Injection Molding: Know your resin choices

By Richard Maldanis, Ph.D., Nerac Analyst

Injection molding of plastics is continuing its dominance within the processing of polymers to render products for everyday use including kitchenware, toys, and packaging. This process is also used on polymers to create thin parts needed for commercial applications including piping and roofing products used within the building and construction industry, stents and prosthetics for medical device uses and exterior/interior trim and electronic assemblies for automotive utilities. Given its importance to fabricate plastics into a diverse array of products, it is no surprise that the worldwide injection molding plastic market is expected to blossom to a worth of about $162 billion dollars by 2020 and having a compound annual growth rate (CAGR) of 4.9% from 2015-2020 [1].

Polypropylene is one of the more predominately polymers used in injection molding given its outstanding chemical and mechanical properties that is needed when injection molding, including being lightweight, responsiveness to rapid temperature and pressure profiles during injection molding, and fast setting rates within molds. Acrylonitrile Butadiene Styrene (ABS), high density polyethylene and polystyrene are examples of others being used in injection molding processing. Below is a graph from a recent market report that illustrates the revenues based on polymer types used within the US injection molding market from 2012, projected to 2022 [2].

Source: [Grand View Research](https://www.grandviewresearch.com)
As the market of injection molding of plastics continues, so will innovations in resin selection, injection molding machinery and processing guidelines. With the emergence of new resins with improved properties, molders are able to process polymers to fabricate new designs with different properties. This report will provide a look into resin selection for injection molding, typical problems with resins during injection molding and new developments within polymer selection. Also, a case study will be presented on locating commercial resin options to use in a targeted application meeting certain specifications.

**Injection molding: The process**

The basics principles behind injection molding are relatively straightforward, in which a solid resin typically in the form of pellets is placed in a hopper, melted and fed through a barrel, typically a heated screw conveyor and then injected in a mold at high pressures (from 2000 to 30,000 psi). Cooling in the mold then occurs and conforms to the shape of the mold. After cooling, the molded plastic is then ejected from the mold. Below is a schematic of a general injection molding process.

![Injection Molding](www.substech.com)

While the process seems simplified, several critical factors are needed to be optimized for the molding process to be successful. These include selection of resins to meet the properties/specifications of the molding procedure and the final part, temperature profiles that are used within the assembly (barrel, etc) during molding and cooling, shape of the molds used, barrel designs, etc. All of these factors must be researched and optimized to avoid problems during molding.
When vetting a resin to use in an injection molding process, molders will typically search for a resin having certain attributes that are critical to their injection molding capabilities, whether they are limited based on their in-house equipment or have a targeted part they want to manufacture having certain properties. Thermoplastics and thermosetting resins are two categories of polymers that are used. Thermoplastics are the predominate resins used in injection molding applications as they are able to undergo repeated heating profiles without changing their inherent nature, unlike thermosets.

The resin itself must have the intrinsic properties to be able to undergo molding procedures. During the process of injection molding, the polymer undergoes extreme conditions (high pressures, rapid temperature changes, etc) in a relatively short time. Because of this, the molded polymer can undergo several deformations. The most common types are below:

- **Warpage**: The distortion of the shape of the final molded part, being caused by one area of the part having different degree of shrinkage of the other part. This can happen due to the mold having different thicknesses.

- **Shrinkage**: Occurs when the molded part is smaller than the dimensions of the mold. Happens after the part has been cooled and ejected.

- **Degradation**: The presence of moisture within the resin during the molding process can lead to hydrolytic degradation of the resin (especially for polar plastics such a polyesters and polycarbonates) as well as alter the mechanical strength, density and cosmetics of the molded part. It also can cause the melt flow of the polymer to increase, resulting in flashing or leakage of the resin from the two halves of the mold.

The book titled *Handbook of Molded Part Shrinkage and Warpage* [2] offers a detailed review on the shrinkage and warpage phenomena and other processing factors that affect this occurrence.

In terms of resins that are generally known to have low shrinkage properties, amorphous polymers such as ABS and polycarbonate are known to undergo less shrinkage versus crystalline and semi-crystalline materials such as polypropylene, polyamides, etc. This is due to amorphous systems having similar microstructures throughout the heating and cooling phases. Crystalline and semi-crystalline materials have varied densities and crystalline segments within the polymer structure during the heating and cooling cycle, which results in varying shrinkage rates throughout the resin. Fillers and modifiers within the resin can be used to mitigate shrinkage concerns.

Mold shrinkage values are typically reported for resins using ASTM standard D955 [3] and is a useful specification needed in developing an injection molded...
part. Below are comparable mold shrinkage values [4] for typically used polymers.

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Shrinkage/in/in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene Semi-Crystalline</td>
<td>0.010 – 0.025</td>
</tr>
<tr>
<td>Polyethylene Semi-Crystalline</td>
<td>0.015 – 0.040</td>
</tr>
<tr>
<td>Nylon (6-6) Semi-Crystalline</td>
<td>0.007 – 0.018</td>
</tr>
<tr>
<td>Acetal Semi-Crystalline</td>
<td>0.018 – 0.025</td>
</tr>
<tr>
<td>ABS Amorphous</td>
<td>0.004 – 0.009</td>
</tr>
<tr>
<td>Polycarbonate Amorphous</td>
<td>0.005 – 0.007</td>
</tr>
<tr>
<td>Polystyrene Amorphous</td>
<td>0.004 – 0.007</td>
</tr>
<tr>
<td>PPO Amorphous</td>
<td>0.005 – 0.008</td>
</tr>
</tbody>
</table>

The [Rodon Group](https://www.rodon.com), an ISO certified high volume injection molding company provides a good blog on resin selection, including a chart on typically used amorphous vs semi-crystalline resins, their cost profiles, chemical properties and targeted applications.

In choosing between an amorphous versus semi-crystalline resin, the following serves as a good characteristics tool between the two in terms of their properties and characteristics:

**Amorphous resins:**
Pros:
Less shrinkage
Improved transparency
Suitable for tight-tolerance applications

Cons:
Are generally brittle and lack chemical resistance.

Semi-crystalline resins:

Pros:
Good abrasion and chemical resistance
More flexible parts can be made

Cons:
Tend to be opaque so not suitable for transparent applications
Have higher shrinkage rates.

Within the resin, fillers and additives can be used to alter the properties of the polymer for injection molding, such as decreasing the shrinkage properties of amorphous resins or aiding in the mold release properties of the resin. Additives can also be used to impart new characteristics to the polymer such as flame retardance, clarity or antimicrobial properties.

The physical and mechanical properties of the resin also must be researched and chosen carefully. In addition to the shrinkage, warpage and degradation profiles, resins that are not able to meet the temperature, mechanical or rheological characteristics during the injection molding process can cause issues during processing. Also, the ability for the final plastic part to undergo stresses such as bending or flexing must be taken into account as well. There are many types of property data available on resin systems that can provide such information. Such properties include:

Flexural Modulus:

The measure of the flexibility/stiffness of the polymer and its ability of absorb mechanical energy without fracturing. Values are reported in pascals or pounds per square inch. The higher the value, the higher the stiffness.

Glass Transition Temperature:

The temperature in which the resin undergoes a change in properties. Plastics are typically brittle and stiff below this temperature and above this temperature they become ductile and are able to flow.
Melt index:

Is used to assess how much plastic is able to flow through a space at a specified temperature and load. It is a general guide to how well a resin will be able to move through an injection molding machine. Generally a higher melt index is for flowable materials while low melt index is for viscous polymers.

Heat Deflection (Distortion) Temperature:

Temperature in which a plastic loaded with a bending stress deflects by 0.010. It is used to assess a plastics ability to respond to loads at a given temperature extreme.

Izod impact strength, notched

Is used to measure the impact resistance of materials at a certain temperature. Its formal definition is based on the energy per unit thickness required to break a test specimen under flexural impact. The test specimen is held as a vertical cantilevered beam and is impacted by a swinging pendulum. The energy lost by the pendulum is equated with the energy absorbed by the test specimen. The higher the value, the higher the amount of energy is needed to break the object, thus having better impact properties.

There are several other physical, mechanical and electrical properties for resins that are critical either to the injection molding process or to the final molded part. To get the best out of your process, it is best to have a variety of resin options available, to be able to vet which materials will work based on your requirements and test them in house to determine its overall performance capabilities.

Case Study:

One area emerging in injection molding is in the automotive sector, especially in injection molding of plastics for creation of lightweight automotive parts such as exterior bumpers and interior trim. A case study is presented below on available grades of injection moldable polymers that have the closest specifications to the following properties:

- Density below 1.0 g/cm
- Melt flow rate above 10g/10 minutes at 230 C and under a load of 2.16kg
- A flexural modulus from 1 GPa to 2.5 GPa
- Izod Impact Strength, notched at 23 C above 1.0 ft-lb/in
Of special interest are any grades that have low temperature Izod Impact Strength notched below 0 C above 0.5 ft-lb/in

In this study, the goal is to create a lightweight, automotive trim material by injection molding, having balanced flexibility and stiffness, and good impact resistance at low and ambient temperatures and the resin having good flow properties during molding procedures. The chart below contains a selection of grades that were found that match these specifications.

<table>
<thead>
<tr>
<th>Trade name</th>
<th>Polymer Type</th>
<th>Company</th>
<th>Density (g/cm)</th>
<th>Melt Flow Rate (g/10 min)</th>
<th>Flexural Modulus (GPa)</th>
<th>Izod Impact Strength, notched at 73 F (ft-lb/in)</th>
<th>Izod Impact Strength, notched at low temps. (ft-lb/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP03B</td>
<td>PP Impact Copolymer</td>
<td>Exxon</td>
<td>0.900</td>
<td>30</td>
<td>1.26</td>
<td>3.80</td>
<td>1.90 at 0 C</td>
</tr>
<tr>
<td>Pro-fax SG899</td>
<td>Polypropylene Copolymer</td>
<td>Lyondell Basell</td>
<td>0.900</td>
<td>35</td>
<td>1.10</td>
<td>5.60</td>
<td>2.62 at -40 C</td>
</tr>
<tr>
<td>4720WZ</td>
<td>Impact PP</td>
<td>Total</td>
<td>0.905</td>
<td>25</td>
<td>1.5</td>
<td>2.0</td>
<td>0.9 at -20 C</td>
</tr>
<tr>
<td>PolyfortF PP 2181HU</td>
<td>PP Impact resistant</td>
<td>A. Schulman</td>
<td>0.990 - 0.996</td>
<td>15</td>
<td>2</td>
<td>1.0</td>
<td>NA</td>
</tr>
<tr>
<td>Hypro PP-CP20/10</td>
<td>Polypropylene Copolymer</td>
<td>Entec</td>
<td>0.9</td>
<td>20</td>
<td>1.21</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>C702-20NA</td>
<td>Polypropylene Impact Copolymer</td>
<td>Dow</td>
<td>0.9</td>
<td>18</td>
<td>1.75</td>
<td>3.5</td>
<td>1.4 at -4 C</td>
</tr>
<tr>
<td>BP FLEX D 7023 UG</td>
<td>Thermoplastic polyolefin</td>
<td>Buckeye Polymers</td>
<td>0.985</td>
<td>21</td>
<td>1.45</td>
<td>5</td>
<td>2 at -22 C</td>
</tr>
<tr>
<td>7450 PP</td>
<td>mineral filled, impact modified polypropylene</td>
<td>SABIC</td>
<td>0.970</td>
<td>21</td>
<td>1.1-1.4</td>
<td>8.37</td>
<td>2.38 at -22 C</td>
</tr>
<tr>
<td>Maxxam PPC-10G</td>
<td>Reinforced PP</td>
<td>Polyone</td>
<td>0.958</td>
<td>10</td>
<td>1.93</td>
<td>1.59</td>
<td>NA</td>
</tr>
<tr>
<td>Multi-Pro 1012 C</td>
<td>Mineral Filled Polypropylene</td>
<td>Multibase</td>
<td>0.990</td>
<td>11</td>
<td>1.303</td>
<td>1.20</td>
<td>NA</td>
</tr>
<tr>
<td>LUPOL TE5108H</td>
<td>PP and Rubber modified</td>
<td>LG Chemical</td>
<td>0.960</td>
<td>19</td>
<td>1.08</td>
<td>9.18</td>
<td>1.47 at -22 C</td>
</tr>
<tr>
<td>CP500</td>
<td>Polypropylene Copolymer</td>
<td>M. Holland Company</td>
<td>0.900</td>
<td>23</td>
<td>1.21</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>EP640S</td>
<td>PP Impact resistant</td>
<td>PolyMirae</td>
<td>0.900</td>
<td>40</td>
<td>1.57</td>
<td>1.47</td>
<td>0.735 at -4 F</td>
</tr>
<tr>
<td>AN16(LW)-D56</td>
<td>Polypropylene, Talc filled, elastomer modified</td>
<td>Mytex Polymers</td>
<td>0.930</td>
<td>17</td>
<td>1.15</td>
<td>8.43</td>
<td>NA</td>
</tr>
<tr>
<td>CAP 702</td>
<td>PP Nanocomposite</td>
<td>Asia Tech Pioneers</td>
<td>0.960</td>
<td>13</td>
<td>1.65</td>
<td>2.20</td>
<td>NA</td>
</tr>
</tbody>
</table>

Source: Richard Maldanis, Ph. D., Nerac Analyst
**Highlights and Conclusions:**

Polypropylene resins containing various modifiers including talc, rubber and minerals were found to provide material performance meeting these specifications.

The Pro-fax SG899 from Lyondell Basell and the 7450 PP grade from Sabic offered the best low temperature impact performance. The Pro Fax grade also is of lower density, has high melt flow properties and is claimed to be tailored for use in automotive interior head impact applications.

The Maxxam PPC-10G grade available from Polyone was found to offer the lowest shrinkage rates, reported between 0.0020 - 0.0050 in/in.

Several weatherable and UV resistant options were located in this search. They include the LUPOL TE5108H grade that is suitable for injection molding of bumper fascia parts, and the Maxxam PPC-10G grade that can be customized with UV stabilizers.

The companies Exxon, Lyondell Basell and SABIC were companies that were found to have other resin grades meeting the specifications needs. They may be able to provide you with further options to consider during your vetting process.

How Nerac can help?
Proper material selection is vital to maximize the performance properties of a product, avoid production problems due to unforeseen incompatibilities/failures as well as enhance the processability of a part. Nerac services can assist in this selection process, and in vetting specialty chemicals and advanced materials that have certain attributes or properties meeting your targeted requirements. Whether entering into a new market or looking for alternative materials, Nerac assists clients every day in material selection to get the most out of their research and production lines. Contact us today to learn more.

**Bibliography:**


About the Analyst

Richard Maldanis, Ph.D.

For over a decade, Richard Maldanis, Ph.D. has been assisting Nerac clients in the specialty chemistry and material science fields. His diverse expertise in organic, inorganic, organometallic and polymer chemistry provides clients with solutions to a broad range of chemistry-related challenges.

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