Compound Solutions for High Voltage Wire Insulation

AGC Chemicals Americas, Inc.

Fluon+™
Enhanced Material Science

Your Dreams, Our Challenge

Fluon+ Benefits

- Excellent electrical and insulating properties
- Wide range of operating temperatures
- Heat and chemical resistant
- Lower dielectric constant
- Higher partial discharge inception voltage (PDIV)

Material	Dk	Dk @200 ℃	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	$>10^{14}$

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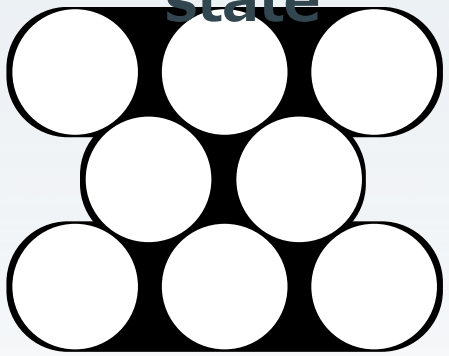
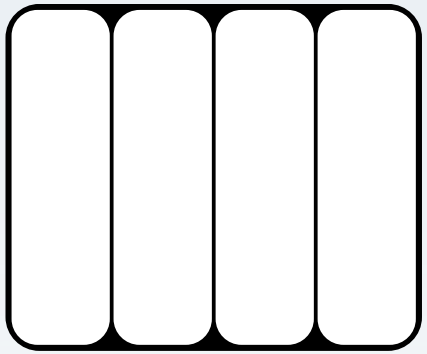
Evolution of Magnet Wire for EV, HEV, PHEV

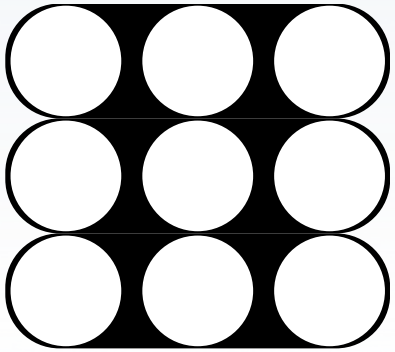
Round wire current state



Occupancy: **78%**



96%



88%

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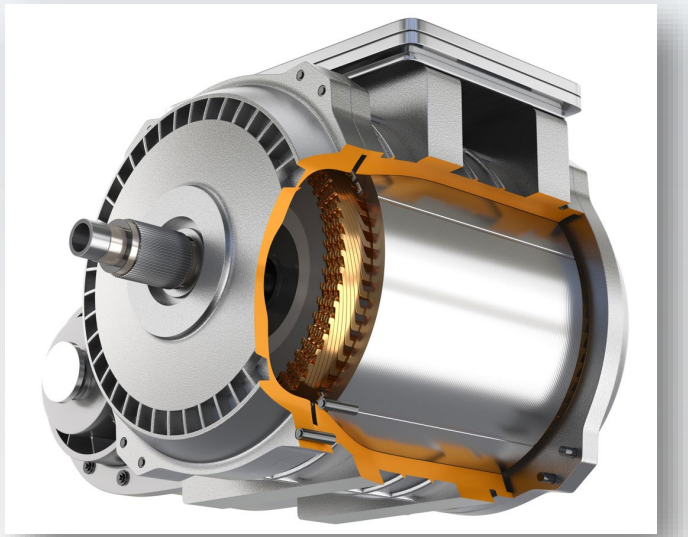
Requirements for Next Generation Magnet Wire

- Fuel/motor efficiency
- Increased output density (>800 V)
- Increased PDIV (1500+ V)
- Space saving
- Higher motor output



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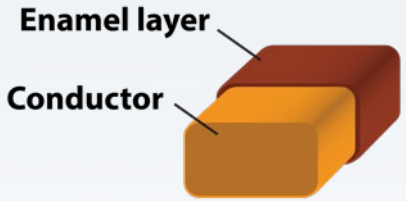
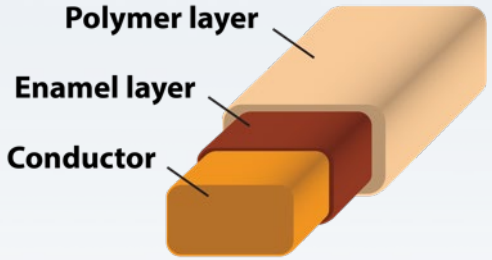
Evolution of Wires for EV, HEV, PHEV Inverter-Drive Motors



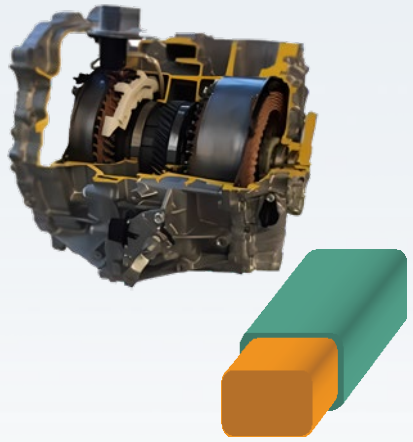
Enamel layer: PI, PAI, etc

200 V



Enamel layer: PI, PAI, etc.
Polymer layer: PEEK, PPS, etc

400 V



Single polymeric layer

Next generation=800 V+

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Structural Changes of Wires for EV, HEV, PHEV Inverter-Drive Motors

Current Structure
200 V

- Enamel layer
- Maximum 50μm thickness
- Insufficient reliability for high voltage
- Pinhole defect

Current Structure
400 V

- Primer required to overcome lack of adhesion
- Cracking/wrinkles when bent
- Poor flexibility

Next Generation
800 V+

- Single layer structure
- Heat resistant
- High flexibility
- Low dielectric constant
- High PDIV
- Varnish/enamel-free

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Why is Higher PDIV Required?

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

Next generation-800 V+

- Instantaneous voltage during sudden braking and sudden acceleration is 2 to 3 times the normal voltage
- **For 400 V motor**, instantaneous voltage can be within PDIV ⇒ Partial discharge does not occur
- **For 800 V+ motor**, instantaneous voltage exceeds PDIV ⇒ Partial discharge occurs

>> Higher PDIV

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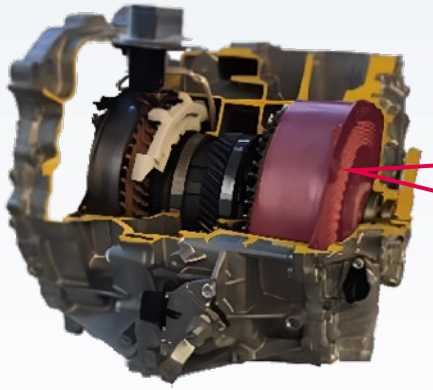
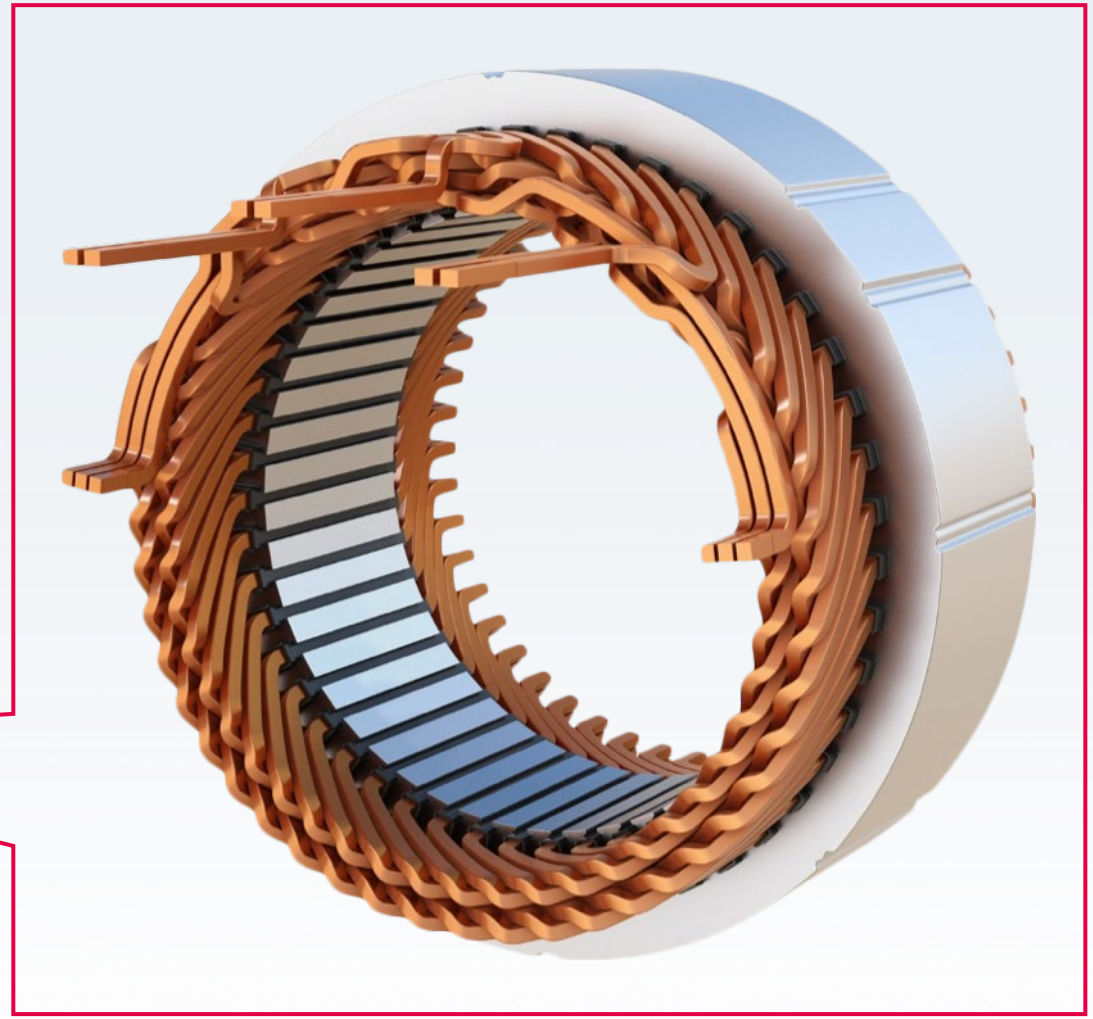
Why Flexibility Requirement?

Wires in motor stator are winded and bended for more occupancy rate of the stator



Main motor



Wires in motor stator

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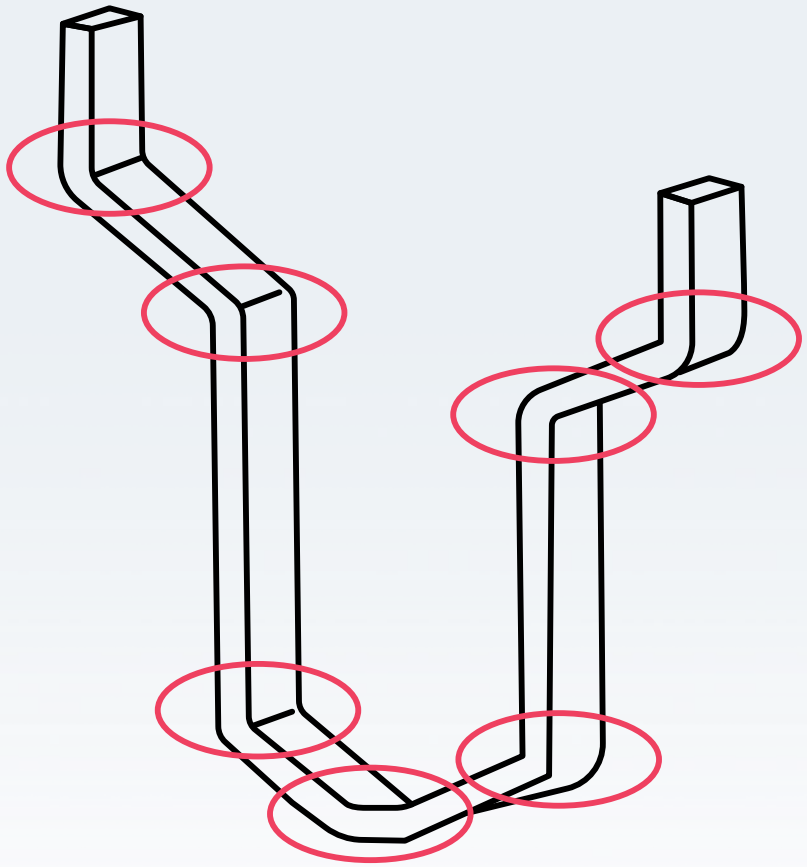
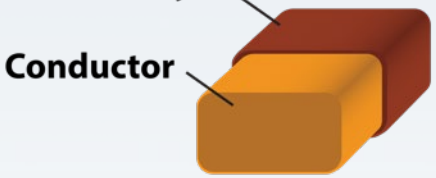
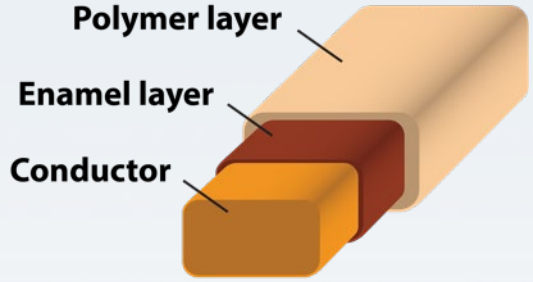
Why is Flexibility Required?





Enamel layer: PI, PAI, etc



Enamel layer: PI, PAI, etc.
Polymer layer: PEEK, PPS, etc

- Avoids cracking and wrinkles when bending
- Partial discharges are easier to occur at corners

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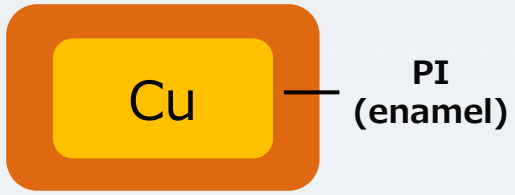
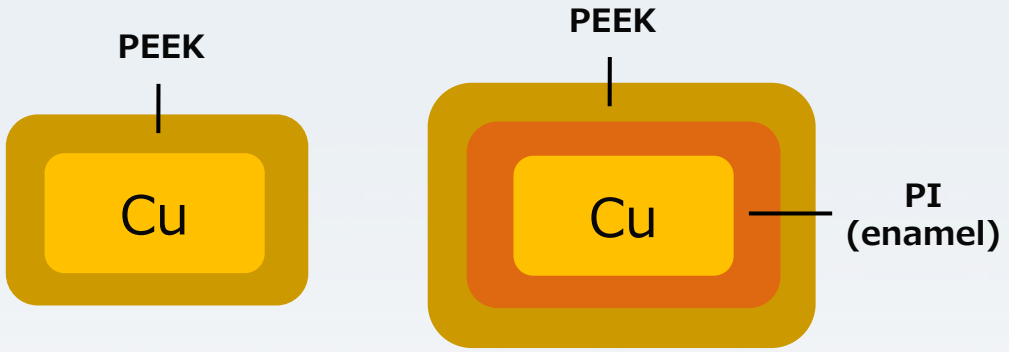
Existing Materials for Extrusion Coating



- Insufficient reliability for high voltage
- Pinhole defect



- Poor adhesion (primer needs)
- Cracking when bending
- Poor flexibility

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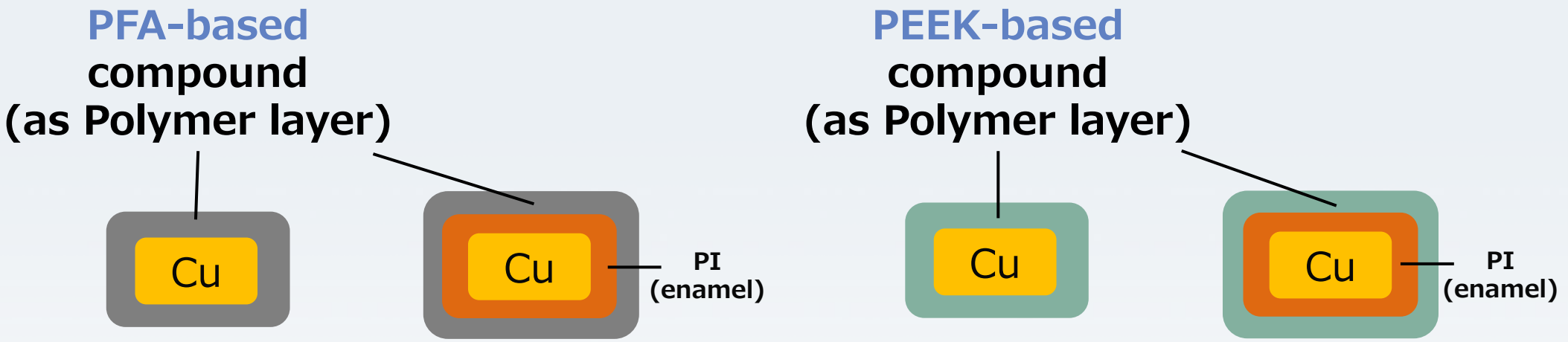
AGC's Solution for Extrusion Coating



Benefits

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

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High Voltage Wire Insulation Materials

Test	Neat PEEK	PPS compound	ETFE compound	XL-ETFE compound	PFA compound	PEEK compound
Dielectric constant, εr	3.2	3.0	2.6	2.6	2.1	2.8
PDIV, RT	Poor	Poor	Very Good	Very Good	Excellent	Good
PDIV, 200 °C	Poor	Good	Very Good	Very Good	Excellent	Good
Flexibility (adhesion to the copper core and reduced cracking)	Poor	Good	Good	Good	Excellent	Excellent
Corona resistance	Poor	Poor	Good	Good	Excellent	Excellent
ATF resistance	Good	Good	Excellent	Excellent	Excellent	Excellent

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PFA-Based Compound

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

Adhesion to Cu/PI

Flexibility

Flat wise + edge wise bending testing

No damage, no cracking, no wrinkles

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PFA-Based Compound

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/10 min	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	–	2.09	< 2.10
	Tanδ 1kH/z/1MHz	tanδ	< 0.0003	< 0.0003
	Corona resistance	Hour	> 200	> 200
	PDIV	V	1,600	1,700
	Withstand voltage	V	> 10,000	> 10,000
Adhesion	to Polyimide	N/cm	Delamination	**28.0**
	to Copper		2.1	**29.1**
Thermal	TGA-5wt%	C	505	508
	TGA-10wt%		520	525

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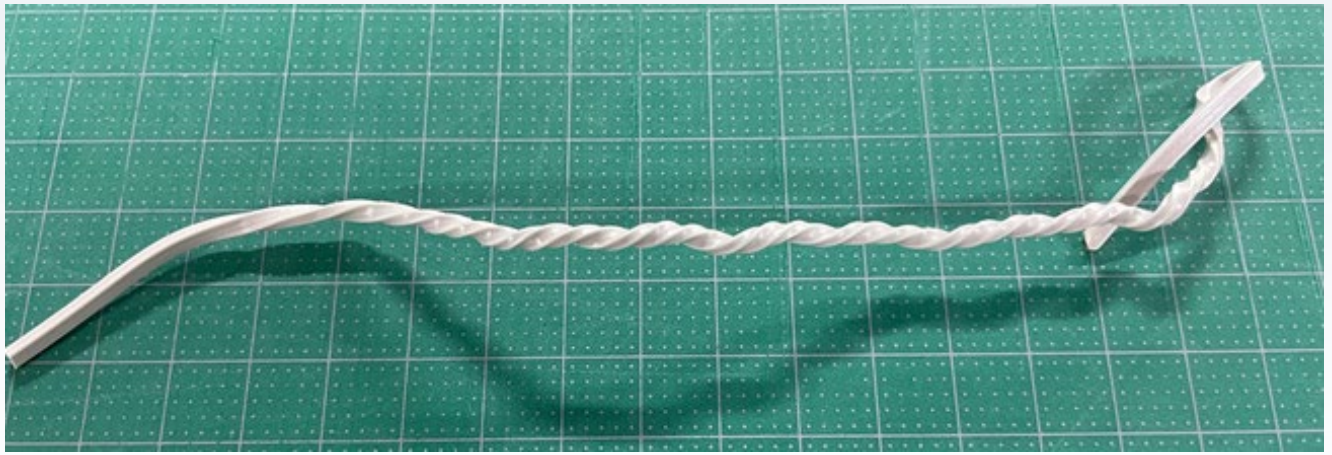
PEEK-Based Compound: mPEEK

- Better flexibility and impact strength than PEEK
- Flexible
- Impact resistant
- Tests under evaluation: mPEEK High flow-2



Flat wise + edge wise, 180° bending testing

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PEEK-Based Compound : mPEEK

Test		Unit	PEEK A	mPEEK Low Flow KB-2220	mPEEK Medium Flow KB-2020	mPEEK High Flow - 2
Physical	Melt flow rate (MFR) 372 °C/5kg	g/10min	22	8	23	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**	**2.9**
	tanδ 1kHz/1Mhz	Tanδ	0.003	0.004	0.005	0.005

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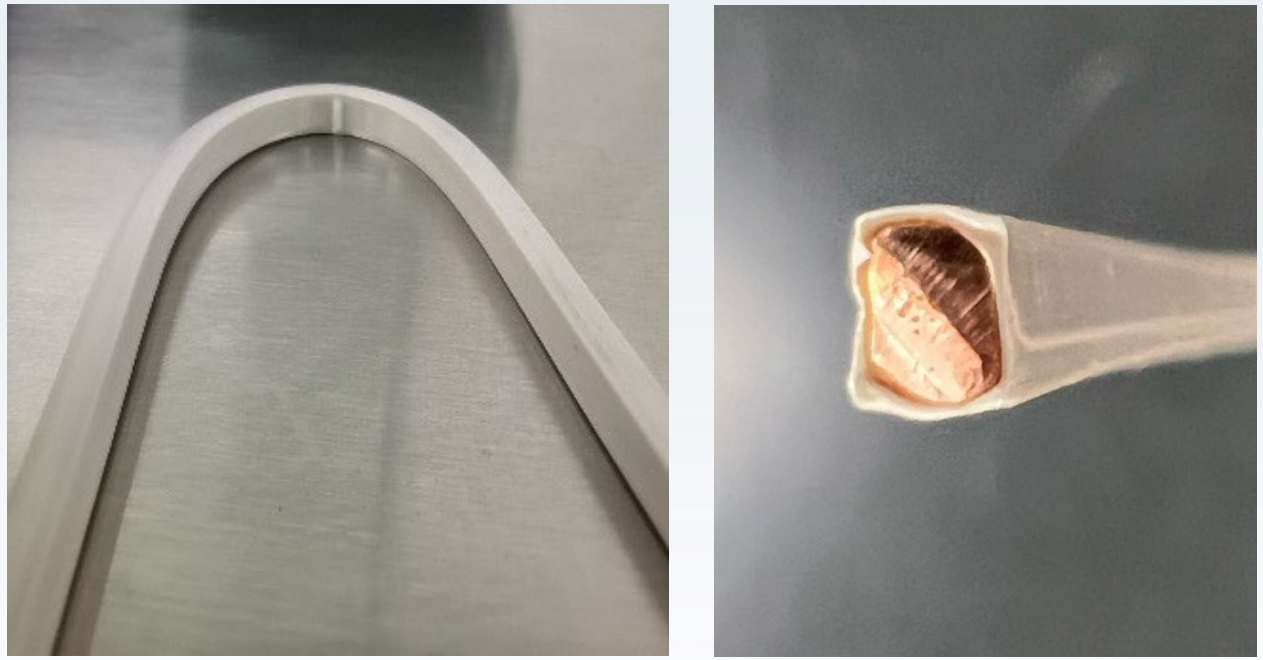
PEEK-Based Compound: PDX-K

- Better insulation properties, flexibility
- Better adhesion to polyimide and copper
- No damage, cracking or wrinkles
- Tests under evaluation (PDIV, adhesion)



Flat wise + edge wise, 180° bending testing

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PEEK-Based Compound: PDX-K

Test		Unit	PEEK A	PDX-K-22026	PDX-K-22027	PDX-K-22029
Physical	Melt flow rate (MFR) 375C/5kg	g/10min	22	10	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 at 23C	J/m	38	**No break**	**180**	**86**
	Impact strength at -40C	J/m	34	**161**	**125**	**52**
Electrical	Corona resistance	Hour	-	**>200**	**>200**	**>200**
	Dielectric constant - εr	-	3.2	**2.7**	**2.7**	**2.7**
	Tanδ 1kHz/1MHz	tanδ	0.003	0.004	0.002	0.002

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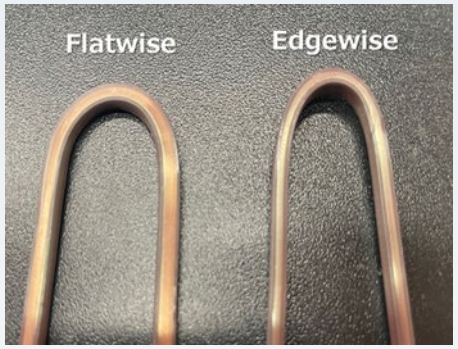
PEEK-based Compound: PDX-K

Mandrel winding test (IEC 60851-3)

Test machine



Material:PDX-K-22027

Conductor:1.8*2.3 (mm)
Insulation thickness:apprx.0.12mm

No damage
No cracking
No wrinkles

- ε_r/PDIV
- Flexibility
- Adhesion to Cu/PI

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

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