DuPont™ Delrin® Acetal Homopolymer
White Paper

How to Maximize the Property Advantages of Delrin® Acetal Homopolymer over Acetal Copolymer

A GUIDE FOR DESIGN ENGINEERS

Overview

DuPont™ Delrin® acetal homopolymer resin - also called Delrin® POM-H - is one of the most crystalline engineering thermoplastics available. Delrin® is a highly adaptable material that bridges the gap between plastics and metals and offers unique properties. It is specified for high load mechanical applications and precision parts, where strength, stiffness, stability and reliability are important. Applications range from gears, safety restraint components, door system and conveyor systems components to medical delivery devices, ski bindings, zip fasteners and many other applications across a wide range of products and industries.

When compared to acetal copolymers, Delrin® homopolymer combines higher fatigue and creep resistance with overall higher toughness and higher tensile strength and stiffness, allowing for thinner and lighter part design, and the potential for reduced part production cost.

This white paper describes the differences between Delrin® homopolymer and acetal copolymer in detail and explains how to make the best use of the higher level of mechanical performance of Delrin® homopolymer over that of acetal copolymer in order to extract the most value for all stakeholders.

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1. Introduction

The need for reduced energy consumption and cost through metal-replacement with lightweight engineering polymers is a confirmed trend in the automotive industry, and is increasingly gaining ground in general engineering and many other industry sectors.

Acetal polymer already plays a major role in the advanced materials revolution. It is being used in a broad range of applications in the automotive, food processing, life sciences, safety and manufacturing industries, to name but a few. There are different kinds of acetals with different levels of performance. Suppliers of acetals often offer "equivalent" grades of copolymer as a substitute for a certain grade of homopolymer, and it is not always clear why one would use acetal homopolymer over acetal copolymer, or vice versa. However, it would be a mistake to think that all acetal resins are the same.

As the plastics industry has evolved, so have **the needs of the stakeholders** concerned:

- **The design engineer** wants the best possible properties to maintain a good safety factor while pursuing an efficiently-designed lightweight part, and may require design validation support.
- **The molding operator** wants the highest resin flow rates.
- **The procurement manager** wants the lowest raw material price, consistent quality, and, ideally, multi-location production of raw materials.
- **The plant manager** wants a high production rate and the ability to ramp up production without capital investment.
- **The process engineer** wants technical support during production startup and for continuous improvement efforts.
- **The customer** generally wants to create durable, reliable, high-quality parts that deliver on promise and minimize the risk of costly recalls.

The material selection process must counterbalance the needs of all these stakeholders.

2. What is an acetal polymer?

Acetal, also called polyoxymethylene (POM), was first discovered in 1920, but was not produced on a large scale until DuPont opened the world's first commercial production plant in 1960. At its simplest, POM represents a repeating unit of CH_2O. Whereas the DuPont™ Delrin® acetal homopolymer manufacturing process maintains a straight chain of CH_2O monomers with end caps, other manufacturers of acetals add one of several possible comonomers that appear in the chain on average every 70 -100 repeating units (see Fig. 1: molecular structure).

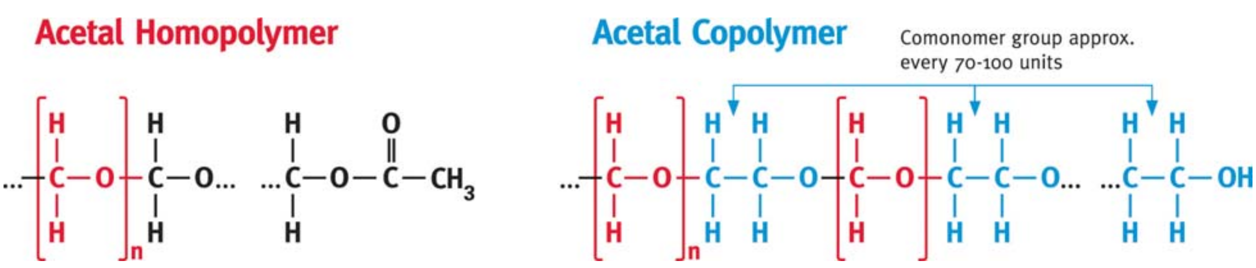

Figure 1: Molecular structure of acetals

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In addition, the typical chemistry of acetal copolymer polymerization produces roughly 2-8 weight percent of cyclic low molecular weight chains (oligomers) that, in general, do not participate in the structure and function of the material.

The consequences of that molecular difference are exhibited in the crystalline packing of the polymer (Fig. 2). The purity of the uniform backbone in Delrin® homopolymer allows for a more organized stacking of the polymer into larger crystalline domains as the polymer solidifies. Meanwhile, the additional comonomer units in the copolymer disrupt this organization, ending the stacking locally and, ultimately, limiting the size of the crystalline domains.

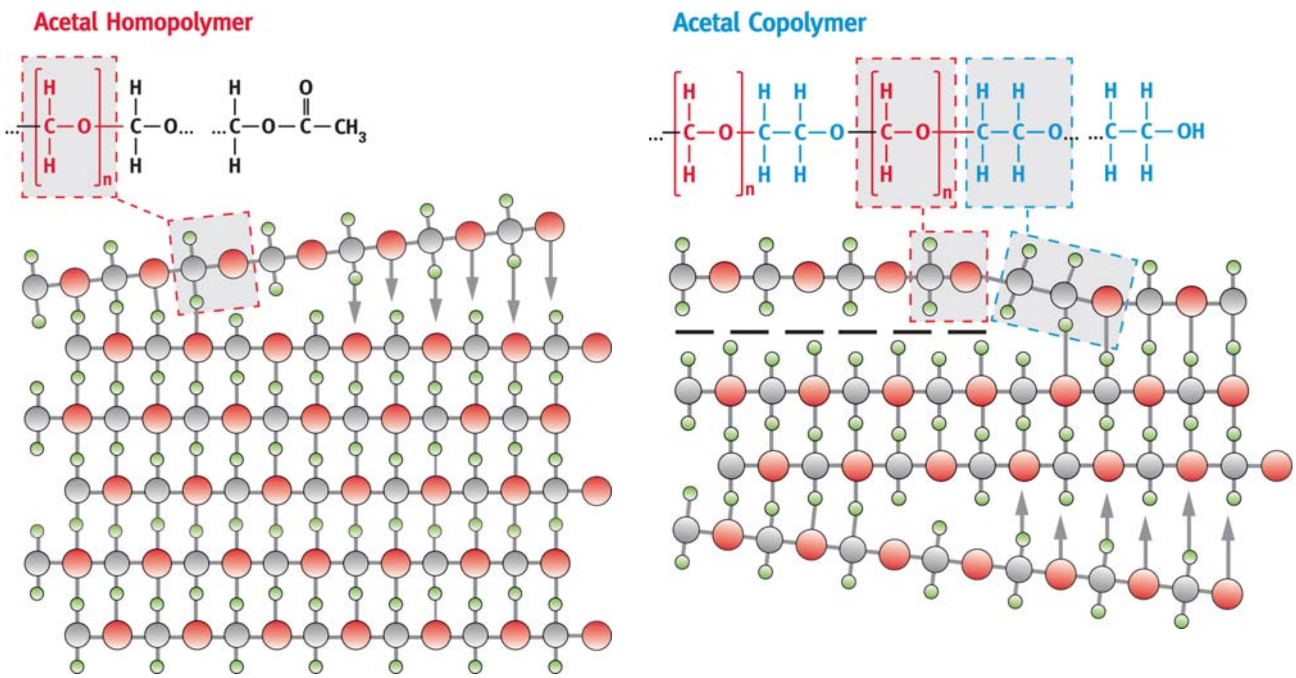

Figure 2: Delrin® homopolymer vs. acetal copolymer crystalline structure in 2-D.

On zooming out, the full significance of having a pure uniform backbone can be seen. As the diagram of the 3-D crystalline domains shows (Fig. 3), the larger the domain, the more entanglement strands emerge from each domain. These entanglements engage in a more extensive and intricate network with neighboring domains, reducing their mobility relative to each other. This highly networked structure is key to the increased level of mechanical properties extended by the uniform backbone of Delrin® homopolymer versus acetal copolymer. The cyclic oligomers are shown in bold blue. They cannot participate in the crystalline organization of the molecule and may even negatively affect the crystallization and mechanical properties.

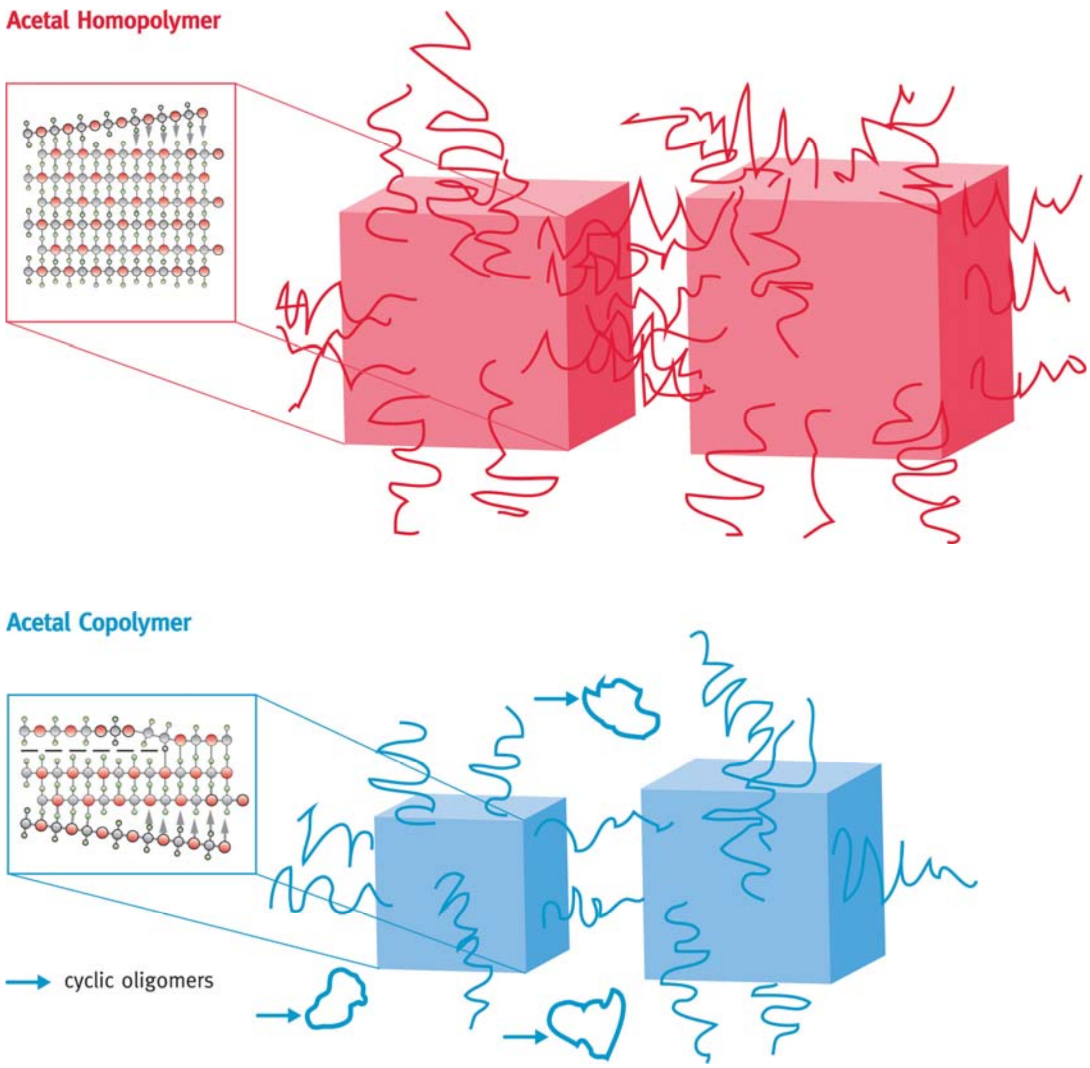

Figure 3: The relationship between crystalline blocks and entanglements in 3-D. The uniform backbone of Delrin® homopolymer allows the formation of larger blocks with more entanglements leading to a tighter network and, subsequently, superior mechanical properties.

The mechanical properties that are exhibited by the acetal resins can be envisioned as resulting largely from the interactions of the large crystalline domains with the entanglements — elongation across any axis will first stretch/straighten the entanglements along that axis before the polymer chain can begin “peeling” off from the crystalline domains. As the number of entanglements between each adjacent pair of domains increases, more stress will be required. This is akin to stretching 2 rubber bands at the same time compared to stretching 4 rubber bands at the same time.

More entanglements can also absorb more energy during impact and help reset the structure after impact energy is absorbed, retaining the original shape. As the network of crystalline domains becomes more complex, there is more limited mobility of domain relative to each other. If mobility is difficult, it becomes more difficult for the domains to shift during elongation, resulting in higher modulus and stiffness. The same phenomenon of increasingly limited mobility can contribute to higher creep and fatigue resistance, and better spring back after momentary tensile or flexural deformation, or after fast deformation during an impact, as the crystalline domains relax back into their original configuration.

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3. Key properties of Delrin® acetal homopolymer

Delrin® is a highly adaptable thermoplastic material that bridges the gap between plastics and metals for a wide range of technical applications, and offers unique properties.

The table below illustrates how the properties of Delrin® can translate to the functional performance of parts.

Properties and features of Delrin®	Applicability to parts
Very hard and stiff, combining high mechanical strength with rigidity.	The stiffest, strongest and most fatigue-resistant un-reinforced (unfilled) engineering polymer available. Suitable for wide range of high performance components with long use lifetimes.
Low creep and low moisture absorption.	Excellent dimensional stability and long operational lifecycles.
High fatigue life under cyclical loadings.	Suitable for long life, wear-resistant parts.
High Impact resistance even at low temperatures.	Can withstand repeated shock-loads.
High yield strain.	Good spring-back capabilities, ideal for 'snap-fit' connections.
Low coefficient of friction with inherent lubricity for non-stick properties.	Suitable for maintenance-free moving and sliding parts.
Retains toughness over wide temperature span from -40°C to +90°C (intermittent to 120°C).	Doesn't get brittle at low temperatures; suitable for winter sports equipment.
High electrical resistivity with low static properties.	Suitable for electrical applications and in fuel-related and similar applications.
Corrosion-resistant with high tolerance to moisture, petrol, solvents and organic chemicals at ambient temperatures.	Ideal for many automotive and industrial process components.
Outstanding acoustic properties.	Provides low-noise components for doors, etc.
Favorable molding characteristics.	Exhibits better flow rates than standard copolymer acetals for consistent precision molding performance.
Smooth, glossy, aesthetic surface finish.	Ideal for visible applications and premium consumer products.
Easily worked/processed with conventional machinery and skills.	Minimal investment and 'learning curve' required.
Very low weight alternative to metals.	Half the weight of aluminum and six times lighter than steel.
Recyclable.	As a thermoplastic material, Delrin® can be recycled using industry standard recovery techniques.
Specific application requirements.	DuPont offers an unparalleled range of modified resins for special applications and extended performance: ultra-low friction, antistatic, UV stabilized, fiber reinforced, food contact and very-low VOC emission grades.

4. Mechanical properties comparison in detail

Delrin® can be used to replace metal to achieve corrosion resistance, lighter weight, and single-stage manufacturing while by-passing multiple machining steps.

Delrin® can also be used to replace polyamides (i.e. nylons) when higher stiffness and thinner parts with better creep and fatigue resistance are needed. More significantly, Delrin® is not as sensitive to moisture as polyamides, resulting in more consistent mechanical properties and part dimensions. Compared to polypropylene and polyesters (i.e. polybutylene terephthalate), Delrin® also exhibits many advantages including higher stiffness for thinner parts and better performance in wear and friction environments. Measured against amorphous engineering plastics (i.e. ABS and polycarbonate), Delrin® outperforms in chemical resistance and stiffness, and shows better performance in wear and friction environments.

Acetal polymers come in various molecular weight families, depending on the manufacturer. Delrin® homopolymer is available in molecular weight families designated 100 through 900, with 100 being the highest molecular weight. They are shown in the table below (Fig. 4) with the general property trends that arise as a direct consequence of molecular weight.

Higher molecular weight and viscosity delivers increased toughness, impact strength and elongation.

Preferred by **Designers** ↑

Flow family	Melt-mass flow rate	Melt-volume flow rate
100	2.4	2
300	7	6
500	15	13
900	25	21

↓ Preferred by **Molders**

Higher flow rates deliver ease of filling in thinner walled parts, a more crystalline structure and increased stiffness and strength.

Figure 4: Property trends with changes in flow family.

These trends are shown in more detail in the graph below (Fig. 5). The high molecular weight of Delrin® 100P delivers dramatically better toughness characteristics while exhibiting only slight decreases in strength/stiffness characteristics. In general, a designer may prefer to work with the highest molecular weight materials since they typically deliver the best combination of properties, while the molder may prefer to work with the lowest molecular weight material for its high flow characteristics to ensure proper part filling and better surface finish. Thus, a balancing act must be achieved during material selection.

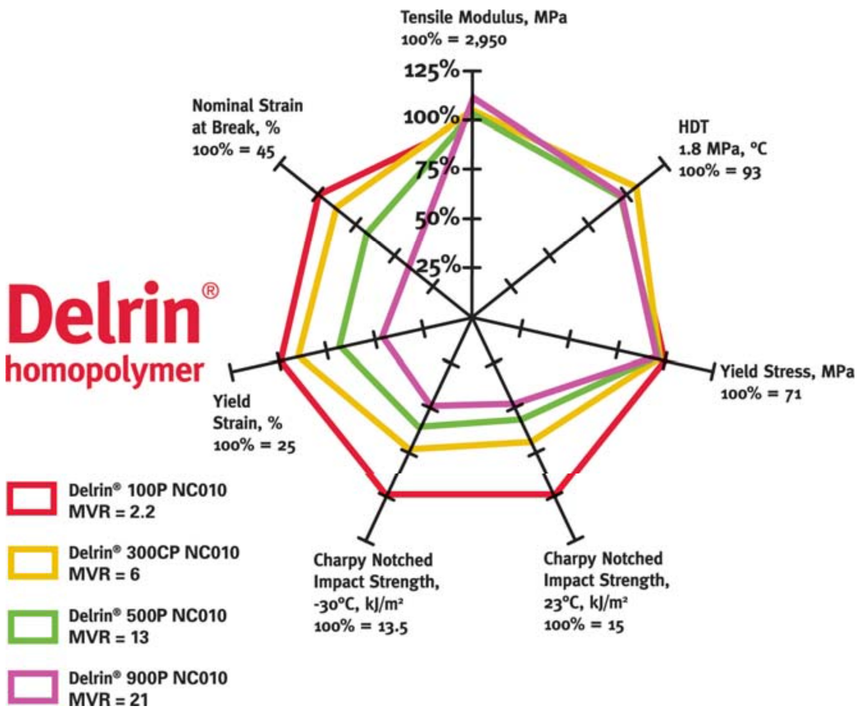


Figure 5: Detailed comparison of properties of Delrin® homopolymer grades as a function of flow rate.

Figure 6 below shows the comparison of the general purpose offering in the Delrin® product line: Delrin® 500P against general purpose acetal copolymer offerings. Not only does Delrin® homopolymer outperform the strength and stiffness characteristics of acetal copolymer, but it surpasses the toughness characteristics such as impact strength and strain, at the same time delivering a significant increase in flow rate, resulting in easier molding.

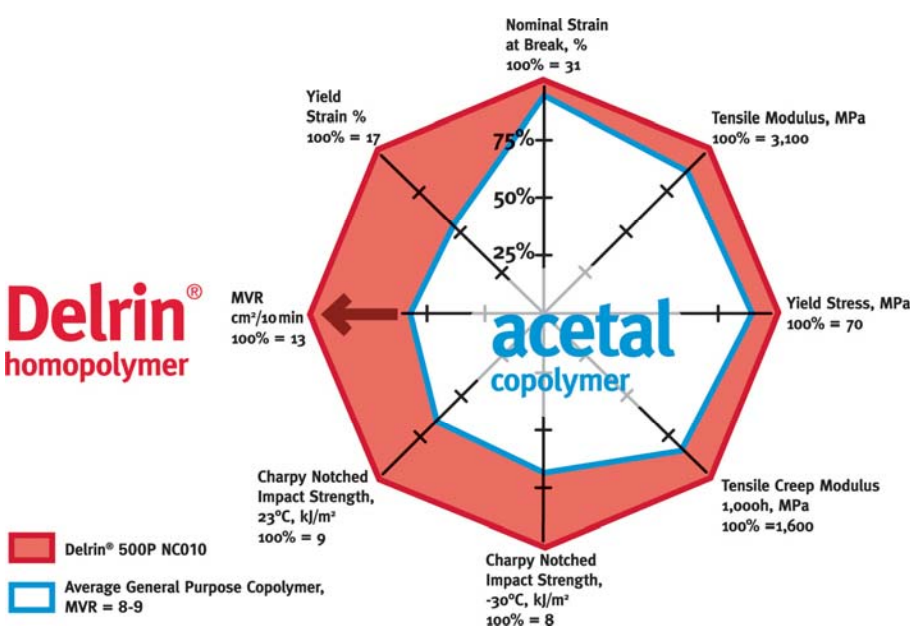


Figure 6: Comparison of Delrin® 500P homopolymer vs. general purpose acetal copolymer.

The mechanical performance gap is magnified when the "higher performance" high molecular weight acetal copolymer is stacked up against a medium-high molecular weight Delrin® homopolymer resin, Delrin® 300CP (Fig. 7). The much higher mechanical performance to molecular weight ratio of Delrin® delivers the balance between the needs of the designer and the molder.

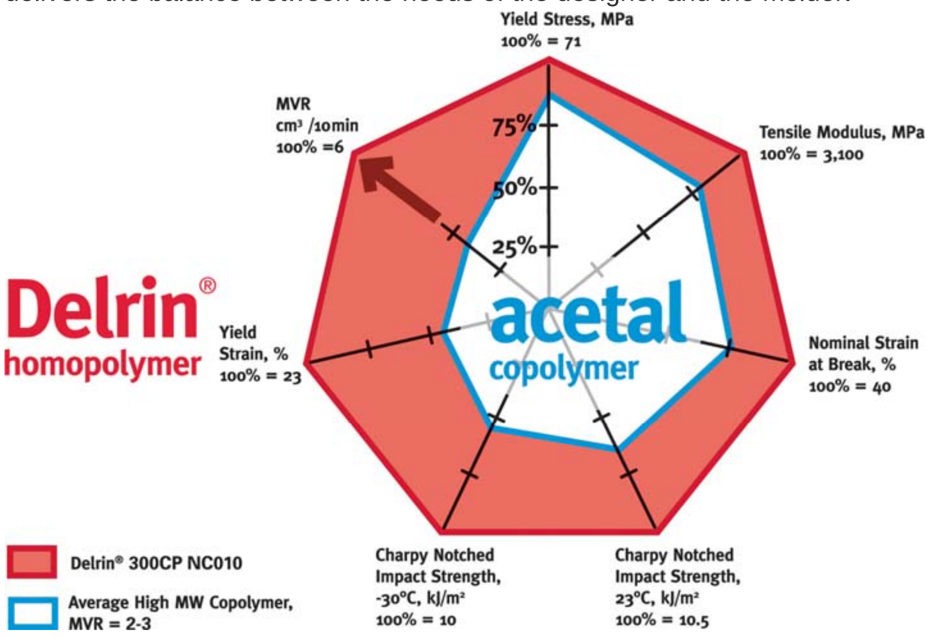


Figure 7: Comparison of Delrin® 300CP homopolymer vs. high molecular weight standard acetal copolymer.

The gap widens further when equally high molecular weight resins are matched up. The graph below (Fig. 8) of high molecular weight copolymer vs. Delrin® 100P, the flagship of the Delrin® brand, illustrates why Delrin® homopolymer is clearly the premium acetal. With toughness characteristics generally twice those of acetal copolymer and higher strength and stiffness, Delrin® homopolymer can provide the safety margins needed for critical parts.

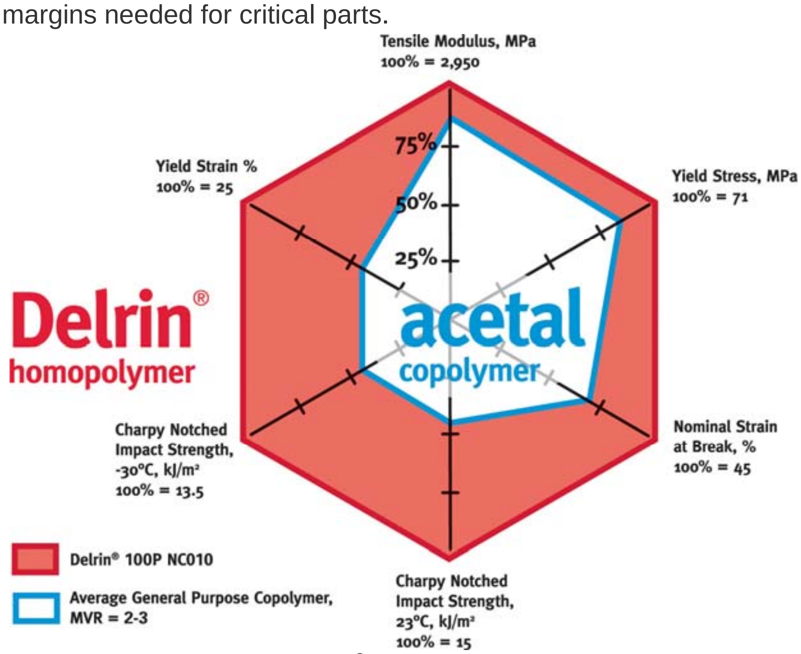


Figure 8: Comparison of Delrin® 100P homopolymer vs. high molecular weight standard acetal copolymer.

The inherent toughness of unmodified Delrin® homopolymer grades is in many cases much higher than that of impact-modified copolymer grades.

Figure 9 shows how Delrin® 100P homopolymer, unmodified for impact toughness, stacks up against acetal copolymer modified with what is estimated to be approximately 20% reinforcement. The higher inherent stiffness is magnified further, and the added toughener provides only small improvements in the low temperature impact resistance of acetal copolymer. In other words, many *impact-modified acetal copolymer grades are more brittle* than standard Delrin® 100P acetal homopolymer at low temperatures.

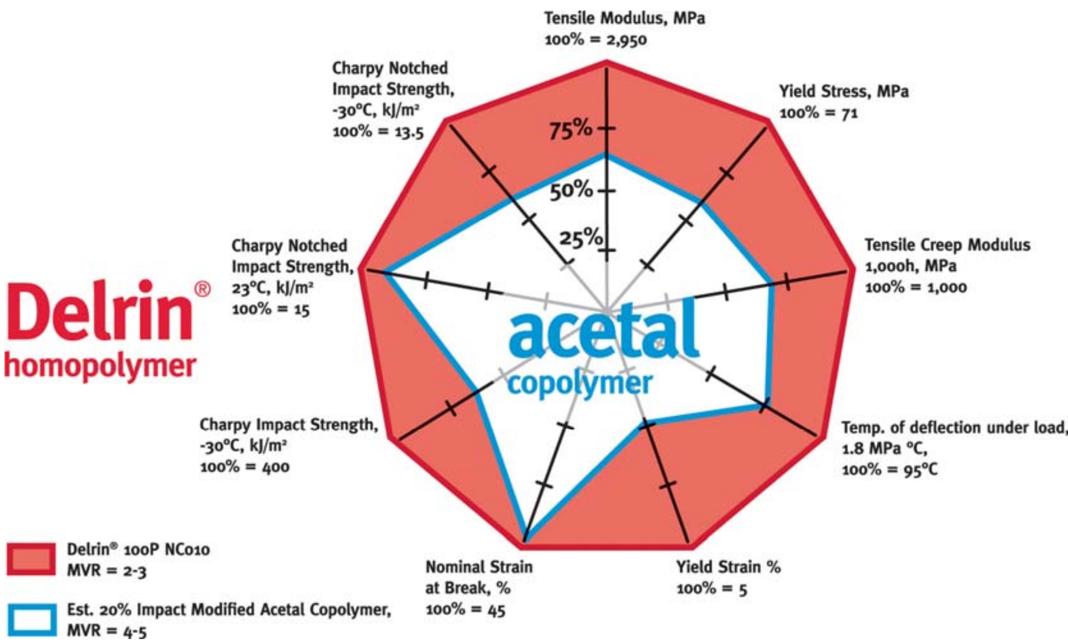


Figure 9: Comparison of Delrin® 100P homopolymer vs. acetal copolymer grades enhanced with up to 20% toughener.

In addition to the standard tests shown above, Delrin® 500P outperformed general purpose acetal copolymer by a factor of five in internal flexural fatigue resistance testing, while Delrin® 100P outperformed HMW acetal copolymer by a factor of ten. Even more significantly, the nucleated grades Delrin® 111DP and 311DP outperformed both acetal copolymer resins by almost three orders of magnitude, as shown below.

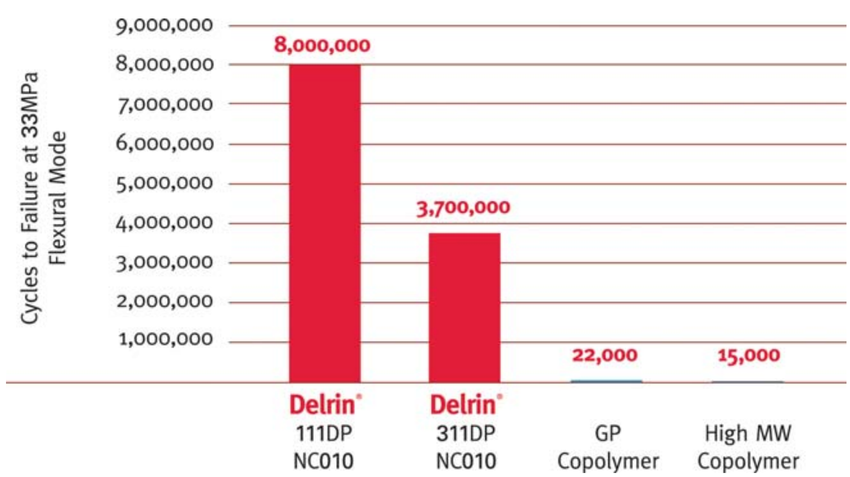


Figure 10: Comparison of resistance to flexural fatigue at 33MPa loading of various Delrin® homopolymer grades vs. standard acetal copolymer grades.

5. When to use Delrin® acetal homopolymer

It is recommended to use Delrin® when the part will be subject to:

- cyclic loading.
- constant heavy load over long periods of time or permanently high impact loads, repeated impact loads, or impact at low temperatures (down to -40°C).
- back-and-forth or rotating sliding motion against metal or another plastic.
- humid environments, when dimensional stability and property retention is important.

or when:

- light-weighting is critical to the application.
- lubrication needs to be avoided.
- high strength and stiffness without glass reinforcement is desired (e.g. load-sharing between gear teeth is desired for longer gear life).
- superior chemical resistance (relative to other engineering plastics) against industrial solvents, lubricants, agricultural chemicals, fuels, weak acids and bases, and water is required.

Do not use Delrin® if the part will be subject to:

- strongly basic environments (pH >9) or strongly acidic environments (pH <4).
- environments with chloride or zinc chloride solutions.
- aggressive fuels with acidic character.
- long term exposures to temperatures >90°C.
- long term immersion in hot water (>60°C).
- plumbing applications behind walls (as a matter of policy).
- applications requiring flammability ratings above HB.

6. Customer benefits of mechanical properties

The table below highlights how the advantages of the properties of Delrin® acetal homopolymer versus acetal copolymer typically described on datasheets can translate to real-life improvements for the parts being designed.

ADVANTAGES OF DELRIN® ACETAL HOMOPOLYMER VERSUS ACETAL COPOLYMER	
Properties of Delrin® homopolymer	**Customer benefits**
Higher yield stress and yield strain.	Better memory of original shape after deflection. Useful for snap-fits/buckles and simplicity in assembly.
Higher modulus.	Stiffer material allows design of thinner-walled parts leading to more efficient use of resin.
Higher flow rates with better mechanical properties.	Better filling of thinner-walled cavities. Useful for effectively designing thin-walled parts.
Much higher notched Charpy impact strength, even at low temperatures.	Parts that are more resistant to fracture and capable of absorbing much more energy. Useful for gears in motors that change direction or stop abruptly, and for mechanical/moving components in refrigerated environments.
Higher strain at break.	Contributes to overall toughness of part. Allows deflection further past yield point w/o part failure. Useful for snap-fits and buckles.
Higher creep resistance.	Better maintains overall shape during long exposures to loads. Maintains tighter fit in snap-fit applications. Better maintains dimensions in spring-loaded applications.
Much higher fatigue resistance.	More durable in high-cycle applications like continuously running gears

7. How to exploit the superior mechanical properties of Delrin® acetal homopolymer vs acetal copolymer

Switching from acetal copolymer to Delrin® homopolymer:

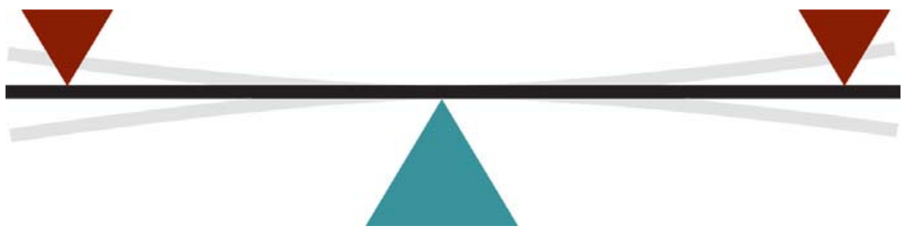
If acetal copolymer is already being used for a component part, it may be possible to use Delrin® homopolymer as a drop-in replacement to solve processing or performance issues without having to make any costly modifications to the tooling. Consider using Delrin® in the following situations:

- **A part molded out of acetal copolymer is breaking in use at an unacceptable rate** – there is likely to be a Delrin® homopolymer grade available that has better mechanical properties for a longer lasting part, most likely with the side benefit of a higher flow rate.

- **The acetal copolymer resin is not able to fill the cavity for optimum performance** – there is likely to be a Delrin® homopolymer grade available that has a higher flow rate and better mechanical properties for a well-packed, higher performing part.

- **A part molded out of an impact modified acetal copolymer part is failing at low temperatures** – there may be a standard unmodified or a lightly-reinforced Delrin® homopolymer resin that can deliver the necessary impact resistance at room temperatures, low temperatures, and higher stiffness/strength for higher performance across all temperatures.

- **A part molded out of an impact modified acetal copolymer is not stiff enough to maintain shape under creep conditions or perform in cyclic fatigue situations** – there may be a standard unmodified or a lightly-toughened Delrin® homopolymer resin with higher stiffness to maintain shape under load at higher temperatures and resist fatigue in cyclic loading situations, while delivering the impact resistance necessary for the application.



Selecting Delrin® for a new part:
If acetal copolymer is being considered for a new part, a number of benefits can be realized by considering the critical-to-quality (CTQ) part properties, by designing specifically for the superior mechanical properties of Delrin® acetal homopolymer and by focusing on wall-thinning:

- **Use of a higher-flow resin -** Delrin® homopolymer has higher strength/stiffness, fatigue, and toughness at all analogous flow rates relative to acetal copolymer, allowing the move from a slow-flowing acetal copolymer to a higher-flowing Delrin® homopolymer, while maintaining part properties and ensuring proper filling of hard-to-fill parts.

- **Increase in impact toughness** - Delrin® homopolymer by nature has significantly higher (50%-200%) baseline impact toughness compared to copolymer. Even after accounting for thinner walls, there may be a gain in overall toughness.

- **Lower part weight** - After thinning the part walls to maintain a desired amount of flexibility/stiffness per part performance criteria, and validating and optimizing the design with DuPont designers, the part may be substantially lighter than the original copolymer-based design.

- **Higher productivity - shorter injection molding cycle time,** primarily due to a shorter hold pressure time period from having to pack out a thinner-walled parts. The higher flow rate may also lead to shorter injection time, further reducing cycle duration.

These benefits can be amplified further if an **impact-modified copolymer that was originally under consideration can be replaced with an unmodified Delrin® homopolymer**. The inherent toughness of unmodified Delrin® homopolymer grades, combined with the significantly higher stiffness, will offer substantial opportunity for reducing the wall thickness of the part, while maintaining the critical part properties. Considering the higher resin cost for toughened copolymer grades, the reduced resin consumption of Delrin® homopolymer alone can be considerable.

8. Case study: toughened acetal copolymer replaced by Delrin® 300TE

A major customer of Delrin® homopolymer was considering using a toughened acetal copolymer for the next generation of a component part since it was being offered acetal copolymer at a discount to the price of Delrin®. The part concerned had a CTQ property of a 180N spring force. The copolymer-based design used 8.8g to accomplish the CTQ. DuPont offered design support to demonstrate how, by designing for Delrin®, the part could deliver the CTQ with only 7g of resin. The design team focused on thinning the walls throughout the part, removing the ribs and shrinking the thicker center section. With a 21% reduction in weight came an 11% faster cycle time, translating into an overall cost-per part savings of 12% relative to the copolymer alternative.

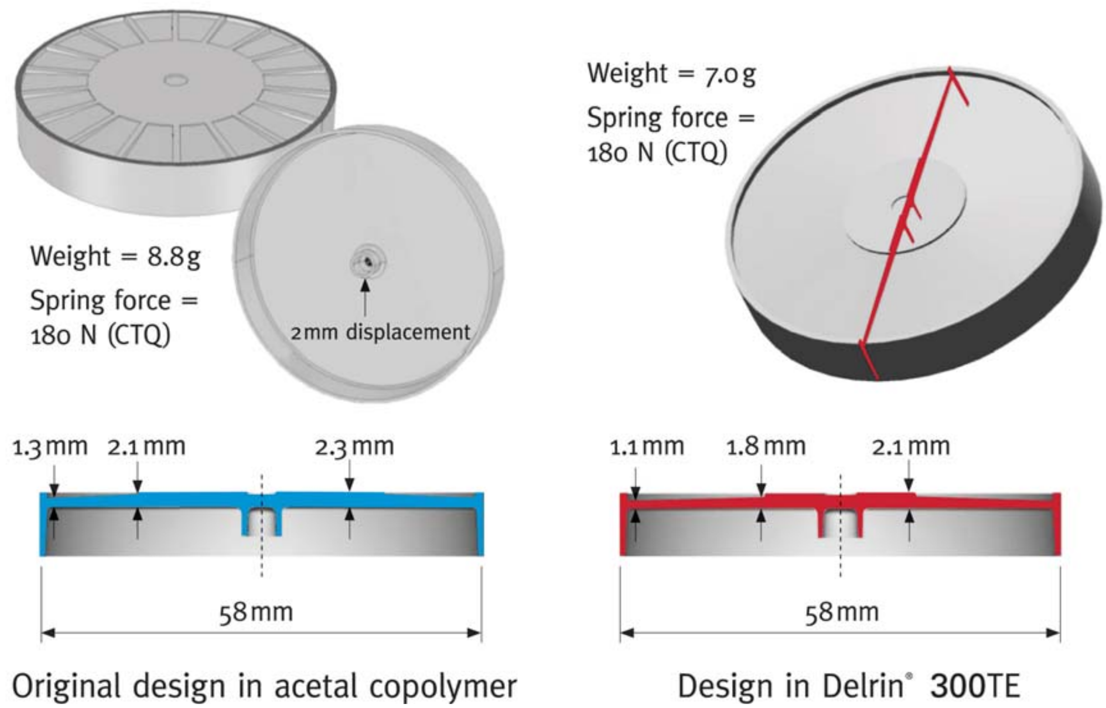


Figure 11: Original design based on acetal copolymer vs. optimized design using Delrin® acetal homopolymer.

9. How all stakeholders can benefit

Selecting Delrin® acetal homopolymer for mechanically demanding or high precision applications results in key advantages for all stakeholders involved:

- **Design engineers: flexible design, efficient material usage and extended performance**
  With Delrin®, the design engineer is afforded the opportunity to work with an adaptable material that combines a high level of toughness and strength to help maintain the appropriate safety factor for the application, and with the design support available from DuPont he/she can ensure minimal resin use. In addition to higher yields and faster throughputs, the technical advantages of Delrin® can, in some cases, permit the integration of discrete components for reduced assembly operations, reduced complexity, and greater reliability.

Taking adaptability to the next level, fully-compounded Delrin® resins that are modified for extended performance are also available, i.e. nucleated for dimensional stability and processing, toughened for safety systems and other applications, lubricated for low wear/low friction, UV-stabilized for auto interiors, very low emission for auto interiors, detectable for conveyors in the food industry, food contact compliant for conveyors and other applications, specialty grades for healthcare applications, and color concentrates.

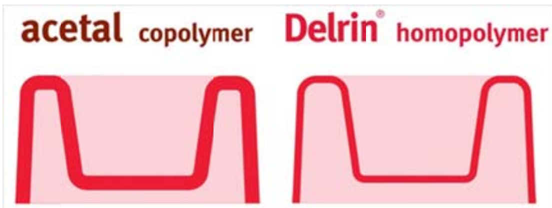


Figure 12: The superior mechanical properties of Delrin® homopolymer can allow thinner wall sections compared to acetal copolymers for the same physical part capabilities.

- **Molding operators: better processing characteristics**
  The molding operator can ensure the optimal packing even in thin-walled parts because better mechanical properties can be obtained with Delrin® homopolymer, even with higher flow grades, than can be achieved with acetal copolymer.

- **Procurement managers: reduced costs and ready availability**
  The procurement manager can often work out cheaper-than-budget copolymer acetals. Due to more efficient material usage and reduced cycle times, the unit cost of parts can be considerably lower using Delrin® homopolymer.
  With more than 80 global grades, globally harmonized manufacturing specifications and multiple locations, the procurement of Delrin® resins is a straightforward process with consistent, reliable supply and batch-to-batch quality.

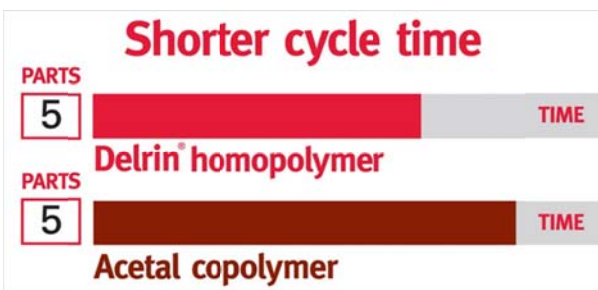


Figure 13: Delrin® offers the potential for reduced material and shorter molding cycles.

- **Plant managers: higher yields, faster throughput**
  The plant manager can count on better production rates on optimized designs. By optimizing the wall thicknesses, the subsequent faster cycle times can result in higher throughput, enabling part production to be ramped up before capital investment in additional tooling needs to be made.

- **Process engineers: technical support**
  The process engineer can access DuPont experts in processing of Delrin® for technical assistance during start up, and for continuous improvement efforts.

- **Customer: quality, reliability and performance of finished part**
  The customer is able to manufacture lightweight yet durable high-quality parts with appropriate safety margins that deliver on promise, thus protecting the company’s brand reputation.

10. Conclusion

Selecting the most appropriate acetal thermoplastic influences part design and performance, material usage, molding cycle time and part production cost. The distinction between Delrin® homopolymer and acetal copolymers may not be immediately apparent.
Both materials perform well. However, for most applications, the part made out of Delrin® homopolymer will almost always give better results across the range of mechanical performance: Delrin® is more resistant to fatigue, creep and impact, and stiffer and stronger than acetal copolymer.

The superior mechanical properties of Delrin® homopolymer lead to multiple advantages for all stakeholders when designing parts:

- Higher performing parts
- Thinner and lighter (less material usage)
- Optimized part design
- Less material usage
- Faster molding cycles
- Opportunity for total part cost reduction.

The most appropriate choice of polymer for industrial applications should be the result of a technical evaluation, both short and long-term, of the material concerned, followed by full in-situ testing in the appropriate application environment.

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