Low wear
low friction
Introduction

Today, customers need more from suppliers than just materials. They require a resource that is willing and able to join in at the earliest stages of the product development process. One that can carry a project from concept through design, component analysis, material selection, prototyping, testing, quality control, and even commercialisation. A fully-fledged partner is a must.

DuPont can be that partner. DuPont believes that true partnership is a dynamic process of teamwork and sharing. And it is recognised that only through continued success will relationships thrive, to bring out the best in both parties.

By allowing DuPont to work with the customer from the initial design concept, and on through every stage from prototyping to full production, DuPont’s unrivalled experience can be shared, and can help you choose the optimum engineering polymer for your needs. The result? A very competitive new product with time-proven success built in.

DuPont Engineering Polymers offers properties and benefits so important to giving your products that extra competitive edge: lightweight materials for light-weight parts and components; resistance to corrosion and abrasion; self lubrication; reduced moulding costs; integral colour; reduced finishing time; easier assembly, and greater customer satisfaction. All these advantages add up to new opportunities in design, manufacture and finished part cost.
Problems with wear, friction or noise? With DELRIN®, the solution can be found!

Wherever two surfaces slide, roll or rub against each other, one can be confronted with problems generated by worn surfaces, problems of high friction forces, frictional heat or problems of squeak. DELRIN® offers a wide range of internally lubricated or wear resistant resins that can help to solve these problems.

Wear resistance and lubrication: the key to longer lifetime of parts

Wear resistant and/or lubricated grades of DELRIN® acetal resin bring added value to applications.

- Parts have longer lifetime due to reduced wear
  Excessive wear often leads to premature failure of the part. Higher wear resistant materials allow an increase of time before the need to change a critical part and reduce maintenance costs.

- Moving systems have higher efficiency due to less energy loss through friction
  A low coefficient of friction between two sliding surfaces reduces the amount of energy that is transformed into heat or noise instead of motion. The motion becomes smoother and more efficient.

- Sliding surfaces can bear higher loads and run at higher velocities
  By making the right choice of materials, the load bearing capacity is higher and the sliding speed can be increased, making the system more reliable and powerful.

- System costs can be reduced by eliminating any external lubricant
  An efficient internal lubrication of the resin can replace the need for external lubricant and guarantees the right lubrication over the lifetime of the parts.

- Squeaking noise can be reduced below audible limit
  The squeaking noise which did not allow the choice of the same resin for the two sliding surfaces can now be eliminated by choosing a grade with a low coefficient of friction.
Why choose Delrin®?

Choosing Delrin® is a good starting point for applications in which wear and friction is a major issue. Figure 1 shows the specific wear rate vs. the dynamic coefficient of friction of different polymers against steel. Non-modified acetal has the lowest coefficient of friction and one of the lowest wear rates. Even further and significant improvements can be achieved by using Delrin® modified with 20% PTFE.

In addition there are the benefits from the outstanding mechanical properties for which Delrin® acetal resins are well known: a unique balance of strength, stiffness and toughness not available either in metals or other plastics.

Tribology is that field of science and technology concerned with “interacting surfaces in relative motion”. Wear and friction are not material properties but the properties of a tribological system.

Wear is the progressive loss of material due to interacting surfaces in relative motion. It is quantitatively measured as the specific wear rate $W_s$ (defined as volume loss per sliding distance and load $[10^{-6} \text{mm}^3/\text{Nm}]$) of a material. Numerous distinct and independent mechanisms are involved in the wear of a polymer.

These include:

- Abrasive wear – “cutting” caused by hard irregularities on the countersurface.
- Fatigue wear – failure of the polymer due to repeated stressing from hard irregularities on the countersurface.
- Adhesive wear – loss of polymer by transfer and adhesion to the countersurface.

Fig. 1 Specific wear rate and dynamic coefficient of friction against steel of various Polymers (method: thrust washer).

Fig. 2 Specific wear rate and wear track of Delrin® 500 and Delrin® 500AL after wearing against itself: under equivalent test conditions, Delrin® 500AL shows very little wear and consequently, no wear track can be seen.

Delrin® 500 after wear test (test specimen).

Delrin® 500AL after wear test (test specimen).
**Friction** is a measure of the resistance to motion (loss of energy) of two interacting surfaces. The friction is quantitatively described by the *coefficient of friction* $\mu$ (dynamic/static). It is therefore a function of the real contact area between the two surfaces and the character and strength of the interaction, which can be described as:

- Adhesive.
- Ploughing.
- Deforming.

The coefficient of friction between surfaces normally increases with increasing temperature and decreasing load. The energy lost in the friction phenomena can lead to an increase in temperature, to the emission of noise, and/or to deformation of the contact area. In almost all cases, a lower coefficient of friction will lead to a lower wear rate.

**Noise**

In many applications, where a part is sliding, the noise emitted by the system is undesired and has to be reduced. Noise is a difficult concept to define and therefore it is important to distinguish the two main types of noise which are encountered:

- **Mechanical** noise is in fact not related to friction but relates to impacts between moving parts. However, in the case of high frequency movements, this type of noise can sound like squeaking. An improved design (e.g. of teeth in gears) can often reduce the intensity of this noise. Another solution is to use softer materials with better damping properties.

- **Squeaking** is generated through friction and is linked to the coefficient of friction. As a general rule one can say that if the dynamic coefficient of friction is higher than the static one, the movement between the two surfaces can get discontinuous (slip-stick phenomenon). The noise is perceived as squeaking, when this slip and stick happens at an audible frequency.

![Schematic illustration of sliding friction. The coefficient of friction is defined as friction force F divided by the applied load N ($\mu = F/N$) at a given sliding speed.](image)

![Squeaking noise measured for Delrin® 500P sliding against Delrin® 500P or Delrin® 500AL. The sound pressure level is reduced from 83 dB(A) to 24 dB(A), which is perceived as a factor of 60 in noise reduction.](image)

Using Delrin® 500AL, a performance resin with an advanced lubricant system, Lexmark was able to maximise the performance of a six-gear power train at minimum cost. The gear train is part of a laser printer toner cartridge. The lubricity of Delrin® 500AL avoids the need for oil or grease that could contaminate toner and paper. The low wear helps to maintain high print quality over a long period. Its ability not to squeak provides a quiet and smooth operation.
Working environment: an important factor that influences the part performance

More than for other properties, the working environment has a strong influence on friction, wear and noise. The main factors to consider are:

• Contact pressure (p) and contact force (load) at the surfaces.
• Relative velocity of the surfaces (v).
• Temperature of the surfaces.
• Geometry of motion (sliding, fretting, rolling).
• Nature of the motion (continuous, intermittent, reciprocating, etc.).
• Nature and finish (roughness) of the surfaces.
• Lubrication (initial, continuous, dry-running, moisture…).

Two important implications of this are that:

• Selection of an engineering polymer for an application requires a detailed understanding of the tribological system.
• Although standardised tests can give indications of the relative wear rates of polymers, prototype testing is an essential stage in application development.

Pressure (p) and sliding velocity (v)

Pressure (p) and sliding velocity (v) have a strong influence on the wear rate of a material. An increase in pressure generally leads to an increase in the wear rate and a decrease of the friction, whereas an increase in sliding speed results in an increase of both wear and friction. The product \( p \cdot v \) is often used to describe the severity of a wear situation since, at a given temperature, it is roughly proportional to the wear rate.

The very strong influence of pressure and speed on wear as well as the improvements which can be achieved in this respect are shown in figure 5 and 6: the specific wear rate has been measured against steel at different combinations of speed and pressure. The graphs clearly demonstrate that the wear rate not only depends on the \( pv \)-product, but also if this \( pv \) is composed by high pressure/low speed or low pressure/high speed.

The countersurface

The nature and finish of the countersurface strongly affects wear and friction. Two parameters which define the finish of a surface and which can easily be controlled, are its roughness and its hardness.

For metal as a countersurface, one can express the following general rules:

• The harder the metal surface, the better the wear and friction behaviour of the system.
• The rougher the metal countersurface, the higher the wear.

As far as the coefficient of friction is concerned, there exists an optimum roughness: in case of a metal surface that is too smooth, the coefficient of friction can increase due to adhesion between metal and polymer; a surface that is too rough leads to a ploughing of the plastic part by the metal surface, resulting in a higher coefficient of friction.
3. Low wear / low friction grades of Delrin®

The intrinsically good wear resistance and frictional behaviour of Delrin® acetal often enables the use of a standard grade of Delrin® without any internal or external lubrication. Specific customer needs and technical requirements of the final application can make it necessary to further improve the properties of Delrin®. By making use of different technologies (Teflon® PTFE, Silicone, Kevlar® aramid resin, chemical lubrication, etc.), DuPont Engineering Polymers offers a broad range of grades in Delrin® which can help to reduce the wear or the friction in your application. Even though the number of grades, and therefore the choice of the appropriate resin may seem complex, one can classify them according to their main characteristics like wear rate, \( W_s \), and dynamic or static coefficient of friction, \( \mu \). It is also important that all other parameters like counter-surface, sliding velocity, contact pressure, test method and environmental conditions are also controlled carefully.

All low wear/low friction grades of Delrin® are classified in the graph below according to their specific wear rate and their coefficient of friction measured against either a steel counter-surface or against a counter-surface made in the same grade of Delrin® (against “itself”).

This overview not only shows the effect of the different technologies on wear rate and coefficient of friction, but also the effect of the counter-surface alone. Against steel, the wear rate as well as the coefficient of friction of unmodified Delrin® is much lower compared to the values measured against itself. The use of different ingredients, however, makes it possible to close the performance gap and therefore opens the possibility of using Delrin® against other Delrin® surfaces.

![Graph showing specific wear rate and coefficient of friction against steel and against itself for Delrin® acetal high viscosity grades.](image1)

![Graph showing specific wear rate and coefficient of friction against steel and against itself for Delrin® acetal medium viscosity grades.](image2)

Delrin® is the preferred material for gears due to its unique combination of mechanical properties. In addition to that, the low wear / low friction grades of Delrin® can help to further increase the load and speed thanks to a higher efficiency, increase the lifetime of your gears, eliminate external lubricants and ensure a squeak free motion or power transmission.
DELRIN® 100KM, the chosen BMW solution to eliminate grease

DELRIN® 100KM, an abrasion resistant acetal resin modified with KEVLAR® is used as cladding on the door checks of BMW’s Series 5 limousines and estates, ensuring that the doors open and close smoothly and silently without lubrication.

The standard all-steel door-check is lubricated with grease, to allow it to slide freely. While this design works well, it needs maintenance and the grease leaves marks on garments that come in contact with it. So, in search of a cleaner solution, BMW decided to give the steel strip a permanent cladding of a plastic material.

The cladding had to be able to withstand considerable mechanical abuse from the pressure of the rollers on the strip, from the impact at the end of the door’s swing, and from the abrasion caused by every door movement.

Together with systems supplier Ed. Scharwächter GmbH of Remscheid, BMW undertook extensive tests on several candidate materials. These tests showed that DELRIN® 100KM, a DuPont acetal modified with KEVLAR®, met the requirements between –40°C and +85°C better than all the other materials tested.

“The abrasion resistance as well as the good friction behavior of this special type of DELRIN®, and its ability to withstand mechanical abuse were decisive in our choice of material,” says Werner Schmitt, project leader at Scharwächter. “The hook-shaped end of the door-check is particularly critical in this respect, because it has to stop a heavy swinging door abruptly when it reaches its maximum opening angle.”

Why choose DuPont?

When DuPont is involved early in the process as part of the design team, access to a wealth of resources becomes available:

- The widest range of engineering polymers to meet precise requirements.
- Technical support for design, moulding expertise from a global network of interlinked technology laboratories.
- Long experience in testing and selecting materials for tribological applications.
- World wide support for polymer research and development, with more than 50 years experience and innovation in engineering polymers.
- A broad knowledge of the global market and in all industry segments.

DELRIN® 500AF, a Teflon® fiber filled acetal resin, is used in the black sliding part in the head of this touring binding from Fritschi AG. It was chosen for its easy processing and good low wear and low friction performance against other plastics surfaces.

Automotive door check
5. Choosing the right grade of DELRIN® against metal

**LEVEL 1:**
Tribological system

**LEVEL 2:**
Requirement
How can I avoid...?

**LEVEL 3:**
Solution:
appropriate grade of DELRIN®

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### Delrin with low specific wear rate, \( W_s \), \(^{1,2}\)

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<td>Delrin® 500AF/100AF</td>
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### Delrin with low coefficient of friction, \( \mu \), \(^{2,3}\)

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### High wear resistance against Aluminium, \(^{2}\)

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<tr>
<td>Delrin® 100AL</td>
<td>€€</td>
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<tr>
<td>Delrin® 100KM</td>
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\(^{1}\) Resins are ranked by decreasing wear rate based on results from different test geometries and test conditions.

\(^{2}\) Resins are ranked by decreasing coefficient of friction based on results from different test geometries and test conditions.

\(^{3}\) Price categorization by € signs.
Choosing the right grade of DELRIN® against DELRIN®

LEVEL 1:
Tribological system

LEVEL 2:
Requirement
How can I avoid…?

LEVEL 3:
Solution:
appropriate grade of DELRIN®

Non-squeaking grades2) of DELRIN®

- DELRIN® 500SC @ 10% (€€)
- DELRIN® 500AL (€€)
- DELRIN® 100AL (€€)
- DELRIN® 900SP (€€)
- DELRIN® 520MP (€€€)
- DELRIN® 500AF/100AF (€€€€)

DELRIN® with low specific wear rate, $W_s$1, 3)

- DELRIN® DE9156/9152 (€)
- DELRIN® 500SC @ 5% (€)
- DELRIN® 500AF/100AF (€€€)
- DELRIN® 100AL (€€)
- DELRIN® 500AL (€€)
- DELRIN® 900SP (€€)
- DELRIN® 500SC @ 10% (€€)
- DELRIN® 520MP (€€)

DELRIN® with low coefficient of friction, $\mu$4, 5)

- DELRIN® DE9156/9152 (€€)
- DELRIN® 100AL (€€)
- DELRIN® 500AF/100AF (€€€)
- DELRIN® 520MP (€€)
- DELRIN® 500AL (€€)
- DELRIN® 500SC @ 5% (€)
- DELRIN® 900SP (€€)
- DELRIN® 500SC @ 10% (€€)

DELRIN® toughened grades6)
(external lubrication needed)

- DELRIN® 100T (€)
- DELRIN® 500T (€)
- DELRIN® 100ST (€€)

1) Surface and countersurface are consisting of the same grade of DELRIN®.
2) For all resins listed, the noise emitted at 16 kHz is below 60 dB(A) (audible limit) at a sliding speed of 0.084 m/s and a pressure of 0.624 MPa in a reciprocating movement.
3) Resins are ranked by decreasing wear rate based on results from different test geometries and test conditions.
4) Resins are ranked by decreasing coefficient of friction based on results from different test geometries and test conditions.
5) Price categorisation by €-signs.
6) Resins ranked by increasing toughness (ISO179-1993(E) 1eA: notched charpy impact strength).
### 6. Properties of DELRIN®

| Property                          | Test method ISO | Units | High viscosity | High viscosity | High viscosity | High viscosity | High viscosity | High viscosity |
|----------------------------------|-----------------|-------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| MECHANICAL                      |                 |       | 100            | 100           | 100AF          | DE9156         | 100AL          |                 |
| Yield stress ¹)                  | 527-1/2         | MPa   | 71             | 60            | 54             | 71             | 70             |                 |
| Yield strain ¹)                  | 527-1/2         | %     | 25             | 15            | 14             | 22             | 18             |                 |
| Strain at break ¹)               | 527-1/2         | %     | 70             | 15            | 18             | 51             | 71             |                 |
| Nominal strain at break ¹)       | 527-1/2         | %     | 45             | 9             | 15             | 30             | 47             |                 |
| Tensile modulus ²)               | 527-1/2         | MPa   | 3100           | 2900          | 2800           | 3200           | 2700           |                 |
| Charpy notched impact strength-edgewise impact | 179/1eA | kJ/m² | 15             | 4.5           | 4.5            | 10             | 9              |                 |
| FRICTION AND WEAR               |                 |       | 100            | 100           | 100AF          | DE9156         | 100AL          |                 |
| Specific wear rate against itself ³) | –             | (10⁻⁶ mm²/N m) | 1500        | 92            | 40             | 900            | 41             |                 |
| Dynamic coefficient of friction against itself ³) | –             | – | 0.4            | 0.31          | 0.18           | 0.29           | 0.23           |                 |
| Noise (squeak) against itself ³) | –             | yes | yes            | yes           | no             | yes            | no             |                 |
| Specific wear rate against steel ⁴) | –             | (10⁻⁶ mm²/N m) | 14           | 2             | 2              | 6              | 2              |                 |
| Dynamic coefficient of friction against steel ⁴) | –             | – | 0.30          | 0.41          | 0.19           | 0.27           | 0.19           |                 |
| MELLELAUS                      |                 |       | 100            | 100           | 100AF          | DE9156         | 100AL          |                 |
| Melt Flow Rate (= MFI)          | 1133            | g/10 min | 2.3           | 2             | –*             | 2.4            | 2.2            |                 |
| Melting temperature             | 3146 method C2  | °C    | 178           | 178           | 178            | 178            | 178            |                 |
| Density                         | –              | g/cm³  | 1.42           | 1.41          | 1.54           | 1.43           | 1.40           |                 |
| Shrinkage                      | parallel       | %     | 2.1            | 1.8           | 2.1            | –              | 2.0            |                 |
|                                | normal         | %     | 1.9            | 1.5           | 1.5            | –              | 1.8            |                 |

<table>
<thead>
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<tr>
<td>High viscosity DELRIN®</td>
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<tr>
<td>DELRIN® 100</td>
<td>High viscosity Standard resin, best combination of stiffness and toughness. Very good creep resistance.</td>
</tr>
<tr>
<td>DELRIN® 100KM</td>
<td>DELRIN® 100 grade with 5% KEVLAR®.</td>
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<tr>
<td>DELRIN® 100AF</td>
<td>DELRIN® 100 grade with 20% TEFLON® PTFE fibers.</td>
</tr>
<tr>
<td>DELRIN® DE9156</td>
<td>DELRIN® 100 grade with 1.5% TEFLON® PTFE micropowder.</td>
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<tr>
<td>DELRIN® 100AL</td>
<td>DELRIN® 100 grade, Advanced lubrication. General purpose low wear and low friction grade.</td>
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<tr>
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<td>Medium viscosity resin. Optimum combination of flow and physical properties.</td>
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Masterbatch

DELRIN® 500SC               Masterbatch of DELRIN® 500 grade containing 20% of silicone oil.

A is DELRIN® 100 grade with 5% of DELRIN® 500SC.
B is DELRIN® 500 grade with 5% of DELRIN® 500SC.

All the above information is subject to the disclaimer printed on the back page of this document.
1) Testing speed 50 mm/min.
2) Testing speed 1 mm/min.
3) Surface and countersurface are consisting of the same grade of Delrin®. The specific wear rate was measured at low speed (0.084 m/s) with a contact pressure of 0.624 MPa in a reciprocating motion (total sliding distance: 1.52 km).
The coefficient of friction was measured at a similar speed (0.08 m/s) with a contact pressure of 0.196 MPa, also in a reciprocating motion.
4) Surface roughness Ra [µm]: 0.10 and hardness HRB: 50. The specific wear rate was measured at low speed (0.084 m/s) with a contact pressure of 0.624 MPa in a reciprocating motion (total sliding distance: 4.25 km).
The coefficient of friction was measured at a high speed (0.5 m/s) with a load of 10 N in a sliding motion (Block-on-Ring).

* Melt Flow Rate not appropriate due to high Teflon® PTFE content.

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