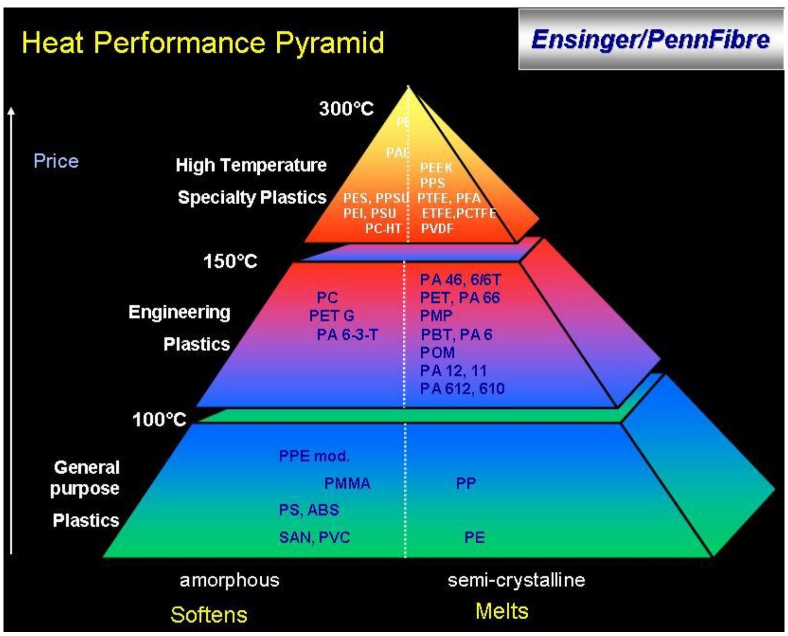
## High performance thermoforming materials from Penn Fibre Plastics, Inc

The material performance pyramid shown in figure 1 is probably one of the most widely used figures in the plastics industry. While it compares plastics generically, it says nothing about how they will perform in any given manufacturing process. However it does give some sense of how materials perform in high temperature environments and relate that property to costs and morphology (crystallinity).

Figure 1. Heat performance Pyramid



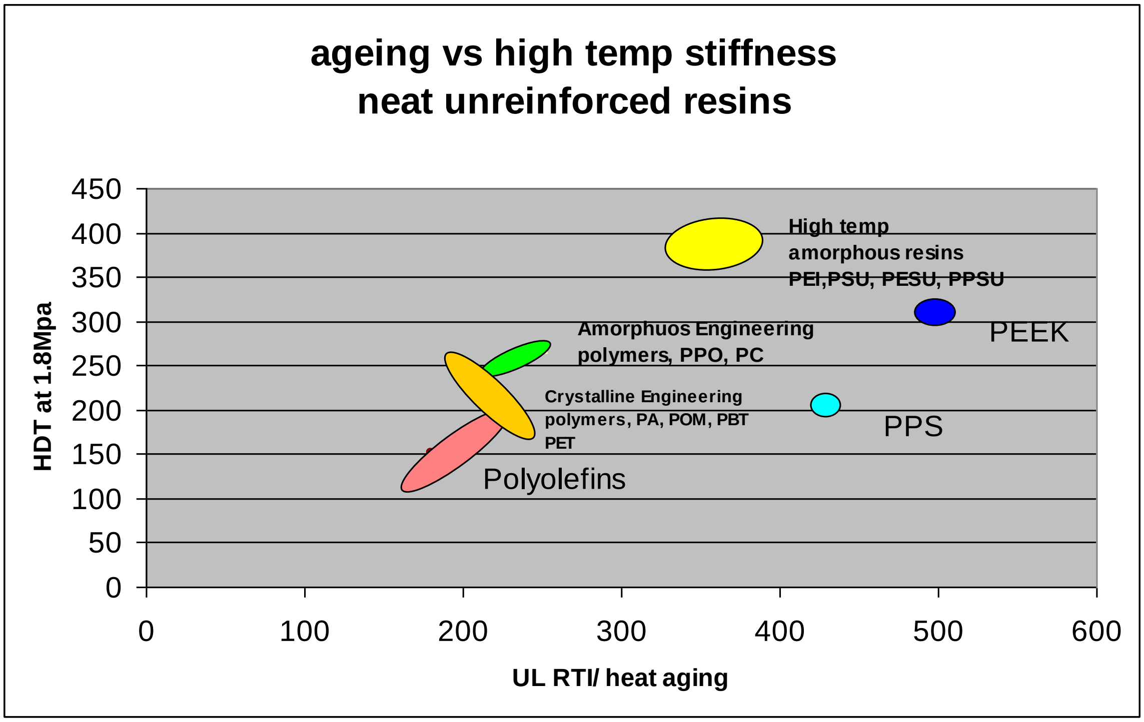

### Material selection for Thermoforming:

The best thermoforming materials are amorphous polymers. Crystalline resins can be formed but have very narrowed processing windows, and may require polymer modification.

As can be seen in figure 2, unreinforced amorphous resin have better high temperature stiffness then their crystalline counter parts, although PEEK and PPS have better heat ageing then even the best amorphous polymers. Penn Fibre recommends TECANYL ™ modified polyphenylene oxide (PPO), TECANAT ™ polycarbonate (PC), TECASON ™ S polysulfone (PSU), TECASON™ P polyphenylsulfone or polyethersulfone, and Ultem® polyetherimde sheet whenever possible if an application is to be thermoformed.

While we do offer crystalline materials for the process, in general parts will form better if made from these amorphous polymers.

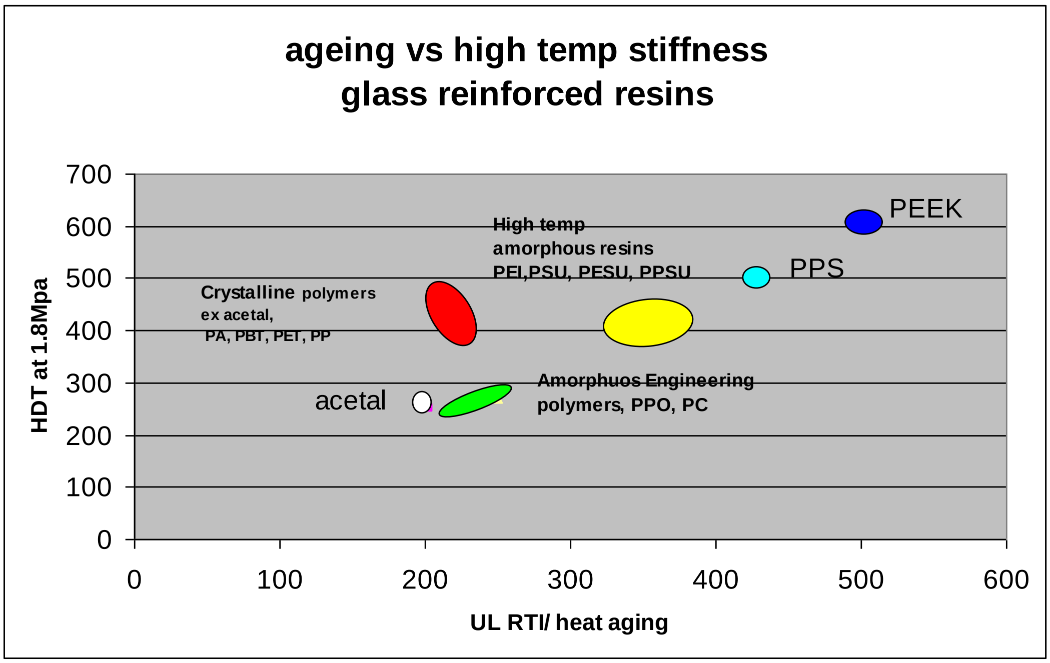
Figure 2. Heat ageing vs. stiffness of neat unreinforced polymers




As can be seen in figure 3, glass reinforcement of most crystalline resins does increase stiffness at elevated temperature to a much greater degree then for amorphous polymers. Also, crystalline polymers generally have better resistance to hydrocarbons, so there are times when amorphous polymers simple can not perform in an application.

For these cases, Penn Fibre offers thermoform-able glass reinforced Pennite™ Nylon 6 and TECATRON™ glass reinforced PPS if crystalline resins are a definite need. Our TECAPEEK ™ polyetherester ketone (PEEK) sheet has also demonstrated an ability to be thermoformed as well if an application requires the absolute highest heat ageing capability. As of today we have not made glass reinforced PEEK for the application, but would expect this to from even better then unreinforced polymer.

Figure 3. Heat ageing vs. stiffness of glass reinforced polymers

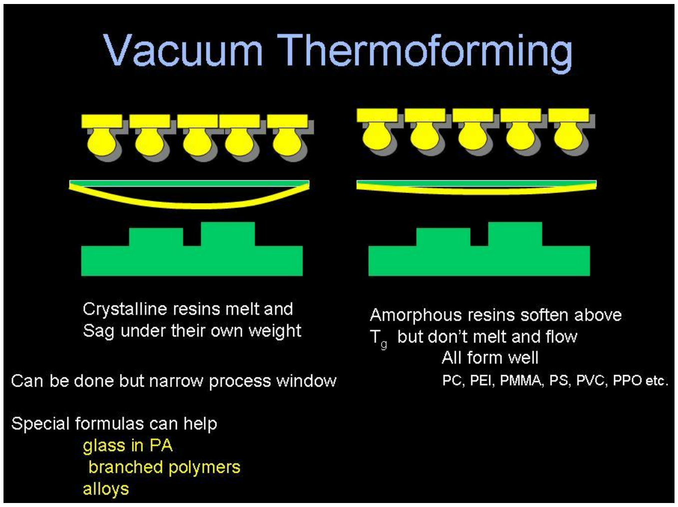



**Processing:**

Crystalline resins soften and have a tendency to sag while being heated. Control of the heating into the sheet as well as tooling temperature requires much closer control, and even then, cycle times may be 2-3X those of amorphous materials. Crystalline resins shrink 1.5-3.5%, while amorphous polymers shrink on the order of .3-.8%.

Heating is very dependent on the type of material. The emissivity of the plastic is very important in how efficiently it will heat up. Most of the heat imparted is radiant heat hitting the sheet stock. The heat may be reflected, pass through or be absorbed by the sheet. Only the latter heats the material. Cycle times are heavily dependent on the heating time, with times be on the order of 30 seconds-1 minute/mm of stock wall thickness. Crystalline resins may also require significant cooling from the tool before they can be removed.

Figure 4, The thermoforming process




Vacuum thermoforming is an extremely low pressure process compared to most other plastic forming processes. However, the techniques vary by application, and can be quite an artful process. There is drape forming, with or without plug assist over male or female tools. The process may employ pre-blow to the sheet to create a thinner stock before drawing. There is match mold forming (akin to stamping), twin sheet forming for hollow parts, and free forming (aka bubble forming) where the stock never meets the tool (used often for clear parts).

Heating of the sheet is done by various radiant heaters such as Calrods, ceramic, black panel, catalytic gas or quartz heaters. Depending on the equipment there can be many well controlled zones or very limited control. The tools may be made of wood, epoxy, cast aluminum, or porous aluminum as well as other materials that have small holes strategically placed to draw down the sheet. There may or may not be cooling associated with the tooling.

The increased sagging shown above consistent with crystalline polymers will generally require better heating capability, tooling (cooling capability) and process control capability to make acceptable parts. For deep drawn parts, plug assists, (not shown) are mandrels that push the sheet into deep draw areas of the tool either before or at the same time the vacuum is drawn.

Many materials require drying prior to forming to avoid blistering, degradation or bubbling during the forming process.

After forming the part it is usually trimmed with a saw, stamp, or router to eliminate the excess material that seals the sheet to the platen.

Below are the properties some of the high performance materials Penn Fibre and or Ensinger offers for thermoforming. Others are available on request.

| Standard values | Unit | TECASON P VF | TECATRON LAM VF | TECATRON GF 15 VF | TECATRON GF 30 VF | TECATRON GF 40 VF | TECAMID 6 VF |
|---|---|---|---|---|---|---|---|
| DIN-abbreviation | | PPSU | PPS | PPS | PPS | PPS | PA 6 |
| Density (ASTM D 792, DIN 53 479) | ρ g/cm³ | 1,29 | 1,35 | 1,44 | 1,58 | 1,65 | 1,20 |
| Tensile strength at yield (ASTM D 638, DIN EN ISO 527) | σS MPa | 70 | 90 | | | | 105/ 60* |
| Tensile strength at break (ASTM D 638, DIN EN ISO 527, ASTM D 1708 (a)) | σR MPa | | | 120 | 160 | 185 | 105/ 55* |
| Elongation at break (ASTM D 638, DIN EN ISO 527, ASTM D 1708 (a)) | εR % | >50 | 8 | 2 | 2 | 1,9 | 5/ 19* |
| Modulus of elasticity, after tensile test (ASTM D 638, DIN EN ISO 527) | $E_Z$ MPa | 2350 | 1900 | 7700 | 11000 | 14000 | 5400/ 2500 |
| Modulus of elasticity after flexural test (ASTM D 790, DIN EN ISO 178) | $E_B$ MPa | 2600 | | 7500 | 10400 | 14000 | 4200/ 210 |
| Hardness (ball indentation: ISO 2039/1, Shore D: ASTM D 2240, DIN 53 505 (d), Rockwell: ASTM D 785, ISO 2039/2 (r), Others: ASTM D 785 (a), DIN 43 456 (s)) | $H_K$ MPa | | | | | 320 | 140 |
| Impact resistance (DIN EN ISO 179, Izod: ASTM D 256, DIN EN ISO 180 (i), Charpy: DIN EN ISO 179 21, notch Impact strength: DIN 53 456 (k)) | $a_n$ kJ/m² | 31 (k) | | 32 | 9,5 (i) | 45 | 70/ 105* |
| Melting point (DIN 53 736) | Tm °C | | 280 | 280 | 280 | 280 | 222 |
| Glass transition temperature (DIN 53 736) | $T_g$ °C | 220 | 87 | 90 | 90 | 90 | |
| Heat distortion temperature after ISO-R 75 method A, (DIN 53 461) | HDT/A °C | 207 | 110 | 220 | 255 | 260 | 170 |
| Heat distortion temperature after ISO-R 75 method B, (DIN 53 461) | HDT/B °C | 214 | | 115 | | | 205 |
| Maximum service temperature short term / long term | °C | 190 / 170 | 260 / 230 | 230 | 230 | 260 / 230 | 140 |
| Thermal conductivity (23 °C) | λ W/(K·m) | 0,35 | 0,25 | | | 0,25 | |
| Specific heat (23 °C) | c J/(g·k) | | | | | 1,18 | |
| Coefficient of linear thermal expansion (23 °C, ASTM D 696, DIN 53 752, ASTM E 831) | α $10^{-5}$ 1/K | 5,6 | 5 | | | ca. 3 | 4 |
| Dielectric constant ($10^6$ Hz, ASTM D 150, DIN 53 483, IEC-250) | $\varepsilon_r$ | 3,45 | | | | 4 | |
| Dielectric loss factor ($10^6$ Hz, ASTM D 150, DIN 53 483, IEC-250) | tan δ | | | | | 0,004 | |
| Volume resistance (ASTM D 257, EC 93, DIN IEC 60093) | $R_D$ Ω · cm | $10^{16}$ | $10^{13}$ | | $10^{16}$ | $10^{12}$ | |
| Surface resistance (ASTM D 257, EC 93, DIN IEC 60093) | $R_o$ Ω | $10^{13}$ | $10^{16}$ | $10^{16}$ | $10^{16}$ | $10^{16}$ | |
| Dielectric strength (ASTM D 149, IEC-243, VDE 0303 part 2) | $E_d$ k V/mm | 15 | | | | 20 | |
| Resistance to tracking (DIN 53 480, VDE 0303 part 1) | Stufe | | | | | KC 175 | |
| Moisture absorption to equilibrium 23 °C/50% rel. humidity (DIN EN ISO 62) | W($H_2O$) % | 0,37 | 0,01 | 0,02 | 0,02 | 0,02 | |
| Flammability acc. to nach UL-Standard 94 | | Vo | Vo | Vo | Vo | Vo | HB |

* humid, after storage in standard atmosphere 23°C 50 RH (DIN 50 014) until saturation.

## Design considerations for Thermoforming:

There are several issues to consider with thermoforming that may not be concerns for injection molding:

One is limitations on draw ratio, where draw ratio is defined as the surface area of the finished part divided by the area of the material available for forming (inside clamps). For example if one were forming a cube 8 inches on a side, one would need 5 (sides) X 8 X 8 = 320 square inches in the final part. If the initial blank was 11 X 11, the draw ratio would be 320/121 or about 2.64. In a perfect draw, the part in this case would be 62% thinner then the feedstock. Unfortunately, instead, there are usually thicker (where the sheet hits the tool first), and thinner areas (the last place to form) in a part. Draw ratios should always be less then three to avoid excessive part thinning. Pre stretching the blank and or using plug assists can help to alleviate inconsistent stretching, but high draw ratios in complex parts are very susceptible to thinning. The lower the draw ratio, the more uniform the part wall may be.

Another limitation is surface texture. Basically the surface is imparted to the sheet during extrusion. The surface texture may be deformed during thermoforming, especially in deeply drawn parts matte or textured surfaces may be lost, elongated and/or matte surfaces my become shiny.

Ribs are imparted as corrugations rather then true ribs.

Designs should incorporate generous draft angles. In female tools draft angles of 2-3% are recommend and designers should double that for male tools.

One positive feature of the process is substantial undercuts may be possible if the material has high enough elongation to strip it from the tool after forming, although this is likely to have a negative impact on cycle times.

## Why is thermoforming used?

Thermoforming has several advantages and disadvantages vs. other thermoplastic forming techniques:

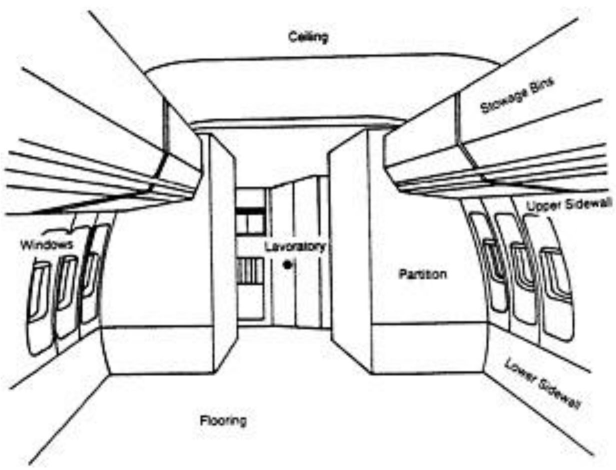
Extremely large parts can be formed. The part size is limited only by the size of the platen. Boats, golf cart bodies, industrial equipment, etc. are frequently made from thermoformed sheet. Penn Fibre supplies many of our sheets up to four feet wide for such applications. Contact your Penn Fibre/Ensinger rep for availability.


Thermoforming has very low tooling costs compared to other processes, but by its nature may have high material scrap losses, unless the part is rectangular (matches the sheet). It tends to be the process of choice in lower production volume parts where tool cost amortization make it competitive with injection or blow molding.

There is almost no limitation on how thin the part may be. For this reason, it is frequently used in packaging. Penn Fibre offers some specialty packaging products such as Topaz® Cyclic polyolefins (COC) for unique medical applications requiring clarity and high temperature capability.

**What materials:**

Anywhere fire safety is a concern, there may be an opportunity for high performance naturally flame retarded plastics. Ultem ® PEI, TECAPEEK ™ PEEK, TECASON ™ P PPSU, or TECASON ™ PPES are good candidates for these applications. All these materials are used in aerospace applications, and many are already approved by commercial aircraft producers. These materials are finding utility in rail and ship board applications as well, where smoke generation, toxicity and corrosion are considerations in the event of a fire.




While injection molded polypropylene is the standard material of choice for car batteries, higher temperature and flame retardancy in uninterrupted power supply batteries have created opportunities for PPESU. Thermoforming is a logical process for many for these applications.

PPESU has demonstrated value in cookware. The materials low thermal conductivity (relative to metal) improves safe handling, and the clarity, chemical resistance, high temperature stiffness, and ability to handle cleaning and sterilization is appreciated by users and is often seen in commercial restaurant applications.

Tubs, trays and enclosures in medical, food service or agricultural/dairy industries where autoclaving and sterilization techniques favor resins from PPO to PPESU depending on the requirements of the application.

Tray for sizing trials for hip implants

Surgical tray made from TECASON P VF

Automotive uses of thermoformed materials include ski boxes, storage containers, truck interiors, and body liners, wind and rain deflectors, seat backs, headliners and instrument panel skins, camper tops.  Other vehicular uses include Golf cart bodies, heavy truck fairings and shrouds, motorcycle windshields, camper tops and surrounds, boat hulls, hatches, dashboards and enclosures. Materials here are often olefins such as Thermoplastic olefins or ASA capped ABS. While Penn Fibre does not offer these materials, our high performance materials are used under the hood in fan shrouds and air intake ducts.

Thermoforming fits well where total production volumes may not justify injection mold cost such as in customized or limited production medical equipment. Higher performance materials that allow sterilization may be of value.

From prosthetics to blister packaging, thermoforming has demonstrated value to making many parts in a cost effective manner. Its low tooling cost and short lead times make it very suitable for prototype parts and limited pre production manufacturing. Designers should be aware of it as a production option and knowledgeable to its strengths and weaknesses as a process.

Contact your Penn Fibre/Ensinger representative for more information.