*Innovative Tooling Materials for Thermoforming*

| REVISION RECORD | | | |
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| Drawn By | Date | Description | Rev Level |
| | | **Plug Assist Material Selection Guide** | |
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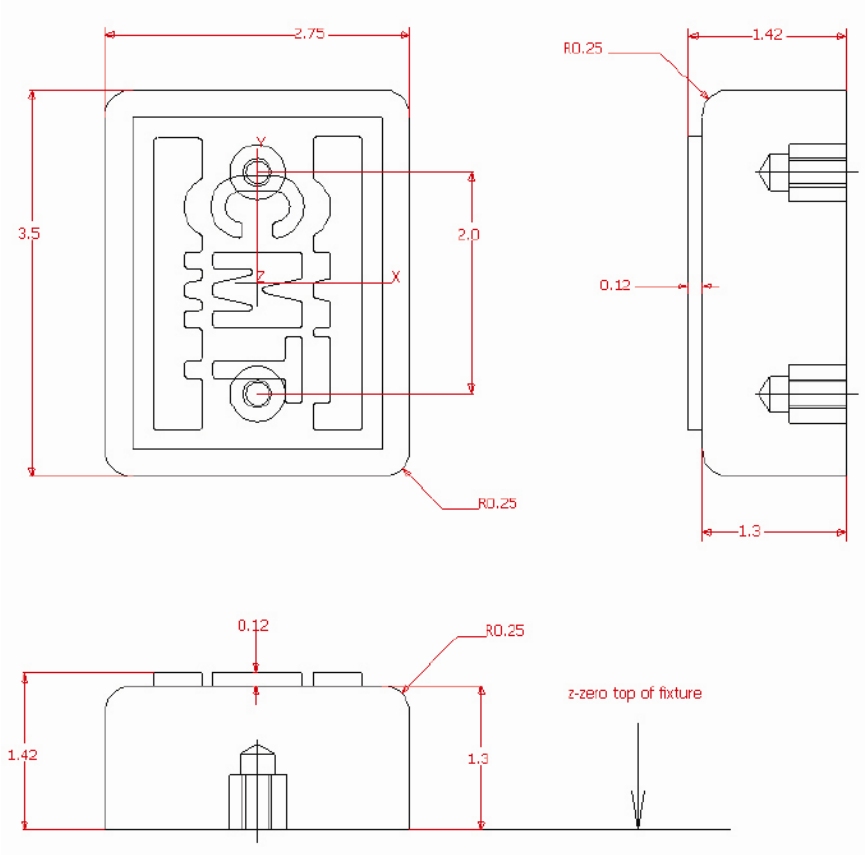


| Notes: *CMT is the world's leading manufacturer of plug assist thermoforming materials. Products are available in a wide variety of rod, sheet and block sizes.* | | Forming Material: |
|---|---|---|
| | | Process Temperature: |
| | | Cycle Time: |
| | | Stock Thickness: |
| | | Transparency: |
| Sheet Fed | Tooling Cavities: | Deep Draw: |
| Rotary | High Stick: | Multi-Layer: |
| In-Line | Low Stick: | Pharmaceutical: |

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Plug Assists (aka plugs, assists, pushers) are solid shapes used in thermoforming to actively stretch pre-heated plastic into position in a mold. Because the plug contacts the heated/softened plastic, plug material selection is critical to the overall quality of the final molded product. Properly selected, the right plug material and design improve material distribution, allowing a thermoformer to reduce starting sheet thickness. Carrying/releasing the right amount of material at the right time improves overall quality and part clarity. For the tool maker, selection of the right plug material simplifies machining and improves performance of the entire mold.

**Syntactic Foam:** Syntactic foam describes a class of material which has pre-formed hollow spheres as a main constituent. Syntactic foams are the most widely used plug assist material today as a result of their excellent forming characteristics, ease of machining, reliability in manufacturing and low cost. Two types of syntactic foam are available for use as plug assists.

**Thermoset:** This class of syntactic foam is a homogeneous blend of microspheres in a low thermal conductivity epoxy. The term thermoset refers to the fact that this class of materials takes a "set" shape/form when cured. The selection of epoxy and microsphere size/type allows the creation of a wide variety of materials for different surface characteristics and/or use at different service temperatures.

**Thermoplastic:** Thermoplastic syntactic foams are less brittle than thermosets, resulting in a more easily machined surface, creation of fine detail and a tougher, more durable plug for abusive environments. Thermoplastics may typically be machined 3x faster than thermosets with no dust resulting from the machining process.

## Key considerations in choosing a plug material:

**Temperature:** Selection of a plug material should be made to ensure the Service Temperature is suitable for use with the sheet and process temperature. Use the manufacturer's data sheet for the plastic to determine the appropriate thermoform processing temperature.

Typical* forming temperatures for common plastics:

| Plastic | Recycle Code | °F | °C | Plastic | Recycle Code | °F | °C |
|---|---|---|---|---|---|---|---|
| ABS | 7 | 300 | 149 | PC | 7 | 375 | 191 |
| APET | 1 | 300 | 149 | PETG | 1 | 300 | 149 |
| EVOH | 7 | 212 | 100 | PLA | 7 | 212 | 100 |
| HIPS | 7 | 302 | 150 | PP | 5 | 330 | 165 |
| HDPE | 2 | 295 | 146 | Rigid PVC | 3 | 280 | 138 |
| PMMA | 7 | 350 | 177 | PS | 6 | 300 | 149 |

* Typical temperature values are reference only and are core (center of sheet) temperatures. Actual molding requirements may vary. See supplier material data sheet for details relative to your specific material.

**Transparency/Surface scratch:** Plug materials that are easily polished are preferred to minimize/eliminate surface scratching and to optimize material distribution in high transparency applications. Modifying the binder and the size/type of spheres in syntactic foam has resulted in the creation of plug materials for easy polishing. Ra values (shown in the chart on page 4) may be used to compare typical surface finish values achieved by machining. Additional polishing with fine grit sandpapers (see the technical literature section of www.cmtmaterials.com for specific procedures) will provide a smoother surface. The lower the Ra value, the smoother the finish.

**Mark off:** A mark on the part may result from contact with a plug that is too cool or from a surface condition on the plug. Syntactic plug materials have very low heat transfer and are preferred as the chance of mark off may be isolated to machining conditions or other easily identified variables.

**Stick:** High forming temperature requirements or certain material properties (i.e. when forming EVOH, PETG, CPET or RPET) can cause a material to stick or leave residue on the plug. In these cases, a plug material formulated for low stick is preferred. Syntactic plug materials impregnated with Teflon® (WFT and FLXT) eliminate the wear issues associated with coating/recoating the surface of a plug.

**Durability:** Syntactic foams are durable, long lasting plug materials. Fine detail requirements or general manufacturing practices can result in hostile environments which can chip or break the more brittle thermoset syntactics. Thermoplastic (B1X) or copolymer thermoset (FLX, FLXT) syntactic plug designs are preferred for these applications. Use the Flexural Toughness Rating on the specification chart to compare durability of various plug choices.

**Food or pharmaceutical contact:** Plastics used to package food or pharmaceuticals are regulated in regard to the plastic used, the amount of recycled material that may be added and the processing methods/tools used. Always select plug materials suitable for use in FDA controlled applications. Utilizing plug materials with an FDA registered Drug Master File (DMF) offers additional security to the pharmaceutical packaging thermoformer.

**Machining:** Syntactic foam is best machined using solid carbide cutters designed for hard abrasive plastics. Tools designed for metal cutting result in lower surface quality and may irreparably damage the plug surface or require significant polishing effort. Thermoplastic (B1X) and copolymer (FLX, FLXT) syntactic plugs may be machined at a much faster rate than thermoset syntactic plugs and result in no dust in the machine. Thermoplastic syntactic plugs are preferred when it is necessary to machine fine detail into the plug. See the technical literature section of www.cmtmaterials.com for machining recommendations on any HYTAC material.

**Polish:** Properly machined, HYTAC materials are commonly used with no additional polishing required. Syntactic foams are formed using microscopic hollow spheres as insulators held in suspension inside a matrix material (binder). The size and type of the microspheres, along with the choice of matrix material make some syntactic foams better than others for surface polish. When an ultra smooth surface polish is needed, thermoset or copolymer thermoset syntactics are generally the best choice. HYTAC-FLX and HYTAC-WFT have been optimized for surface polish requirements.

**Plug attachment:** Syntactic foam materials for plug assists were developed to optimize forming capability within a mold. As the materials generally have low tensile and shear strength, direct threading is not recommended. Instead, most thermoformers use some type of insert which is bonded in to the plug (see HYTAC inserts, page 7). A bonded insert can typically be repaired and reseated with fresh adhesive if a failure occurs. With thermoplastic (B1X) syntactic, threaded inserts may be used to further increase the pull-out load strength, with pull-out failure limiting itself to damage to the threads. In all cases, inserts should be installed/machined flush with the surface of the plug. This will prevent over tightening if the insert is below the surface and prevent wobbling/cantilever stress should an insert rise above the surface of the plug.

**HYTAC-W** *(Thermoset Syntactic)*
*Entry level thermoset for use with PVC, PS or PE*

**HYTAC-WF** *(Thermoset Syntactic)*
*High strength, high clarity for smooth surface finish*

**HYTAC –WFT** *(Thermoset Syntactic)*
*Teflon® impregnated, ultra smooth surface*

**HYTAC-FLX** *(CopolymerThermoset Syntactic)*
*Toughened blend for easy machining and polishing in a durable copolymer syntactic.*

**HYTAC-FLXT** *(Copolymer Thermoset Syntactic)*
*Teflon® impregnated, easy release for multi-layer or barrier plastics*

**HYTAC-B1X** *(Thermoplastic Syntactic)*
*Industry leading syntactic for durability and fine detail*

**HYTAC-A** *(Solid Polymer)*
*Tough material for deep draw transparent PP applications*

**HYTAC-Rx-L1** *(Thermoset Syntactic)*
*Specifically formulated and registered for pharmaceutical blister packaging. Low Stick surface version*

**HYTAC-Rx-H1** *(Thermoset Syntactic)*
*Specifically formulated and registered for pharmaceutical blister packaging. High Stick surface version*

**CUSTOM CAST** *For unique shapes/sizes/requirements, CMT offers both custom casting/cutting capability and a premixed yet uncured castable product that may be cast/poured at a customer site. Contact CMT with your requirements.*

| Product | Color | Service Temperature | | Thermal Conductivity | | Flexural Toughness (ASTM D790) | | Typical CNC Finish (µin) | Coefficient Thermal Expansion | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $^0$F | $^0$C | BTU/hr-ft-$^0$F | W/m$^0$K | Psi | kPa | Ra* | x10$^{-6}$in/in$^0$F | x10$^{-6}$ m/m/ $^o$C |
| **HYTAC-W** | White | 350 | 176 | 0.07 | 0.11 | 2.7 | 18.6 | 54 | 22 | 41 |
| **HYTAC-WF** | White | 450 | 232 | 0.11 | 0.19 | 4.7 | 32.4 | 28 | 18 | 32 |
| **HYTAC-WFT** | Light Green | 425 | 218 | 0.11 | 0.19 | 4.5 | 31.0 | 24 | 20 | 37 |
| **HYTAC-FLX** | Almond | 350 | 176 | 0.07 | 0.11 | 7.6 | 52.4 | 22 | 23 | 42 |
| **HYTAC-FLXT** | Dark Green | 350 | 176 | 0.10 | 0.17 | 7.2 | 49.6 | 21 | 20 | 36 |
| **HYTAC-B1X** | Light Blue | 350 | 176 | 0.11 | 0.19 | 11.6 | 80.0 | 39 | 38 | 68 |
| **HYTAC-A** | Amber | 400 | 204 | 0.07 | 0.11 | 63.6** | 438.5** | 7 | 31 | 56 |
| **HYTAC-Rx-L1** | White | 450 | 232 | 0.10 | 0.17 | 3.9 | 26.9 | 24 | 25 | 46 |
| **HYTAC-Rx-H1** | Cream | 450 | 232 | 0.08 | 0.14 | 4.3 | 29.7 | 22 | 25 | 46 |

* Ra values from CNC milled surface using 2 straight flute plastic cutting end mill. Measurements taken with Mahr Federal Pocket Surf III.

** Samples did not break. Toughness value at 5% strain reported.

Photos courtesy of J & R Plastics Inc.

## Application and Machining Considerations:

| Attribute | W | WF | WFT | FLX | FLXT | B1X | A | Rx-L1 | Rx-H1 |
|---|---|---|---|---|---|---|---|---|---|
| **Eliminates Dust in Machining** | 1 | 2 | 3 | 4 | 4 | 5 | 5 | 3 | 2 |
| **Resistance to Abuse** | 2 | 3 | 3 | 4 | 4 | 5 | 4 | 3 | 3 |
| **Durability with Fine Detail** | 2 | 3 | 3 | 4 | 4 | 5 | 4 | 3 | 3 |
| **Material Distribution** | 3 | 4 | 4 | 5 | 5 | 5 | 2 | 4 | 4 |
| **Polishing** | 2 | 4 | 5 | 4 | 5 | 3 | 5 | 4 | 4 |
| **Use with Transparent Plastic** | 3 | 3 | 4 | 4 | 4 | 4 | 5 | 4 | 4 |
| **Minimal Scratch of Sidewall** | 2 | 3 | 4 | 3 | 4 | 4 | 5 | 4 | 4 |
| **Low Stick Surface** | 2 | 3 | 5 | 2 | 5 | 3 | 3 | 5 | 2 |
| **High Friction Surface** | 3 | 2 | 0 | 4 | 0 | 3 | 3 | 0 | 5 |
| **Deep Draw Use** | 3 | 4 | 4 | 5 | 5 | 5 | 5 | 4 | 5 |
| **Multi-layer Use** | 2 | 3 | 4 | 4 | 5 | 3 | 2 | 5 | 4 |
| **Meets FDA Guidelines for Food Contact** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 0 | 0 |
| **Has FDA Drug Master File on record** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 |
| **Sheet Material** | | | | | | | | | |
| **APET** | Y | R | Y | R | Y | R | Y | Y | R |
| **CPET** | Y | R | R | R | R | R | N | R | Y |
| **EVOH** | N | Y | R | Y | R | Y | Y | R | Y |
| **HDPE** | R | R | Y | Y | Y | R | N | Y | Y |
| **HIPS** | Y | Y | Y | R | Y | R | N | R | Y |
| **LDPE** | R | Y | R | Y | R | R | N | Y | Y |
| **OPS** | N | R | Y | R | Y | R | N | Y | R |
| **PC** | N | R | R | Y | Y | Y | R | Y | Y |
| **PETG** | Y | R | Y | R | Y | R | Y | Y | R |
| **PLA** | N | Y | Y | R | Y | R | Y | Y | R |
| **PMMA** | Y | R | R | Y | Y | Y | Y | Y | Y |
| **PP** | Y | R | Y | R | Y | R | R | Y | R |
| **PS** | R | Y | R | Y | Y | R | N | Y | R |
| **Rigid PVC** | R | R | Y | Y | Y | R | N | Y | Y |
| **RPET** | Y | R | R | R | R | R | Y | Y | R |

Legend:

0 = Not recommended → 5 = Best performance
R = Recommended  Y = Acceptable  N = Not Suitable

Chart usage:
1. Select a product listed as suitable for use with the material to be formed.
2. Select attributes based on what is most critical to the part to be formed.
3. Sum up the attribute score to determine the optimal plug material for your application.

This chart is for directional reference only. Review your requirements/selection with a CMT specialist to optimize the performance of any HYTAC material prior to use.

## HYTAC-LP for Large Plug Applications

In the past, heavy gauge thermoformers were not able to obtain the benefits achieved when using syntactic thermoset plastics as plug assists. High syntactic plug costs and design challenges required formers to live with the webbing, inconsistent sheet distribution and chill marks that result from wood, felt or wood/felt combination used as plugs/pushers.

HYTAC-LP is a new epoxy syntactic plug assist system specifically designed to provide a light weight and low heat transfer system that reduces plug costs while dramatically increasing performance. HYTAC-LP as a plug assist material results in improved thickness control and more consistent quality of the final part. Proper design of the plug and surface finish eliminates webbing and reduces sticking of difficult to process polymers.

HYTAC-LP is a two-part system consisting of a core of large, hollow composite spheres and a skin of thick, non-sloughing syntactic foam. This design allows for the creation of plugs that may be machined to final shape at a customer site or provided to shape directly from CMT.

Example of a HYTAC-LP plug in the finished shape for use in thermoforming a full size freezer liner.

Key benefits in use include:

- Low thermal conductivity and specific heat – the syntactic foam structure of HYTAC-LP provides the low heat transfer desired in a plug assist material.
- Dimensional stability and a service temperature up to 350°F (176°C).
- Lightweight – increases the life of capital equipment due to reduced wear and tear on moving parts.
- Low cost – the system is about half the cost of a similar solid syntactic foam plug.
- Easily formed or machined – HYTAC-LP can be easily shaped or cast to any size or shape, and machined using conventional equipment.

HYTAC-LP may be used in a wide variety of applications on sheet-fed, rotary or in-line machines. It may also be used with most commonly thermoformed materials and many of the more exotic materials available today. Contact your local CMT Specialist to discuss your requirements.

## HYVAC Vacuum Fixture Material

For a fast and economical way to hold contoured parts in place during the trimming process, try the new HYVAC system. This porous material may be easily shaped using existing parts, eliminating the need for costly machining of large holding fixtures. Its final structure allows vacuum airflow throughout the entire fixture providing a strong and uniform hold-down during manual or automated trimming.

HYVAC is provided as a simple three-part kit of resin, catalyst and fiber reinforced spheres. The resin and catalyst are combined and poured into the provided mixing bag to coat the spheres. The contents are easily poured and lightly compacted in a formed part. A non-porous anchor block is pressed to the back side of the fixture prior to cure.

Following room temperature or oven cure, the HYVAC system provides a stiff but porous and highly effective custom fixture that may be installed on an automated router table or manual system.

The system utilizes high volume rather than high pressure vacuum, meaning it may be operated from a basic shop vacuum system or connected directly to a high volume vacuum line on automated trimming machines. A minimum 2.0" diameter vacuum line with unrestricted flow is recommended for optimal performance.

Key benefits in use include:

- Low cost
- Easily formed without machining
- Light weight
- Easily stored initial kit form allows for creation of custom shaped fixturing at a moment's notice

HYVAC is supplied in a 0.5 $ft^3$ kit, conveniently separated into two distinct 0.25 $ft^3$ mixtures. (0.25 $ft^3$ is approximately 1.9 gallons.)

Properties:

Color: Blue
Compressive Strength: 125 psi (.87 MPa)
Density: 12 – 18 $lb/ft^3$ (192 – 288 $kg/m^3$)
Compressive Modulus: 11,000 psi (75.8 MPa)
Service Temperature: $240^0$F ($115^0$C)

## HYTAC Inserts

Ribbed aluminum inserts provide a secure method to attach HYTAC materials to a supporting base structure and reduce the chance of plug damage from over tightening or improper screw length.

Inserts are sold in bags of ten (10) pieces each.

US ¼-20 Thread – Part number "INSERT STD THREAD"

Metric 6mm Thread – Part number "INSERT METRIC THREAD"

CMT Materials provides products and technical assistance to thermoformers and tool makers around the world. Standard products are typically available for same day shipment; specialty products are available with a short lead time. Visit our website at www.cmtmaterials.com to find the technical specialist nearest you.

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