



FDM Tooling for Sheet Metal Forming: Hydroforming and Rubber Pad Press

From simple bending on a press brake to automated fine blanking, stamping or progressive die—there are many ways to form, fabricate and manufacture sheet metal parts. Two methods are hydroforming and rubber pad forming. Commonly used for aerospace, military, commercial and automotive part production, these methods are ideally suited for low-volume production.

Their methods of operation are in stark contrast to the sharp, rapid-fire strike of a metal die on sheet metal stock. Using a slow buildup of high-pressure, rather than impact force, hydroforming and rubber pad presses can produce complex part configurations.

Although counterintuitive, the high-pressure forming methods create an opportunity to make sheet metal parts from lightweight, plastic tools produced from fused deposition modeling (FDM). Compared to machined metal tools, the FDM approach is quicker, less expensive, and less labor intensive. It is also automated, which allows for lights-out tool making. These characteristics combine to make FDM an interesting alternative for repair and refurbishment work—as found with aging aircraft—or products with a high probability of design revisions.



TABLE OF CONTENTS

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

1. OVERVIEW	3
1.1. Application	3
1.2. FDM is a best fit	3
2. SHEET STOCK SPECIFICATIONS	4
2.1. Materials formed on FDM tools	4
3. TRADITIONAL PROCESS OVERVIEW	4
3.1. The steps in the traditional metal forming	4
3.2. FDM adjustments	5
4. TOOL DESIGN	5
4.1. Form block	5
4.2. Intensifier	6
4.3. Export STL file	6
5. FILE PREPARATION	6
5.1. Modeler > Setup	6
5.2. Orient STL	6
5.3. Create custom group	6
6. MATERIAL SUGGESTIONS	8
6.1. Options	8
6.2. Tool life	8
7. POST PROCESSING	8
7.1. Venting	8
7.2. Surface finishing	8
8. METAL FORMING	9
8.1. Lubrication	9
8.2. Cleaning	10
9. TOOLS & SUPPLIES	10
9.1. Items required	10
9.2. Orient STL	10
9.3. Sources	10
10. RECAP - CRITICAL SUCCESS FACTORS	10
10.1. FDM tools	10

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

1. OVERVIEW

1.1. Application:

FDM is an alternative tool-making method for sheet metal forming with hydroforming or rubber pad press processes. FDM may be used to manufacturing tooling that includes:

- Form blocks.
- Intensifiers.
- Drill templates.
- Trim tools.

1.2. FDM is a best fit when:

1.2.1. Forming pressures.

- Hydroforming: up to 10,000 psi (69 MPa)

Note that maximum forming pressures are dependent on the material used in the FDM tool. See Section 6.1 for details.

- Rubber pad press: up to 1,000 ton (907 metric ton)

Note that draw depth must not exceed 3.0 in. (76 mm).

1.2.2. Sheet metal specification.

Test show that aluminum, stainless steel and titanium, with sheet thicknesses up to 0.090 in. (2.29 mm), are compatible with FDM tooling. Other untested materials may also be viable. See Section 2.1 for details. (Figure 2)

1.2.3. Low-volume forming runs.

FDM tools have exceeded 400 cycles without failure. Note, however, that tool life is dependent on the FDM material used, sheet metal material, bend radii, part configuration, and most importantly, forming pressure. (Figure 3)

Ideal applications include:

- Low-volume production.
- Repair and refurbishment of legacy products.
- Custom products.
- Prototype development.

1.2.4. Other qualifiers.

- Part size: Most effective when the FDM tool does not exceed 16 in. x 14 in. x 16 in. (406 mm x 356 mm x 406 mm). Yet, larger tools are feasible, especially if they are larger in only one dimension.
- Part design: Gains are greatest when the sheet metal component is complex and feature-laden.



Figure 1: Structural aircraft component that was hydroformed on an FDM form block (intensifier in rear).



Figure 2: Sheet stock up to 0.090 in. (2.29 mm) has been formed.



Figure 3: FDM ULTEM 9085 tool (with sheet metal blank) has exceeded 400 cycles.

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

2. SHEET STOCK SPECIFICATIONS

2.1. Materials formed on FDM tools.

An ongoing evaluation program has shown that the materials listed in Table 1 are suitable when forming on FDM tools. For softer materials, sheet thicknesses of up to 0.090 in. (2.29 mm) have been processed (Figure 4).

The material list is not exhaustive and exclusion does not imply incompatibility.

Material	Grade	Thickness
Aluminum (Al)	2024-0	0.050 – 0.090 in. (1.27 – 2.29 mm)
	2024-T3	0.050 – 0.080 in. (1.27 – 2.03 mm)
	6061-0	0.016 – 0.080 in. (0.41 – 2.03 mm)
	7075-0	0.040 – 0.090 in. (1.02 – 2.29 mm)
Stainless Steel (SS)	4130	0.080 in. (2.03 mm)
	420XF	0.040 in. (1.02 mm)
	321	0.049 in. (1.24 mm)
	347	0.002 in. (0.51 mm)
Titanium (Ti)	Unspecified	0.040 in. (1.02 mm)
Inconel	Exploratory	

Table 1: Sheet metal materials formed on FDM tools.

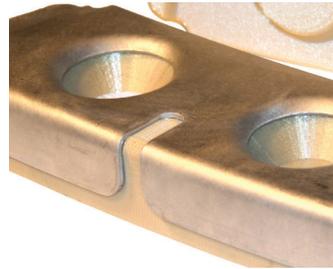


Figure 4: Thick aluminum (2024-0) sheet metal parts, up to 0.090 in. (2.29 mm) are possible with FDM form blocks.

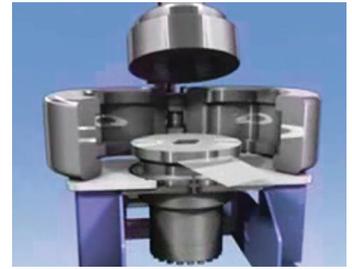


Figure 5: Place form block in hydroforming press (punch shown.)

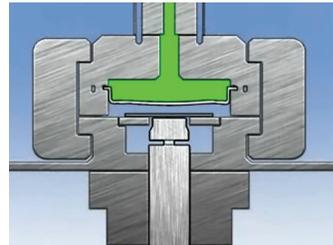


Figure 6: Fill bladder with hydraulic fluid.

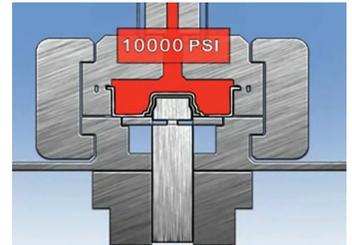


Figure 7: Raise fluid pressure to form sheet metal part.

3. TRADITIONAL PROCESS OVERVIEW

3.1. The steps in the traditional metal forming process are:

3.1.1. Hydroforming:

- Fabricate form block (typically CNC machining).
- Place form block and sheet metal blank in chamber (Figure 5).
- Fill bladder with hydraulic fluid to raise pressure (Figures 6 and 7).
 - As high as 15,000 psi (105 MPa).
- Raise punch (optional).
- Sheet metal formed to the shape of the form block (Figures 8 and 9).

3.1.2. Rubber pad press:

- Similar to above, except:
 - Flexible pad replaces hydraulic fluid.
 - Pad presses down over tool to form sheet metal.

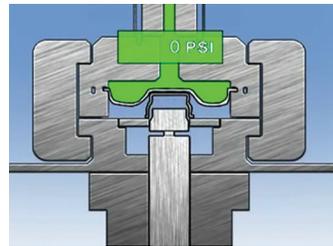


Figure 8: Release pressure.

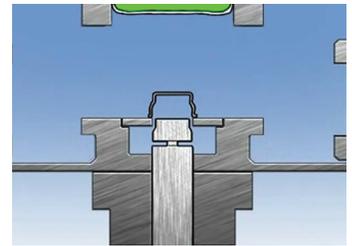


Figure 9: Remove formed part.

Figures 5 through 9 – Images courtesy of Pryer Technology Group (www.pryerotechgroup.com)

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

3.2. FDM adjustments:

To incorporate FDM tooling into the metal forming process, adjustments, alterations and substitutions are made to the following steps:

3.2.1. Form block.

- Adjust (decrease in most cases) springback compensation.

3.2.2. Forming pressures.

- Limit forming pressures to 3,000 – 10,000 psi
- (21 MPa – 69 MPa); material dependent.
- To reduce pressure if it will exceed the maximum recommended, add an intensifier. (Figure 10)

3.2.3. Forming.

- Lubrication is unnecessary.
- Cycles per part may be reduced in some cases. Inherent porosity of FDM form blocks bleed air that would otherwise be trapped.



Figure 10: intensifier (top component of tool set) reduces forming pressure. See Figure 11 for reference.

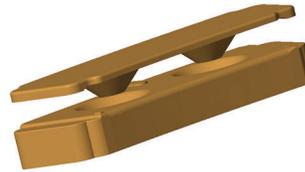


Figure 11: Hydroforming tool set comprised of form block (bottom) and intensifier.

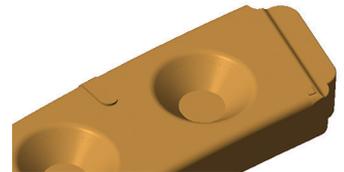


Figure 12: CAD model of form block for structural aircraft component.

4. TOOL DESIGN

To apply FDM tooling to the metal forming process, the form block and intensifier designs need only minor adjustments. If making companion tooling, such as trim templates, no alterations are needed. (Figure 11)

4.1. Form block. (Figure 12)

Use conventional tool design practices with a slight adjustment to the springback compensation. Under the forming pressures, an FDM tool may have a small amount of deflection that decreases or eliminates the amount of springback in the sheet metal component. (Figures 13 and 14)

4.1.1. Springback compensation.

The amount of tool deflection will vary by FDM material, FDM build parameters, forming pressure and part design. So, springback compensation will be adjusted on a part-by-part basis.

To avoid overcompensation, it may be best to start with a tool design that has no compensation. As with conventional tools, if a sample run shows that adjustment is needed, the FDM form block may be machined. Alternatively, the springback correction may be added to the CAD design before rebuilding the tool.

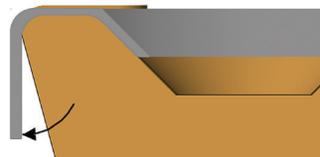


Figure 13: Conventional (metal) form blocks compensated for sheet metal springback (arrow) by insetting/angling the forming surface.

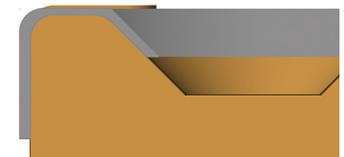


Figure 14: FDM form block needs little (or no) springback compensation.

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

4.2. Intensifier. (Figure 15)

FDM intensifiers must be designed for use with a specific sheet metal thickness. If gaps exist between the intensifier, sheet metal blank and form block, the forming pressures may cause the intensifier to crack (Figure 16).

4.2.1. Specifications.

Design the intensifier with a minimum material thickness of 0.38 in. (9.7 mm). Next, offset the intensifier from the form block by the thickness of the sheet metal blank. Then extend any surfaces that are not in contact with the blank such that they are flush with the form blocks surface.

4.3. Export STL file.

After the tool design, export all CAD model as an STL file. Ensure that settings, such as chord height, chord deviation and angle control, will produce a fine mesh (small facets). This will minimize post processing efforts and preserve accuracy.

5. FILE PREPARATION

Import the STL files into Insight (Figure 17) and follow the standard workflow for job processing.

The key alteration when constructing an FDM form block is to make it a dense part with multiple surface contours (the toolpaths around the perimeter of a curve). The density is achieved with negative air gaps between adjacent contours and between adjoining rasters and contours.

Intensifiers, templates and guides may be constructed with default parameters for a solid fill style.

5.1. *Modeler > Setup.*

If using ULTEM 9085, confirm that **System mode** is set to **Normal**. This parameter is available from the **Modeler > Setup** window after selection of ULTEM 9085 as the model material. For some systems, the default is **Thin wall**, a style that may cause the form block to lift from the build sheet.

5.2. Orient STL.

When orienting the form block, consider total process time (build time and finishing labor), feature strength under a compressive load, and surface smoothness. Typically, this leads to an orientation that is the same as that for the tool when it is placed in the forming press (or inverted). (Figure 18)

5.3. Create custom group.

To give the form block a dense fill with thick contours, create a custom group and apply it to all layers.

5.3.1. Create “Metal forming CG.” (Figure 19)

Select **Toolpaths > Custom groups > New** and name the group “Metal forming CG.” Select the checkmark to save.

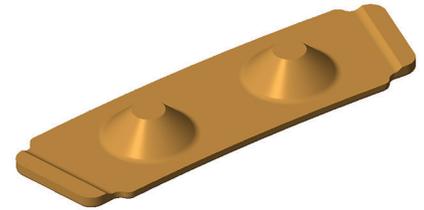


Figure 15: CAD model of intensifier for structural aircraft component.

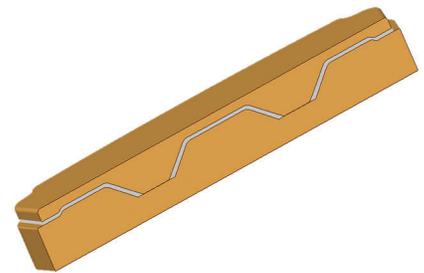


Figure 16: Intensifier (top) must be flush with the sheet metal part (gray) and the form block.

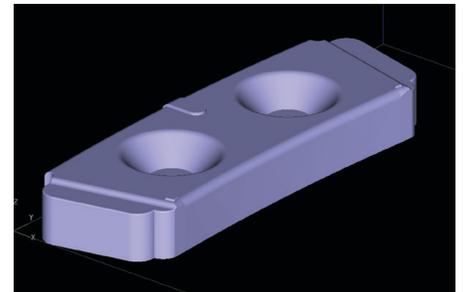


Figure 17: In Insight, open the STL file for the form block.

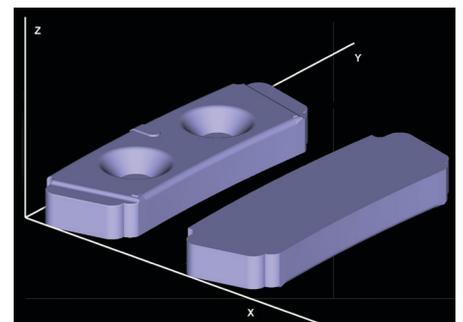


Figure 18: Typical orientations place the form block in the same position as it will be in the press (left) or inverted (right).

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

5.3.2. Adjust toolpath parameters.

Select **Modify** and change the following:

- **Contour style** = Contours to depth.
- Depth of contours = 3.

This adjustment creates a thick perimeter around each feature (Figures 20 and 21). Next, adjust the air gaps to increase the internal density and strength of the form block. While still in the **Modify** screen, adjust the air gaps for:

- **Contour and contour** = -0.001 in. (-0.03 mm).
- **Contours and rasters** = -0.001 in. (-0.03 mm).
Caution: if overfilling occurs around the edges, adjust **Contours and rasters** air gap to -0.0005 in. (0.013 mm). This condition is most likely to occur if default raster widths are set to larger values.

5.3.3. Apply “Metal forming CG.”

Select all curves on all layers and click **Add**.

5.3.4. Toolpath adjustments (optional).

To refine the tool, alter or build from “Metal forming CG.” Alterations may produce either faster builds or smoother surfaces.

5.3.4.1. Adjust custom group for speed.

Open “Metal forming CG” custom group and select **Modify**. Increase the value for **Raster width**. The value may be adjusted to user discretion, but when using at T16 tip, it may be safely increased to 0.024 in. to 0.028 in. (0.61 mm – 0.71 mm). (Figure 22)

Click OK to accept the changes. Then (re) generate toolpaths to apply the changes to the job.

5.3.4.2. Add a custom group for surface finish.

This custom group is for visible, upfacing surfaces—downfacing if the tool is inverted—that contact the sheet metal blank. It uses a smaller raster to improve the smoothness of forming surfaces.

Go to **Toolpaths > Custom groups > New** and select the template icon. From the **Template** group dropdown menu, select “Metal forming CG.” Click the checkmark to accept and then change **Group name** to “Forming surfaces.” Next, adjust the following settings:

- **Raster width** = 0.017 in. (0.43 mm).
- **Adjacent raster air gap** = -0.001 in. (-0.03 mm).
- **Display color** = Cyan.

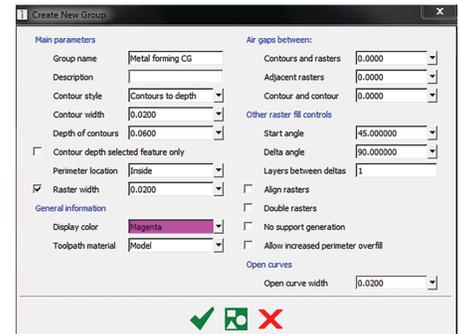


Figure 19: After slicing the form block, create a new custom group.

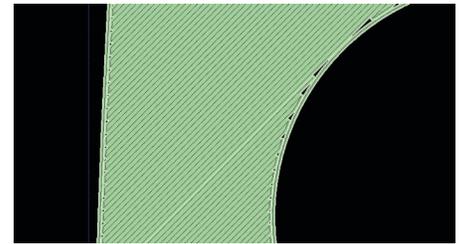


Figure 20: Default toolpaths produce a single contour around the perimeter.

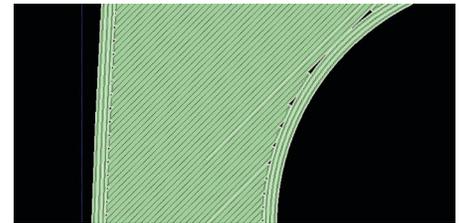


Figure 21: The custom group increase the perimeter contours to three.

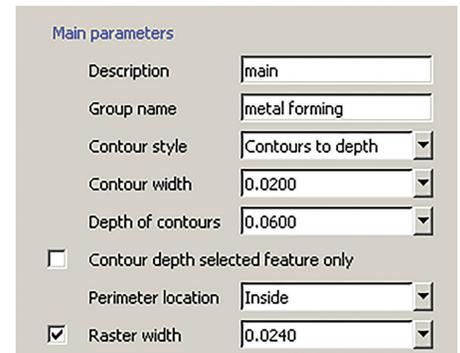


Figure 22: To reduce build time, increase the Raster width.

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

Select the checkmark to save the settings.

To apply this new custom group, view all slices with upfacing, visible curves. Select these curves and click **Add** to apply the new group. (Figures 23 and 24)

6. MATERIAL SUGGESTIONS

Three FDM materials have been evaluated for form block fabrication. The key selection criterion is forming pressure.

6.1. Options.

- ABS-M30: < 3,000 psi (21 MPa).
- Polycarbonate (PC): < 6,000 psi (41 MPa).
- ULTEM 9085: < 10,000 psi (69 MPa).

For low-pressure applications, ABS-M30 is an option. Although tool life will be shorter for ABS-M30 form blocks, 100+ cycles is a reasonable expectation and 400+ is possible with sheet materials like 2024-0 aluminum.

ULTEM 9085, on the other hand, should be reserved for high-pressure forming. (Figure 25)

Polycarbonate (PC) is the ideal material for all other applications. Its mechanical properties produce durable form blocks that can withstand mid-range pressures. (Figure 26)

6.2. Tool life.

Form blocks made from these FDM materials will stabilize within ten cycles. In the first few cycles, the forming pressure may cause a slight amount of compression of the tool. In most cases, the most noticeable effect is minor rounding of sharp corners.

The upper threshold of tool life has not been determined for any of these FDM materials. There have been no programs or research projects in which an FDM tool has been run until failure, when the proceeding design and operation guidelines have been followed. However, due to the low quantities required in these programs, there is no data or information on any tool that has had more than 400 cycles.

7. POST PROCESSING

After the FDM building process is complete, remove support material from the form block. No other post processing is necessary.

7.1. Venting.

Venting that may be needed in some form blocks is unnecessary in any tool made with FDM. The FDM form block has a natural porosity that allows air that would otherwise be trapped to pass through the tool.

7.2. Surface finishing (optional).

If forming thin sheets (< 0.040 in./1.0 mm) of soft metals, such as

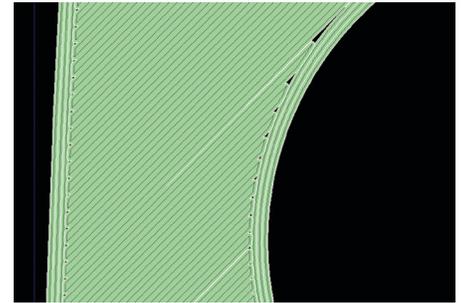


Figure 23: Narrow rasters will improve the surface finish when applied to the forming surfaces of the tool

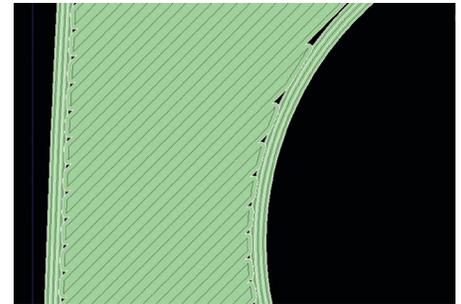


Figure 24: Default raster width (shown) may yield a texture on parts formed from thin, soft sheet metals.

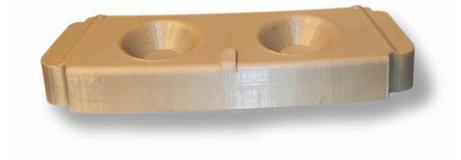


Figure 25: ULTEM 9085 form block.



Figure 26: PC (polycarbonate) form block.

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

aluminum, the raster pattern of the FDM form block may transfer to the sheet metal part. A noticeable pattern is most likely if the tool uses large **Slice heights** and wide rasters.

If this occurs and if a texture is undesirable, smooth all forming surfaces.

7.2.1. Option 1 – sanding.

Using 120- to 320-grit sandpaper, smooth all surfaces that contact the metal blank. Since the outermost point of a surface is created at the nominal dimension, material removal can affect accuracy. To counter this, either minimize the amount of material removal or offset the CAD surfaces prior to exporting the STL file. Alternatively, the form block may be filled and sanded.

7.2.2. Option 2 – filling and sanding. (Figure 27)

Begin by filling all depressions and valleys with a body filler (following manufacturer's instructions). There are a number of suitable fillers. Two materials that work well and are relatively common in a metal forming shop are:

- PTM&W PT1158: (two-part epoxy surface coat)
- PTM&W Polyfill RT: (two-part polyester)

After the filler has dried, sand all surfaces with 120- to 320- grit sandpaper. When an alternative stripe pattern appears—alternating between the color of the filler and the color of the FDM material—shift to a finer grit paper for light material removal with smoother surfaces.



Figure 27: When using fillers, sand the surface until a striping pattern appears.



Figure 28: FDM form block made from ULTEM 9085.



Figure 29: Sheet metal blank on form block.



Figure 30: Blank and form block are placed in hydroforming press.



Figure 31: Formed sheet metal part.



Figure 32: Formed sheet metal part and form block.

Figures 28 through 32 – Images courtesy of Pryer Technology Group (www.pryertechgroup.com)

8. METAL FORMING

No alternation or adjustments are required for forming press operations. FDM form blocks and intensifiers need no special handling instructions. The only caution is to confirm that the forming pressures are compatible with the FDM material used to create the tool. (Figures 28 - 32)

8.1. Lubrication.

The thermoplastic FDM materials offer natural lubricity, so the form block does not need any lubrication between cycles.

If lubrication is ever warranted, use a mild, water-based detergent. DO NOT lubricate an FDM tool with a petroleum-based product.

FDM TOOLING FOR SHEET METAL FORMING: HYDROFORMING AND RUBBER PAD PRESS

8.2. Cleaning

Should tool cleaning be needed, simply wash the form block with a mild, water-based detergent, such as Dawn or Simple Green. DO NOT clean it with petroleum- or alcohol-based degreasers or solvents.

9. TOOLS & SUPPLIES

9.1. Items required:

None. Beyond the items used in a routine metal forming operation, nothing is required.

9.2. Optional items:

- Fillers:
 - PTM&W Polyfill RT.
 - PTM&W PT1158.
- Sandpaper.
- Water-based detergents.

9.3. Sources

- PTM&W (www.ptm-w.com) or its distributors.
- Hardware retailers.

10. RECAP - CRITICAL SUCCESS FACTORS

10.1. FDM tools:

- Match FDM material to forming pressures.
 - Do not exceed those recommended for each material.
 - Use intensifiers for higher pressures.
- Increase contour thickness and decrease air gaps.



Finished product hydroformed from an FDM tool.

CONTACT

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