Delrin Material Profile

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I. Overview

Delrin is a thermoplastic polyacetal material. Polyacetals come in various forms (determined by their molecular structure. Delrin is a polyacetal homopolymer formed from pure formaldehyde molecules.

Delrin is a great engineering material. It has a high stiffness and high toughness. It has low friction, low water absorption, and a high resistance to scratching and scuffing. This makes it a fantastic material in industry and for laser cutting. In industry, it is often used to create small gears, ball bearings, ski fasteners, knife handles, joint clips, zippers, instrument picks, insulin pens. In the laser cutting world, vector and raster cutting of precision parts have been very well explored.

Delrin, however, is one of the more expensive laser cuttable thermoplastics. You cannot use adhesives with Delrin and it is always opaque, limiting its aesthetic possibilities. As a result, we suggest that Delrin is used as a "final product" material for engineering designs that are very well planned.

II. Manufacturing Process

The production of Delrin is patented by the Du Pont Company in the 1940s. It begins with the creation of anhydrous (water-free) formaldehyde. For Delrin (polyacetal homopolymer), methanol is converted into formaldehyde by catalytic vapor phase oxidation. The resulting aqueous formaldehyde is then mixed with the alcohol. The alcohol bonds with the carbonyl group in the formaldehyde to form a hemiacetal group.

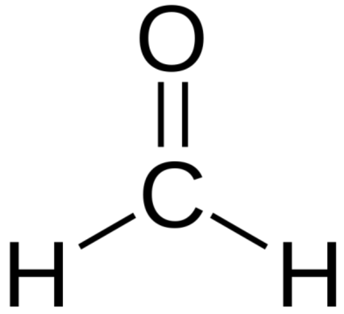


Figure 1: Formaldehyde molecule
Source:
http://en.wikipedia.org/wiki/File:Formaldehyde-2D.svg

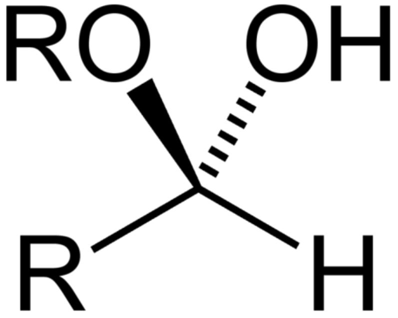


Figure 2: The R grounps are the carbonyl group of the formaldehyde molecule (Figure 1)
Source:
http://en.wikipedia.org/wiki/File:Hemiacetal-2D-skeletal.png

The formaldehyde is then purified via extraction or vacuum distillation. The resulting molecules are typically polyformaldehydes with a few impurities such as sulfur.

This formaldehyde from the reaction is then further purified by pyrolysis (heating the material in the absence of oxygen) at 150-160°C. This breaks the polyformaldehyde molecules into sole formaldehyde molecules. The lone formaldehyde molecules are then passed through a set of cold traps at -15°C to turn the vapor formaldehyde into solid formaldehyde pellets.

These formaldehyde pellets and a set of polymerization initiators are then introduced into the polymerization vessel. The mixed is stirred rapidly and then dried over an inert medium. Polymerization is an inefficient process so when 20% solid yield of polyacetal homopolymer (Delrin) is obtained, the content is isolated by filtration and cleaned. It is then dried into polyacetal pellets.

Delrin forms linear, flexible chains with a carbon-oxygen backbone making it a thermoplastic. Since the backbone is flexible, it is able to pack extremely tightly. This makes for a more crystalline material (75-85%) which then results in a higher melting temperature (175°C). This crystallinity value can be increased by annealing at higher temperatures.

Thermoplastics are materials that become pliable and plastic (so to speak) when heated beyond a certain point and then can return to any form upon cooling. This is because they are composed of flexible chains that do not cure-they do not form irreversible cross-links. This means that the material can be reprocessed a number of times.

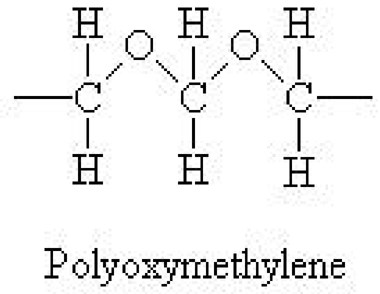


Figure 3: The resulting polyacetal/polyoxymethylene molecule from polymerization
Source:
http://dwb4.unl.edu/Chem/CHEM869E/CHEM869ELinks/qlink.queensu.ca/~6jrt/chem210/Page5.html

At this point, the polyacetal homopolymer pellets need to be extruded into a useable form. Sheets are created by plastic extrusion into a die with a set of cooling rolls.

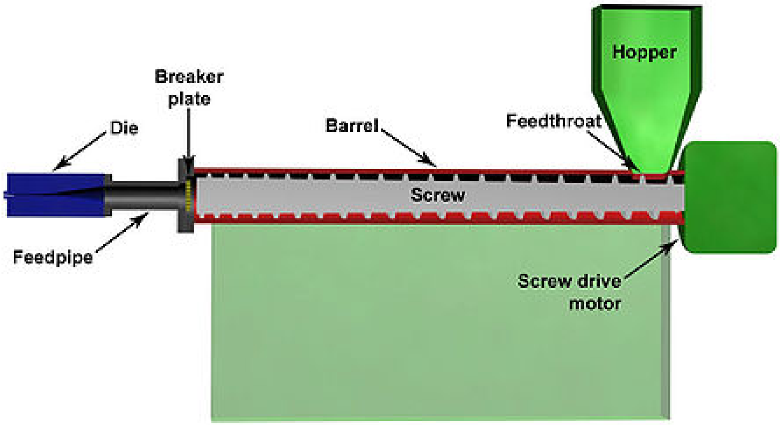


Figure 3: The typical extrusion process
Source: http://en.wikipedia.org/wiki/File:Extruder_section.jpg

In the typical extrusion process, the Delrin pellets are placed into the hopper. The pellets (along with any additives such as color) enter the screw at the feedthroat. The barrel of the screw is heated to Delrin's melting temperature (178°C for all melt flow rate grades). As the screw turns, the pellets become molten Delrin that is then passed through the breaker plate. The feedpipe guides the Delrin to the die. The Delrin sheet is then pulled through a set of cooling rolls to ensure that the plastic sets.

III. Material Specifications

Delrin is available in various melt flow rate grades including 100, 500, 900, and 1700. The melt flow rate grade refers to the material's relative viscosity. Delrin standard sheets with a 100 melt flow rate grade are the most viscous while those with a 1700 melt flow rate grade are the most fluid. Delrin specialty sheets may also have added material properties such as UV stability, faster cycling, lower friction and wear, and great toughness.

For laser cutting of Delrin, we suggest the selection of Delrin 100 as the lower melt flow rate is actually very desirable as it ensure dimensional stability. Delrin 500, 900, and 1700 are better suited for molding. In addition, Delrin 100 is far cheaper and more available in the marketplace. Also, between the different grades of standard Delrin, Delrin has mechanical, thermal, and electrical properties are better suited for structural purposes (See table 1).

Toughness refers to the material's ability to absorb energy and plastically deform without fracturing.

Dimensional stability indicates how accurate a Delrin part is to its intended dimensions.

Table 1: Delrin's material properties between the 100 and 1700 grades are almost identical.

Property	**Unit**	**Delrin 100**	**Delrin 1700**
Tensile Elongation at Break at 23°C	%	75	17
Tensile Strength at 23°C	MPa	69	68
Shear Strength at 23°C	MPa	66	58
Poisson Ratio	n/a	0.35	0.35
Tensile Impact	kJ/m^2	358	213
Melting Point	°C	175	175
Thermal Conductivity	W/m•K	0.4	0.33
Flexural Modulus at 23°C	MPa	2900	3000
Flexural Fatigue Endurance Limit at 50% RH and at 23°C	MPa	32	n/p
Dissipation Factor at 50% RH and at 23°C	n/a	0.005	0.011
Rockwell Hardness	n/a	M94	M91
Coefficient of Friction (Static and Dynamic, respectively)	n/a	0.2 & 0.35	n/p
Melt Flow Rate	g/10 min	1.0	16.0

For more material properties, please use the following link: http://plastics.dupont.com/plastics/pdflit/americas/delrin/230323c.pdf .

Delrin is opaque and white in color however it can be bought in black (as a result of additives that were included in the hopper).

Polyacetal plastics similar are offered by companies throughout the world. Similar polymers such as BASF's Ultraform, Asahi Chemical's Tenal, and Hoechst's various polyacetal blends exist, however they are copolymers (include additional functional groups) and therefore tend to have a more complex reaction when laser cut. Mitsubishi Engineering Plastics and SABIC Innovative Plastics also offer polyacetal products. Note that Delrin is a trade name and is specifically produced by Du Pont only. This chapter deals only with Delrin.

IV. Material Composition and Impact on Mechanical Properties

Delrin is known for its superior toughness, fatigue endurance, resistance to creep, and a low coefficient of friction. Delrin is probably one of the best engineering materials that can be processed with a laser cutter.

The material is particularly tough because it has a balance of crystalline and amorphous regions. The polyacetal chains form lamellae (crystalline sections) and have occasional amorphous (formless) regions. The crystalline regions of the material make it strong while the amorphous regions allow the material to bend. This ensures that cracking in Delrin does not occur (like in acrylic). For Delrin, the orientation of the part with respect to its extrusion direction has a negligible effect.

Delrin’s fatigue resistance is affected by the material’s thermal conductivity (ability to transfer heat). In thermoplastics, fatigue occurs due to viscous damping and hysteresis within the material. Since the material has a relatively low thermal conductivity, the material does not generate a lot of heat when stressed overtime resulting in a high fatigue resistance.

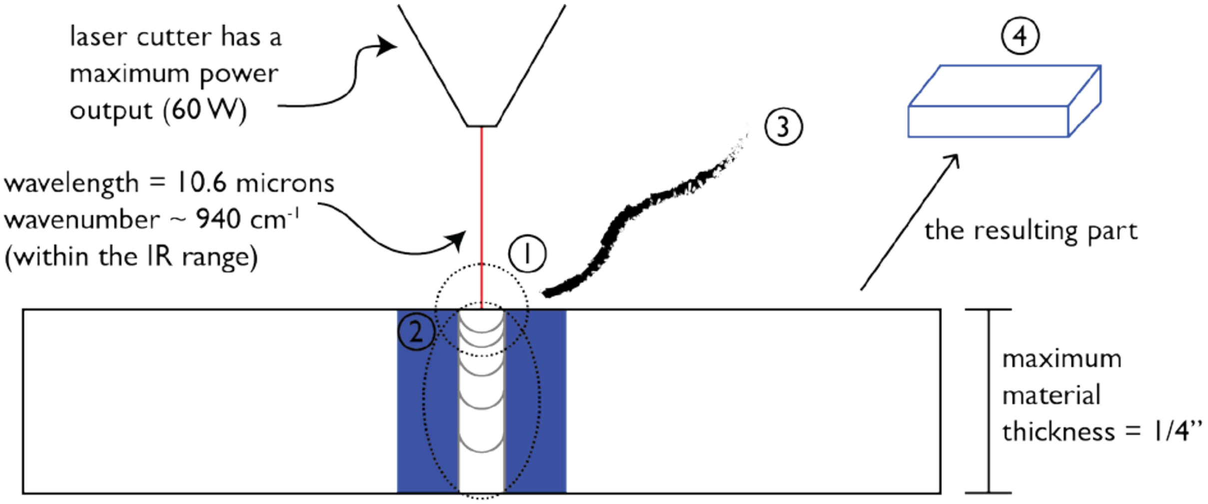
Finally, the material has a low coefficient of friction because of the flexible stacking of the polyacetal chains. This, combined with even extrusion, results in a superiorly smooth material.

Delrin is also completely opaque because it is semicystalline (it has crystalline and amorphous regions).

There are a few ways that Delrin can be degraded however:

1. Stepwise thermal- or base-catalyzed hydrolytic depolymerization (cleavage of polymers by the introduction of water)
2. Oxidative attack leading to chain scission and therefore depolymerization (forceful introduction of oxygen atoms)
3. Acid-catalyzed cleavage of C-O bond
4. Thermal depolymerization via scission of the C-O bond occurring above 270^0C

V. Material removal mechanism



Step 1 (Absorbance): Due to their chemical structure, certain materials are better equiped to absorb the laser's wavelength. Within the range of 970-1250 cm^{-1}, C-O bonds within a material experience stretch vibrations (which create heat).

Step 2 (Heat Capacity & Thermal Conductivity): The material deals with the heat that is being generated based upon its heat capacity (the material's ability to absorb heat from its surroundings) and its thermal conductivity (the material's ability to transfer heat). Materials with a lower heat capacity and lower thermal conductivity generally produce better cut surfaces as they require less energy to reach their vaporization point and do not result in excessive residual melt.

Step 3 (Vaporization/Melting): Materials with a degradation point below 400°C, in our experiments, tend to cut by mainly by vaporization. Otherwise, the materials melt and are then blown away by the laser cutter's air assist.

Step 4 (Cut surface of part): Each material has a distinctive cut surface based on their material properties and cutting parameters.

Figure 4: The laser cutting cycle for thermoplastics is outlined above.

Laser cutting Delrin involves energy absorption at the polyacetal chain's C-O backbone. Since the material has a low heat capacity and thermal conductivity, the cut is contained within the laser's kerf (if using optimized settings). Delrin has a degradation point at around 360°C and is therefore an ideal material for vaporization.

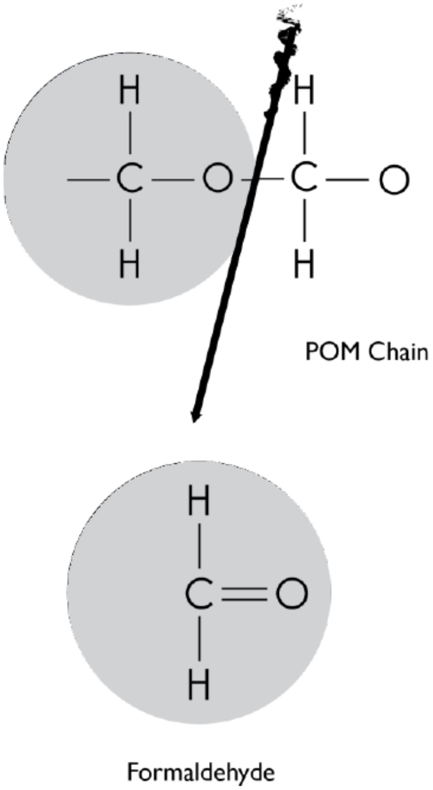


Figure 5: Polyacetal (POM) chains are broken as formaldehyde molecules vaporize.

Once the backbone has absorbed enough energy, formaldehyde molecules break away as a vapor and are blown away by the laser cutter’s air assist. For this reason, IT IS ESSENTIAL TO USE AN AIR FILTER WHEN LASER CUTTING DELRIN.

VI. Techniques

Delrin is ideal for laser cutting high precision, low friction parts such as gears.

Laser cut edges of Delrin are consistently smooth and have reasonable dimensional stability. It is important to place a material layer below Delrin or to prop it on a stand when vector cutting; otherwise, the plastic may melt slightly and result in a honeycomb pattern on the bottom of your parts.

It is also important to note that Delrin rasters to white. As a result, rastering on white Delrin is really only effective when trying to create a depth effect. Rastering on black Delrin for rough designs may yield high, clear contrast. However, for high detail images, fiber laser with a wavelength of 1.06 microns (it breaks down the black pigment) is more effective.

Figure 6: A rasted and vector cut Delrin gear. Note that the writing was accomplished with a fiber laser.
***Source*: http://www.ulsinc.com/material-profile/delrin#prettyPhoto**

Synthetic Raster Contrast

As stated before, rastering white is limited. But you can create “synthetic” contast. After rastering a design, blot the area with a dry erase marker and let it wick into the Delrin. Once it seeps long enough, wipe away the excess to reveal your design. Make sure to do some prototyping with this technique.

Figure 7: Synthetic contrast on white Delrin
Source: http://www.built-to-spec.com/blog/2012/05/12/adding-colored-etching-to-laser-cut-parts/

Dealing with no adhesives

As previously mentioned, no adhesives work with Delrin. This means that you must be a little more creative with appending parts.

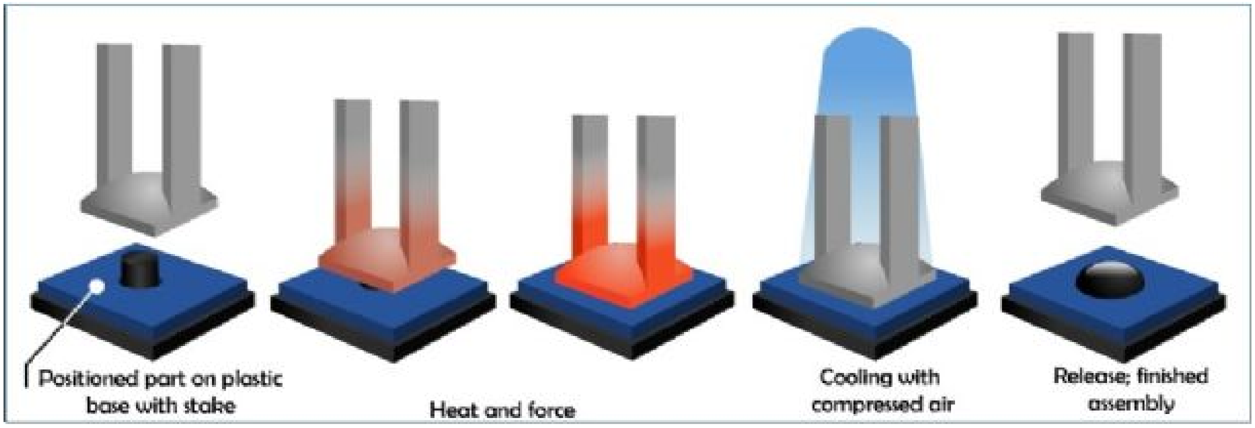


Figure 8: Heat staking involves a machine that allows you to apply pressure and heat to a protrusion on a part. This part can go through a hole in another part. The resulting dome serves as a mock-tenon for a mortise-and-tenon joint. This technique is limited in that it requires an entire other machine for safe use and air assist to ensure that heat formaldehyde is not inhaled.
***Source*: http://www.miyachieurope.com/technologies/heat-staking/**

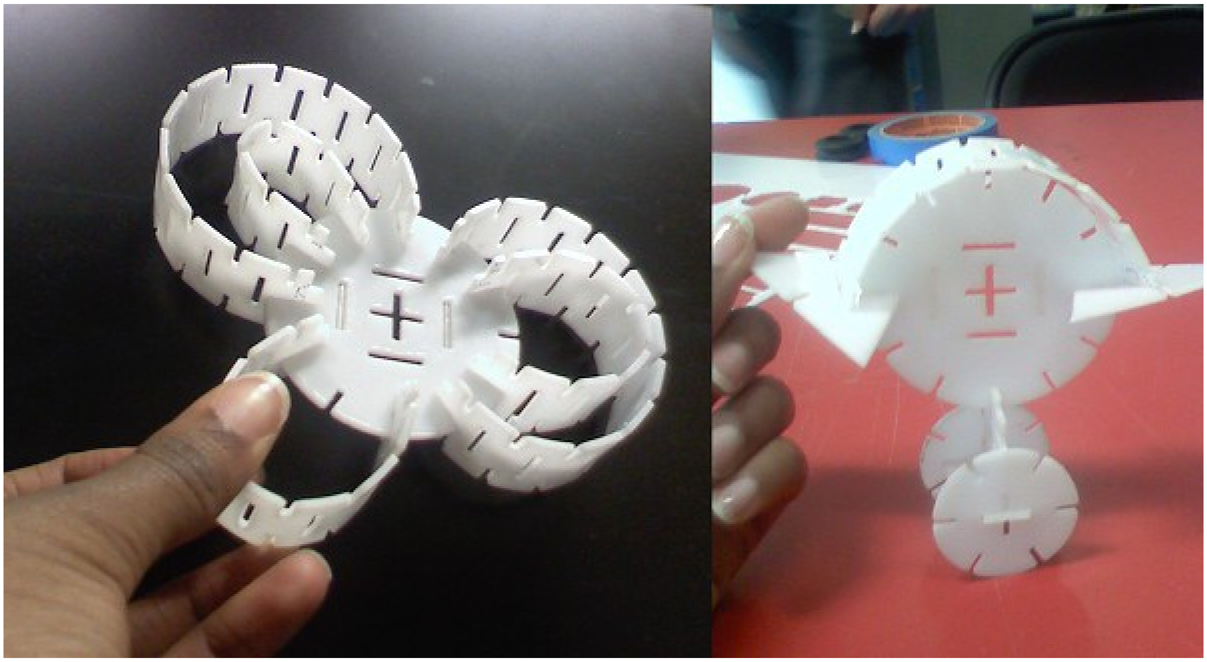


Figure 9: To create a rougher finish, this maker changed the frequency of her laser cutter to create a more jagged surface that could grab hold of a surface.
***Source*: http://makezine.com/2010/01/14/letters-from-the-fab-academy-part-1/**

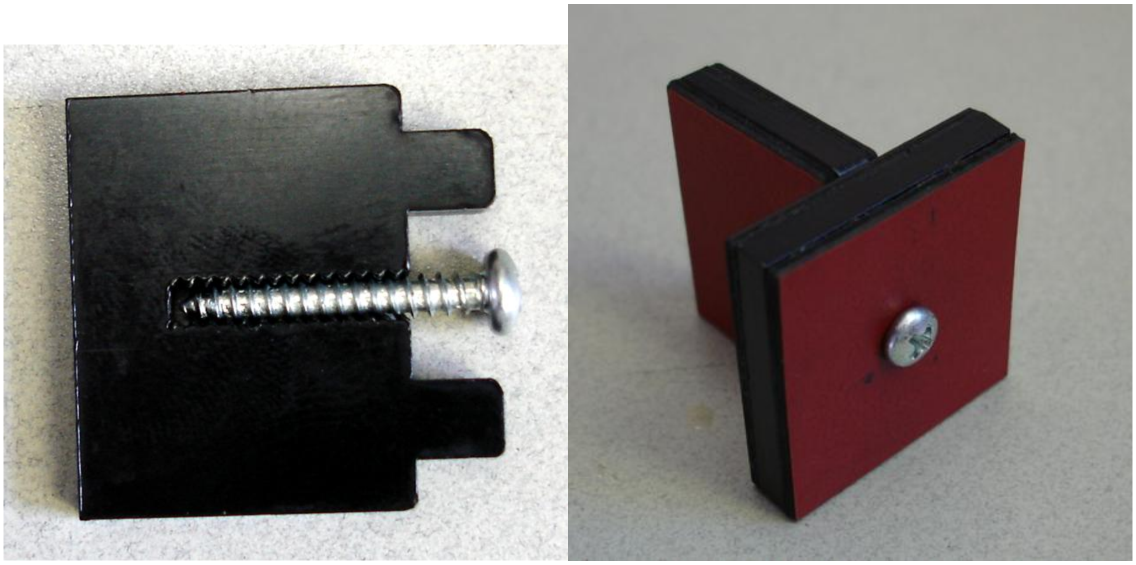


Figure 10: A modified captive nut is shown above where the Delrin part has been pre-threaded. This precludes the use of a nut but requires a more complex cut sheet.
Source: **http://makezine.com/2010/01/14/letters-from-the-fab-academy-part-1/**

VII. Delrin Sources

Delrin can be purchased in small quantities from McMaster-Carr in 100 grade in both black and white. For laser cutting, we suggest a thickness no greater than 3/8”.

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