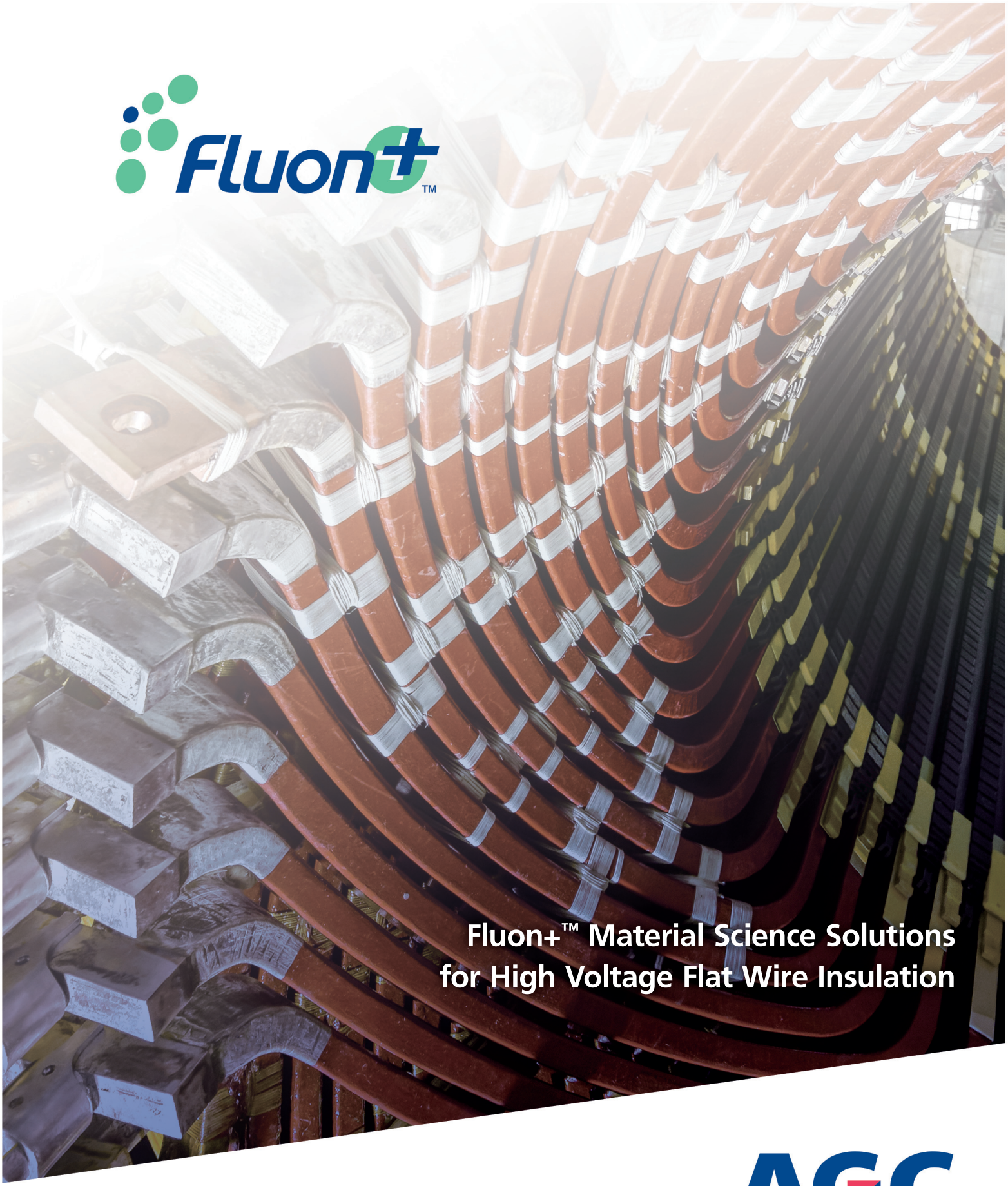


Fluon+™ Material Science Solutions for High Voltage Flat Wire Insulation

AGC

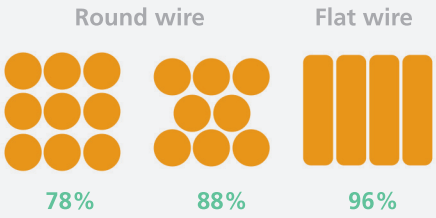
Your Dreams, Our Challenge

The efficiency of electric engines in EVs has been advancing rapidly with the aim of reducing environmental impact. At present, electric and plug-in vehicles are running with inverter-drive motors that work at 200 and 400 volts. But demand for voltage continues to climb, and it's likely that next generation EVs will need 800 volts and more.

Wires for EV, HEV, PHEV Inverter-Drive Motors

Auto makers are finding that the shape of the wiring in the motor stators can limit performance. So vehicle makers are moving away from the traditional rounded wires and relying more heavily on flat wires that provide more efficiency and greater power.

By nature, flat wires do something round wires can't: they save space. When it comes to making the best use of space within a motor stator, rounded wires—on average—fall somewhere in the 78-88 percent occupancy range. Flat wires, on the other hand, can achieve 96-percent occupancy. And packing more wires into the same amount of space allows for higher voltages, giving EVs a power boost.



Flat wires have more occupancy rate of the stator

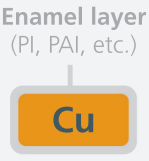
↓

Space saving + Higher output

Wire jacketing

The higher voltages and wiring shapes demand new materials, particularly when it comes to wire jacketing. PI and PAI, used in the enamel layers of these structures are not reliable enough for high voltage due to thickness limitations and pinhole defects. PEEK and PPS, used as polymer layers in extrusion processes, result in the need of a primer and they have poor flexibility, cracking when bent.

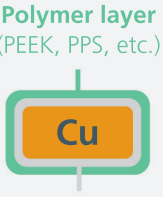
Current structure 200V



Enamel layer thickness is 50μm at most

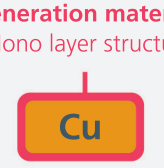
- × Insufficient reliability for high voltage
- × Pinhole defect

Current structure 400V

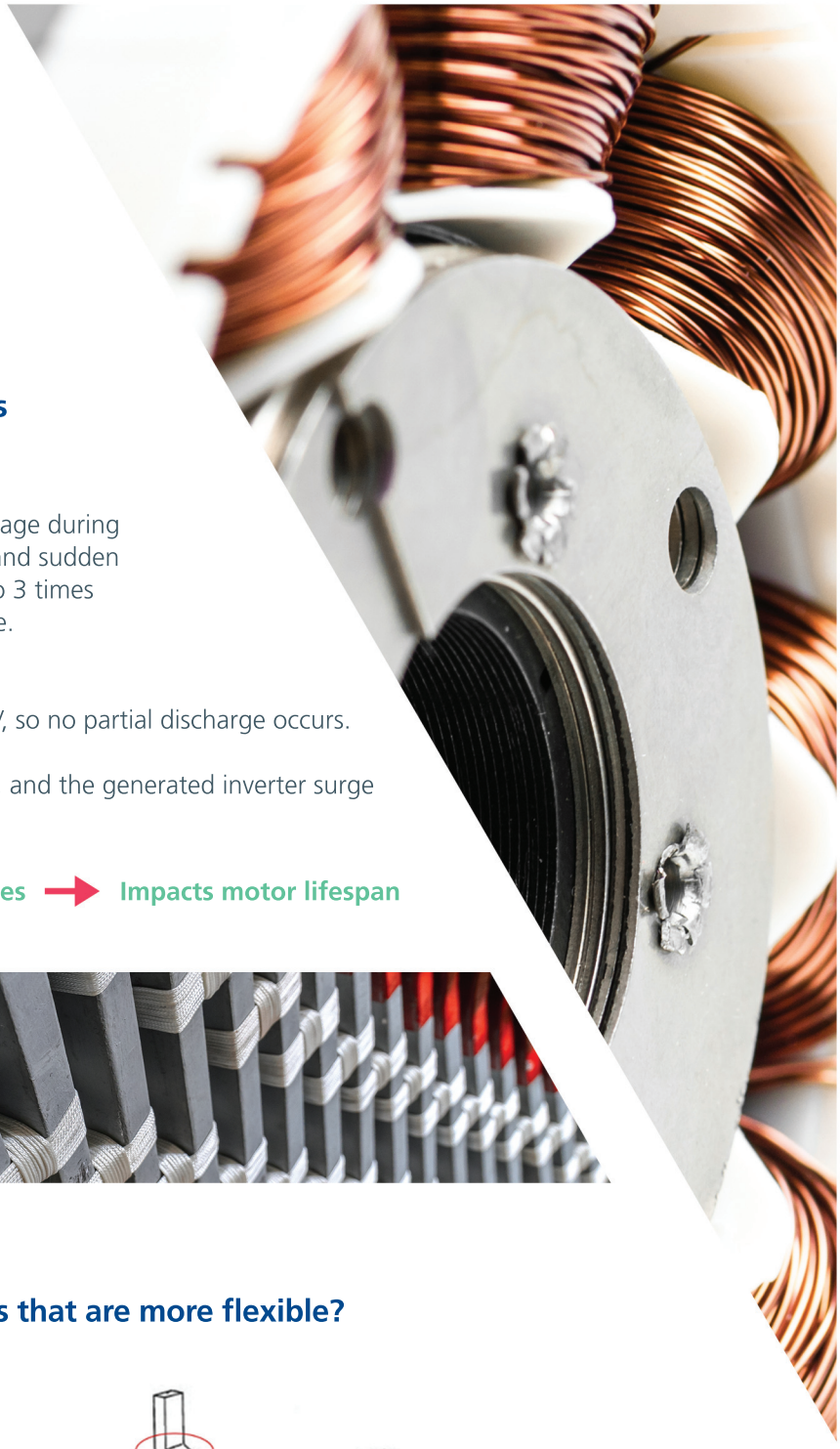


- × Poor adhesion (primer needs)
- × Cracking/wrinkles when bending
- × Poor flexibility

Next generation 800V+



- ✓ Heat resistance (W=AxV)
- ✓ Anti-corona
- ✓ Flexibility
- ✓ Lower dielectric constant
- ✓ Higher PDIV
- ✓ No surge issue
- ✓ Varnish/enamel-free



Why we need next generation compounds with higher PDIV?

	PDIV/V
PI enamel	800~900
PI enamel + PEEK layer	1400
New criteria	> 1500

Instantaneous voltage during sudden breaking and sudden acceleration is 2 to 3 times the normal voltage.

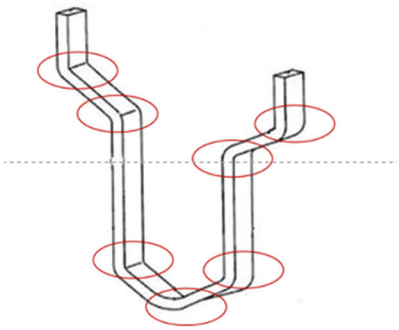
For a 400V motor, instantaneous voltage is within PDIV, so no partial discharge occurs.

For a 800V motor, instantaneous voltage exceeds PDIV, and the generated inverter surge invades into winding wires and parts.

Discharge occurs → Insulating film deteriorates → Impacts motor lifespan

Why we need next generation compounds that are more flexible?

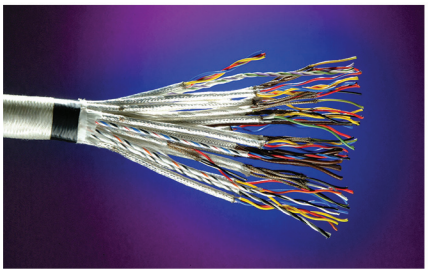
Wires in motor stators are winded and bended for more occupancy rate

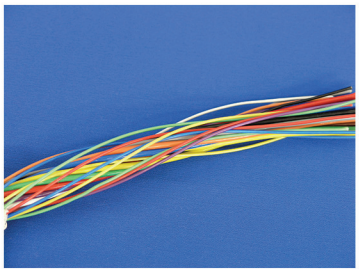


Partial discharges are prone to occur at corners

Higher flexibility → No cracking / wrinkles when bending → No partial discharges

Fluoropolymers
as wire insulation materials





Due to their excellent electrical and insulating properties in a wide range of temperatures, and heat and chemical resistance, fluoropolymers are suitable for wire and cable coatings.

Material	εr	εr @ 200°C	Volume resistivity Ω·cm
PFA/PTFE	2.09	2.10	$>10^{18}$
ETFE	2.50	2.40	$>10^{18}$
PEEK	3.30	5.40	$>10^{17}$
PI	3.50	4.20	$>10^{14}$
PAI	3.80	4.80	$>10^{14}$

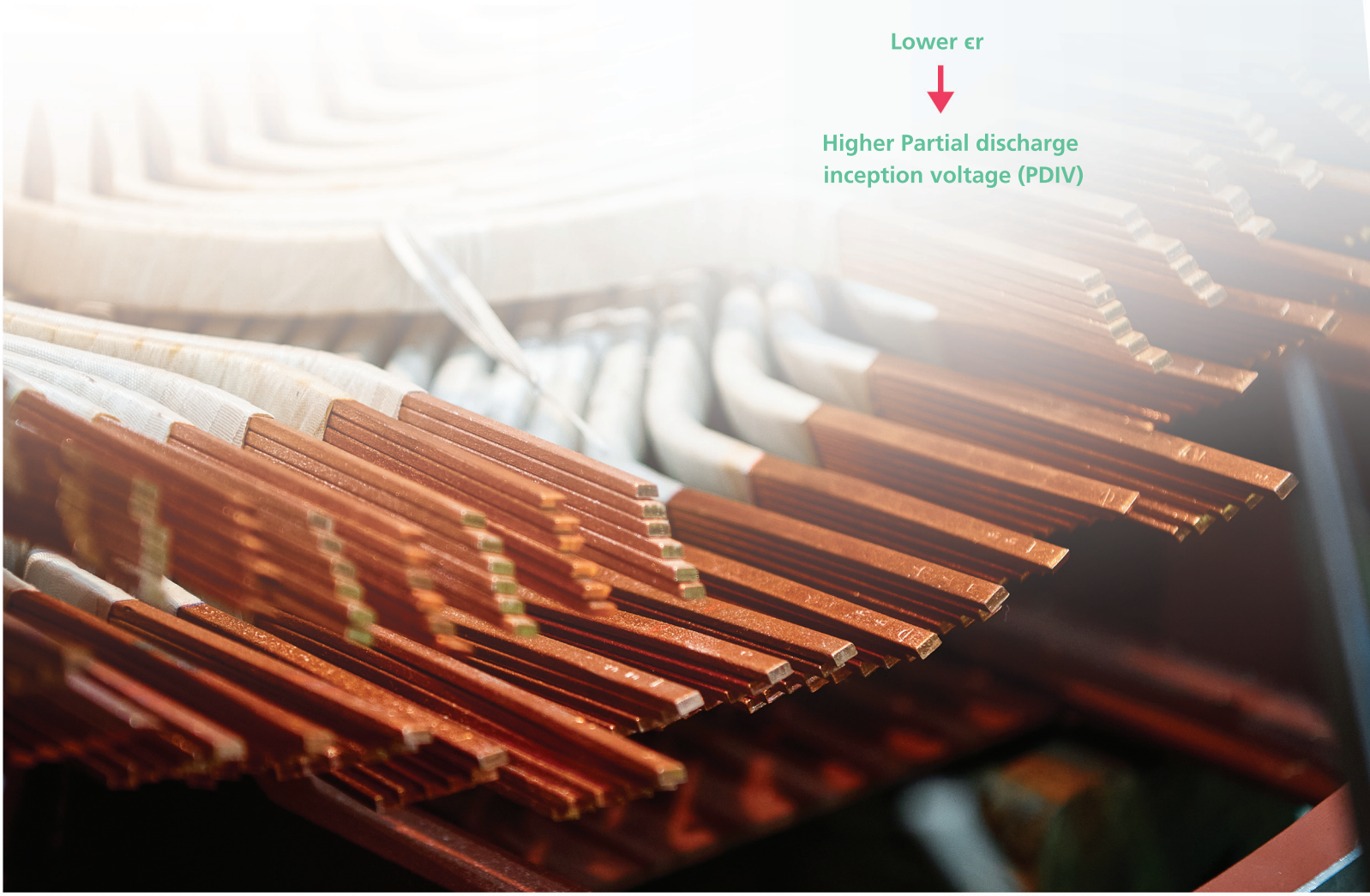
Dielectric Constant

$$\epsilon_r = \frac{\epsilon}{\epsilon_0}$$

Lower εr

↓

Higher Partial discharge inception voltage (PDIV)



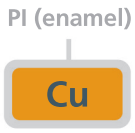
Fluon+ EA-2000

Fluon+ Adhesive PFA EA-2000

- Recommend powder and water-based dispersion
- Processed by dipping/oven-curing

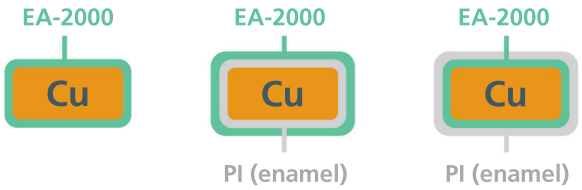
Current Construction

- Insufficient reliability for high voltage
- Pinhole defect

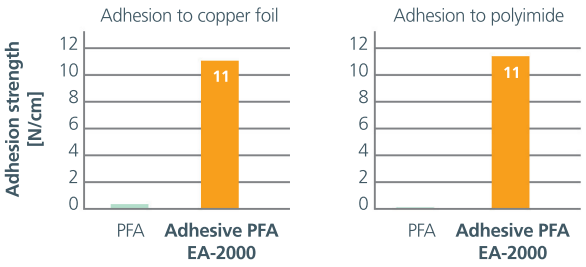


Our Solution

- Strong adhesion to Cu/PI
- Better electrical insulation



Adhesion to Copper and Polyimide



Fluon+ EA-2000 provides
better adhesion to PI and Cu as compared to
neat PFA without sacrificing original performance.

Water-based dispersion

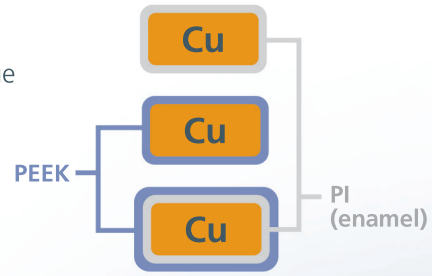
Powder

Fluon+ PFA and PEEK-based Compounds

- Customized compounds to your specification in pellet form
- Processed by extrusion coating method

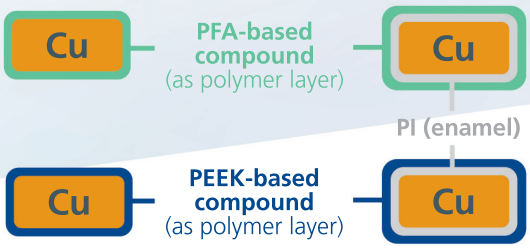
Current Construction

- Insufficient reliability for high voltage
- Pinhole defect
- Poor adhesion (primer needs)
- Cracking when bending
- Poor flexibility



Our Solution

- Strong adhesion to Cu/PI
- No cracking (good flexibility)
- Better electrical insulation



PFA-based compound

Better flexibility and adhesion to polyimide and copper without losing outstanding insulation and thermal properties of PFA

Test		Unit	PFA	PFA-based compound
Physical	Melting point	°C	300	300
	Specific gravity	-	2.1	2.1
	Melt flow rate (MFR) 327C/5kg	g/10min	11	11
Mechanical	Tensile strength	Mpa	39	35
	Tensile elongation	%	440	400
	Flex modulus	MPa	560	380
Electrical	Volume resistivity	Ω·cm	$>10^{18}$	$>10^{18}$
	Dielectric constant - εr 1kHz/1MHz	-	2.09	< 2.10
	tanδ 1kHz/1MHz	tanδ	< 0.0003	< 0.0003
	Corona resistance	Hour	> 200	> 200
	PDIV - Mono layer	Hour	1,600	1,700
	Withstand voltage	V	> 10,000	> 10,000
Adhesion testing	to Polyimide	N/cm	Delamination	28.0
	to Copper		2.1	29.1
Thermal	TGA-5wt%	°C	505	508
	TGA-10wt%		520	525

Crack Resistance (Bending Test) - Anti ATF

Immersion condition: 150°C, 500 hr, automatic transmission fluid - 95.5 wt%

MIT Folding Endurance Tester (ASTM D2176)
Flex life count:

PEEK	PI	PFA	PFA-based compound
10^2~10^3	10^2~10^3	10^4	**10^4**

Good Flexibility

Adhesion to Cu/PI

- No damage
- No cracking
- No wrinkles

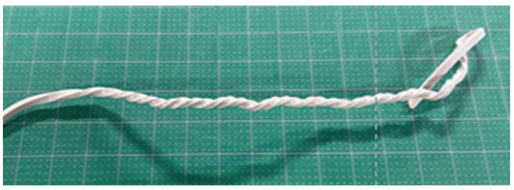
PEEK-based compound: mPEEK

Better flexibility and impact strength than PEEK

Some tests under evaluation

Test		Unit	PEEK A	mPEEK Low flow KB-2220	mPEEK Medium flow KB-2020	mPEEK High flow-2
Physical	Melt flow rate (MFR) 327C/5kg	g/10min	11	8	25	123
Mechanical	Tensile strength	Mpa	96	78	71	54
	Tensile elongation	%	20	99	24	16
	Flex modulus	MPa	3800	3000	2800	2710
	Impact strength - Izod at 23°C	J/m	38	No break	102	135
	Impact strength - Izod at -40°C	J/m	34	95	38	91
Electrical	Dielectric constant - εr 1kHz/1MHz	-	3.2	3.0	2.9	2.9
	tan δ 1kHz/1MHz	tan δ	0.003	0.004	0.005	0.005

Flat Wise + Edge Wise, 180° Bending Test



Material: mPEEK High flow-2
Conductor: 1.5*2.3 mm
Insulation thickness: ~0.11 mm

- No damage
- No cracking
- No wrinkles

Good Flexibility

Impact Resistance

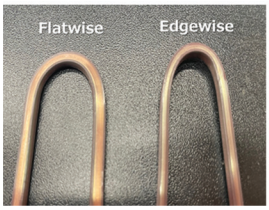
PEEK-based compound: PDX-K

Better insulation properties and flexibility, and adhesion to polyimide and copper

Some tests under evaluation (PDIV, adhesion, etc.)

Test		Unit	PEEK A	PDX-K-22026	PDX-K-22027	PDX-K-22029
Physical	Melt flow rate (MFR) 327C/5kg	g/10min	11	8	25	42
Mechanical	Tensile strength	Mpa	96	98	93	80
	Tensile elongation	%	20	26	31	28
	Flex modulus	MPa	3800	2616	2663	2748
	Impact strength - Izod at 23°C	J/m	38	No break	180	86
	Impact strength - Izod at -40°C	J/m	34	161	125	52
Electrical	Corona resistance	Hour	-	> 200	> 200	> 200
	Dielectric constant - εr 1kHz/1MHz	-	3.2	2.7	2.7	2.7
	tan δ 1kHz/1MHz	tan δ	0.003	0.004	0.002	0.002

Flat Wise + Edge Wise, 180° Bending Test



Material: PDX-K-22027
Conductor: 1.8*2.3 mm
Insulation thickness: ~0.12 mm

Mandrel winding test IEC 60851-3

- No damage
- No cracking
- No wrinkles

εr/PDIV

Good Flexibility

Adhesion to Cu/PI

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