PBI Blends & Alloys

GAZOLE™ 6000 Series

High Temperature Resistance

GAZOLE™ 6000 Series blends are the most thermally stable available thermoplastics in the market, offering excellent mechanical performance at high temperatures up to 300°C. The semi-crystalline material retains its mechanical properties well above the polymer's glass transition temperature.

GAZOLE™ blends are currently the highest performing melt processable thermoplastics for use in applications requiring physical property retention and wear resistance at elevated temperatures. They are a great replacement option for metal & non-melt processable high temperature plastics.

Excellent Tribology

GAZOLE™ Blends are inherently lubricious with very smooth surface finish. They show low sloughing and offer exceptional abrasion resistance

Advantages of GAZOLE™ 6000 Blends

- GAZOLE™ 6000 Blends outperform PAI and PI wear grades in areas of wear resistance.
- Excellent mechanical properties at high temperatures.
- Melt processable thermoplastic.
- No post treatment necessary.
- Offers outstanding chemical resistance and property retention after extended exposures.

1.0 GAZOLE™ 6000 Grades

GAZOLE™ 6000 Series (PEK/PBI) are inherently lubricious with a very smooth surface finish thereby exhibiting low coefficient of friction. They have excellent wear resistance properties, superior to any Engineering Thermoplastic. GAZOLE™ 6000 Series (PEK/PBI) blends are available in variety of grades for specific applications, and the main grades available are the following:

Standard Unfilled GAZOLE™ 6000 Polymers

PEK/PBI blend polymers are available as powder or granules in the following grades:

PEK/PBI (GAZOLE™ 6000), semi crystalline, fine powder for extrusion compounding and compression molding, highly uniform particle size distribution, easy flow, color natural green.

Grade	Flow	Application
GAZOLE™ 6200P	Medium Viscosity	Compression Molding/ Extrusion Compounding
GAZOLE™ 6400P	Low Viscosity	Extrusion Compounding

Granules, For the general purpose extrusion and Injection molding application. The standard flow (6200G) and high flow (6400G) materials are suitable for Injection Molding.

Grade	Flow	Application
GAZOLE™ 6200G	Medium Viscosity	Stock shape extrusion/ Injection Molding
GAZOLE™ 6400G	High Flow	Injection Molding

Glass Fiber & Carbon Fiber Filled Grades

The addition of glass fiber & carbon fiber reinforcement greatly increases the general mechanical properties at a given temperature. The glass fiber & carbon fiber filled composites are thermally stable thermoplastics with excellent mechanical performance at very high temperatures up to 300°C. Carbon fiber filled grades of GAZOLE™ 6000 series have much reduced thermal expansion coefficients making them ideal for metal replacement application. The blends filled with milled carbon fiber gives fixed electrostatic dissipative control with extremely low warpage. GAZOLE™ 6000 Series grades have very low outgassing.

Grade	Glass/ Carbon Fiber Filled
GAZOLE™ 6430GF	30% Glass Fiber Filled with Standard flow, Natural green in color
GAZOLE™ 6430CF	30% Carbon Fiber Filled with Standard flow, Natural black in color
GAZOLE™ 6430CFM	30% Milled Carbon Fiber Filled with Standard flow, Natural black in color

Tribological Grades

GAZOLE™ 6000 Series (PEK/PBI) blends have excellent inherent wear resistance. Tribological grades are a combination of carbon fiber, PTFE, graphite/MoS_2 reinforced in PEK/PBI blends and GAZOLE™ 6430FC have very low wear rate: 2.31 $X10^{-16}m^3/Nm$ at very high PV_{limits} 63 MPa.m/s. Moreover, they have an coefficient of friction of 0.05.

Grade	Tribological Grade
GAZOLE™ 6430FC	Standard Flow, Carbon/Glass Fiber, Graphite, PTFE & MoS_2
GAZOLE™ 6415FC	Standard Flow, Graphite, PTFE & MoS_2

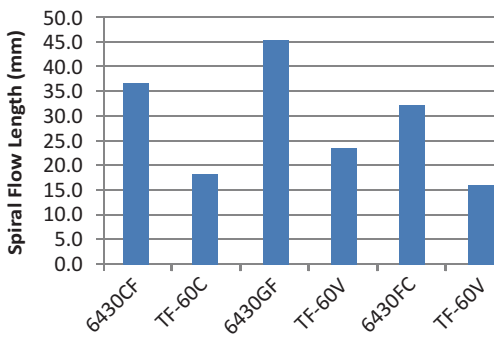


Fig.1 Spiral flow length of GAZOLE™ versus competitive polymer at 440°C and constant injection pressure

2. Mechanical Properties

2.1 Tensile Properties

The tensile properties of PEK/PBI blend polymer surpasses those of most engineering thermoplastic polymers at elevated temperatures. GAZOLE™ 6000 series polymer is used at elevated temperatures for long lasting components under high pressures, a pre-requisite for structural materials. Fig. 2, A plot of Tensile Strength versus Temperature for GAZOLE™ 6200G polymer,

illustrates high retention of mechanical properties over a broad temperature range.

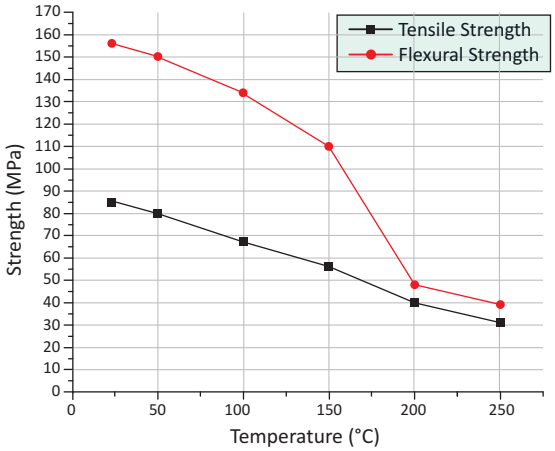


Fig.2, Tensile Strength & Flexural Strength versus Temperature for GAZOLE™ 6200G Polymer materials.

2.2 Flexural Properties

GAZOLE™ 6000 Series (PEK/PBI) blends exhibit outstanding flexural performance over a wide range.
Fig. 2, a plot of Flexural Strength verses Temperature for GAZOLE™ 6200G polymer, illustrates high retention of mechanical properties over a broad temperature range.

3. Thermal Properties

GAZOLE™ 6000 Series (PEK/PBI) blends have a glass transition temperature of 152°C and, since it is a semi-crystalline thermoplastic, it retains its mechanical properties close to its melting temperature 372°C.

3.1 Heat Distortion Temperature

The short term thermal performance of a material may be characterized by determining the Heat Distortion Temperature (HDT, ASTM D 648).

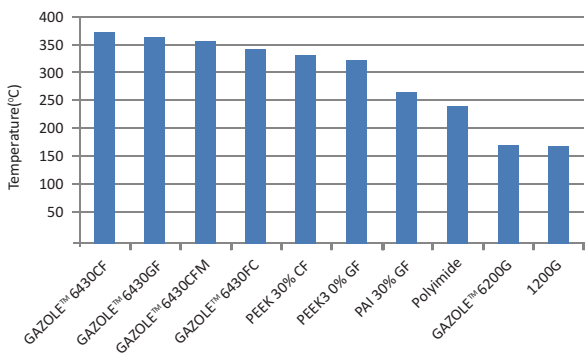


Fig. 3 Heat Distortion Temperature for Range of High Performance Polymers.

A comparative chart of high performance material using ASTM D 648, HDT values (Fig. 3) for a defined applied stress of 1.8 MPa shows that GAZOLE™ 6000 Series compounds are superior to all of the other polymeric composites.

3.2 Dynamic Mechanical Analysis (DMA)

The Dynamic Mechanical properties of 6000 Series compounds surpass those of all engineering thermoplastics. The thermomechanical and viscoelastic behavior of GAZOLE™ 6000 compounds are provided by Dynamic Mechanical Analysis (DMA). This storage modulus represents the recoverable elastic energy stored in a viscoelastic material during deformation.

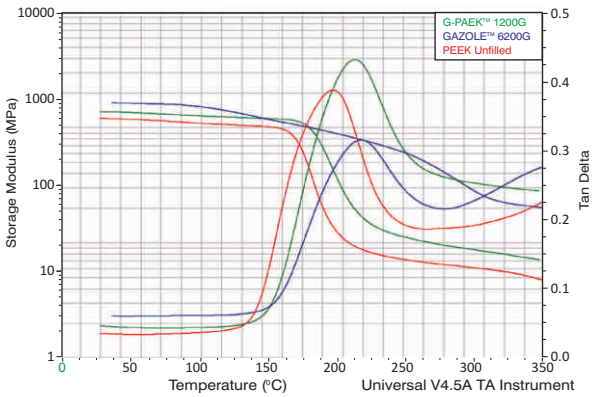


Fig. 4 DMA Scan of GAZOLE 6200G verses PEK 1200G & PEEK Unfilled Storage Modulus and Tan delta versus temperature.

In Fig.4, GAZOLE™ 6200G compound shows glass transition temperatures of 180°C compare to 173°C for PEK 1200G & 160°C for PEEK unfilled. The storage modulus of the GAZOLE™ 6200G compound is stable up to 300°C and hence it retains its mechanical properties upto 300°C. Fig. 4 shows a temperature sweep scan of GAZOLE™ 6000 Series Compounds depicting Storage Modulus (E') and Tan delta against temperature.

3.3 Coefficient of Linear Thermal Expansion

The thermal expansion of a material is characterized by determining the coefficient of linear thermal expansion (ASTM D 696). CLTE is an inherent property of the material. When an object is heated or cooled, its length changes by an amount proportional to the original length and the change in temperature.

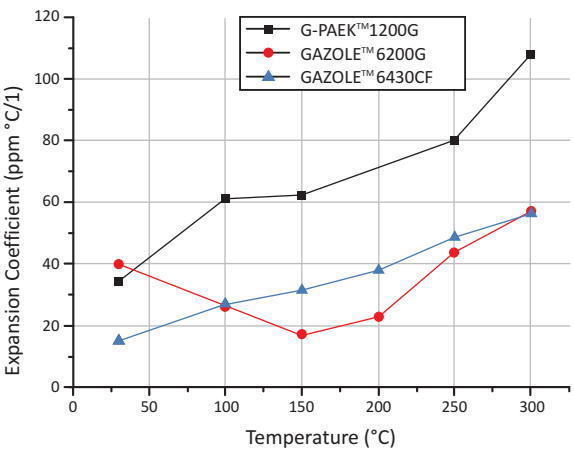


Fig. 5, Coefficient of Liner Thermal Expansion for GAZOLE™ 6000 Series Compounds

GAZOLE™ 6000 Series compounds have lower CLTE values compare to Virgin PEK. Carbon fibers filled grades of GAZOLE™ 6000 Series shown (Fig.5) the lowest thermal expansion.

Table: 1 Properties of GAZOLE™ 6000 Series Compounds

PROPERTY	TEST METHOD	UNIT	GAZOLE™ 6200G	GAZOLE™ 6430GF	GAZOLE™ 6430CF	GAZOLE™ 6430CFM	GAZOLE™ 6430FC	GAZOLE™ 6415FC
General Properties								
Solid Density	23°C	g/cc	1.3	1.55	1.4	1.41	1.43	1.40
Moisture Content	GSRF	%	0.27	0.24	0.23	0.23	0.24	0.27
Hardness Rockwell	ASTM D 785	A	25	30	31	31	29	27
Hardness Shore D	ASTM D 2240	D	92	95	96	96	94	92
Spiral Flow Length(440°C nozzle)	ASTM D 3123	mm	33	45	37	37	35	33
Thermal Properties								
Glass Transition Temperature (Tg)	DSC	°C	152	152	152	152	152	152
Melting Temperature	DSC	°C	372	372	372	372	372	372
Heat Deflection Temperature(HDT)	ASTM D 648/1.8 MPa	°C	174	353	358	353	348	345
Continuous Use Temperature (Expected)	UL 746B	°C	300	300	300	300	300	300
Coefficient of Linear Thermal Expansion	TMA/ at 30°C	ppm $°C^{-1}$	39.82	-	15.05	-	-	-
	TMA/ at 150°C	ppm $°C^{-1}$	17.37	-	31.57	-	-	
Mechanical Properties at 23°C								
Tensile Strength	ASTM D 638	MPa	90	167	230	198	110	100
Tensile Modulus	ASTM D 638	MPa	5600	13500	28500	26400	22500	8700
Elongation at Break	ASTM D 638	%	2	2.7	3.7	2.4	1.1	2.2
Flexural Strength	ASTM D 790	MPa	150	182	380	312	198	162
Flexural Modulus	ASTM D 790	MPa	6100	13600	28800	26500	18500	7750
Izod Impact Strength (Notched)	ASTM D 256	J/m	30	45	45	40	35	33
Electrical Properties								
Dielectric Strength	ASTM D 149	kV/mm	10.7	11.4	-	-	-	-
Dissipation Factor	ASTM D 149	-	0.0092	0.0048	-	-	-	-
Dielectric constant	ASTM D 149	-	3.6	3	-	-	-	-
Volume Resistivity	ASTM D 257	Ω cm^{-1}	2.00E+15	2.70E+15	6.00E+05	-	3.00E+05	-
Surface Resistivity	ASTM D 257	Ω	-	-	-	4.00E+05	-	-
Arc Resistance	ASTM D 495	sec	183	183	-	-	-	-
Fire Properties								
Flammability	UL 94/0.8 mm		V-0	V-0	V-0	V-0	V-0	V-0
Recommended Processing Conditions								
Barrel Temperature	-	°C	390-420	390-440	390-440	390-440	390-440	390-440
Mould Temperature	-	°C	220	220	220	220	220	220

4. Tribological Properties

GAZOLE™ 6430FC polymer, based on GAZOLE™ 6000 Series polymers, are used for tribological components due to their outstanding resistance to wear under high pressure and high velocity conditions. Tribology may be defined as the interaction of contacting surfaces under an applied load in relative motion.

4.1 Specific Wear Rate

The lower the wear rate or wear factor, the more resistant the material is to tribological interactions. Table 2 shows the comparative wear rate bar chart for GAZOLE™ 6430FC verses Celazole TL 60, Torlon wear grades & Vespel SP21. GAZOLE™ 6430FC showed the most consistent tribological performance over range of test speeds from 1.5 m/s – 2.5 m/s; surviving to over 63 MPa.m/min PV factor.

PV (MPa.m/s)	GAZOLE™ 6430FC	CELAZOLE TL 60	G-PAEK™ 1230FCT	G-PAEK™ 1230FC	TORLON 4435	TORLON 4275	VESPEL SP21
Specific Wear Rate K_0 at 1.5-2.5 m/s (10^{-16} X m^3/Nm)							
18.64	3.97	4.55	4.71	3.36	2.39	3.84 PV_{limit} Reached	Fail
23.30	3.06	3.25	3.80	4.01	2.18		
27.97	2.09	2.83	2.39	5.09	1.48 PV_{limit} Reached		
32.62	3.76	3.21	2.51	6.09 PV_{limit} Reached			
37.29	2.31	2.79	1.96				
41.94	1.41	2.60	2.67 PV_{limit} Reached				
55.93	2.23	2.98 PV_{limit} Reached					
62.91	2.31 PV_{limit} Reached						

Table: 2 The comparative wear rate bar chart for GAZOLE™ 6430FC, Celazole TL60, Torlon wear grades & Vespel Sp21

4.2 Coefficient of Friction

The friction of sliding tribological contact may be defined as the tangential force required to move a slider over a counterface. The special grade GAZOLE™ 6430FC contains optimum levels of PBI to reduce & maintain the coefficient of friction at a low value compare to high performance engineering plastics. A comparative bar chart of GAZOLE™ 6430FC, Celazole TI60, Torlon wear grades & Vespel SP21 in Table 3.

PV (MPa.m/s)	GAZOLE™ 6430FC	CELAZOLE TI60	G-PAEK™ 1230FCT	G-PAEK™ 1230FC	TORLON 4435	TORLON 4275	VESPEL SP21
Coefficient of friction μ at 1.5- 2.5 m/s							
18.64	0.08	0.12	0.10	0.15	0.12	0.14	
23.30	0.08	0.14	0.09	0.18	0.09		
27.97	0.07	0.11	0.08	0.19	0.07		
32.62	0.06	0.12	0.08	0.17			
37.29	0.06	0.11	0.07				
41.94	0.06	0.10	0.10				
55.93	0.05	0.11					
62.91	0.05						

Table: 3 The Comparative COF bar chart for GAZOLE™ 6430FC, CELAZOLE TL60, Torlon wear grades & Vespel Sp21

4.3 Abrasion Resistance

The ability of a material to withstand mechanical action such as rubbing, scraping or erosion, that tends progressively to remove from its surface.

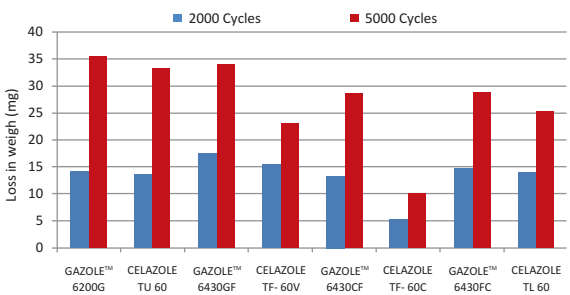


Fig. 6 Abrasion resistance at 1.0 Kg load & CS-17 abrasion wheel of GAZOLE™ 6000 Series & its competitive grades.

The Abrasion resistance of GAZOLE™ 6000 Series compounds were evaluated using the Abrasion Resistance test (ASTM D 1242, Wheel: CS-17, Load: 1000 gm) The data in Fig.6 shows that GAZOLE 6430FC polymer has the lowest value of loss in weight.

5.0 Processing

GAZOLE™ 6000 Series compounds 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 GAZOLE™ 6000 Series compounds is 372°C and therefore, barrel and cylinder temperature should be set at a higher value than that, between 390~ 440°C. The mold temperature should be around 200-220°C. GAZOLE™ 6000 Series compounds absorb about 0.2 -0.5 % moisture and therefore, they need pre-drying at 150-180°C for 3-4 hours by dehumidifier or air circulating type dryer. Processing temperature of GAZOLE™ 6000 Series is high as described below.

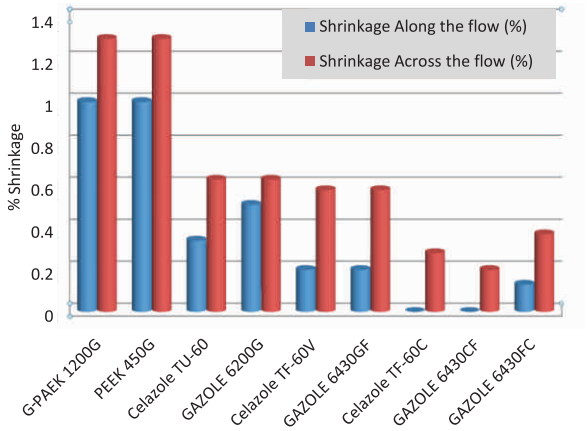
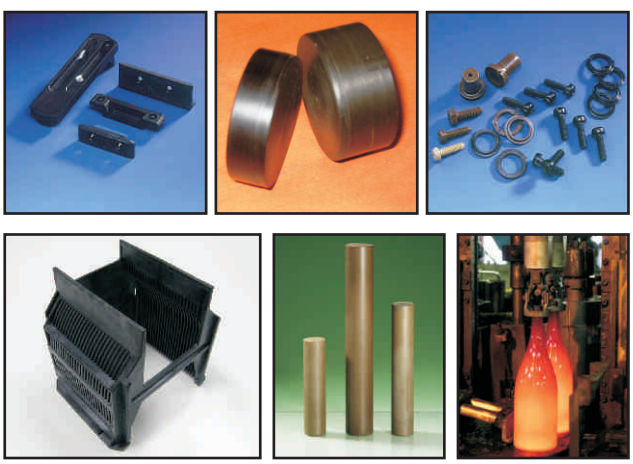


Fig. 7 % Shrinkage of GAZOLE™ 6000 Series compound verses other Engineering Plastics

6.0 Applications

A wide range of applications are found for GAZOLE™ 6000 Series compounds because of its melt processability behavior, design flexibility, longer durability, lower operation cost and exceptional wear resistance, mechanical & chemical performance at high temperatures. The polymer having below variety of applications,

- Thrust washers
- Bushings
- Soldering tools
- Seals
- Plasmas torches
- Glass Handling equipments
- Bearings cages
- Wafer cassettes
- Compressors parts
- Pumps & Turbines



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