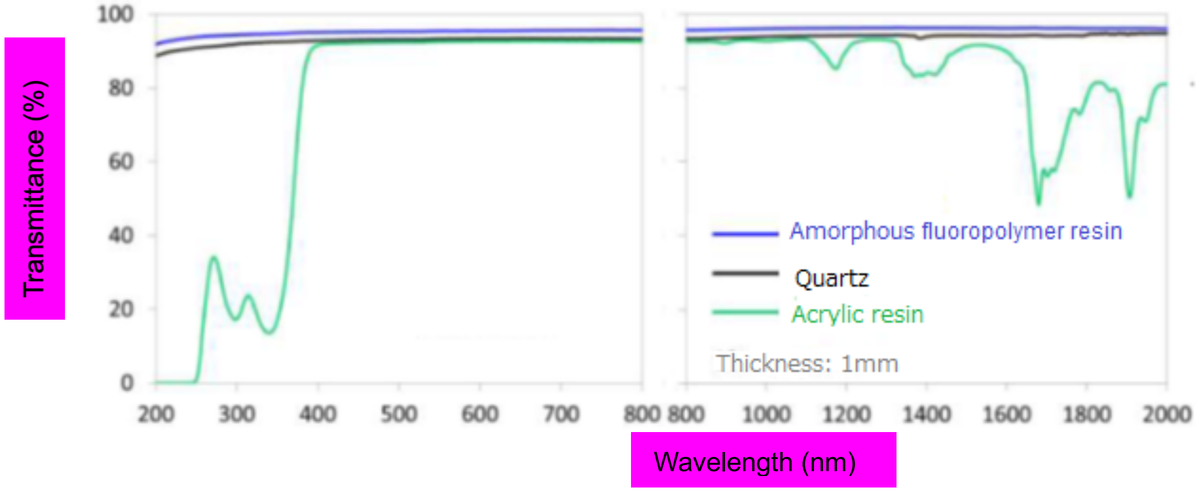


Figure 3 Comparison of transmittance [14]

Weatherability

Fluoropolymer resin has high weatherability and can be used outdoors. It does not react to sunlight such as ultraviolet rays. It is not susceptible to oxidizing effects of atmospheric oxygen and other substances (see "chemical resistance"). It can be used in a wide temperature range from low to high (see "heat resistance"). It has high water repellency and does not absorb water, so it is not affected by humidity changes. It can be said that fluoropolymer resin has high weather resistance because it has the above points.

Table 11 Fluoropolymer resin weatherability comparison [15]

	Fluoropolymer resin						General resin	
	PTFE	PFA	FEP	ETFE	PCTFE	PVdF	PP	PVC
Weatherability	◎	◎	◎	◎	◎	◎	×	×

◎ Excellent, ○ Good △ Not very good ▲ Needs attention × Not good

Regarding the graph below, it can be seen from the accelerated weatherability test with the Sunshine Weather Meter that the gloss retention rate decreases by no more than 10% even after 4000 hours of exposure. [16]

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[14] https://www.agc-chemicals.com/file.jsp?id=file/Cytop_tech14_EN.pdf . Last accessed on 11 Augst, 2023

[15] DAIKIN INDUSTRIES, LTD. (2009) ダイキン フッ素樹脂ハンドブック, Page 4

[16] https://www.kyoeishoji.co.jp/business/chemical/fusso_toryo.html translated from the document in Japanese. Last accessed on 21 July, 2023

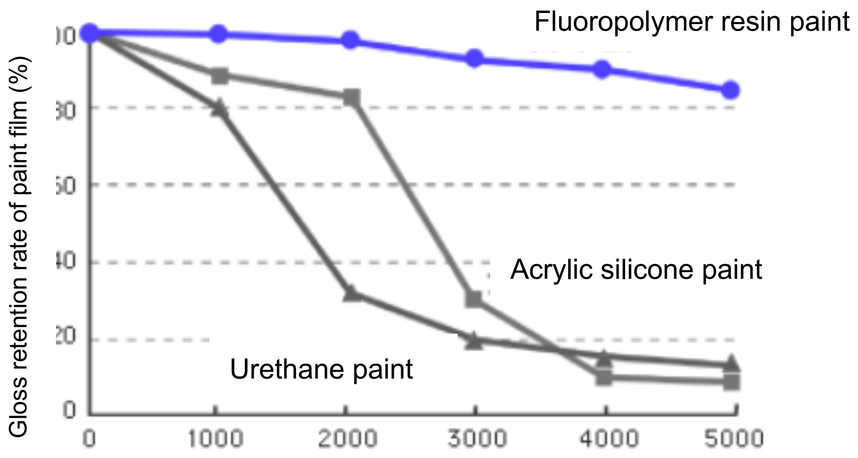

Figure 4 Accelerated weatherability test of paint

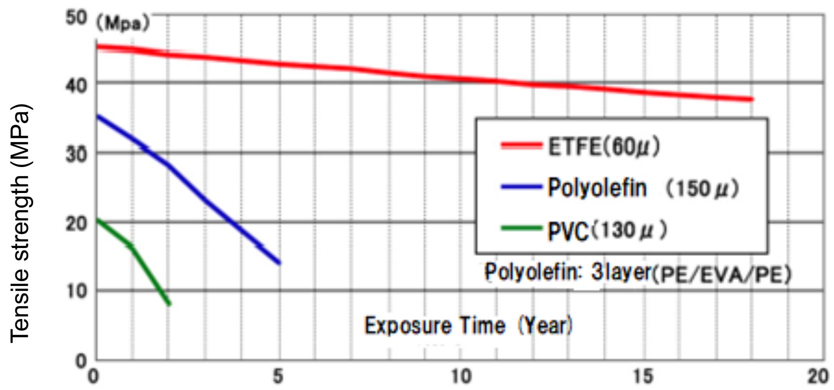

Figure 5 Outdoor exposure test Comparison of tensile strength between ETFE and other materials [17]

Durability

It means that it can be used for a long time. Due to its high chemical resistance and high weatherability, PFAS can achieve high durability.

Resistance to creep / Compression set

When a constant load is applied to a polymeric material, creep occurs, in which deformation progresses over time. Similarly, compression set occurs where the deformation does not recover when the force is removed. Both properties are known to be correlated. When rubber materials are used in elastic applications such as packings or diaphragms, it is required to minimize the effects of both properties.

Experimental examples of "30% creep time (Hour)" for major rubber materials are shown below.

[17] https://www.taiyokogyo.co.jp/feature/etfe_film.html translated from the document in Japanese. Last accessed on 21 July, 2023

Creep is known to be worse at higher temperatures, Experiments have shown that FKM and silicon exhibit good properties.

	50 degree Celsius	70 degree Celsius	100 degree Celsius	120 degree Celsius	150 degree Celsius
NR	190	103	3.8	–	–
SBR	1250	203	14	–	–
CR	4200	550	45	7.4	–
NBR	3900	380	41	12.2	–
IIR	–	–	2.7	–	–
FKM	–	–	1650	305	180
Silicon	–	–	–	1550	190

Table 12

Quoted from the journal of "the Society of Rubber Science and Technology, Japan", 1960(Vol33), P882-892, "Stress relaxation and creep properties of various vulcanized rubbers".

Examples of compression set test results are shown below. In general, it is difficult to quantitatively compare materials because the measured values differ depending on the compounding and hardness of the rubber. Here, the compression set of the materials was compared by comparing the minimum value of each material in the database. FKM and silicon showed relatively good properties, showing the same tendency as creep.

	Compression set JISK6301 100 degree Celsius×70h
NR	–
SBR	Min 20%
CR	Min 23%
NBR	Min 9%
IIR	–
EPDM	Min 23%
FKM	Min 11%
Silicon	Min 6%

Table 13

The minimum value of each material was quoted from the data described in "Material Database / Organic Materials" (1989), The Nikkan Kogyo Shimbun".

Uses of PFAS in Specialist Equipment

Summary

PFAS are a very important group of substances for Specialist Equipment, which depends on these uses to maintain safety, as they are highly effective in chemical resistance, Repellency from water and oil, and electric insulation.

PFAS polymer resins are two to ten times more expensive than other commodity plastics. There is no use other than where the equipment does not work without the use of PFAS.

General electronics components are not covered in this document. However, since our equipment also uses common electronic circuit parts, we also use parts common to information equipment and general consumer EEE. For usage and non-substitutable information for such parts, please refer to Japan 4EE Opinion RCOM21, No.4543 and additional Opinion Information and Non-Substitutable Information to be submitted in September 2023. Semiconductors are also used in our products. Many PFASs are used in semiconductors and semiconductor manufacturing equipment. Comments on most of the items in this section have been submitted by industry associations that specialize in the respective items. We hope that dossier submitters consider the manufacturer's opinions.

electric wires and insulation

An electric wire is a linear member for transmitting electricity. Metal, which is a good conductor, is used for the part that transmits electricity, and plastic resin that has electric insulation is used around the wire in order to block the influence on anything other than the transmission destination of electricity.

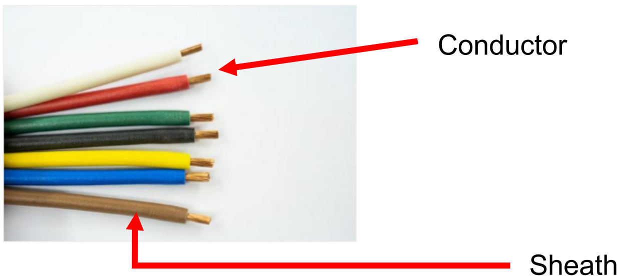

Figure 6

Polyvinyl chloride is generally used for covering parts where plastic resin is used, which is called as sheath, but PTFE, PFA, FTPE, etc. are selected depending on the suitability of use and electric insulation requirements. Since these are more expensive than polyvinyl chloride, they are used only when it is difficult to use other materials such as polyvinyl chloride.

PFAS functions required by PFAS wires and availability of alternatives.

Wires using PFAS for coating have high electrical insulation when the coating is thin (100 μm or less). PFAS also has a high heat resistance of 150-200°C. In addition, PFAS wires can be used even when there are chemicals around the device because PFAS has chemical resistance.

Examples of devices equipped with electric wire and insulation

Medical cables of probe cable for ultrasound diagnostic equipment

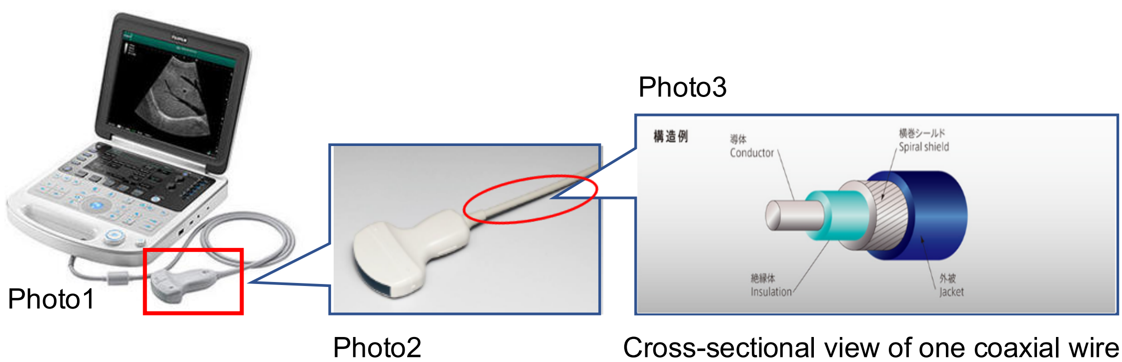

Figure 7

The ultrasonic diagnostic device is shown in Photo 1 and consists of an image analysis unit and a cable with a transducer.

The cable with transducer shown in Photo 2 is composed of about 200 coaxial wires in order to transmit and receive about 200 signals.
The inside of the red circle cable in Photo 2 is as shown in Photo 3.
Photo 4 shows a cross-sectional view of one of Photo 3.
The performance required for these coaxial wires is (electric insulation / low dielectric constant), heat resistance, and extrusion suitability. PFA/FEP is used as a material that satisfies these three elements.

Table 15 Comparison with alternative candidate material PEEK shows the comparison results with the alternative candidate material PEEK.
In order to obtain a diagnostic image with high accuracy, the attenuation of coaxial wire must be 2 dB / m or less in terms of the size shown in Table 15 Comparison with alternative candidate material PEEK, and the required performance is not satisfied unless PFA/FEP is applied.
In order to satisfy the attenuation, it is necessary to reduce the capacitance, and for this purpose, the dielectric constant must be 2.1 or less.
The cross-sectional view of one coaxial wire is shown in Photo 4, and the red arrow part is the insulating layer and the green arrow part is the outer skin layer.
Both layers require thickness control of 0.05 mm or less, and PEEK cannot be controlled, especially for the outer layer because it does not stretch.
In order to evenly cover the outer layer without destroying the shield layer, stretching is necessary.
PEEK meets only heat resistance requirements.

		PFA		PEEK		Required characteristics
electrical characteristics	dielectric constant	2.1	○	3.15	×	≦2.1
	Attenuation*1	1.75	○	≧2	×	@10MHz <2 d B/m
heat resistance	Rated temperature	≧200	○	≧200	○	200° C or higher
extrusion suitability	Coating thickness control	GOOD	○	BAD	×	≦0.05㎜t
	Non-stop extrusion time	GOOD	○	BAD	×	≧2hr

*1Conductor 48AWG (7/0.012), OD 0.18mmΦ

Table 14 Comparison with alternative candidate material PEEK

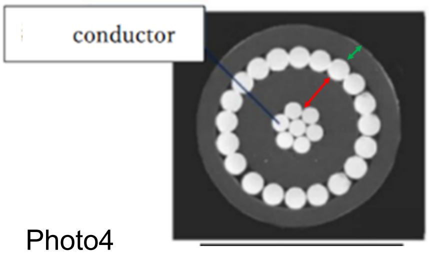

Photo4

Figure 8 Cross-sectional view of one coaxial wire

Computed Radiography (CR) for Non-Destructive Testing

CR generates an X-ray image by converting the X-ray information recorded on an imaging plate (IP), a type of X-ray detector used in X-ray photography, into an electrical signal by exciting it with a laser beam.

PTFE is used for the sliding bearings in IP transport unit inside CR.

PTFE is used to coat the plunger of the solenoid motor and the bobbin pipe in the mechanism that locks the IP cassette that stores IP in CR.

The durable life of CR is about 6 years. In order to achieve this, it must be durable enough to withstand 64 million times of IP cassette loading from the assumed frequency of use of CR. PTFE's low friction property is essential, and replacing it with nickel plating reduces the durability to about 1/6, reducing the durable life of the equipment from 6 years to 1 year.

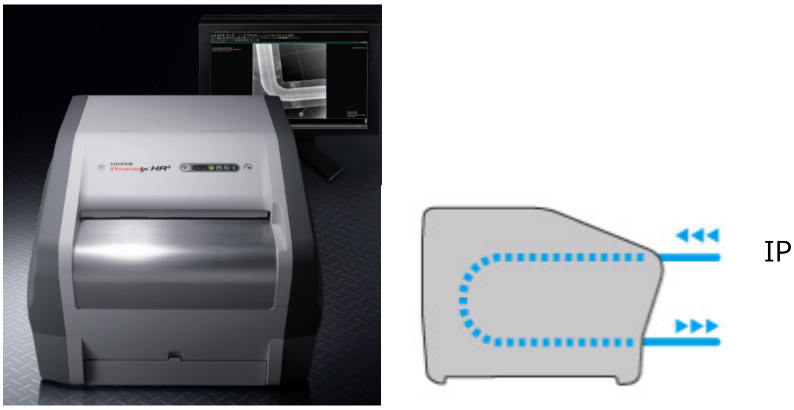

Figure 9 Computed Radiography (CR)

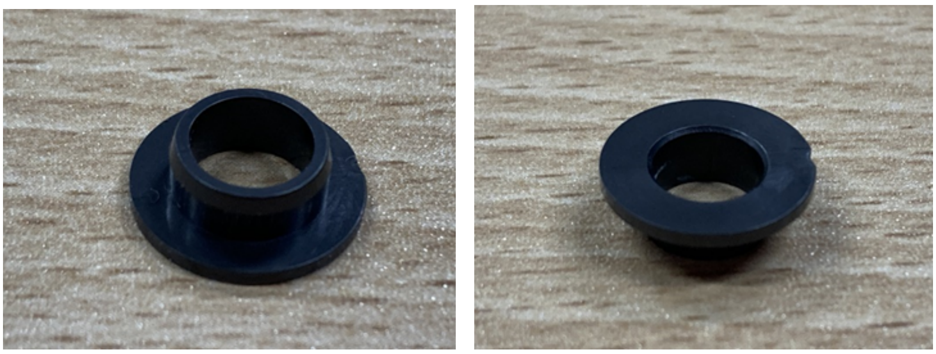

Figure 10 The bobbin pipe in the mechanism that locks the IP cassette that stores IP in CR

Imaging Plate (IP) for Non-Destructive Testing

Imaging plate (IP) is an X-ray image conversion panel used in Computed Radiography (CR). When performing X-ray photography, the radiation that passes through the inspection object is temporarily recorded in the IP in the form of electronic energy distributed over the entire surface in proportion to the dose. The CR reads the X-ray information recorded in the IP and generates an X-ray image. After reading with CR, the X-ray information recorded on the IP is erased by irradiating it with white light, and the IP can be used repeatedly.

The layer structure of the imaging plate (IP) is shown in Figure 11. A phosphor is coated on a polyethylene terephthalate (PET) base approximately 350 μm thick, which has excellent flatness and flexibility.

A transparent "front protective layer" is applied to the surface of the phosphor layer to prevent dirt and scratches from sticking to the phosphor layer.

Fluoropolymer is used for "front protective layer".

The role of the surface protective layer is to prevent dirt and scratches on the IP surface due to repeated transport of the IP within the CR.

Dirt and scratches on the surface of the IP will cause defects in X-ray images, making accurate inspections and diagnoses impossible. Therefore, the "front protective layer" on IP surface is required to be antifouling and low-friction.

Fluoropolymer is the only material that satisfies the following property (antifouling, low-friction) and manufacturing suitability for coating.

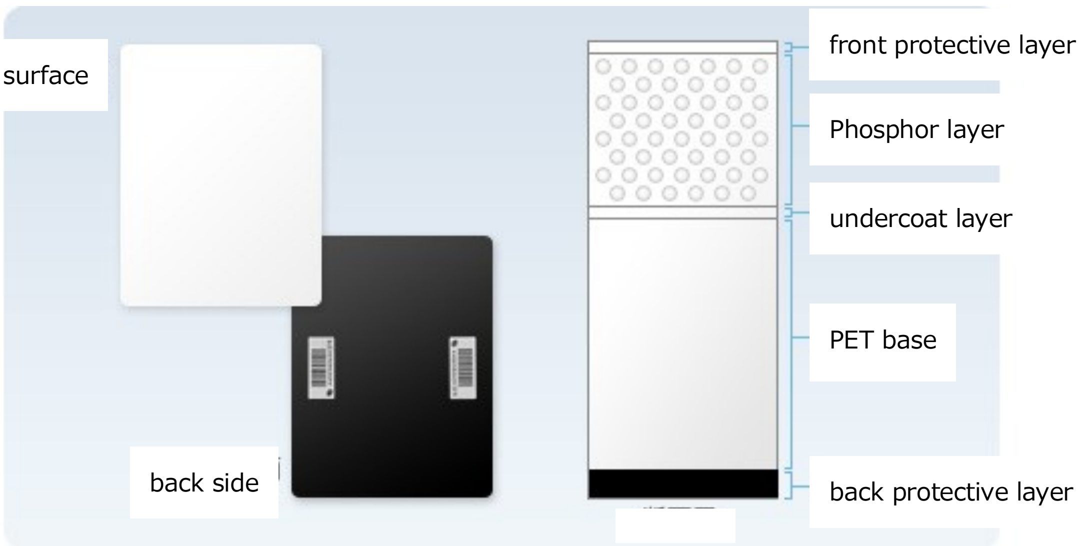

Figure 101 The layer structure of the imaging plate (IP)

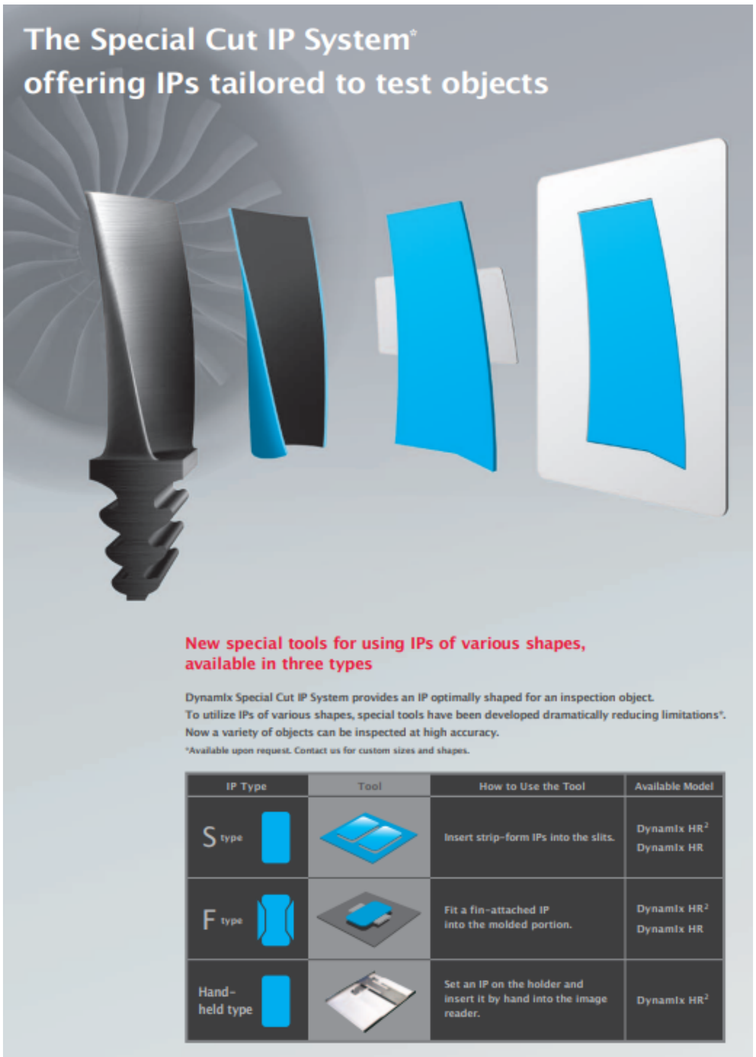

Figure 112 The Special Cut IP System

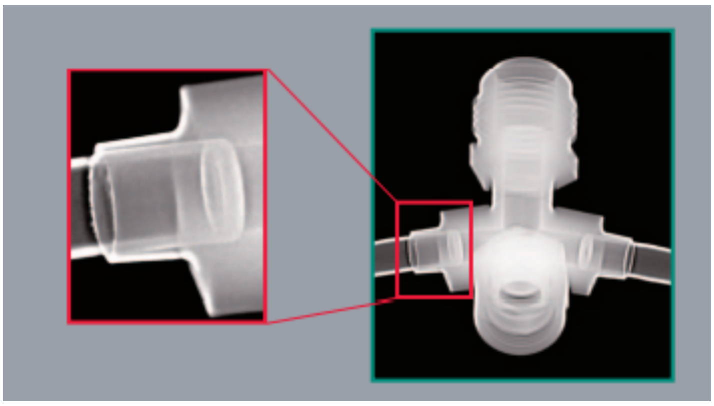

Figure 123 Imaging Example

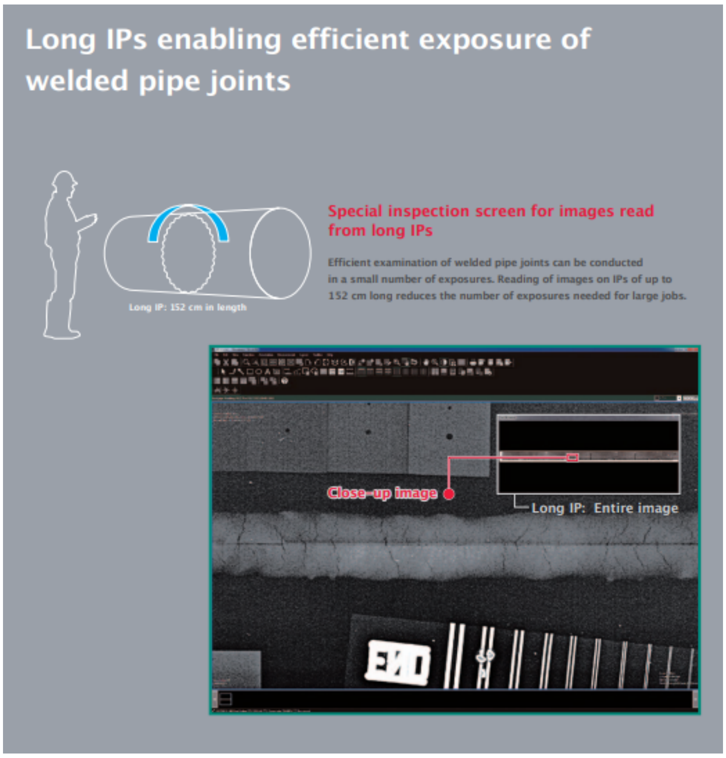

Figure 134 Example of applying IP to welded pipe