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ceramer™

ceramerplus™

Polyphenylene sulfone (PPSO<sub>2</sub>)

Innovative  
high performance polymers  
and additives

ceramer

• • • • • high performance polymers •

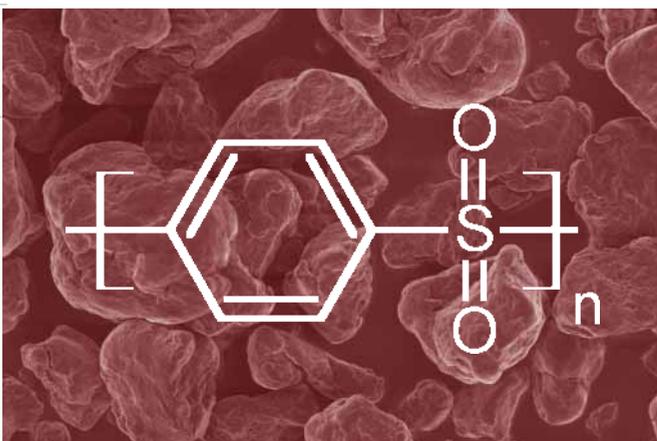
The Ceramer product line was developed by Hoechst AG and introduced into the market by Ticona in 1998. The manufacturing process on industrial scale is well established. Ceramer products have a broad application spectrum in the polymer and coatings industry as well as semi-finished parts. In order to fully develop the market potential in all application areas and to further explore new application possibilities, in May 2003 Ceramer GmbH was founded jointly by Ticona and Professor Hans-Werner Schmidt, Chair of Macromolecular Chemistry at the University of Bayreuth.

Ceramer GmbH is located within the newly established Competence Center for New Materials in Bayreuth, Germany. The combination of scientific expertise in polymers and of non-injection moldable materials and the possibilities at the Competence Center in conjunction with the excellent research facilities at the University of Bayreuth are a profound base to fully develop the market potential of this outstanding high performance polymer.

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### Structural formula of ceramer



## With new grades to higher performances

The Ceramer range has grown larger:

New grades, which are differentiated by their particle size, offer a wide range of applications. With Ceramer Plus a new material is introduced. Particularly the temperature and chemical resistances have been developed further. Also, Ceramer Plus ensures an outstanding metallization. For this reason, Ceramer Plus can be considered for applications in which extreme demands are made on the materials.

Ceramer and Ceramer Plus are sinterable high performance polymers made from polyphenylene sulfone (PPSO<sub>2</sub>) with a glass transition temperature (T<sub>g</sub>) of approx. 360°C.

The material has no melting point and is therefore processed through hot pressing and sinter technology.

Due to their properties, the Ceramer products are exceptional as additives for fluoropolymers, especially in the improvement of wear and creep, without reducing the typical PTFE advantages such as chemical and temperature resistance. Ceramer and Ceramer Plus are also used as an additive for other technical polymers, for example LCP, PSU, PEEK, PAI, POM, PPS, PI, PEI and polyester, and for thermosets.

They make it possible to change key properties such as reducing abrasion and wear, and raise the compressive strength of the materials. Ceramer and Ceramer Plus especially offer advantages for the metallization of polymers which allows new application possibilities.

Ceramer and Ceramer Plus are also processed as a neat resin through hot pressing and in sinter technology, and are recognized for their very high chemical and temperature resistance, inherent flame resistance, high hardness and stiffness. The good composite structure of the particles leads to a mirror finish surface after hot pressing.

Ceramer and Ceramer Plus are also used in coatings which are applied using thermal spraying.

The materials are also available as high purity grades, which are ideal for semiconductor applications.

## Meets FDA requirements for food contact applications

Ceramer and Ceramer Plus meet all FDA requirements as an additive for PTFE in repeat-use food contact applications. Ceramer can likely be used as an additive for other materials as well. The FDA petition for repeat-use articles has been submitted. This also includes the use of Ceramer and Ceramer Plus as additives in other materials.

The European food contact directive does not regulate the polymers, but, for toxicological reasons, the monomers on which the polymers are based. The monomers of Ceramer and Ceramer Plus are already regulated by the EU Commission. To be sure that Ceramer and Ceramer Plus are in compliance with the EU directive, manufacturers are required to test the finished article made from Ceramer or in which Ceramer is incorporated, whereby the restricting specific migration limits of the monomers are fulfilled.

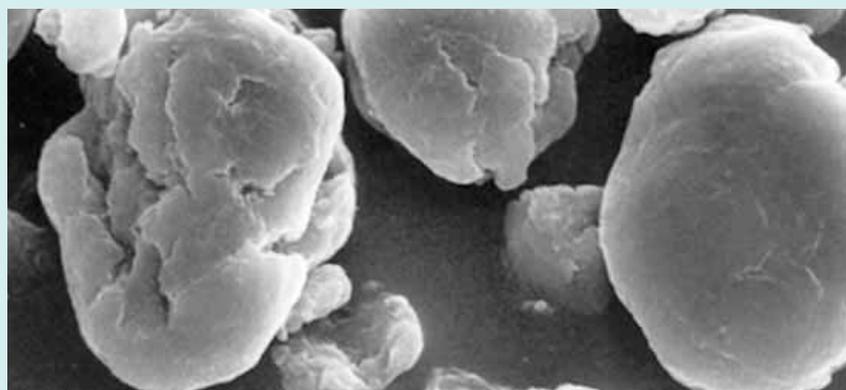
**Study showed: Ceramer**

**is non-toxic to rats**

**(LD<sub>50</sub> rat > 5,000 mg/kg)**

Figure 1

Scanning electron micrograph of Ceramer.



## Optimized for various tasks

Ceramer is a very fine, light beige powder that is delivered in various grades with different particle sizes.

Figures 2 and 3

The particle shape, spherical with a rough, cracked surface, enables the material to form an intimate mechanical bond with matrix substances such as fluoropolymers.

Figure 1

The specific surface area of the standard grade Ceramer 20 is approximately 10 m<sup>2</sup>/g according to BET.

Ceramer and Ceramer Plus are delivered in 20 kg containers which are sealed air and watertight.

Ceramer can also be produced as a high purity grade for semiconductor applications. The data in figure 4 shows typical values for high purity Ceramer 20 powder. Special grades with even higher purity level can be produced at request.

Properties	Ceramer 15	Ceramer 20	Ceramer 60	Ceramer Plus 20
Average particle size	15 μm	20 μm	60 μm	20 μm
Maximum particle size	30 μm	70 μm	215 μm	70 μm
Temperature resistance <sup>1)</sup>	> 460 °C	> 460 °C	> 460 °C	> 500 °C
Chemical resistance <sup>2)</sup>	++	++	++	+++

Figure 2 Ceramer's most important powder data of its grades.

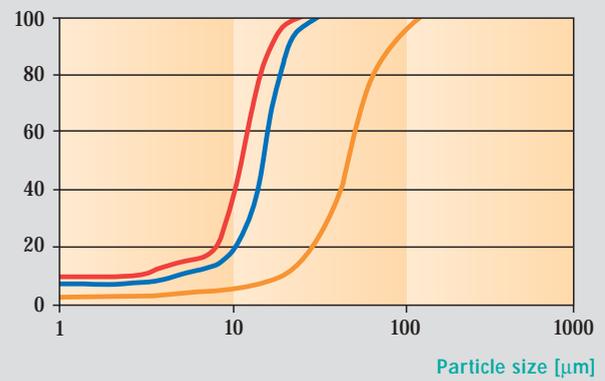
<sup>1)</sup> Short term (see figure 5) <sup>2)</sup> Comparable with PTFE (see figure 8)

Figure 3

Particle size distribution of

- Ceramer 15 — red line
- Ceramer 20 — blue line
- Ceramer 60 — orange line

Frequency [%]



[ppm]

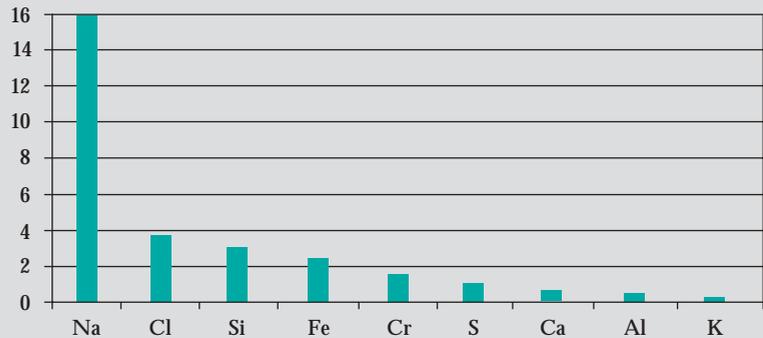


Figure 4

Impurities in specially produced high purity grade Ceramer 20 powder, analyzed by X-ray fluorescent analysis. (See also extractable data determined on neat Ceramer parts. Page 32, figure 66.)

High purity grade Ceramer 20 powder. ■

## The low density makes cost effective material applications possible

The density of Ceramer is approximately 1.44 g/cm<sup>3</sup>, of Ceramer Plus approximately 1.54 g/cm<sup>3</sup>.

Compared to the fluoropolymers, whose density lie at >2 g/cm<sup>3</sup>, the low density of the Ceramer and Ceramer Plus enables a high volume load with little weight gain.

High thermal stability even over prolonged periods

The Ceramer grades show a very high level of thermal stability. Noticeable decomposition of the polymer in air occurs only at temperatures above 460 °C. The typical decomposition product is sulfur dioxide (SO<sub>2</sub>). Ceramer Plus is thermally stable up to 500 °C.

Figure 5

During processing, very high temperatures often occur over long periods. Figure 6 and 6a clearly show the very high thermal stability of Ceramer and Ceramer Plus. In long periods of up to 12 hours at 375 °C, loss of weight for Ceramer is 10%, for Ceramer Plus only 2%.

Figures 6 and 6a

Ceramer Plus:  
Thermal stability improved  
5-fold

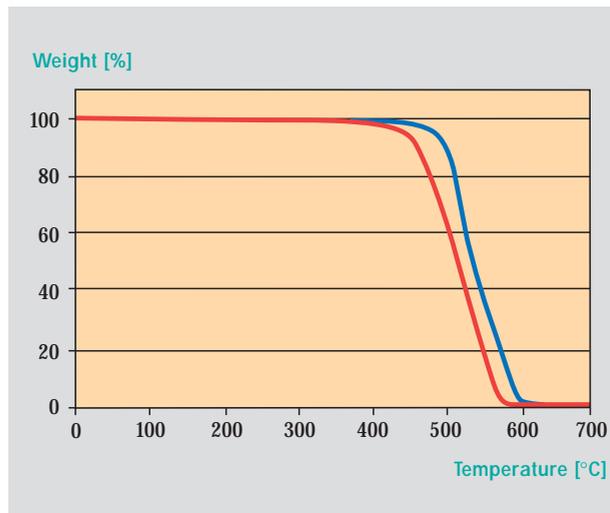


Figure 5

Thermogravimetric Analysis (TGA) measured in air; heating rate 10 K/min.

Ceramer —  
Ceramer Plus —

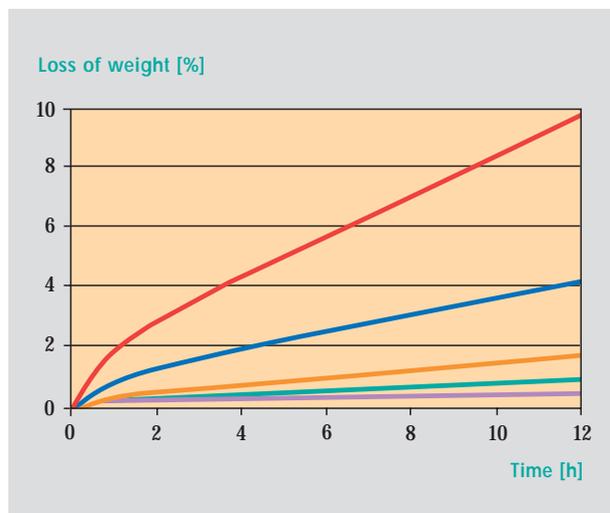


Figure 6

Isothermal TGA of Ceramer measured in air.

300 °C —  
320 °C —  
340 °C —  
360 °C —  
375 °C —

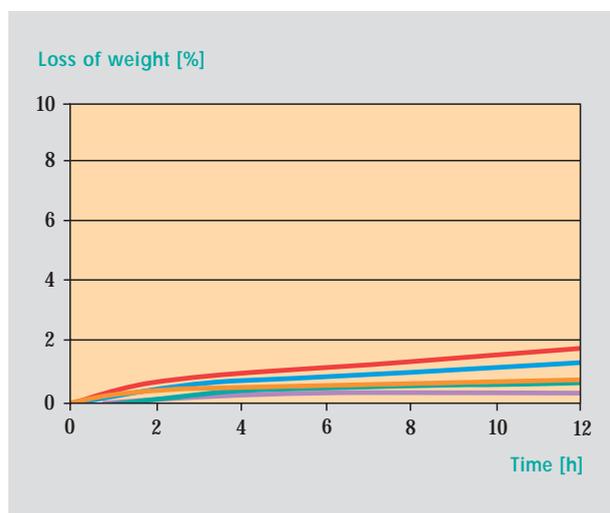


Figure 6a

Isothermal TGA of Ceramer Plus measured in air.

300 °C —  
320 °C —  
340 °C —  
360 °C —  
375 °C —

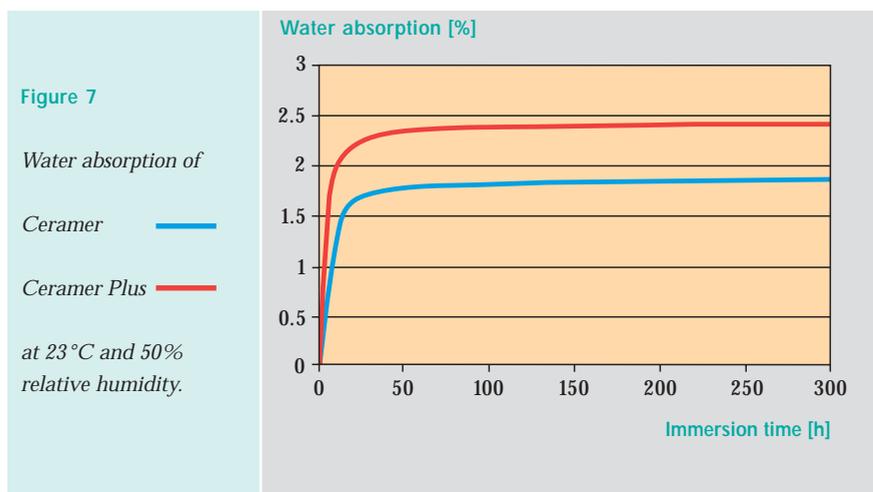
## Degree of crystallization

Ceramer and Ceramer Plus are partially crystalline polymers. The degree of crystallization for Ceramer as supplied is approximately 60%. The degree of crystallization for Ceramer Plus as supplied is slightly higher.

## Water absorption

Ceramer is slightly hygroscopic. The water absorption of the powder under standard conditions (23 °C and 50% relative humidity) is about 1.8%, with Ceramer Plus about 2.4%. This equilibrium concentration is reached very quickly within 24 hours. Water absorption occurs reversibly.

Figure 7



## Outstanding chemical resistance

The outstanding resistance of Ceramer and Ceramer Plus to nearly all chemicals comes very close to that of Polytetrafluoroethylene (PTFE). There is no known solvent even at very high temperatures - which will dissolve them. Their chemical resistance is very much better than that of PPS, as shown in the next table. Chemical immersion tests were carried out on fibers.

Figure 8

## Surface tension

The surface tension is very high for a polymer. According to Neumann it is 47.4 mN/m against water. According to Wu, the surface tension is 39.3 mN/m, which is divided into a disperse part of 20.5 mN/m and a polar part of 18.8 mN/m (Figure 48, page 23).

The surface tension was tested on hot pressed neat Ceramer parts. For Ceramer Plus, even higher surface tensions are expected.

## Color stability

When Ceramer is subjected to high temperatures, e.g. in hot press molding or sintering together with PTFE, it loses its slightly beige color and becomes dark brown to black. This is not due, however, to thermal degradation but to color reactions of the end groups of the polymer, which occur at high temperatures. This in no way affects the other properties of Ceramer.

The color stability of Ceramer Plus is visibly higher compared to that of Ceramer.

	Temperature	Time	PPS fibers	Ceramer Plus fibers
Conc. sulfuric acid	250°C	24 h	-	+
Nitric acid (100%)	23°C	24 h	-	+
Nitric acid (65%)	70°C	48 h	-	+
α - Chloronaphthalene	190°C	24 h	-	+
Caustic soda (40%)	80°C	48 h	+	+
HBF <sub>4</sub> in HF	60°C	24 h	-	+

Figure 8

Chemical resistance of Ceramer Plus compared with PPS.

+ "resistant"  
- "not resistant"

## Reinforcement for fluoropolymers

Ceramer and Ceramer Plus are ideal as reinforcing materials for fluoropolymers, and greatly improve the abrasion resistance and creep tendency of PTFE and thermoplastic fluoropolymers. The general chemical resistance of the fluoropolymers, and the high temperature resistance are not affected as the properties of Ceramer and Ceramer Plus in these areas are very similar to those of PTFE. No other known organic or inorganic filler achieves this overall performance.

Due to the low density (Ceramer approx. 1.44 g/cm<sup>3</sup>, Ceramer Plus approx. 1.54 g/cm<sup>3</sup>), a large volume load can be achieved with little weight gain.

Technical measurements show that Ceramer Plus is especially well suited for large parts which require a very good chemical resistance at high temperatures.

## Compounds from PTFE/Ceramer or Ceramer Plus used for compression molding

The enhancement of PTFE properties, especially in regard to the tribological behavior and the creep tendency, as well as the unchanged chemical resistance show themselves as positive in their application in the automotive industry and in chemical process engineering, e.g. for seals, bearings, gaskets and pump housings. In many other markets such as: oil and natural gas and food processing, PTFE/Ceramer bearings, seals and gaskets have offered superior performance. This is especially true in the case of parts facing high abrasion at high temperatures and in corrosive environments.

With Ceramer Plus a material is offered that widens the range of applications, particularly for large sized or extremely stressed parts. *Figure 9*

### Extended applications through Ceramer Plus

Figure 9  
Application examples



Seal rings made from PTFE/Ceramer compounds are remarkable for their abrasion and wear resistance.

## Tribological peak values achieved

Abrasion and wear of PTFE against metallic partners clearly show improved values even beginning at very low loading of Ceramer or Ceramer Plus in PTFE. The coefficient of friction of PTFE is hardly changed by the addition of Ceramer and Ceramer Plus.

Measurements were carried out in air with a pin-on-disc test instrument, using hardened steel (100 Cr6, Rockwell hardness HRC >50) abrasive discs as abrasive partners. The surface roughness ( $R_z$ ) of the abrasive discs was determined before each test. Only the stationary phase was used for evaluating the test data. In this phase the coefficient of friction is constant and there is uniform wear, i.e. wear increases linearly with time. Test data were determined on-line and the test duration was 20 hours, except in the case of pure PTFE, since these test specimens very quickly wore out. Here the tests lasted four hours.

Figures 10-12

**Figure 10**  
K-factor  
[ $10^{-6} \text{ mm}^3/\text{Nm}$ ] of PTFE filled with Ceramer, measured at a sliding speed of 4 m/s

	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
Contact pressure: 1 N/mm <sup>2</sup> $R_z$ : approx. 1 $\mu\text{m}$	168	43	4.6	1.9
Contact pressure: 5 N/mm <sup>2</sup> $R_z$ : approx. 1 $\mu\text{m}$	354	104	5.3	1.1

**Figure 11**  
K-factor  
[ $10^{-6} \text{ mm}^3/\text{Nm}$ ] of PTFE filled with Ceramer measured at a sliding speed of 0.5 m/s

	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
Contact pressure: 1 N/mm <sup>2</sup> $R_z$ : approx. 1 $\mu\text{m}$	319	5.2	2.8	2.1
Contact pressure: 5 N/mm <sup>2</sup> $R_z$ : approx. 1 $\mu\text{m}$	494	1.8	1.0	0.4
Contact pressure: 5 N/mm <sup>2</sup> $R_z$ : approx. 2 $\mu\text{m}$	72	5.2	2.2	1.8

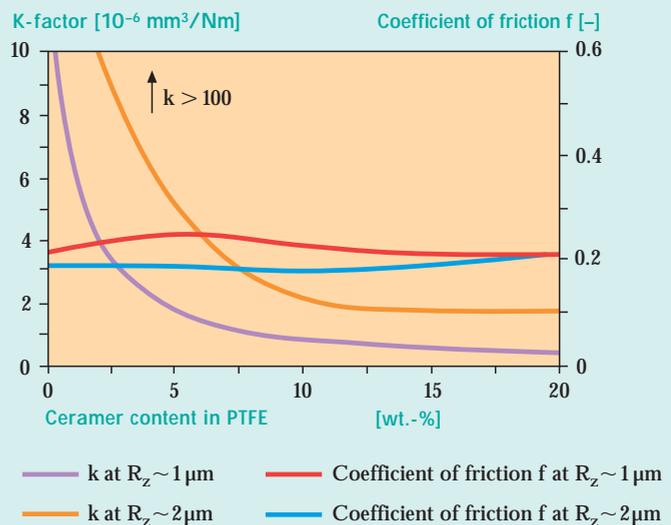
**Figure 12**  
K-factor  
[ $10^{-6} \text{ mm}^3/\text{Nm}$ ] of PTFE filled with Ceramer as a function of temperature (Sliding speed:  $v = 0.5 \text{ m/s}$ , Contact pressure:  $p = 1 \text{ N/mm}^2$ , Surface roughness:  $R_z \sim 1 \mu\text{m}$ )

	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
23°C	319	5.1	2.8	2.1
150°C	43	2.3	1.2	0.6
200°C	material flows	3.2	1.1	1.3

The K-factor is a widely used term to describe abrasive properties. It is made up of abrasion in [mm/m] divided by the contact pressure in [N/mm<sup>2</sup>].

## At high and low sliding speeds

Figure 14 clearly shows the improvement of the wear properties of PTFE through the addition of Ceramer at various sliding speeds.



**Figure 13**  
K-factor  $k$  and coefficient of friction  $f$  of PTFE/Ceramer compounds in the pin-on-disc machine (conditions:  $p = 5 \text{ N/mm}^2$ ,  $v = 0.5 \text{ m/s}$ ,  $T = 23 \text{ }^\circ\text{C}$ , technically dry) at various surface roughnesses  $R_z$ .

	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
Contact pressure: 1 N/mm <sup>2</sup> R <sub>z</sub> : approx. 1 μm	0.31	0.30	0.29	0.28
Contact pressure: 5 N/mm <sup>2</sup> R <sub>z</sub> : approx. 1 μm	0.30	0.22	0.26	0.28
	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
Contact pressure: 1 N/mm <sup>2</sup> R <sub>z</sub> : approx. 1 μm	0.20	0.28	0.20	0.29
Contact pressure: 5 N/mm <sup>2</sup> R <sub>z</sub> : approx. 1 μm	0.22	0.25	0.23	0.21
Contact pressure: 5 N/mm <sup>2</sup> R <sub>z</sub> : approx. 2 μm	0.19	0.19	0.18	0.21
	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
23°C	0.20	0.28	0.20	0.29
150°C	0.30	0.43	0.39	0.35
200°C	material flows	0.21	0.15	0.13

**Figure 10a**  
Coefficient of friction of PTFE filled with Ceramer measured at a sliding speed of 4 m/s.

**Figure 11a**  
Coefficient of friction of PTFE filled with Ceramer measured at a sliding speed of 0.5 m/s.

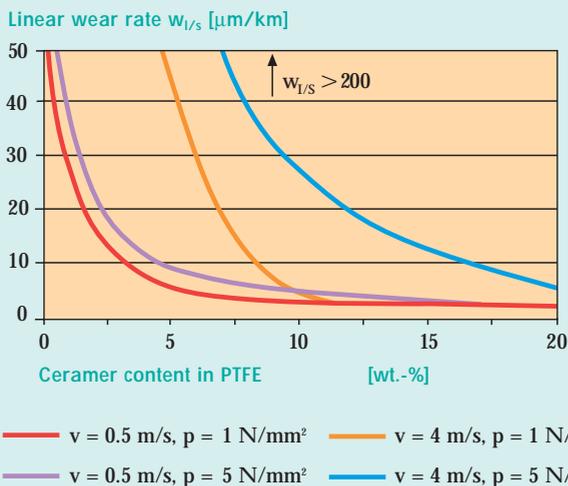
**Figure 12a**  
Coefficient of friction of PTFE filled with Ceramer as a function of temperature (sliding speed:  $v = 0.5$  m/s, contact pressure:  $p = 1$  N/mm<sup>2</sup>, surface roughness:  $R_z \sim 1$  μm).

## At high and low contact pressures

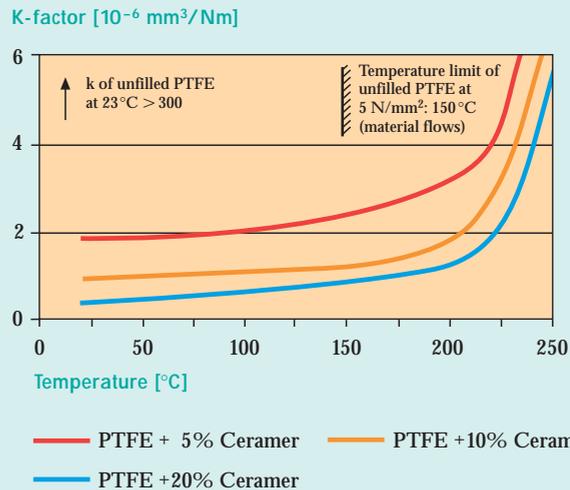
With 20% Ceramer addition, PTFE can also be used at high surface pressure ( $p = 5$  N/mm<sup>2</sup>) and equally at high sliding speeds ( $v = 4$  m/s). Under low stress ( $v = 0.5$  m/s;  $p = 1$  N/mm<sup>2</sup>) the addition of 10% Ceramer is sufficient. *Figure 14*

## At high temperatures up to 260°C under different PV conditions

The temperature resistance of PTFE/-Ceramer compounds was measured in tests with the sliding surface temperature upwards of 23°C. At temperatures over 150°C, unfilled PTFE flows under stress. Through the addition of Ceramer, the temperature can be raised to over 200°C. The maximum temperatures at which PTFE/Ceramer compounds can be used lies at between 220°C and 260°C, depending on the load. In this region, Ceramer content should be at least 10% to 20%. *Figure 15*



**Figure 14**  
Linear wear rate  $w_{l/s}$  of PTFE/Ceramer compounds as a function of contact pressure  $p$  and the sliding speed  $v$  in the pin-on-disc machine (conditions:  $R_z \sim 1$  μm; technically dry).



**Figure 15**  
K-factor of PTFE/Ceramer compounds as a function of the sliding surface temperature in the pin-on-disc machine (conditions:  $R_z \sim 1$  μm,  $v = 0.5$  m/s,  $p = 5$  N/mm<sup>2</sup>, technically dry).

## Reduction of creep in PTFE

Significant reduction of creep

The creep behavior of PTFE is one of its main weaknesses. Its tendency to creep is much reduced by incorporating Ceramer as an additive.

Figure 16

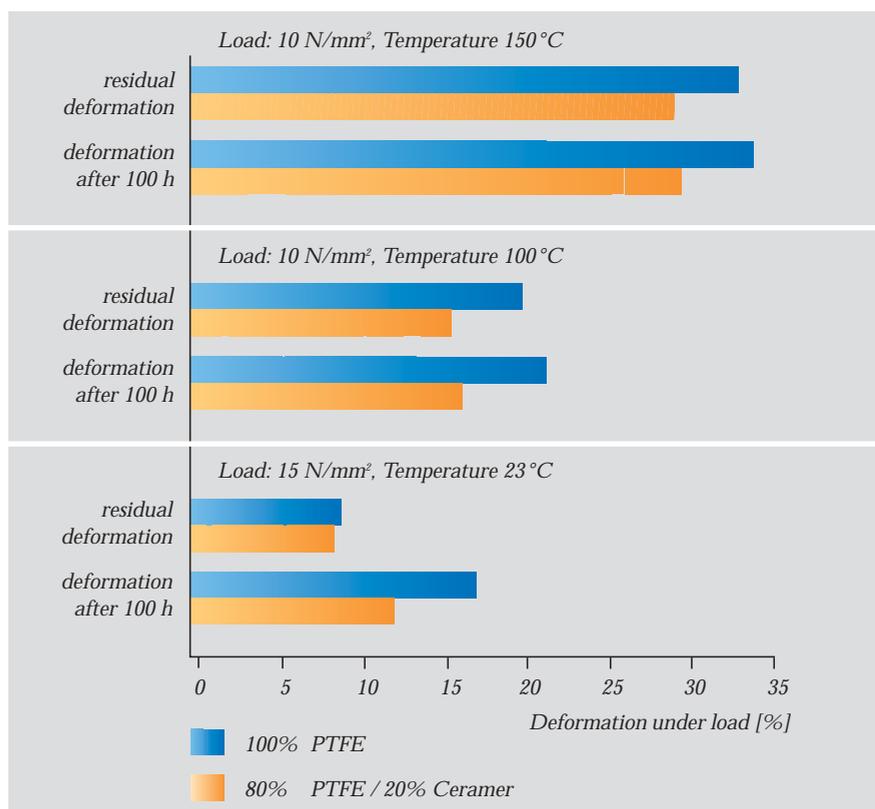


Figure 16 Deformation under load of pure PTFE and PTFE filled with Ceramer.

## Physical properties

The test data refers to mixtures with Ceramer 20.

Figure 17

Figure 17 Physical properties of PTFE filled with Ceramer.	Properties	Unit	Test method	100% PTFE	95% PTFE 5% Ceramer	90% PTFE 10% Ceramer	80% PTFE 20% Ceramer
	Density	[g/cm <sup>3</sup> ]	ISO 1183	2.17	2.08	1.96	1.90
	Tensile strength	[N/mm <sup>2</sup> ]	ASTM D 4894 ASTM D 4895	29	17	18	13
	Elongation at break	[%]	ASTM D 4894 ASTM D 4895	380	470	400	300

## Coefficient of linear thermal expansion

The coefficient of linear thermal expansion of pure PTFE varies considerably with temperature. This can cause problems with the dimensioning and practical use of components constantly exposed to changing temperatures.

Increasing amounts of Ceramer as reinforcing material in PTFE not only reduces the dependence of the coefficient of the linear thermal expansion on temperature, but also lowers its absolute value. This makes it much easier to dimension components, whose shape will tend to change less with the changing ambient temperatures.

Figure 18

	Coefficient of linear thermal expansion [ $10^{-6} \text{ K}^{-1}$ ]			
	10-30°C	30-100°C	100-170°C	170-270°C
100% PTFE	231	107	126	172
95% PTFE 5% Ceramer	220	100	110	150
90% PTFE 10% Ceramer	194	83	99	123
80% PTFE 20% Ceramer	189	76	86	111
50% PTFE 50% Ceramer	80	57	63	88
25% PTFE 75% Ceramer	46	46	50	60

Figure 18  
Coefficient of linear thermal expansion of pure PTFE and PTFE filled with Ceramer.

PTFE-compounds	Volume resistivity [ $\Omega \cdot \text{cm}$ ]	PFA-compounds	Volume resistivity [ $\Omega \cdot \text{cm}$ ]
unreinforced	$>10^{15}$	unreinforced	$>10^{15}$
5% Ceramer	$>10^{15}$	5% Ceramer	$>10^{15}$
10% Ceramer	$>10^{15}$	10% Ceramer	$>10^{15}$
20% Ceramer	$>10^{15}$	20% Ceramer	$>10^{15}$

Figure 19  
Volume resistivity according to IEC 93 of unreinforced fluoropolymers and fluoropolymers reinforced with Ceramer (determined at 23°C, 50% relative humidity, voltage: 100 V).

## Reduction of linear thermal expansion

## Electrical properties are practically unaffected

The addition of Ceramer to PTFE has hardly any effect on the material's electrical properties. The outstanding electrical insulating properties of PTFE are therefore unchanged.

Figures 19-21

Dissipation factor  $\tan \delta$  [ $\cdot 10^{-4}$ ]

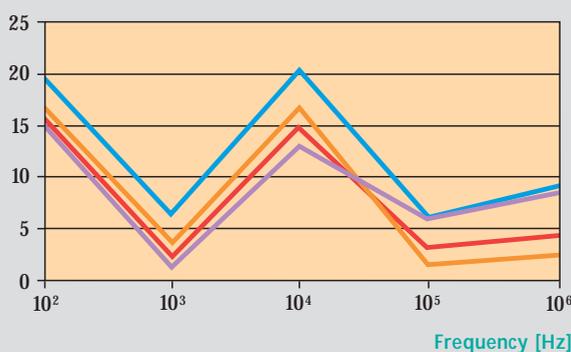


Figure 20  
Dissipation factor  $\tan \delta$  according to IEC 250 of unreinforced PTFE and PTFE reinforced with Ceramer (determined at 23°C, 50% relative humidity).

- unreinforced — purple
- 5% Ceramer — red
- 10% Ceramer — orange
- 20% Ceramer — blue

Dielectric constant  $\epsilon_r$  [-]

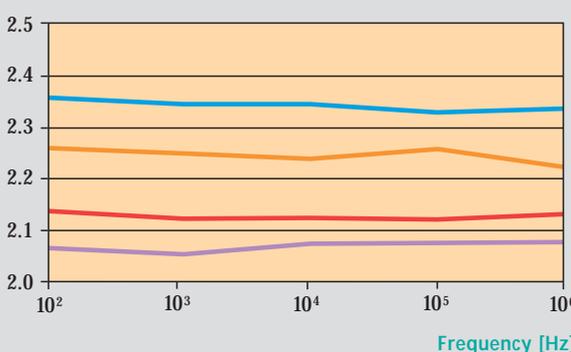


Figure 21  
Dielectric constant  $\epsilon_r$  according to IEC 250 of unreinforced PTFE and PTFE reinforced with Ceramer (determined at 23°C, 50% relative humidity).

- unreinforced — purple
- 5% Ceramer — red
- 10% Ceramer — orange
- 20% Ceramer — blue

## Free sintering of PTFE/Ceramer compounds

Before processing, i.e. before mixing with PTFE powders, Ceramer should be dried to remove possible residual moisture in the Ceramer powder.

Recommended drying conditions:

- Drying temperature: 120-160 °C.
- Drying duration: Several hours, at best over night.
- Drying atmosphere: Air or nitrogen.

If parts of large volume (wall thickness >100 mm) are being sintered, the pre-treatment of the Ceramer powder is recommended under the following conditions: 330 minutes at 375 °C in an oven with recirculating air.

The Ceramer powder should be completely covered by an aluminum or glass plate during the tempering process to minimize direct contact to the hot air. Only a small vent should remain open. During the tempering process the Ceramer powder loses approx. 8% of its own weight. The outgasing compounds consist mainly of sulfur dioxide (SO<sub>2</sub>).

## Ram extrusion of PTFE/Ceramer compounds

For Ram extrusion, the same powder pre-treatment is recommended as with the free sintering of large volume parts:

- Drying temperature: 375 °C.
- Drying duration: 330 minutes.
- Drying atmosphere: Circulating air in a covered but vented container.

## Free sintering and Ram extrusion of PTFE/Ceramer Plus Compounds

For both processing technologies it is sufficient to dry only the Ceramer Plus powder:

- Drying temperature: 120-160 °C.
- Drying duration: Several hours, at best over night.
- Drying atmosphere: Air or nitrogen.

A special pre-treatment as required in the processing of Ceramer is not necessary with the use of Ceramer Plus due to higher thermal stability.

## Easy processing of PTFE/Ceramer Plus Compounds

## PTFE/Ceramer compounds in paste extrusion processing



Figure 22



Figure 23  
Bowden gear with push-pull cable made by using PTFE/Ceramer.

Tubing for Bowden gears (push-pull cables) produced by Norton Pampus, Willich, Germany.



Figure 24  
Tubing for Bowden gears (push-pull cables) produced by Scantube, Knivsta, Sweden.

A typical area of application for paste extrusion compounds is the production of tubing for Bowden gears – so-called push-pull cables, which are typically used in the automotive industry. The polyethylene tubings used up to now are being increasingly replaced by those made of PTFE because of the higher temperatures encountered. In the past PTFE tubing was normally reinforced with PPS for enhanced abrasion resistance. It was found that the abrasion resistance of the push-pull cables

was drastically increased by Ceramer, compared to PPS. This results in safer, more reliable operation, even with insufficient or no lubrication. The push-pull cable will not be rubbed through. Even the total absence of a lubricant will not cause the push-pull cable to rub through, in contrast to PPS. Compared to push-pull cables made out of PTFE/PPS compounds, the wear dependant life span could be raised more than 20-fold.

Figures 22-25

**Dramatic enhancement of abrasion resistance through Ceramer**

Filler	Filler content [weight-%]	Loss of weight [%] after					
		500,000 cycles			1,000,000 cycles		
		23 °C	150 °C	180 °C	23 °C	150 °C	180 °C
Unfilled PTFE	0	rubbed through after 30,000 cycles					
PPS	7	rubbed through after 50,000 cycles					
Ceramer	3	1.6	3.5	not measured	2.3	not measured	not measured
Ceramer	7	0.4	0.6	1.8	0.9	1.5	2.8
Ceramer + Additives	4	0.3	0.2	not measured	0.9	0.5	not measured

Figure 25  
Abrasion behavior of push-pull cables made of PTFE paste extrusion powder filled with Ceramer or PPS.

All abrasion tests were carried out without using any lubricant such as silicone fluid.

## Life span increased

### more than 20-fold

The abrasion resistance of the tubes was tested according to the Bowden gear method:

Two jigs were used, each with a test section of push-pull cable, bent into a quarter circle, the tubing radius being 120 mm. One of the jigs was placed in a drying oven for tests at elevated temperatures, the other remaining at room temperature. A steel cable with a 60 kg weight at either end was passed through the push-pull cable specimens. This steel cable (diameter 3 mm, 19-strand, 0.6 mm) was moved alternately 40 mm in each direction using a cylinder (frequency 60 strokes/min), so that there was frictional contact between the push-pull cable and the steel cable.

The loss of weight of the push-pull cable specimens was determined after a specified number of cycles.

Whereas push-pull cables filled with 7% PPS were rubbed through after only about 50,000 cycles, push-pull cables containing the same amount of Ceramer were still intact after 1 million cycles.

Even reducing the amount of Ceramer by more than half to 3% prevented rubbing through of the push-pull cables. It was found that the abrasion resistance could be increased still further by incorporating special additives.

## Mechanical properties

Ceramer can be used instead of PPS to increase the abrasion resistance of paste extruded PTFE tubing without any loss of mechanical properties.

Figure 26

Figure 26 <i>Mechanical properties of push-pull cables made of PTFE paste extrusion powder filled with Ceramer or PPS.</i>	Compound	Properties	23 °C	200 °C
	93% PTFE paste extrusion powder 7% PPS	Tensile strength [N] Elongation at break [%]	96 410	27 190
93% PTFE paste extrusion powder 7% Ceramer	Tensile strength [N] Elongation at break [%]	94 440	28 210	

## Further examples

PTFE paste extrusion powders filled with Ceramer are used advantageously for seals, gaskets, slide bearings, cable insulation and abrasion resistant tubing.

Figure 27



Figure 27

*Slide bearings made of PTFE paste extrusion powder filled with Ceramer to enhance abrasion and wear resistance.*

## Processing recommendations

- Separate cooling at 0-5 °C of PTFE, Ceramer and lubricant, e.g. Shellsol T.
- Mixing of PTFE and Ceramer in a tumble mixer for approx. 20 minutes at <15 °C.
- Addition of cooled lubricant, (ideally 26 weight parts Shellsol T relative to PTFE), 20 minutes in tumble mixer at <15 °C.
- Hold over night at 30 °C.
- Sieve mixture into preforming press, (wire mesh: 3 to 4 mm).
- Extrude tube.

## Coating systems made from Ceramer and Ceramer Plus



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I-61033 Fermignano (PS) Italy  
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tel +39 722 0722 3381 (ric. aut.)  
fax +39 722 0722 330035

Higher hardness and scratch resistance through Ceramer

Ceramer is already used successfully in PTFE coating systems. The main benefit of Ceramer here is:

- Enhancement of scratch resistance
- Higher hardness
- Reduction of abrasion and wear

The coating of household utensils is only one typical area of use for PTFE/-Ceramer and Ceramer Plus compounds.

*Figure 28*

These compounds also offer substantial advantages for applications in technical coatings.



Figure 28

Pans with a PTFE/Ceramer coating. Produced by TVS, Fermignano, Italy.

## Additive for thermoplastic fluoropolymers

Ceramer is also used very successfully as a filler for thermoplastic fluoropolymers such as PFA and ETFE.  
 Figure 29



Figure 29

*Pump housing made from a PFA/Ceramer compound. Produced by Venus GmbH, Heidenheim, Germany.*

*PFA filled with Ceramer shows higher strength (in the case of the pump housing 30%), hardness and stiffness than unfilled PFA. The chemical resistance of the compound is nearly the same as that of unfilled PFA.*

## Drastic reduction of abrasion also seen in thermoplastic fluoropolymers

The test results prove that there is also a drastic reduction in abrasion for thermoplastic fluoropolymers when Ceramer is added. Abrasion was determined at 50 °C using a roller abrasion instrument, and an applied load of 1 N/mm<sup>2</sup>. The contact partner was cast Perlite iron type GGG 60 with a roughness height of about 1.5 µm. The sliding speed was 2 m/s.

Figure 30

Ceramer	Abrasion [mg]			
	0% Ceramer	5% Ceramer	10% Ceramer	20% Ceramer
PFA	660	not measured	47	not measured
ETFE	96	18	not measured	11

Figure 30

*Abrasion of unfilled thermoplastic fluoropolymers and those filled with Ceramer:*

*PFA: Perfluoroalkoxy is a completely fluorinated thermoplastic, whose properties substantially resemble those of PTFE.*

*ETFE: Tetrafluoroethylene/ethylene copolymer is a partially fluorinated thermoplastic with a long-term heat resistance of up to 150 °C.*

*It is used for making cable sheeting and wire insulation, monofilaments, injection moldings and transparent, weather resistant films.*

## Physical properties

The following test data was compiled using compounds of 2 typical thermoplastic fluoropolymers (PFA and ETFE) and Ceramer.

Figures 31 and 32

Properties	Unit	Test method	PFA		Figure 31
			0% Ceramer	10% Ceramer	
Density	[g/cm <sup>3</sup> ]	ISO 1183	2.15	2.06	Physical properties of unfilled PFA and PFA filled with Ceramer.
Ball indentation hardness	[N/mm <sup>2</sup> ]	ISO 2039 I	39	42	
Yield strength	[N/mm <sup>2</sup> ]	ASTM D 4894 ASTM D 4895	14	17	
Elongation at break	[%]	ASTM D 4894 ASTM D 4895	340	50	

Properties	Unit	Test method	ETFE			Figure 32
			0% Ceramer	5% Ceramer	20% Ceramer	
Density	[g/cm <sup>3</sup> ]	ISO 1183	1.73	1.71	1.66	Physical properties of unfilled ETFE and ETFE filled with Ceramer.
Ball indentation hardness	[N/mm <sup>2</sup> ]	ISO 2039 I	40	44	57	
Yield strength	[N/mm <sup>2</sup> ]	ASTM D 4894 ASTM D 4895	21	22	21	
Elongation at break	[%]	ASTM D 4894 ASTM D 4895	250	130	25	

## Excellent chemical resistance

The chemical resistance of thermoplastic fluoropolymers filled with Ceramer is almost the same as that of the pure fluoropolymer. The table shows the results from a compound made of 70% PFA and 30% Ceramer in reference to its resistance against strong acids, solvents and hydraulic oils at temperatures from 23 °C to 120 °C.

The tests were carried out on approx. 2 mm thick tensile specimens machined from pressure sintered blocks. The test specimens were not subjected to external stresses during immersion in the chemical agents.

Except for highly concentrated nitric acid and fuming sulfuric acid, to which even unfilled PFA is not resistant at very high temperatures, none of the chemical agents caused any damage.

Figure 33

Chemical	Chemical resistance at				
	Ambient temperature		100 °C		120 °C
	72 h	1.000 h	72 h	1.000 h	72 h
Hydrochloric acid (37%)	A	A	A	A	
Sulfuric acid (96%)	A				A
Fuming sulfuric acid	B	C	C	C	
1:1 mixture of hydrogen peroxide (30%) and sulfuric acid (96%)	A				A
Phosphoric acid (85%)	A				A
Nitric acid (85%)	C	C	C	C	
Nitric acid (100%)	C				C
Caustic soda (50%)	A	A	A	A	A
Caustic potash (50%)	A	A	A	A	
N-Methyl-2-pyrrolidone (>99.5%)	A	A	A	A	
N,N-Dimethylformamide (>99%)	A	A	A	A	
HyJet IV-A, Chevron, Hydraulic fluid	A	A	A	A	
Skydrol LD-4, Monsanto, Hydraulic fluid	A	A	A	A	
Jet Oil II, Mobil, Hydraulic fluid	A	A	A	A	

Figure 33 Chemical resistance of a PFA/Ceramer (70:30) compound.

Key to chemical resistance table:

- A: No significant effect (increase in weight <3% or loss of weight <0.5% and/or decrease in tear strength <15% and/or change in dimension <3%).  
 B: Significant, but usually not conclusive (increase in weight 3–8% or loss of weight 0.5–3% and/or decrease in tear strength 15–30% and/or change in dimension 3–8%).  
 C: Usually significant (increase in weight >8% or loss of weight >3% and/or decrease in tear strength >30% and/or change in dimension >8%).

## Electrical properties remain almost unchanged

The outstanding electrical insulation properties of PFA, the fully fluorinated thermoplastic material, is not affected by the addition of Ceramer.

Figures 34 and 35

Figure 34

- unreinforced
- 5% Ceramer
- 10% Ceramer
- 20% Ceramer

Dissipation factor  $\tan \delta$  according to IEC 250 of unreinforced PFA and PFA reinforced with Ceramer (determined at 23°C and 50% relative humidity).

Dissipation factor  $\tan \delta$  [ $\times 10^{-4}$ ]

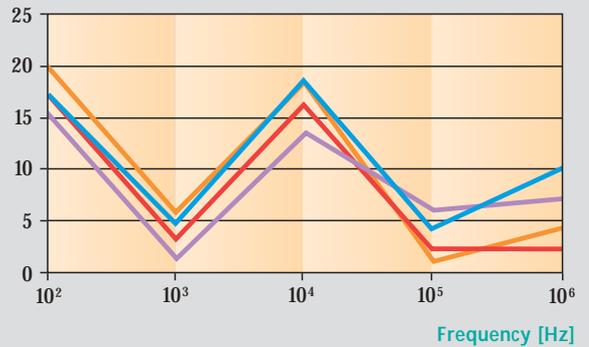
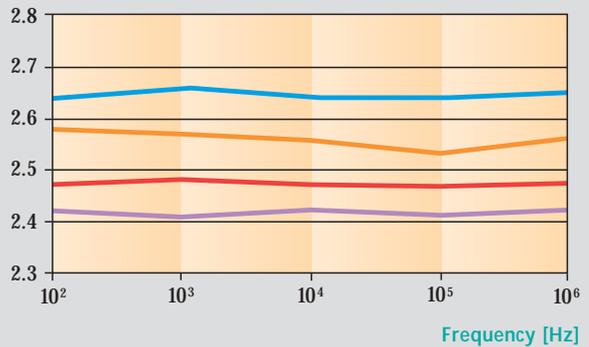


Figure 35

- unreinforced
- 5% Ceramer
- 10% Ceramer
- 20% Ceramer

Dielectric constant  $\epsilon_r$  according to IEC 250 of unreinforced PFA and PFA reinforced with Ceramer (determined at 23°C and 50% relative humidity).

Dielectric constant  $\epsilon_r$  [-]



## Improved tribological results in all thermo-plastic polymers

Because of its small particle size, Ceramer is very suitable as a reinforcing agent for many other polymers, such as LCP, PEEK, PBT, POM, PEI and PESU. It is also possible to substantially reduce abrasion and wear by adding Ceramer, and in addition, to raise the pressure resistance. The extended number of grades makes a choice of the correct material for a particular purpose possible.

Figures 36-44

The surface roughness of the individual particles offers a very good physical bonding with the matrix materials. Since Ceramer has no melting point, the particle shape remains unchanged during processing.



Figure 36

Gears made out of high performance polymers filled with Ceramer.

Wear and abrasion of the gears could be drastically reduced by using Ceramer as a filler.

Properties, Standard [Unit]	100% LCP	95% LCP	90% LCP	85% LCP
		5% Ceramer	10% Ceramer	15% Ceramer
Density, ISO 1183 [g/cm <sup>3</sup> ]	1.399	1.402	1.405	1.408
Tensile test, ISO 527				
Tensile modulus [N/mm <sup>2</sup> ]	8600	8110	7510	7200
Tensile strength [N/mm <sup>2</sup> ]	153	174	157	146
Elongation at break [%]	4.2	5.3	5.2	5.0
Bending test, ISO 178				
Flexural modulus [N/mm <sup>2</sup> ]	8950	8040	7370	6880
Flexural strength [N/mm <sup>2</sup> ]	154	151	146	142
Compression test, ISO 604				
Compressive strength [N/mm <sup>2</sup> ]	67.7	68.6	69.1	76.1
Compressive strain at break [%]	9.5	10.6	6.6	18.2
Charpy impact resistance ISO 179/1eU [kJ/m <sup>2</sup> ]	73.6	78.3	71.2	60.8
Charpy V-notched impact resistance ISO 179/1eA [kJ/m <sup>2</sup> ]	39.3	44.8	25.9	15.6
HDT C, DIN 53461 [°C]	96	95	92	92
Tribological properties				
K-factor k* [10 <sup>-6</sup> mm <sup>3</sup> /Nm]	0.39	0.24	0.35	0.78
Coefficient of friction* [-]	0.64	0.39	0.17	0.24

Figure 37 Physical properties of LCP/Ceramer compounds.

\* Pin-on-disc machine, sliding speed:

0.5 m/s, contact pressure: 1 N/mm<sup>2</sup>, R<sub>z</sub> = 3 μm, ambient temperature.

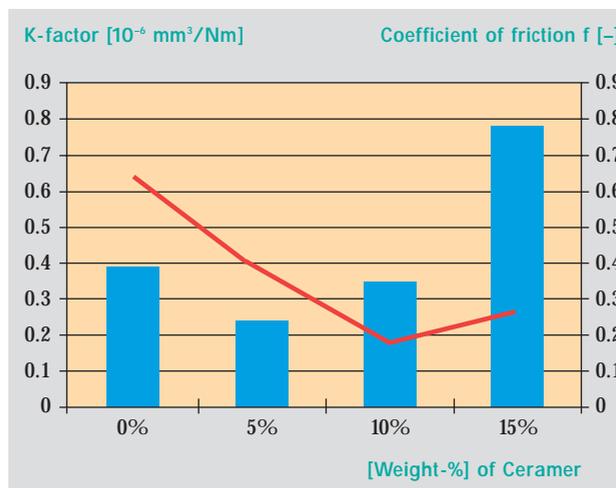


Figure 38

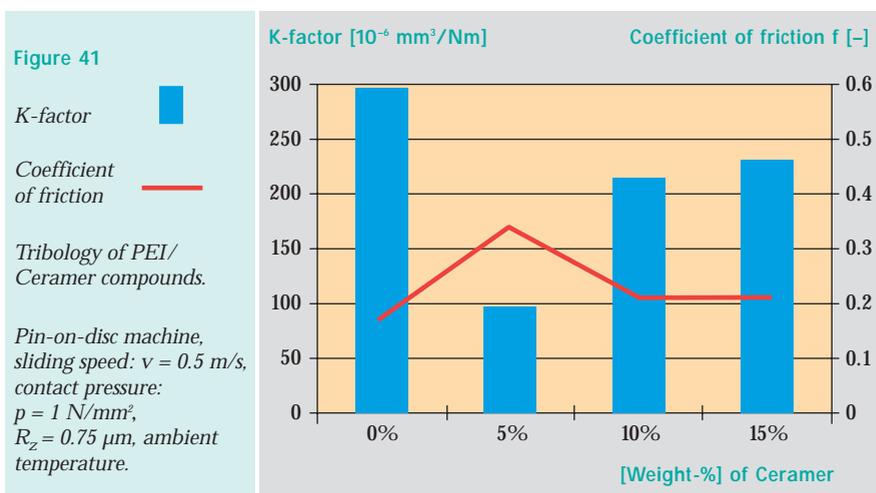
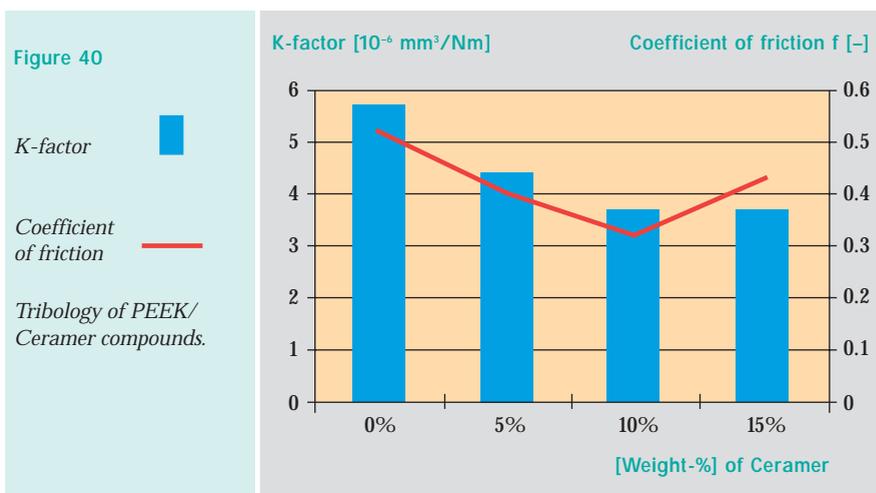
K-factor

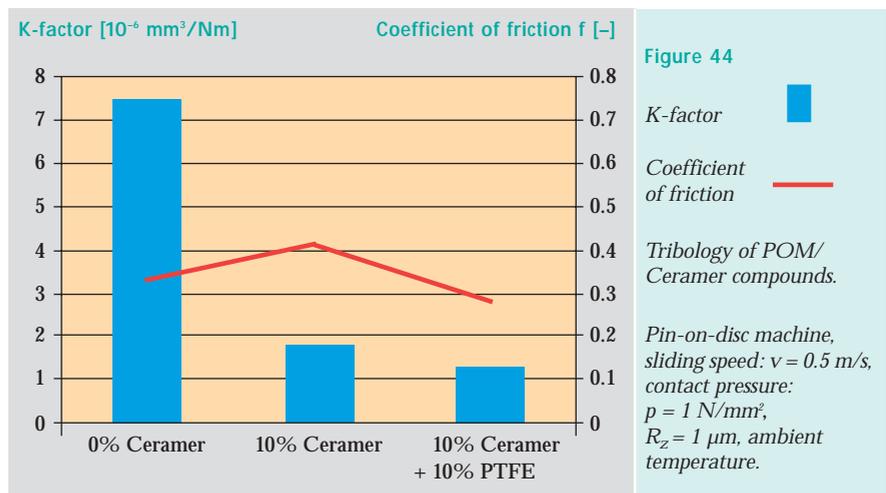
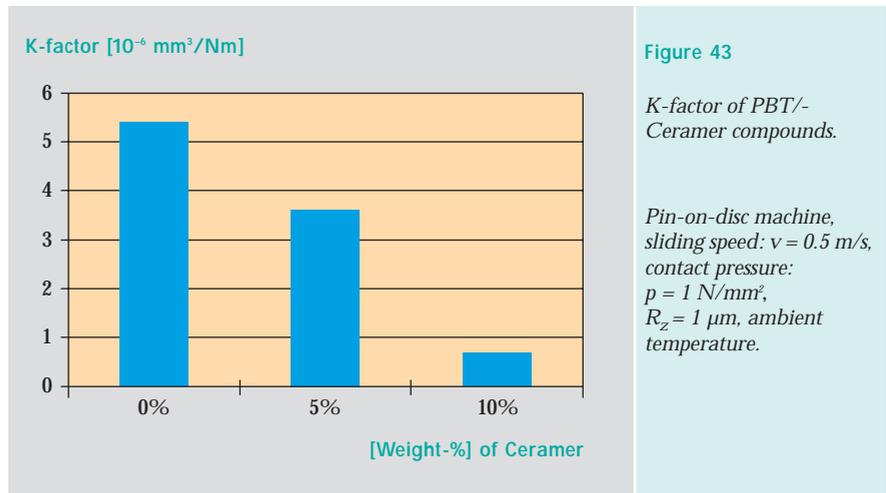
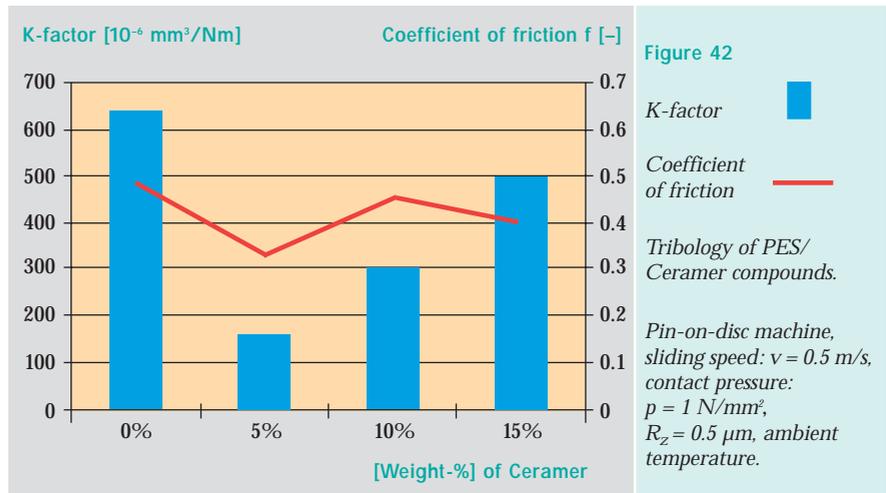
Coefficient of friction

Tribology of LCP/Ceramer compounds.

Properties, Standard [Unit]	100% PEEK	95% PEEK	90% PEEK	85% PEEK
		5% Ceramer	10% Ceramer	15% Ceramer
Density, ISO 1183 [g/cm <sup>3</sup> ]	1.290	1.295	1.295	1.309
Tensile test, ISO 527				
Tensile modulus [N/mm <sup>2</sup> ]	3930	3810	3820	3960
Tensile strength [N/mm <sup>2</sup> ]	96.3	90.4	72.7	70.8
Elongation at break [%]	9.2	5.6	2.4	2.1
Bending test, ISO 178				
Flexural modulus [N/mm <sup>2</sup> ]	3990	3980	4060	4070
Flexural strength [N/mm <sup>2</sup> ]	155	151	151	145
Compression test, ISO 604				
Compressive strength [N/mm <sup>2</sup> ]	147	149	153	160
Compressive strain at break [%]				
Charpy impact resistance ISO 179/1eU [kJ/m <sup>2</sup> ]	not broken	185	49.4	26.5
Charpy V-notched impact resistance ISO 179/1eA [kJ/m <sup>2</sup> ]	7.7	6.6	3.6	2.3
HDT C, DIN 53461 [°C]	140	137	139	137
Tribological properties				
K-factor* [10 <sup>-6</sup> mm <sup>3</sup> /Nm]	5.7	4.4	3.7	3.7
Coefficient of friction* [-]	0.52	0.40	0.32	0.43

**Figure 39** Physical properties of PEEK/Ceramer compounds.  
 \* Pin-on-disc machine, sliding speed:  
 0.5 m/s, contact pressure: 1 N/mm<sup>2</sup>, R<sub>z</sub> = 0.5 μm, ambient temperature.

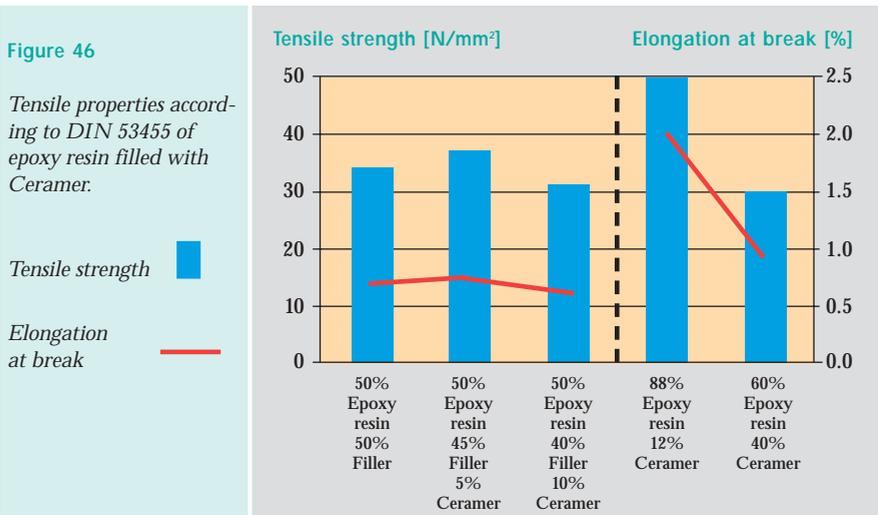
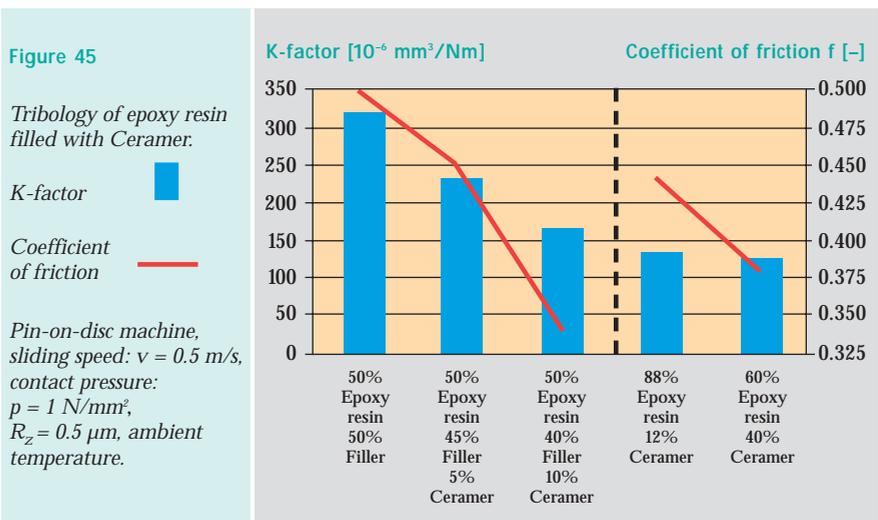




## Excellent tribological results also possible with thermosets

Very good test results are also achieved in thermosets with Ceramer as a filler. In addition to this, better mechanical properties are achieved through the replacement of conventional fillers with Ceramer.

Figures 45 and 46



## The outstanding electrical properties of fluoropolymers remain unchanged

No significant change in the electrical properties of fluoropolymers filled with Ceramer was observed when compared to unfilled fluoropolymers (see pages 11 and 18).

For the tests, an approximately 240 nm thick film of copper was applied to the substrate by sputtering. The bond strength between the copper film and the substrate was subsequently determined by the peel-off method. The data confirms a clear improvement of the adhesion to metals.

Figure 47

The increase of the polar share of the surface tension of the fluoropolymer substrate is the main reason for this.

Figure 48

The thickness of the copper film can be raised further using electrochemical deposition.

## Substantial improvement of adhesion to metals

Non-polar fluoropolymers are notoriously difficult to metallize because of their poor adhesion to other materials, notably metals. This causes severe problems when molded parts have to be metallized for electronic applications such as printed circuit boards.

Figure 49

Fluoropolymers are often not even considered for this type of application, despite the fact that their electrical properties would be ideal for the purpose. By incorporating the polar Ceramer, or extremely polar Ceramer Plus, adhesion to metals such as copper can be drastically increased. Here it must be ensured that there is always a sufficient amount of Ceramer on the substrate surface.

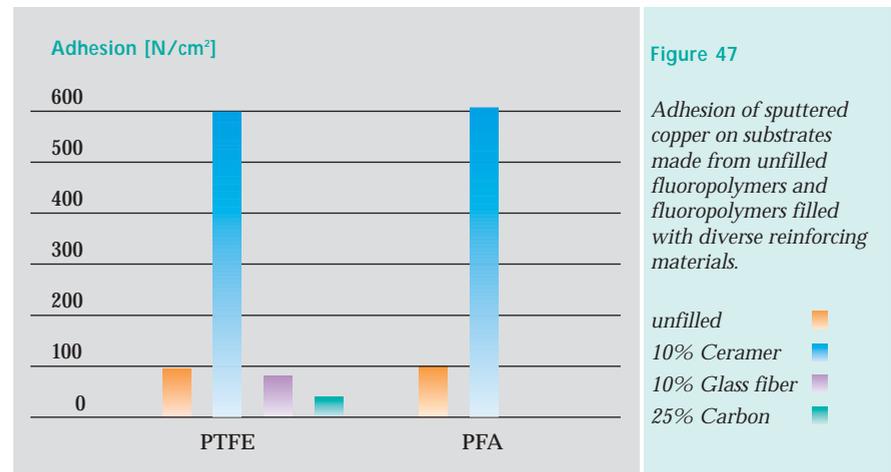


Figure 47

Adhesion of sputtered copper on substrates made from unfilled fluoropolymers and fluoropolymers filled with diverse reinforcing materials.

unfilled  
10% Ceramer  
10% Glass fiber  
25% Carbon

Compound	Surface tension to water according to Neumann	Surface tension according to Wu		
	Total $\sigma_s$ [mN/m]	Dispersive content $\sigma_s^d$ [mN/m]	Polar content $\sigma_s^p$ [mN/m]	Total $\sigma_s$ [mN/m]
100% PTFE	19.4	23.3	2.1	25.4
95% PTFE 5% Ceramer	28.7	19.1	8.3	27.4
90% PTFE 10% Ceramer	29.0	16.2	9.7	25.9
80% PTFE 20% Ceramer	41.7	15.8	17.9	33.7
100% Ceramer	47.4	20.5	18.8	39.3

Figure 48

Surface tension of unfilled PTFE and PTFE filled with Ceramer.



Figure 49

3-D printed circuit board with improved adhesion of the printed conductors through Ceramer.

## Metallization of other polymers

When Ceramer and Ceramer Plus are used as an additive in other polymers, metallization is drastically improved there too.

Here again, an approximately 240 nm thick film of copper was applied to the substrate by sputtering. The bond strength between the copper film and the substrate was determined using the peel-off method.

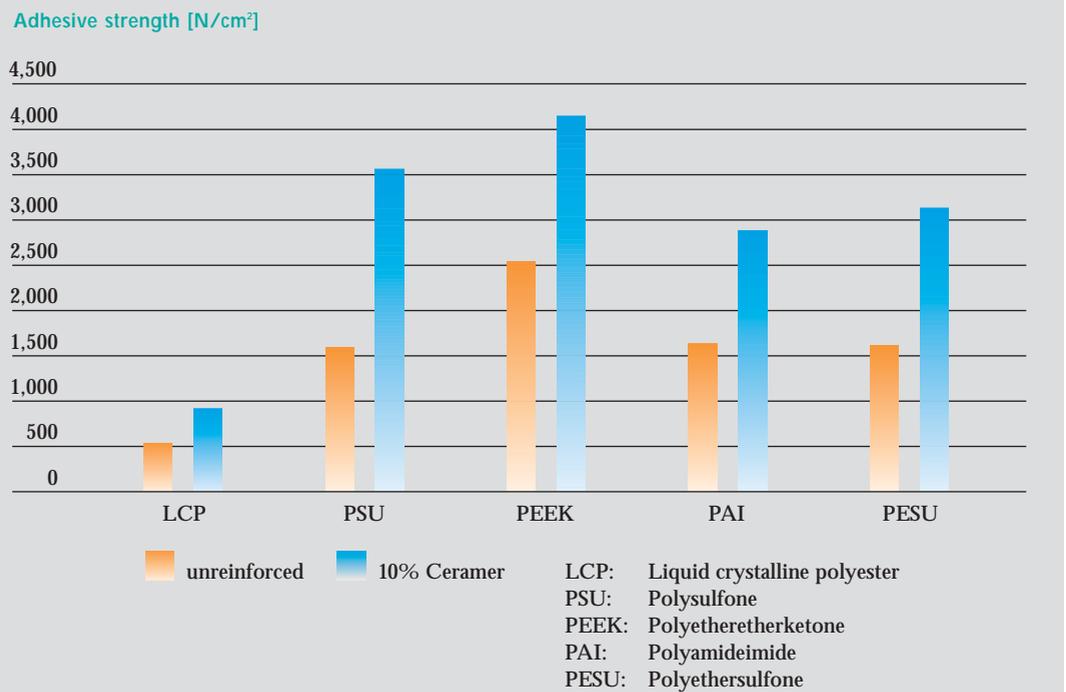
Figure 50

The thickness of the copper film can also be raised using electrochemical deposition.

Ceramer and Ceramer Plus improve metallization

Figure 50

Adhesive strength of sputtered copper to unfilled high performance polymers and those filled with Ceramer.



## Consolidated neat Ceramer and Ceramer Plus

### High performance polymers with outstanding chemical and temperature resistance

The use of Ceramer and Ceramer Plus as neat resins covers a wide range of applications.

Above all, the polymers distinguish themselves through:

- universal chemical resistance which is comparable with PTFE,
- steam resistance and sterilization possibilities (stable at 180°C for 6 h),
- extremely high service temperature (short term to 500°C, Tg approx. 360°C),
- inherent flame resistance (≥ 1.5 mm UL 94 V-0),
- high hardness, strength and stiffness,
- excellent surface quality which makes a mirror finish surface possible,
- excellent creep resistance.

The materials are also available as high purity grades, which show exceptional performance for semiconductor applications. The proportion of metal ions here lies in the lower ppm range, or in the ppb range. The proportion of iron and sodium ions, for example, can each be reduced to <1 ppm. Ionic impurity was total content measured by X-ray fluorescent analysis.

(Pages 4 and 32).

## Hot Compression Molding operation

Ceramer and Ceramer Plus cannot be processed in the same way as standard thermoplastic resins by using injection molding or extrusion, since they do not

have a melting point.

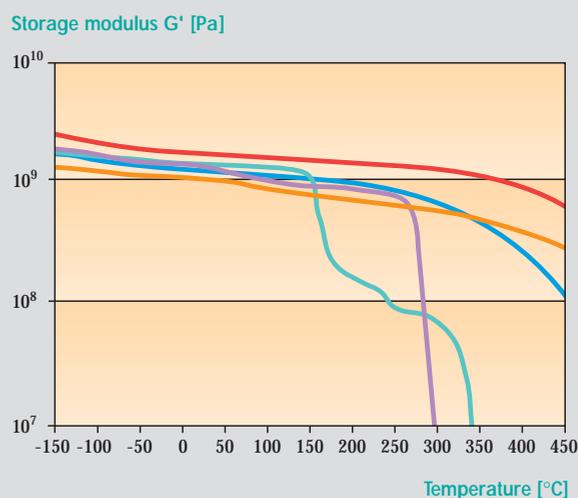
The best processing methods are:

- hot pressing consolidation
- cold pressing and sintering

Figure 51

Ceramer  
Ceramer Plus  
PEEK  
PAI  
PI

Storage modulus as a dependant of temperature, measured on hot pressed specimens made of Ceramer and Ceramer Plus compared to other high performance polymers.



## Hot pressing of Ceramer

To be able to process Ceramer using hot pressing, pre-treatment is necessary.

linked to the size of the parts required. (Figure 52)

The hot pressing parameters are strongly

Powder pre-treatment	375 °C for 330 minutes in air with good oven ventilation to handle gases which are produced. It is recommended that the powder is covered during preheating, leaving a small vent open, i.e. to reduce the amount of contact to the surrounding air. During preheating the Ceramer powder loses approximately 8% of its own weight. The off-gassing products are mainly sulfur dioxide (SO <sub>2</sub> ).
Hot pressing temperature	425–430 °C (Flexural strength drops slowly as the pressing temperature drops to 400 °C).
Hot pressing pressure	140 N/mm <sup>2</sup> (70 N/mm <sup>2</sup> and possibly as low as 50 N/mm <sup>2</sup> work but the flexural strength is reduced; 100 N/mm <sup>2</sup> can be satisfactory). Hot pressing pressure should be applied during heating phase when 400 °C has been reached.
Hot pressing time	30 minutes (15 minutes results in somewhat lower properties and 45 minutes may increase properties).
Cooling with pressure	Cool to 275 °C from the pressing temperature at the pressing pressure

Figure 52

Hot pressing parameters for parts up to 25 mm.

The data shown is typical for cylinders with a diameter up to 25 mm and plaques with thickness to 8 mm. With larger parts, the press temperature should be lowered as cracks may appear in the finished part.

Due to the limited stroke of many presses and the inherent, apparent (bulk) density of the Ceramer powder of 0.54 g/cm<sup>3</sup>, it is often not possible to produce parts of a certain thickness or length. In this case, it is recommended that thinner or shorter parts should be cold pressed first. Because of the compaction achieved in the Ceramer powder by cold pressing, (60% of the theoretical density, i.e. approx. 0.86 g/cm<sup>3</sup>), thicker or longer parts can be produced in the hot press. To achieve the best possible quality in the hot pressed parts, it is recommended that a thin layer of Ceramer powder is applied between the individually cold pressed parts.

Figure 53

The coefficient of linear thermal expansion (CTE) can be significantly reduced by using carbon fibers as a reinforcing agent. In this way it can be adjusted to other materials like aluminum, steel or glass. This lower CTE also allows hot pressing of hollow parts (rings) over metal mandrels.

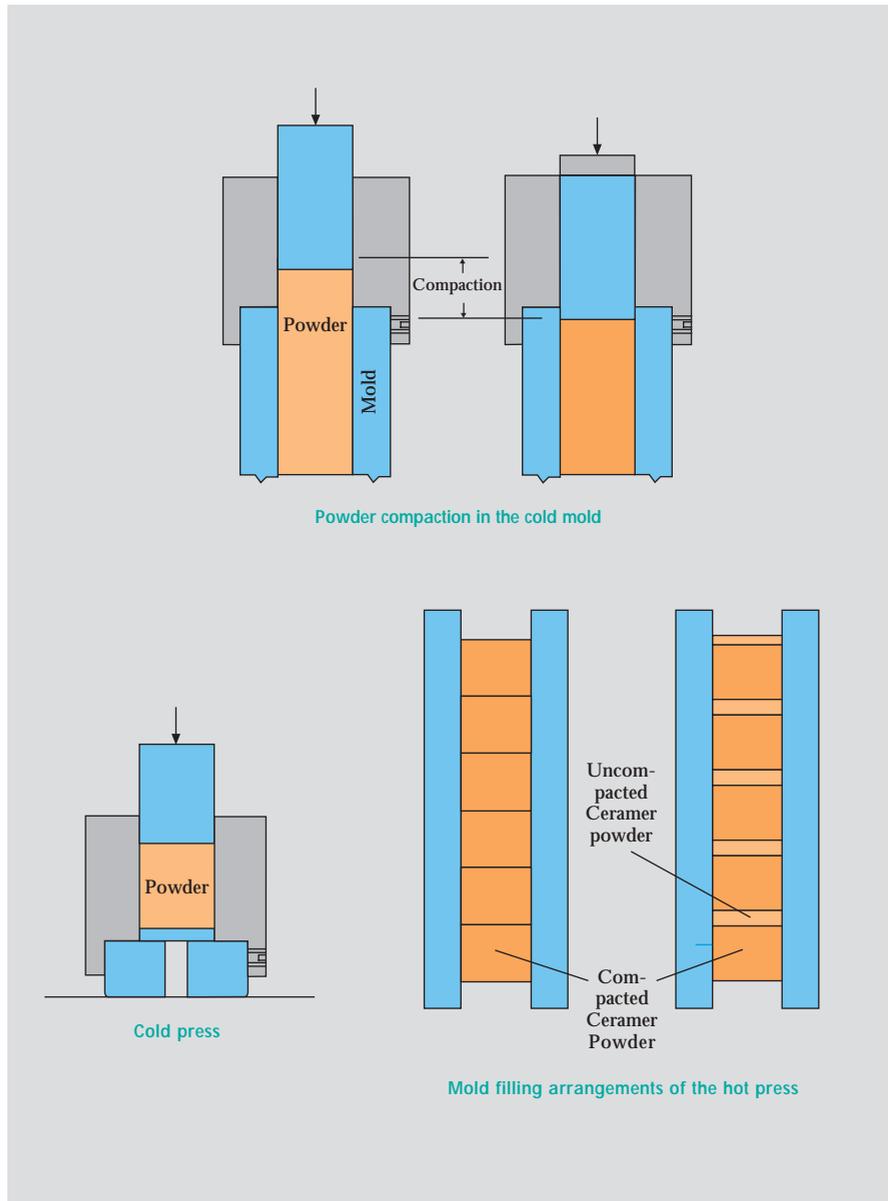


Figure 53 Methods for high density powder packing of Ceramer.



Figure 54

Semi-finished products and final parts made from Ceramer.



Figure 54a

By hot pressing Ceramer it is possible to produce parts with a mirror finish surface.

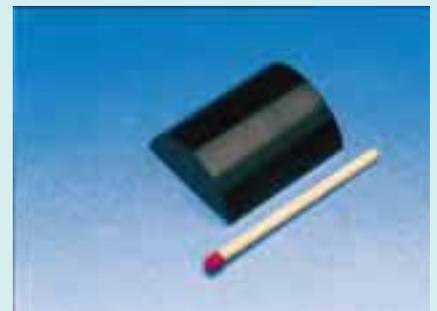


Figure 54b

Hot pressed parts made from Ceramer can be welded together by applying a thin layer of Ceramer powder between them.

Outstanding high temperature properties of hot pressed Ceramer

Property, Standard	Ceramer	
	Metric unit	British unit
Water absorption, ISO 62 after 24 h at 23 °C equilibrium at 23 °C	0.1% 0.4%	0.1% 0.4%
Density, ISO 1183	1.41 g/cm <sup>3</sup>	1.41 g/cm <sup>3</sup>
Ball indentation hardness, ISO 2039 surface as molded surface polished	215 N/mm <sup>2</sup> 141 N/mm <sup>2</sup>	31 kpsi 20 kpsi
Compressive properties, ISO 604 Compressive stress at 1% strain Compressive stress at break Nominal compressive strain at break	24 N/mm <sup>2</sup> 153 N/mm <sup>2</sup> 10%	3.5 kpsi 22 kpsi 10%
Tensile properties, ISO 527 Flexural modulus Tensile strength Elongation at break	3400 N/mm <sup>2</sup> 42 N/mm <sup>2</sup> 1.2%	490 kpsi 6.1 kpsi 1.2%
Bending properties, ISO 178 -30 °C Flexural modulus Flexural strength Elongation at break	3960 N/mm <sup>2</sup> 87 N/mm <sup>2</sup> 2.1%	580 kpsi 13 kpsi 2.1%
+23 °C Flexural modulus Flexural strength Elongation at break	3850 N/mm <sup>2</sup> 84 N/mm <sup>2</sup> 2.1%	560 kpsi 12.3 kpsi 2.1%
+100 °C Flexural modulus Flexural strength Elongation at break	3410 N/mm <sup>2</sup> 65 N/mm <sup>2</sup> 1.9%	500 kpsi 9.5 kpsi 1.9%
+200 °C Flexural modulus Flexural strength Elongation at break	3030 N/mm <sup>2</sup> 47 N/mm <sup>2</sup> 1.6%	440 kpsi 6.9 kpsi 1.6%
+300 °C Flexural modulus Flexural strength Elongation at break	1740 N/mm <sup>2</sup> 43 N/mm <sup>2</sup> 2.8%	250 kpsi 6.3 kpsi 2.8%
HDT A, ISO 75	> 295 °C	> 563 °F
HDT C, ISO 75	250 °C	482 °F
Dielectric constant $\epsilon_r$ , ASTM D150 1 KHz 10 KHz 100 KHz 1 MHz 10 MHz 500 MHz 1 GHz 10 GHz	3.6 3.5 3.5 3.41 3.39 3.37 3.37 3.28	3.6 3.5 3.5 3.41 3.39 3.37 3.37 3.28
Dissipation factor $\tan \delta$ , ASTM D150 10 KHz 100 KHz 1 MHz 10 MHz 500 MHz 1 GHz 10 GHz	20 x 10 <sup>-4</sup> 40 x 10 <sup>-4</sup> 59 x 10 <sup>-4</sup> 52 x 10 <sup>-4</sup> 54 x 10 <sup>-4</sup> 58 x 10 <sup>-4</sup> 95 x 10 <sup>-4</sup>	20 x 10 <sup>-4</sup> 40 x 10 <sup>-4</sup> 59 x 10 <sup>-4</sup> 52 x 10 <sup>-4</sup> 54 x 10 <sup>-4</sup> 58 x 10 <sup>-4</sup> 95 x 10 <sup>-4</sup>
Volume resistivity, ASTM D 257	10 <sup>15</sup> Ω cm	10 <sup>15</sup> Ω cm
Surface resistivity, ASTM D 257	10 <sup>11</sup> Ω	10 <sup>11</sup> Ω
Dielectric strength, ASTM D149	12.4 kV/mm	310 V/mil
Coefficient of linear thermal expansion - 50 °C to 100 °C 100 °C to 200 °C 200 °C to 300 °C 300 °C to 360 °C	48 x 10 <sup>-6</sup> K <sup>-1</sup> 46 x 10 <sup>-6</sup> K <sup>-1</sup> 45 x 10 <sup>-6</sup> K <sup>-1</sup> 40 x 10 <sup>-6</sup> K <sup>-1</sup>	27 x 10 <sup>-6</sup> in/in °F 26 x 10 <sup>-6</sup> in/in °F 25 x 10 <sup>-6</sup> in/in °F 22 x 10 <sup>-6</sup> in/in °F

Figure 55 Physical properties of Ceramer.

## Ceramer Plus for parts with special needs

Ceramer Plus is especially appropriate for technical parts which operate under severe conditions such as bearings and seals for the oil and gas industries, aerospace technology as well as general mechanical engineering. Ceramer Plus is chosen by the semiconductor industry because of its outstanding purity.

Figure 57

Compared to standard Ceramer, parts made from Ceramer Plus show an even higher chemical and thermal resistance. The compression strength of Ceramer Plus is approximately one third higher than Ceramer at elevated temperatures (approx. 150°C to 250°C). However, at ambient temperature Ceramer shows higher compression strength.

## Processing

The processing of Ceramer Plus using the hot pressing technique is very similar to that of Ceramer. Pre-treatment of the powder is not necessary.

Figure 56

Powder pre-treatment	not necessary
Hot pressing temperature	430–435 °C
Hot pressing pressure	140–210 N/mm <sup>2</sup> (the pressing pressure should be applied during the heating phase when 400 °C is reached)
Hot pressing time	30 minutes
Cooling with pressure	under pressure to 275 °C, then without pressure

Figure 56 Typical hot pressing parameters for Ceramer Plus.

The technique of powder compaction can also be used with Ceramer Plus in order to produce thicker or longer parts.

Powder pretreatment for hot pressing not necessary for Ceramer Plus



Figure 57

The part on the left represents a hollow cylinder made of steel, in which Ceramer Plus reinforced with carbon fibers was sintered using hot pressing. Through the addition of the carbon fibers, the coefficient of linear thermal expansion was adjusted to that of the steel. In this way an excellent bond was formed between the carbon fiber/Ceramer compound and the metal housing.

In the part on the right, Ceramer Plus reinforced with carbon fibers was hot pressed using a threaded mold. By applying a lubricant to the threads, it can be unscrewed from the part after hot pressing, thus leaving a perfect internal thread.

## Recommendations for machining parts made from Ceramer and Ceramer Plus

In general, Ceramer can be machined using all standard machine tools. A very low cutting speed should be chosen for this process. The following milling cutters are specially recommended for the machining of Ceramer and Ceramer Plus: Carbide bar (cylindrical - Flat End, End Cut) or Carbide Bar (Cone).

## Ceramer machining instructions



Figure 59

*Lathe setup for facing an approx. 1" diameter cylinder of Ceramer using a rotating tool (1/8" carbide milling cutter). For picture, the lathe rotation, rotating cutter and cooling water were turned off.*

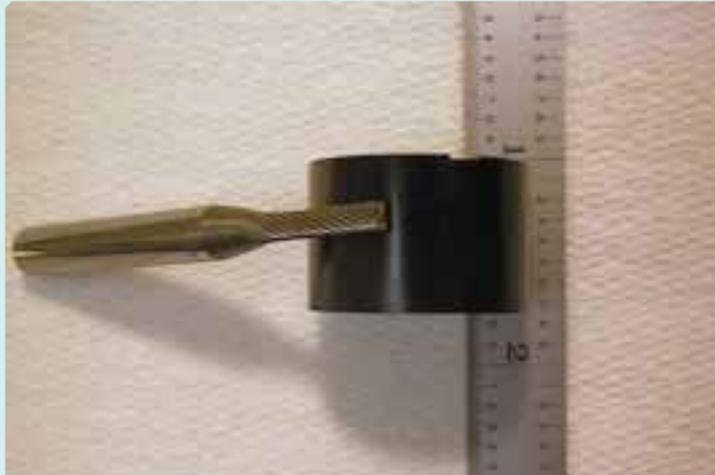


Figure 58

*A Ceramer cylinder machined on a lathe.*

**Figure 60**

*Detail picture of the milling cutter used to machine the Ceramer in the lathe. After the facing cut, a 25  $\mu\text{m}$  deep groove was milled across the cylinder face.*



**Figure 61**

*The cylinder on the right is Ceramer 20 grade and shows a good surface finish. When the same conditions, which included using cooling water, were used on the Ceramer Plus 20 grade shown on the left, they produced chatter and "pull-out". Thus the two grades sometimes require different machining parameters.*



**Figure 62**

*The same cylinders were returned to the lathe and partially machined with a rotating 1/4" carbide milling cutter. The primary difference was that air blast cooling instead of water was used. The Ceramer 20 shows chatter, while the Ceramer Plus grade has a good finish.*



For the processing of Ceramer and Ceramer Plus, various tool surfaces made of the following materials were examined for their suitability:

Figure 63

Recommendations for steel tools

Precipitation hardened stainless steel such as 17-4 PH (1.4542 =

X5 CrNiCuNb 17.4) or 13-8 Mo.

Recommendations for lubricants

Boron nitride is suitable for every tool surface.

For gold plating or hard chromed surfaces however, a graphite spray is recommended, as a single spraying lasts for several pressings. In this way, it is also possible to keep costs low and reduce the possibility of contamination of the surface of the parts.

Surface:	Ceramer	Ceramer Plus
Chrome plating*	suitable	suitable
Ceramic (Al <sub>2</sub> O <sub>3</sub> and Si C)	suitable	suitable
Gold plus a film of "Baked On" Graphite Lube	suitable	suitable
Mica sheet	suitable	suitable
Gold plating	suitable	suitable under given circumstances (partial adhesion of Ceramer powder)
Ti N	suitable	suitable under given circumstances (partial adhesion of Ceramer powder)

Figure 63 Recommended tool surfaces for the hot pressing of Ceramer and Ceramer Plus. \* Repolishing after use generally not required.

## Sintering and green body technology

This processing technology for non-melting technical polymers is widely used since it represents a cost effective alternative to hot pressing.

The mechanical properties achievable through hot pressing are, however, not reached in this case. Thus, a combination of sintering and hot pressing is suitable, in which the powder is pre-pressed cold and then placed directly into a pre-heated hot press for further processing. Because of this, the heating phase is by-passed, which means that the processing time in the machines is substantially reduced. This way of processing combines the assurance of the outstanding properties of hot pressing with the cost effectiveness of sintering. Ceramer Plus is especially suitable for this type of processing.

Figure 65



Figure 64 Parts made from Ceramer and Ceramer Plus sintered without using pressure.

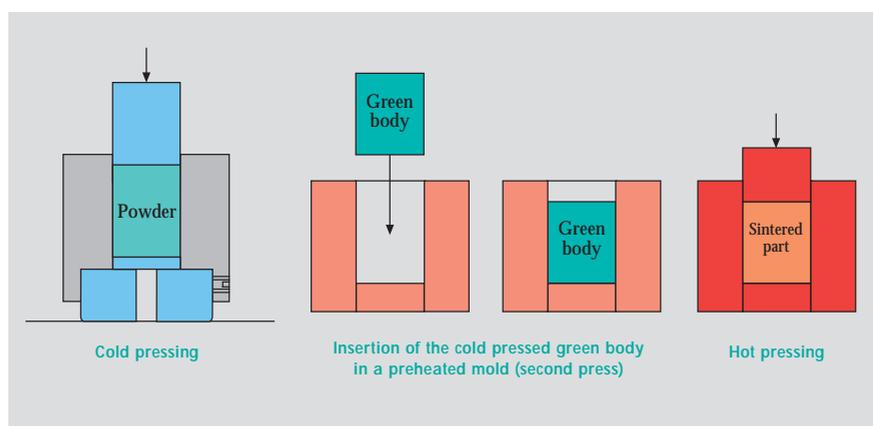


Figure 65 Methods for hot pressing green bodies in pre-heated mold.

## Typical sintering parameters for small parts (diameter 10 mm, thickness 2 mm):

Both Ceramer and Ceramer Plus are excellent for sintering. Sintering temperature and time are dependent on the size of the part.

Oven temperature: 410 °C  
 Time: 1 h  
 Sintering atmosphere: air

A pre-treatment of the Ceramer powder is not necessary in this case. The density achieved through sintering is approx. 75% for Ceramer and 85% for Ceramer Plus of the theoretical density. Ceramer Plus offers particularly good mechanical properties; the achievable property level lies at approximately half the highest density of the hot pressed part.

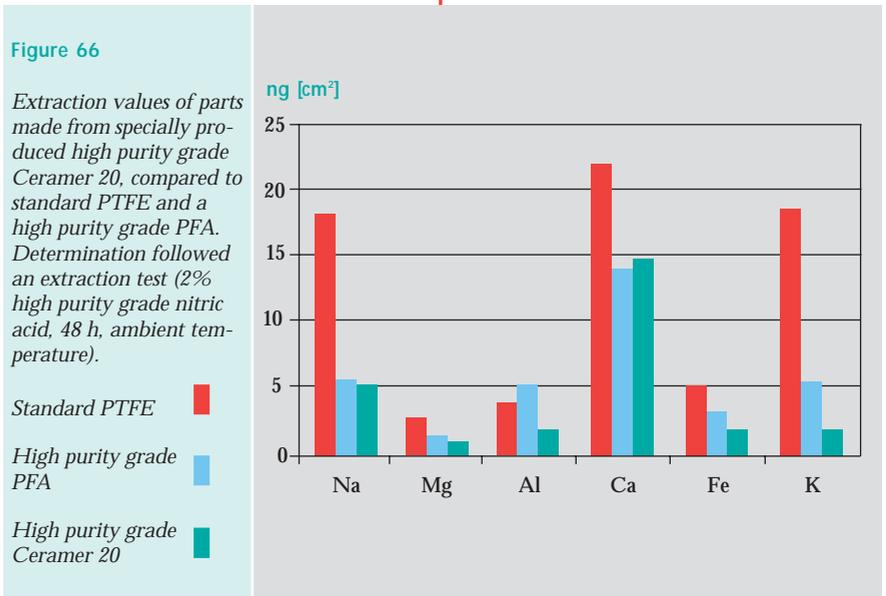
Areas of application for sintered Ceramer and Ceramer Plus are filter materials, and applications which require a high chemical and temperature resistance, but in which the strength is not so important.

Figure 64

## High purity Ceramer for semiconductor applications

The extraction values of high purity Ceramer 20 parts are substantially lower than those of standard PTFE. They are comparable to high purity PFA. High purity Ceramer 20 is, therefore, very suitable for applications in the semiconductor industry.

Figure 66



## Chemical and thermal resistance, excellent bonding and other application driven properties

**T**hermal Spraying is a suitable method for the production of coating systems made of Ceramer or composite coatings comprising Ceramer and other materials such as metals, ceramics or other plastics. This process has been widely used for a long time in the production of metallic and ceramic coating systems, and the technology is equally applicable to Ceramer.

*Figure 67*

Coatings can be deposited onto most substrate materials including metals, ceramics and plastics. Thermal spraying, whilst heating the material being deposited, does not require any significant heating of the substrate material.

It therefore enables components to benefit from surface properties available from Ceramer or composites based on Ceramer without significant detrimental effects on the inherent strength or other properties of the base material. Ceramer or combinations of Ceramer and other materials in a suitable powder form are deposited by one of the following established thermal spray processes:

- **Powder Combustion**  
This process utilizes an oxy/fuel (normally acetylene) flame as a heat source, and powder is introduced into the spray stream either by gravity or suspended in a carrier gas. In relative terms the gas stream velocity and temperature is low.
- **Plasma Arc**  
This process comprises passing a mixture of gases (typically Nitrogen/Hydrogen or Argon/Helium but can be others) through a high current DC arc, causing dissociation and ionization of the gases resulting in a high temperature, high energy and high velocity plasma stream. Powder is normally introduced suspended in a carrier gas, downstream of the arc.
- **High Velocity Oxy Fuel (HVOF)**  
This process utilizes combustion of oxygen and a fuel in a combustion chamber. The expanding gases are discharged through a nozzle providing very high (supersonic) gas velocities, and correspondingly high particle velocities. Powder is introduced into the high velocity gas stream suspended in a carrier gas.

The above processes create a spray stream comprising hot gases in which the powder particles are suspended. During the process, both thermal and kinetic energy is transferred to the powder particles so that on impact with the substrate surface the particles are in a suitably semi molten condition, causing them to adhere both to the surface and to each other to form a coating.



**Figure 67** Thermal spraying of a Ceramer/Silicon Aluminum mixture.

Powders comprising a combination of Ceramer and Silicon Aluminum are sprayed by either the plasma process or the HVOF process to produce abrasion-resistant coatings. These are used for seal clearance control in the compressor section of gas turbines to improve efficiency. The coating is normally applied to the stator or casing. The adjacent rotating element, which may be a labyrinth seal, or rotating blade tips, will cut a groove in the relatively soft and abrasion-resistant coating and create its own envelope thereby reducing running clearances to the absolute minimum.

Figure 68

For cost reasons, this application has to date largely been limited to aircraft

turbine engines. However, Ceramer and improved spraying efficiencies are combining to reduce the cost of thermal sprayed abrasion-resistant coatings. At the same time, environmental and other considerations are highlighting the desirability of improved performance compressors in other applications such as:

- motor vehicle turbochargers
- compressors used for industrial processing and transport of gases in pipelines
- gas turbines for power generation and other land based applications
- gas turbines for marine propulsion.

## Abradable coatings comprising Ceramer and Silicon Aluminium – through Plasma Arc or High Velocity Oxy Fuel (HVOF)

Applications requiring wear and abrasion resistance as well as corrosion resistance are met by engineering composite coatings to include Ceramer and other materials such as oxide ceramics. There is a very wide range of potential properties available and correspondingly, a wide range of potential applications.



Figure 68

*Abradable coatings in gas turbine engines maximize efficiency.*

The ceramer team works very closely with the British specialists, International ThermalSpray Ltd.

**International ThermalSpray**  
**Ludlams Gate**  
**Monks Well**  
**Farnham, Surrey GU10 1RH**  
**England**  
**Phone +44 (0) 1252 782297**  
**Fax +44 (0) 1252 781362**  
**IntTS@Compuserve.com**

**Directors: Chris W. Smith, W. Alan Saywell**

Further information on thermal spraying ceramer can be obtained from our partners at the above address. International ThermalSpray Ltd supply materials in powder form suitable for thermal spraying, these include ceramer, combinations of ceramer and silicon aluminum or ceramer combined with other materials.

Values shown are based on testing of laboratory test specimens and represent data that fall within the normal range of properties for natural material. Colorants or other additives may cause significant variations in data values. These values are not intended for use in establishing maximum, minimum, or ranges of values for specification purposes.

Any determination of the suitability of this material for any use contemplated by the users and the manner of such use is the sole responsibility of the user, who must assure themselves that the material as subsequently processed meets the needs of their particular product of use. To the best of our knowledge, the information contained in this publication is accurate; however, we do not assume any liability whatsoever for accuracy and/or completeness of such information. Moreover, there is a need to reduce human exposure to many materials to the lowest practical limits in view of possible long-term adverse effects. To the extent that any hazards may have been mentioned in this publication, we

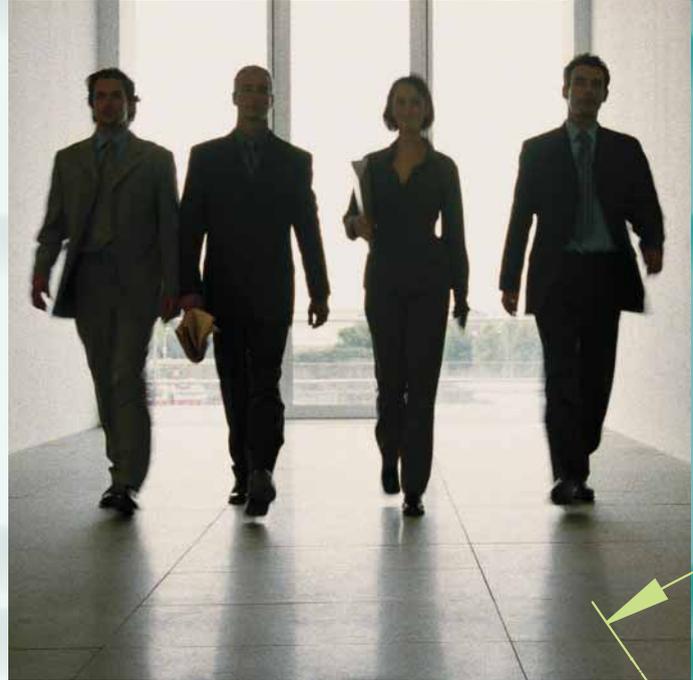
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## Ceramer™ has outstanding properties:

- short-term thermal stability up to 500 °C (930 F)
- exceptional chemical resistance
- inherent flame resistance
- high hardness and stiffness
- reduction of abrasion and wear
- enhanced metallization

## Ceramer™ and Ceramerplus™ find applications:

- as additive for PTFE compression molded compounds.
- as reinforcing material to substantially improve abrasion resistance and creep tendency of PTFE.
- as additive for PTFE paste extrusion powders, PTFE coating systems and thermoplastic fluoro polymers.
- as reinforcing agent for high performance thermoplastic polymers to reduce abrasion and wear and improve pressure resistance.
- as additive for improvement of metallization and in coating systems through thermal spraying.

Ceramer™ and Ceramerplus™ meet the FDA food additive regulations for repeated use in contact with food.

For further information contact the Ceramer team under:

**ceramer**  
• • • • • high performance polymers •

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