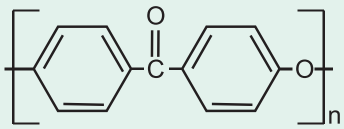
PEK

Polyether Ketone (G-PAEK™)

With a glass transition temperature of 152°C (305°F) and a melting temperature of 372°C (701°F), G-PAEK™ polymer delivers extended high temperature performance over standard PEEK polymer while offering the same advantages such as toughness, strength and chemical resistance. Available as unfilled, glass filled and carbon filled grades.



Polyether Ketone (PEK)

Advantages of PEK polymer

- Delivers up to two times the wear resistance of PEEK standard polymer at high tempertatures.
- Retention of mechanical and physical properties to temperatures of 20°C higher than PEEK standard polymer supporting higher loads without permanent deformation.
- Improved compressive strength.
- A strong candidate for engine parts, subsea connectors and heat exchanger applications.
- Excellent gamma radiation resistance, making it suitable for nuclear power applications.
- Excellent hydrolysis resistance at high temperatures.
- Excellent high temperature performance for all mechanical properties.
- Excellent electrical performance at high temperatures.
- Excellent chemical resistance at high temperatures.

1. G-PAEK™ Grades:

G-PAEK™ is available in a variety of grades for specific applications, and the main grades available are the following:

Standard Unfilled PEK Polymers

Virgin PEK polymers is available as powder or granules in following grades:

Ultra high performance thermoplastic material, unreinforced Poly Ether Ketone (G-PAEK™), semi crystalline, coarse powder for extrusion compounding, easy flow, FDA food contact compliant, colour natural.

Grade	Powder	Applications
1100P/PF	High Viscosity	Compression Molding
1200P/PF	Medium Viscosity	Compounding/Coating
1400P/PF	Low Viscosity	Compounding/Coating

Granules materials may be considered as the general purpose extrusion and Injection molding grades. The standard flow (1200G) and high flow materials are suitable for use in wire coating & monofilament.

Grade	Granules	Applications
1100G	High Viscosity	Stock Shapes
1200G	Medium Viscosity	Injection Molding/Compounding
1400G	Low Viscosity	Injection Molding/Compounding

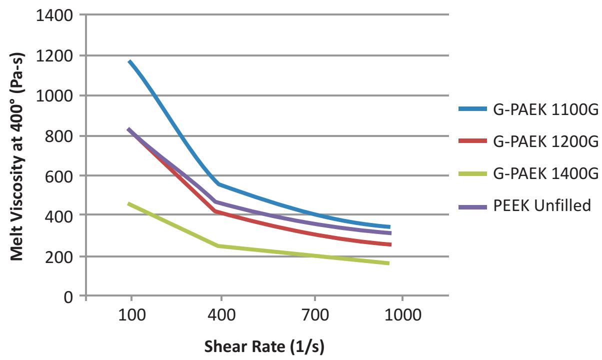


Fig. 1 Shear Rate versus Melt Viscosity of different grades of G-PAEK™ Polymer

Glass Fiber Filled Grades

The addition of glass fiber reinforcement greatly increases the general mechanical properties at a given temperature (tensile strength, flexural strength and flexural modulus), and reduces the elongation at break and impact strength at low temperatures.

Grade	Glass Fiber Filled
G-PAEK 1215GF	15% Glass Fiber Filled with Standard flow, Natural Beige in color and also available in Blue and Black color
G-PAEK 1230GF	30% Glass Fiber Filled with standard flow, Beige in color and also available in Black color
G-PAEK 1220GF	20% Glass Fiber Filled with Standard flow, Beige in color.

The above grades used for injection molding grades and extrusion operation.

Carbon Fiber Filled Grades

Carbon fiber filled grades of PEK also have much reduced thermal expansion rates and greatly improved thermal conductivity.

Grade	Carbon Fiber Filled
G-PAEK 1220CF	20% Carbon Fiber Filled with Standard flow, Black in color.
G-PAEK 1230CF	30% Carbon Fiber Filled with Standard flow, Black in color.

Tribological Grade (1230FC, 1215FC)

G-PAEK™ (PEK) has excellent wear resistance properties as such. Tribological grades are a combination of carbon fiber, PTFE, graphite/MoS_2 reinforced in Polyether Ketone and G-PAEK™ (PEK) 1230FC has very low wear rate: 6-7 X10^{-16} m^3/Nm at very high load of 700 - 800 N. Also have very low coefficient of friction: 0.15.

Grade	Tribological Grades
G-PAEK™ 1215FC	Standard Flow, Carbon/Glass Fiber, Graphite, PTFE & MoS_2
G-PAEK™ 1230FC	Standard Flow, Carbon/Glass Fiber, Graphite, PTFE & MoS_2
G-PAEK™ 1240FC	Standard Flow, Carbon/Glass Fiber, Graphite, PTFE & MoS_2

PEK Blends

G-PAEK™ (PEK) 2000 series is available as blends with PEK/PEEK/PEKK polymers in various proportions. The blends are thermally stable thermoplastics with improved toughness, excellent mechanical performance at very high temperatures up to 300°C. They retain mechanical properties well above glass transition temperature. G-PAEK™ (PEK) 2500G is having improved glass transition temperature (170°C) & HDT (180°C)

Grade	PEK Blends Grades
G-PAEK™ 2300G	Improved Toughness
G-PAEK™ 2500G	Improved Tg & melting point

2. Mechanical Properties:

2.1 Tensile Properties:

The tensile properties of G-PAEK™ polymer surpass those of most engineering thermoplastic polymers.

G-PAEK™ polymer is used to form structural components which experience or continuously operate at high temperature. Fig. 2, A plot of Tensile Strength vs Temperature for G-PAEK™ (PEK) polymer, illustrates a High retention of mechanical properties over a broad temperature range.

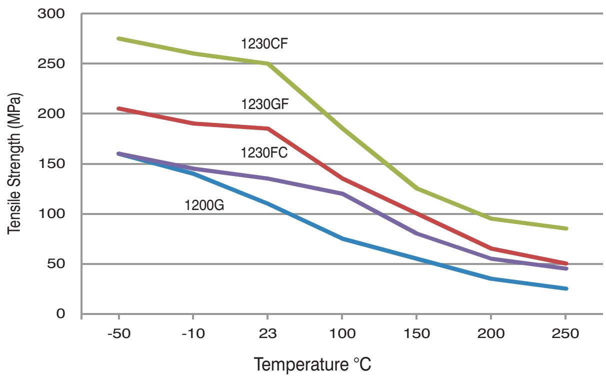


Fig. 2 Tensile strength versus Temperature for G-PAEK™ Polymer materials.

2.2 Flexural Properties:

G-PAEK™(PEK) polymer and the high-performance compounds based on PEK Polymer exhibit outstanding flexural performance over a wide range. Fig. 3, Shows a plot of Specific flexural modulus comparison of PEK compounds vs. Different Metals. PEK with 30% & 40 % CF have better sp. flexural modulus compare to bronze.

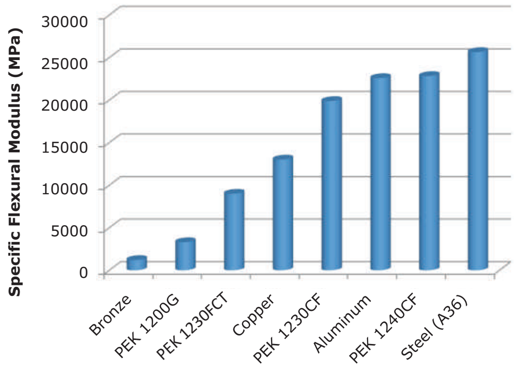


Fig. 3, A plot of Specific flexural modulus comparison of PEK compounds vs. Different Metals.

2.3 Impact Properties:

The impact properties of the material are strongly dependent on test geometry (Notch radius and position), temperature, impact speed and condition of sample.

3. Thermal Properties:

G-PAEK™(PEK) polymer has a glass transition temperature of 152°C and, since it is a semi-crystalline thermoplastic, retains a degree of mechanical properties close to its melting temperature 372°C.

3.1 Short term effects:

The short term thermal performance of material may be characterized by determining the Heat distortion temperature (HDT, ASTM D 648). This involves measuring of temperature at which a defined deformation is observed in a sample under constant applied stress. A comparative chart of high performance material using ASTM D 648, HDT values (Fig. 4) for a defined applied stress of 1.82 MPa shows that G-PAEK™ (PEK) polymer compounds are superior

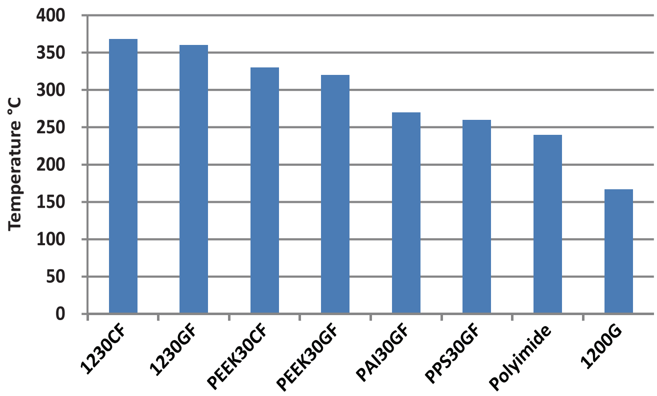


Fig. 4 Heat Distortion Temperature for Range of High Performance Materials.

MPa shows that G-PAEK™ (PEK) polymer compounds are superior to most of the other polymeric composites.

3.2 Heat Ageing:

Heat ageing experiments involve exposing test bars to constant temperatures over a pre defined time and subsequently measuring the tensile property.

The retention of these properties is calculated with respect to control

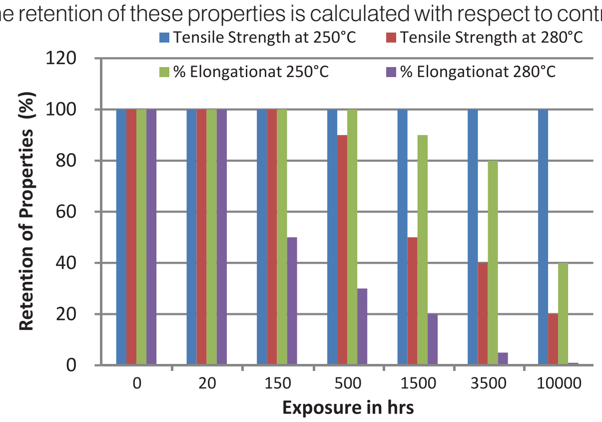


Fig. 5 Tensile strength and Elongation to break Versus Heat Ageing Time for G-PAEK™ 1200G Polymer.

and is used as a measure of the thermal ageing performance. The outstanding percentage retention of tensile strength and elongation to break for G-PAEK™ (PEK) 1200G polymer is plotted versus conditioning time in Fig. 5.

3.3 Dynamic Mechanical Analysis (DMA):

The Dynamic Mechanical properties of G-PAEK™ (PEK) polymer surpasses those of most engineering thermoplastics. The thermomechanical behavior of G-PAEK™ (PEK) materials is

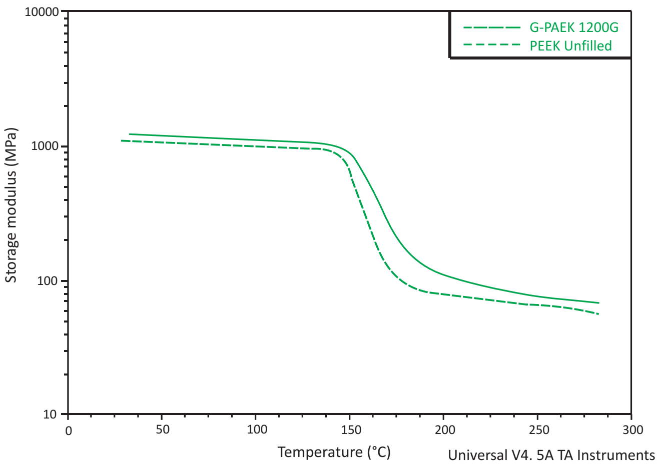


Fig. 6 Storage modulus vs Temprture for G-PAEK™ polymer material

provided by dynamic mechanical analysis (DMA).

This storage modulus represents the recoverable elastic energy stored in a viscoelastic material during deformation. Fig. 6, A plot of Storage Modulus vs. Temperature for G-PAEK™ (PEK) 1200G & PEEK Unfilled, illustrates G-PAEK™ (PEK) 1200G showed highest

Storage Modulus vs. Temperature for G-PAEK™ (PEK) 1200G & PEEK Unfilled, illustrates G-PAEK™ (PEK) 1200G showed highest storage modulus against PEEK Unfilled with respect to Temperature.

3.4 Thermal Conductivtiy:

The thermal performance of material may be characterized by determining the Thermal Conductivity (ASTM E 1530). Thermal conductivity is the property of a material's ability to conduct heat.

Heat transfer across materials of high thermal conductivity occurs at a faster rate than these with materials of low thermal conductivtiy (Fig 7) for a defined applied condition shows that G-PAEK™ (PEK) polymer compounds are superior thermal properties. Conductive carbon fibers & conductive fillers filled grades also improve thermal conductivity of G-PAEK™ (PEK) compounds.

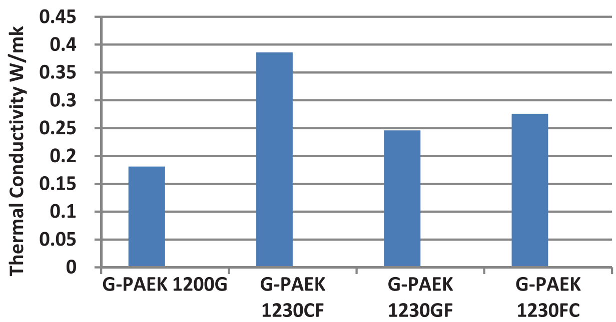


Fig. 7 Thermal Conductivity for range of G-PAEK™ compounds

4. Flammability and Combustion Properties:

In case of fire, the thermal and chemical environment is constantly changing. Therefore it is difficult to simulate the conditions experienced by material in a fire situation. The four commonly accepted variables are flammability, ignitability, Smoke and toxic gas emission. The chemical structure of G-PAEK™ (PEK) polymer is highly stable and requires no flame retardant additives to achieve low flammability and ignitability values. The composition and inherent purity of G-PAEK™ (PEK) polymer results in excellent smoke and toxicity performance.

4.1 Flammability

G-PAEK™ (PEK) polymer has been rated as UL94-V0 [0.8 mm thickness] which is the best possible rating for flame retardancy.

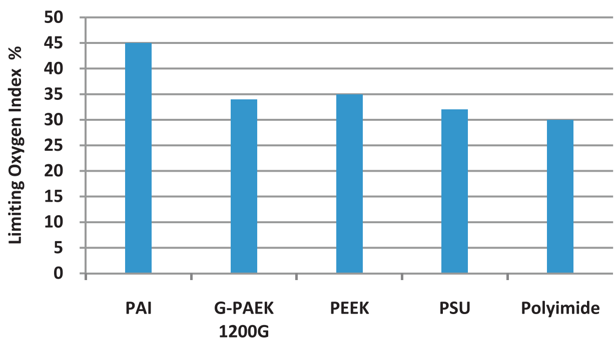


Fig. 8 Limiting Oxygen Index for a range of Engineering Polymers.

4.2 Ignitability:

The ignitability of a material may be considered in terms of minimum concentration of oxygen which will just sustain a flame ignited from high energy source (ASTM D2863- 95). A comparative chart of the limiting oxygen index (LOI) for a range of engineering polymers is shown in Fig. 8

The current standard for the measurement of smoke produced by the combustion of plastic materials is ASTM E662. This uses the National Bureau of Standards (NBS) smoke chamber to measure the obscuration of visible light by smoke generated from the combustion of a standard geometry sample in units of specific optical density. The test may be carried out with either continuous

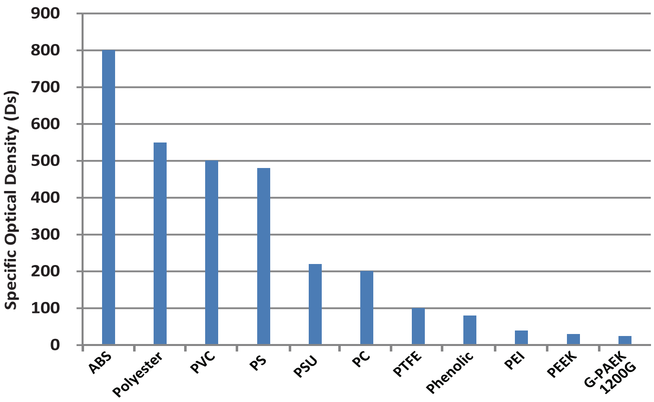


Fig. 9 Specific Optical Density for a Range of Engineering Thermoplastic measured in Flaming mode for 3.2 mm Thick Samples

ignition (flaming) or interrupted ignition (non-flaming). A comparative chart of the specific optical density for a range of engineering plastics is shown in Fig. 9 at natural G-PAEK™ (PEK) polymer has the lowest value of specific optical density of all the materials tested.

4.3 Toxic Gas Emission:

The emission of toxic gases during combustion of a polymer cannot be considered purely as a function of the material. The component geometry, heat release, conditions of the fire and the synergistic effects of any toxic gases affect the potential hazard of the material in an actual fire situation. The extremely low concentrations of toxic gases emitted have been evaluated using the Aircraft Standards (BSS 7239, ATS1000/ABD0031). This procedure involves the complete combustion of a 100 g (0.22 lb) sample in a 1 m^3 (35.3 ft^3) volume and subsequent analysis of the toxic gases evolved. The toxicity index is defined as the summation of the concentration of gases present normalised against the fatal human dose for a 30 minute exposure.

G-PAEK™ (PEK) 1200G gives a low toxicity index with no acid gases detected.

5. Electrical Properties:

G-PAEK™ (PEK) is often used as an electrical insulator with outstanding thermal, physical and environmental resistance.

5.1 Volume Resistant and Resistivity:

The larger the volume resistivity of a material, the longer the time required to reach the steady-state current. G-PAEK™ (PEK) 1200G has an IEC 93 value of 6.5 x 10^{16} cm at ambient temperatures, measured using a steady state current value for 1000 s applied voltage.

5.2 Surface Resistivity:

A comparative bar chart of surface resistivities for some high performance engineering polymers at ambient temperatures is shown in Fig. 10. This shows that natural G-PAEK™ (PEK) 1200G has a surface resistivity typical of high performance materials.

6. Environmental Resistance:

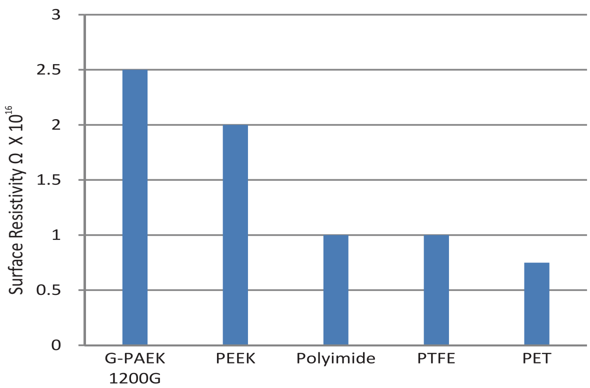


Fig. 10 Surface resistivities for various Engineering Polymers Tested at 25°C with 50% humidity

G-PAEK™ (PEK) polymer can be used to form components which function in aggressive environments or need to withstand frequent sterilisation processes. The useful service life of such devices depends on retention of the physical properties.

6.1 Chemical Resistance:

G-PAEK™ (PEK) polymer is widely regarded to have superb chemicals resistance and is regularly used to form components which function in aggressive environments on need to withstand frequent sterilsation process.

6.2 Radiation Resistance:

Thermoplastic materials exposed to electromagnetic or particle based ionising radiation can become brittle. Due to the energetically stable chemical structure of G-PAEK™ (PEK), components can successfully operate in, or are frequently sterilised by high doses of

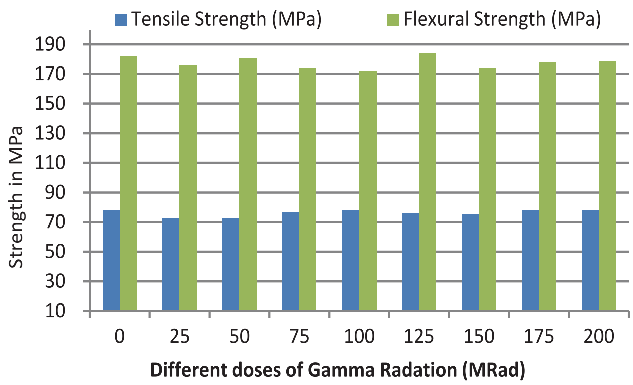


Fig. 11 Tensile Properties Retention versus Gamma Radiation Time for G-PAEK™ 1200G

successfully operate in, or are frequently sterilised by high doses of ionising radiation. G-PAEK™ (PEK) polymer has a greater resistance to radiation damage than the other materials.

6.3 Hydrolysis Resistance:

G-PAEK™ (PEK) polymer and compounds are not chemically attacked by water or pressurised steam. These materials retain a high level of mechanical properties when continuously conditioned at elevated temperatures and pressures in steam or water. The compatibility of these materials with steam was evaluated by conditioning injection moulded tensile and flexural bars at 200°C (392°F) and 1.4 Mpa (200 psi) for the times indicated in Table 1. The data in table 1 demonstrates the ability of components made from

Property	Time/ Hrs			
	0	75	350	1000
Tensile Strength	ASTM D 638, 5 mm/min			
1200G	105	110	105	100
1230GF	185	195	180	175
1230CF	250	260	250	240
1230FC	140	150	140	135

Table 1 Comparison of the Mechanical Properties of G-PAEK™ materials After Conditioning in Steam at 200°C and 1.4 MPa

G-PAEK™ (PEK) to continuously operate in or be frequently sterilised by steam. The initial increase in the mechanical properties is due to the relaxation of moulded-in stresses and further developments in crystallinity due to thermal treatment.

7. Tribological:

PEK polymers, and its compounds based on PEK polymers, are used to form tribological components due to their outstanding resistance to wear under high pressure and high velocity conditions.

Tribological may be defined as the interaction of contacting surfaces under an applied load in relative motion.

7.1 Specific Wear Rate:

The lower the wear rate or wear factor, the more resistant the material is to tribological interactions. Fig. 12 shows the comparative wear factor bar chart for G-PAEK™ (PEK) 1230FC & G-PAEK™ (PEK) 1230FCT has an extremely low wear factor.

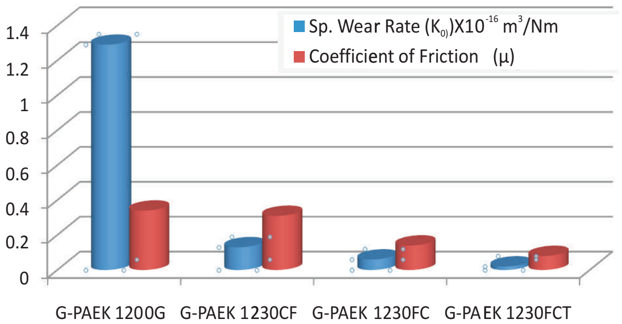


Fig. 12 Specific wear resistance and coefficient of friction at 400 N load, Temperature 23°C of different grades of G-PAEK™

7.2 Coefficient of Friction

The special tribological grades formulated by Gharda Plastics (G-PAEK™ (PEK) 1230FC & G-PAEK™ (PEK) 1215FC), contains optimum levels of PTFE and graphite powder to reduce and maintain the COF at a low value, For G-PAEK™ (PEK) 1230FC the COF is 0.14.

7.3 Abrasion Resistance:

The ability of a material to withstand mechanical action such as rubbing, scraping or erosion, that tends progressively to remove material from its surface. The Abrasion resistance of G-PAEK™ (PEK) Polymer and its compounds range were evaluated using the Abrasion Resistance test (ASTM D 1242, Wheel: CS-17, Load: 1000 gm) The data in Figure shows that natural G-PAEK™ (PEK) polymer has the lowest value of loss in weight.

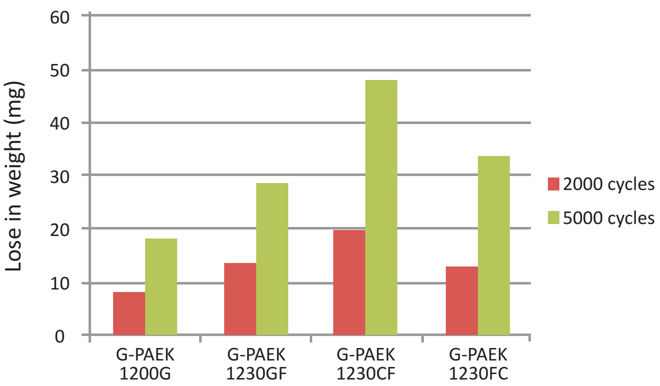


Fig. 13 Abrasion resistance at 1.0 Kg load & CS-17 abrasive wheel of different grades of G-PAEK™

8. Processing:

G-PAEK™ (PEK) can be processed by Injection molding, Extrusion as well as Compression molding similar to other engineering plastics. The screw and barrel assembly should be of bimetallic construction. Melting point of PEK is 372°C and therefore, barrel and cylinder temperature should be set at a higher value than that, between 385 ~ 410°C. The mold temperature should be around 200-220°C.

G-PAEK™ (PEK) absorbs about 0.05 - 0.1 % moisture and therefore, it needs pre-drying at 150-180°C for 2-3 hours by dehumidifier or air circulating type dryer. Processing temperature of G-PAEK™ (PEK) is high as described however thermal stability of G-PAEK™ (PEK) is very high and therefore; chance of thermal deterioration at the time of processing is less.

PROCESSING METHOD	APPLICABLE
Injection Molding	Yes
Extrusion (profile, sheet, monofilament, multi filament, and steaple fibre)	Yes
Compression Molding	Yes
Powder Coating (Electrostatic, thermal spring, and emulsion coating)	Yes

PEK Applications

Typical Applications: The outstanding mechanical properties of G-PAEK™ (PEK) at high temperatures make it suitable for the most demanding applications, but the high cost sometimes limits applications to those where the properties are very necessary. Typical applications are the following:

Automotive: Engine: Oil pump, Mass Balance Gear, Cam Shaft Bearing, Washer, Turbocharger Impeller / **Transmission:** Seal ring, Thrust Washer, Check Ball, Fork Pad / **Steering/Suspension:** EPS Gear, Steering Column Adjust, Ball Joints, and Column Sleeve / **Seat Adjustment:** Worm Gear / **Damper/Clutch:** Friction Ring, Washer / **Lighting:** Lamp Socket / **Fuel Management:** Bushing, Pump Shoe, Fuel Liner, Quick Connect / **Electronic/Sensor:** Wiring, O_2 Sensor / **HVAC:** Compressor Seal, Gears Mode Door / **Door Modules:** Door Hinge, Roller, Gears / **Small Motor:** Thrust Plug, Washer / **Vacuum Pumps:** Tip, Vane, Rotor / **Brakes:** Tappet, Piston /

Aircraft: Unmanned Aerial Vehicle (UAV) structures, transport planes (C-17) fuel line isolator, cargo rollers, avionics, connectors, braided sleeves, fighter and helicopter structures.

Nuclear: Used as a coating because of its exceptional resistance to radiation and also used for cable sheathing.

Electronics: Signal Relays, Interposer Covers, Capacitor Covers, Connectors, Battery Components, Telecom Coaxial Plugs, Microphone Spacer Films, Gaskets for Secondary Batteries or Capacitors, Printer/Copier Parts-Gears, Split Fingers, Bushings, Fuser Rollers.

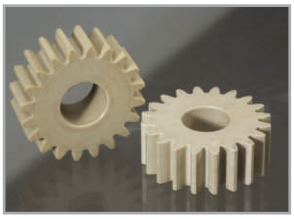
Food Applications: Components for machines and equipment for food and beverage processing, e.g., ovens, freezers, fryers, mixers, ultra filtration membranes, filling machines, etc. Production of food containers for heating or cooking in an oven, microwave or combi-oven. Injection molded parts such as bearings, seats and seals that are used in appliances and food processing equipment. As a coating, predominantly for the coating of metal components in food-processing equipment, consumer and industrial cookware and bakeware.

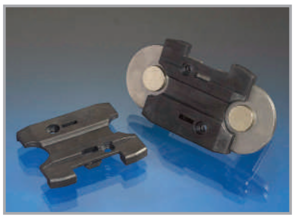
Medical: Tubing Housings, Endoscopy, Chromatography, Catheters, Gears, Laparoscopy, Chemical Testing, Blood Management, Bushings, Electrosurgical, Bio-Hazard Handling, Drug Delivery, Valves, Operating Room, Dialysis Hardware, Sterilizing Hardware, Dental Tools Pumps & Motors

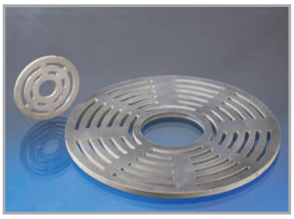
Oil & Gases: Data logging tools, Seals and back up rings, Cable insulation, Cable ties, Down-hole / sub-sea connectors, Plugs and packers, Submersible motor parts, Bearings and bushings, Compressor parts

Textiles: Bearings and Bushings, Yarn and Thread Guides, Wear Plates, Fuse Pressing Belts

Coating: Electrostatic coating, cookware, industrial part coating,







GHARDA CHEMICALS LIMITED
(Marketing & Application Development Center)
GIST, B-26/27/29, Phase-1 MIDC. Dombivili (East), District: Thane, Maharashtra. INDIA.
Tel.: +91-251-2803380–86 Fax: +91-251-2430581 / 2446363 / 2432640 Email: polymer@gharda.com, Web: www.ghardaplastics.com

Corporate Office: 6B Gharda House, 48 Hill Road, Bandra (W) Mumbai - 400050 (INDIA)
Tel.: 91-22-33065600 Fax: 91-22-26404224 Website: www.gharda.com

TYPICAL PROPERTIES	TEST METHOD/CONDITIONS	UNIT	G-PAEK™ 1100G	G-PAEK™ 1200G	G-PAEK™ 1400G	G-PAEK™ 1215GF	G-PAEK™ 1230GF	G-PAEK™ 1230CF	G-PAEK™ 1215FC	G-PAEK™ 1230FC	G-PAEK™ 1240FC	G-PAEK™ 1250FC	G-PAEK™ 1220FE
General Properties													
Density	23°C	g/cc	1.30	1.30	1.30	1.40	1.50	1.40	1.43	1.45	1.50	1.69	1.40
Water Absorption	ASTM D 570-98	%	0.08	0.08	0.08	0.08	0.05	0.05	0.08	0.05	0.07	0.07	0.07
Rockwell Hardness	ASTM D 785/M Scale	-	103	103	103	-	105	108	103	106	105	108	-
Shore D Hardness	ASTM D 2240-05	-	87	86	86	87	90	91	86	91	90	91	83
Mold Shrinkage													
(400°C nozzle, 210°C Mold)	Along Flow	%	1.0	1.0	1.0	0.5	0.3	0.11	1.1	0.11	0.31	0.20	1.4
	Across Flow	%	1.3	1.3	1.3	0.8	1.0	0.80	1.3	0.50	0.70	0.82	1.9
Thermal Properties													
Glass Transition Temperature(Tg)	ASTM D 3418	°C	152	152	152	152	152	152	152	152	152	152	152
Melting Point (Tm)	ASTM D 3418	°C	372	372	372	372	372	372	372	372	372	372	372
Heat Deflection Temperature (HDT)	ASTM D 648 /1.8 MPa	°C	185	180	172	348	354	356	195	126	-	-	167
Coefficient of Linear Thermal Expansion (CLTE)	ASTM D 696/ Below Tg	X 10^{-5}/°C	1.1	1.1	1.1	-	2.3	1.4	-	1.4	-	-	-
	ASTM D 696/ Above Tg	X 10^{-5}/°C	1.9	1.9	1.9	-	2.4	1.9	-	1.5	-	-	-
Thermal Conductivity	ASTM E 1530	w/mk	0.181	0.181	0.181	-	0.245	0.385	-	0.275	-	-	-
Continuous Use Temperature (Expected)	UL 746B	°C	280	280	280	280	280	280	280	280	280	280	280
Mechanical Properties at 23°C													
Tensile Strength	ASTM D 638	MPa	110	105	80	125	185	265	101	140	160	140	85
Tensile Modulus	ASTM D 638	GPa	4.3	4.2	4.3	7.8	11.5	28.4	5.2	11.50	27.2	18.0	3.6
Elongation at Break	ASTM D 638	%	20-25	10-15	2-5	2.8	2-3	2-3	5-6	1.5-2	1.5	2.5	2-4
Flexural Strength	ASTM D 790	MPa	190	185	115	220	280	410	180	210	190	220	164
Flexural Modulus	ASTM D 790	GPa	4.1	4.1	4.5	7.7	10.5	28	4.2	10.5	27.5	16.0	4.1
Compressive Strength	ASTM D 695	MPa	130	125	110	140	150	170	-	112	-	-	-
Izod Impact Strength(Notched)	ASTM D 256	J/m	65	60	40	33	60	60	45	45	45	48	45
Izod Impact Strength(Un-notched)	ASTM D 256	J/m	No Break	No Break	No Break	400	610	No Break	400	610	-	-	No Break
Rheological Properties													
Melt Viscosity at 400°C	ASTM D 3835/@1000 s-1	Pa.s	300-350	250-300	140-200	-	-	-	-	-	-	-	250
Electrical Properties													
Dielectric Strength	ASTM D 149	Kvmm-1	17.6	17.6	17.6	-	17.6	0.70	-	0.30	-	-	-
Dielectric Constant	ASTM D 150	-	2.84	2.84	2.84	-	3.3	7.9	-	6.4	-	-	-
Surface Resistivity	ASTM D 257	Ω	10^{16}	10^{16}	10^{16}	-	10^{16}	-	-	-	-	-	-
Volume Resistivity	ASTM D 257	Ωcm	10^{16}	10^{16}	10^{16}	-	10^{16}	10^{6}	-	-	-	-	-
Arc Resistance	ASTM D 495/@ 500 Volts	Sec	175	175	175	-	160	-	-	-	-	-	-
CTI	ASTM D 3638	Volt	150	150	150	-	150	-	-	150	-	-	-
Fire Properties													
Flammability	UL 94/0.8 mm	-	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0	V-0
Recommended Processing Conditions													
Barrel Temperature	-	°C	380-400	380-400	390-420	390-410	390-420	390-420	390-410	390-420	390-420	390-420	390-410
Mould Temperature	-	°C	200-220	200-220	200-220	200-220	200-220	200-220	200-220	200-220	200-220	200-220	200-220