Design Guide

Design Considerations: FDM Additive Manufacturing Tooling

stratasys

2.0 Tool Design and Construction Considerations - Cont. . . .

1.0

Introduction and Background

1.1. Application Overview

FDM® (Fused Deposition Modeling) additive manufacturing has quickly become the technology of choice for the rapid production of manufacturing tooling. This design guide is focused on design considerations for production tooling, but the vast majority of the principles and guidelines are applicable to other additively manufactured parts as well.

FDM production tools have many similar design and use considerations as traditional tooling, although the technology provides greater design capability and freedom.

This guide describes considerations for the adoption of additively manufactured tooling using Stratasys FDM technology and should be followed whenever possible. Due to various best practices, deviations to this guide may be implemented at the discretion of the individual user's expertise.

1.2. Process Overview

A generic FDM workflow is shown in Figure 1-2. For tooling with specific requirements, the process order may differ. It is advised that the designer coordinates and validates the overall additive manufacturing process with the mechanical engineer and/or materials and process engineer.

1.3. Objectives

The objective of this guide is to provide design and build considerations for production tooling used in manufacturing. The intent is to aid in bridging the knowledge gap between Design for Additive Manufacturing (DFAM) techniques and conventional tooling manufacturing best practices. This design guide aims primarily to provide:

- Additive design considerations for tool designers
- FDM design and process considerations for tooling

Figure 1-1: The technical considerations for using additive manufacturing in tooling.

1. **3D Model in CAD**
2. **Optimize in Computer Aided Engineering Software**
   As required
3. **Release per Approval Policy**
   CAD, drawing, Insight build file (.cmb), materials and process documentation, etc.
4. **3D Print**
   Prepare machine, load material, load job to selected printer, print, remove parts
5. **Support Removal**
   Remove support material from part using a variety of suited tools.
6. **Sanding & Finishing**
   As required. Smooth part surfaces per applicable documentation and prepare for secondary sealing or painting
7. **Painting/Sealing**
   As required. Paint or seal per applicable industry/corporate documentation
8. **Final Inspection & Marking**
   Final inspection (visual, dimensional, conformity checks), tool marking

Figure 1-2: FDM Production Tooling Workflow.

1.4. Approach

This guide is broken into key sections that provide the necessary information to efficiently and successfully produce, prepare and use FDM tooling. It offers design and material considerations to demonstrate the performance of FDM tooling. Stratasys has worked with industry leaders and tooling experts from several manufacturing industries to characterize and validate performance and financial considerations as well as overall equipment effectiveness. Key use cases and examples from these collaborative development efforts are provided, although partner identity is often concealed to protect proprietary information.

One key partner was Volvo Trucks, who is a recognized leader in the automotive industry that specializes in the design and construction of commercial trucks. Volvo Trucks partnered with Stratasys to implement FDM for lifting devices and ancillary tooling (e.g. jigs, fixtures and trim tools).

1.5. Axis Terminology

For the following design principles, the figures may contain axis information. It has been set (according to ASTM/ISO 52921) that the Z-Axis always refers to the printing direction of the machine. The X- and Y-Axes are simply named x and y.

1.6. Fused Deposition Modeling Manufacturing Process Overview

FDM is a Stratasys-patented additive manufacturing technology that builds parts layer by layer by heating and extruding thermoplastic filament. FDM uses a variety of standard thermoplastic resins.

The FDM process begins by processing the CAD file using Insight™ or GrabCAD Print™ software, which comes with the system. This software allows the user to select build parameters like slice height, infill pattern and part orientation, providing the capability for part customization. FDM machines are capable of dispensing two materials during the printing process: the primary model material that makes up the final geometry and a secondary support material used as required to support material overhangs during future deposition layers. The support material is removed after the build. FDM filament is wound onto canisters that feed material through the system to an extrusion nozzle, or "build tip."

The build tip is heated by a liquefier, heating the material while depositing it in both primary horizontal axes (x, y) in a temperature-controlled chamber, following a numerically controlled toolpath. Upon completion of each layer, the build platen moves vertically (z direction), to make room for the next layer to be deposited above.

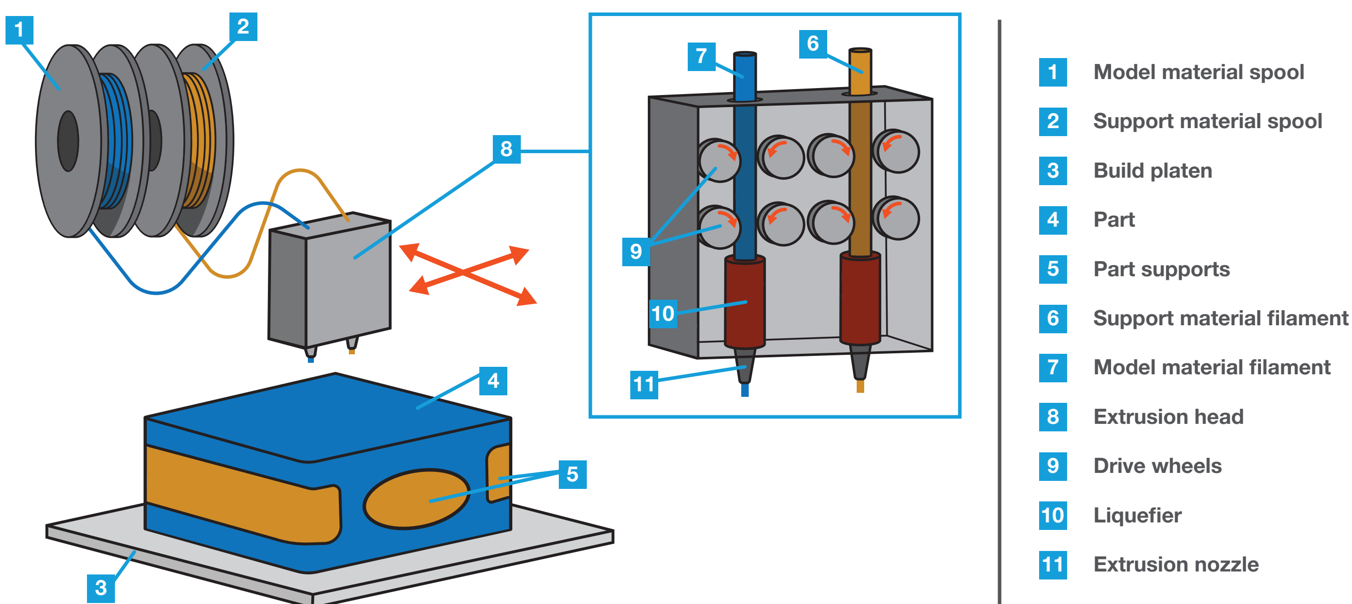


Figure 1-3: Main Components of an FDM Printer.

1.7. Accuracy and Tolerances

Stratasys machine accuracies are stated as ±0.005 inch or ±0.0015 inch/inch, whichever is greater. Actual part accuracies will vary based on geometry, primarily due to the thermal nature of the FDM process.

Additional information on machine accuracy can be found on the FDM printer pages at Stratasys.com. For production tooling that requires greater accuracy than can be achieved directly from the FDM 3D Printer, production of near-net shape tools, combined with machining is a viable option.

Post-processing machine work is one option that has proven extremely effective in mitigating the issues with inherent tolerance issues in current FDM solutions. Machining of critical surfaces or high tolerance holes is a perfectly viable option as tooling produced on FDM systems can be machined similar to their plastic counterparts.

1.8. Related Specifications

- ASTM F2971: Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing.
- ISO/ASTM 52900: Standard Terminology for Additive Manufacturing – General Principles – Terminology.
- ISO/ASTM 5292: Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies.
- ASTM Y14.5: Dimensioning and Tolerancing.

2.0

Tool Design and Construction Considerations

The unique form, fit, and function are key requirements when designing for FDM tooling. Additive manufacturing enables unique design freedoms that help fulfill these key requirements with fewer design restrictions commonly encountered with traditional manufacturing. These design functions include considerations for mechanical properties, materials, time, visual aesthetics and others.

2.1. Engineering Design Requirements

Determining the critical elements of the design is important to the overall effectiveness of the tool. Critical elements such as working environment, measuring surfaces, tolerances, hard-mounting points, datums, static and dynamic loading, handling, tool life expectancy and even storage will affect the way that FDM tools are designed. Having a defined criteria for what is expected of the tool will help in making the most economical and effective tool for its use. FDM will sometimes be a great option for a production line tool and other times it might just be the quickest path to having something that will work while a more robust solution is developed or fabricated.

2.2. Material Considerations

Deciding on tool material should be the first step in the FDM tooling design process. This decision can be simplified by considering the design requirements that were previously set for the tool. The most common materials used for tooling applications are shown in Table 1.

Material Property Considerations			
Material	**Loading**	**Temperature Resistance**	**Chemical Resistance**
ASA	Light	Low	Low-Moderate
PC	Moderate	Moderate	Low
FDM Nylon 12™	Light	Moderate	Moderate
FDM Nylon 12 Carbon Fiber (CF)	Heavy	Moderate	Moderate
ULTEM 9085 resin	Heavy	High	High
ULTEM 1010 resin	Heavy	High	High

Table 1

Other materials are offered but this group of materials is the most suitable for a great majority of tooling applications and uses. However, it can be useful to explore the other options in the case of an abnormal set of requirements. A complete list of Stratasys FDM materials and their material properties can be found at **Stratasys.com/fdm-technology.**

Tool life will depend heavily on how and where they are used as well as any other environmental factors.

2.2.1. In-Service Temperature Considerations

The in-service temperature of plastics is generally the major determining factor that decides their usage. The materials suggested in this design guide cover the entire temperature range of the FDM material suite. Operating conditions for FDM tooling should not exceed a temperature 50 °F (28 °C) below the material's heat deflection temperature (HDT) and 25 °F (14 °C) below the glass transition temperature (Tg). FDM materials will survive for only very short periods above these limits. However, the FDM process does build in some residual stresses which may cause the tool to warp once the temperature approaches and exceeds the HDT or Tg of the material. The values for HDT and Tg can be found on the respective material pages at **Stratasys.com/materials**.

2.2.2. Chemical Compatibility Considerations

The chemical composition of polymers will determine their reaction to different chemical agents. An overview of the chemical compatibility for all FDM materials can be found **here**.

Also, the plastics that Stratasys uses will behave exactly as their counterparts in other manufacturing methods. There are many chemical compatibility charts available from these manufacturers. A brief synopsis for the recommended materials can be found below.

ASA is degraded by concentrated acids, aromatic and chlorinated hydrocarbons, esters, ethers and ketones. Acetone and MEK are going to be the most common cleaning materials that fall under those categories. Nylon is susceptible to strong acids, phenols, alcohols, and halogenated hydrocarbons. One typical example is isopropyl alcohol.

Both ULTEM materials are extremely resistant to most chemicals with the exception of phenols. The most notable example of a phenolic solvent is chloroform, so it would have to be a highly abnormal situation for ULTEM to be chemically ruled out. The only exception is ULTEM 9085 resin, as it is a co-polymer so its chemical resistance is slightly lower than ULTEM 1010 resin for certain categories.

Another compatibility issue to evaluate with plastics is their resistance to ultra-violet (UV) radiation. Fortunately, ASA and ULTEM are both naturally more resistant than most plastics. FDM Nylon 12 and FDM Nylon 12CF™, however, are not UV-stable and are susceptible to this type of degradation if left outdoors permanently. If used indoors or in environments with minimal UV exposure, they will hold up and perform as expected for extended periods of time.

Lastly, many plastics are susceptible to water absorption. Moisture weakens the polymeric structure and degrades mechanical properties in certain polymers. Of the recommended materials, FDM Nylon12, FDM Nylon 12CF and PC are the most water-sensitive materials and may see some slight property loss in wet environments. The other three recommended materials (ASA, ULTEM 1010 resin and ULTEM 9085 resin) naturally saturate from moisture in the air but their absorption limit has very little to no effect on their performance.

2.2.3. Material Creep Behavior Considerations

An important factor to consider when choosing a material is creep, a property that nearly all thermoplastics have. Creep causes plastics to slowly deform when they are under long-term loading; however most tooling is not loaded long enough for this to happen. A major example of where this can occur is during storage. If the tool is stored in a situation where it sees load for an extended period of time, its high-tolerance dimensions can be affected.

2.3. Design for FDM Manufacturing Considerations

2.3.1. Anisotropic Property Considerations

Anisotropic part strength occurs when parts have physical properties that vary in different orientations. It is an issue with additively manufactured parts due to the layer-by-layer material deposition to create the part. The bond strength between layers is the determining factor for z-strength which is always the weakest. The highest values for tensile strength will be in the path of the tool head (x-y plane).

Build orientation, part geometry and pre-processing techniques can all be used to account for and mitigate these process-specific strength characteristics.

Avoid designing sharp deflection points and disturbances by using chamfer and radii features. The larger the radius or chamfer it is possible to add to a tool, the better it will perform.

Stratasys provides different strength values per material for each build orientation. This specification data is
available for all FDM materials and should be used for material comparison and selection. This data can be found at **Stratasys.com/materials/search**.

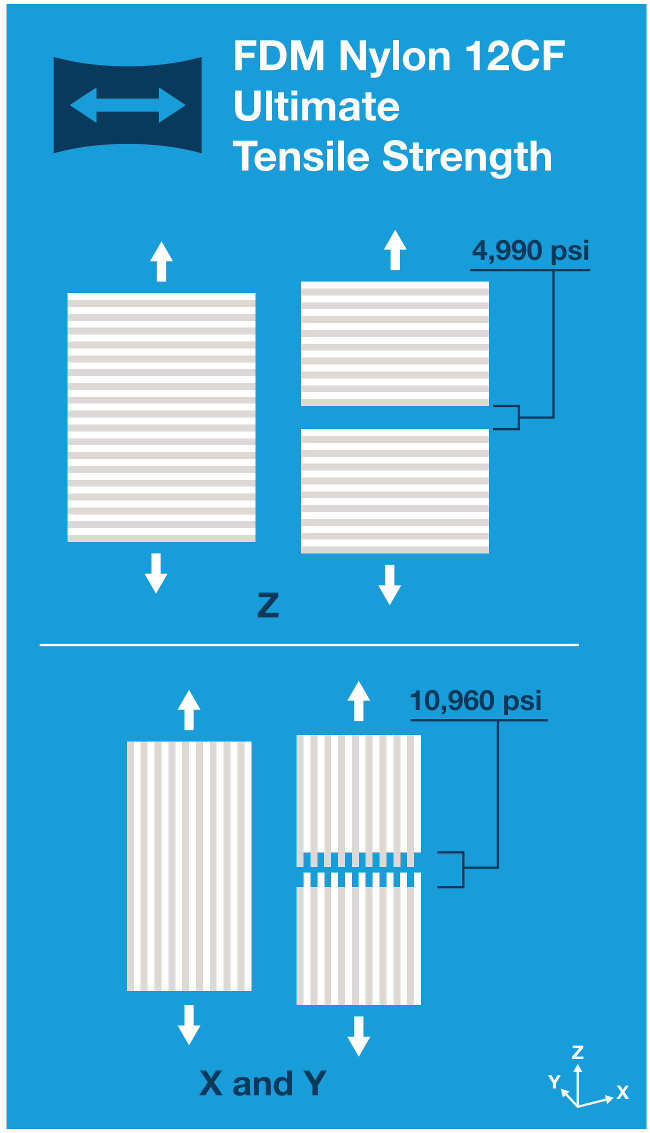


Figure 2-1: Anisotropy results in lower strength values in the z-plane.

2.3.2. Static vs. Dynamic Loading Considerations

When taking into account applied tension, compression, bending, shear and torsional loading conditions for FDM tooling, a direct load path is desired. Designing the shortest load path possible within the constraints of the application is also ideal. FDM is uniquely suited to odd configurations of structures and complex geometries so designers should take advantage of this ability when considering ways to mitigate loading issues. Topology optimization calculates and shows the distribution of material within a user defined boundary based on the design requirements. It can be applied to parts to take full advantage of the geometric freedom FDM provides.

As mentioned earlier, creep can be a major factor when dealing with plastics. Dynamic loading can have similar issues if the load nears the yield point of the plastic. Abrasion from repeat motion can also be an issue. One way to deal with this is to design in hard mounting and wear points through the use of metallic or ceramic inserts. The location can be manufactured to net size if a low tolerance is available or a location feature can be added for post-processing to machine in areas for inserts. Inserts can also be useful to add stiffening members of other materials to resist the dynamic load or overload from high static forces.

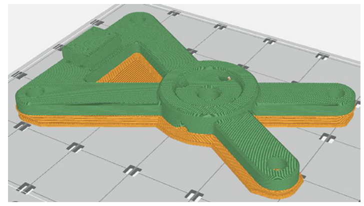


Figure 2-2: Orientation 1.

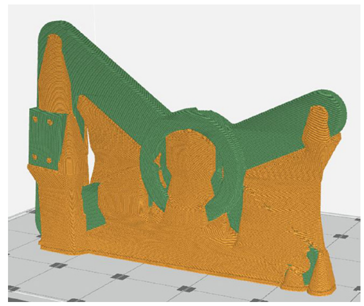


Figure 2-3 Orientation 2.

Figure 2-4 Orientation 3.

2.3.3. Time to Fabricate

Similar to conventional manufacturing processes, additive manufacturing has aspects that must be considered when planning production. Build orientation during the printing process is a key factor for the amount of time it takes to print a tool. The addition of material in the Z direction takes longer than addition of material in the X-Y plane. The extrusion head of most FDM platforms is significantly faster when laying down material in-plane as opposed to repeated deposition followed by Z-direction adjustment. When determining build orientation of a part, the amount of time allowed for production can be a major part of the design requirements although it is generally a by-product. To reduce the amount of time necessary, it is suggested to orient the tool so most of the material is in the X-Y direction. This is also beneficial for overall part strength. Table 2 shows how build orientation affects print time as well as model and support material consumption. Figures 2-2 through 2-4 show the corresponding physical orientation on the build tray.

Another consideration is support material. Each time an FDM system switches from model material to support material it goes through a series of steps. Although these steps only take roughly 30 seconds, they can add up if the process has to be repeated many times. Depending on the size of the tool this can become a major factor in the time for build completion.

Build Orientation Examples

Orientation	Print Time	Model Material (in^3)	Support Material (in^3)
1 (Figure 2-2)	6h 23m	11.7	3.0
2 (Figure 2-3)	12h 16m	12.4	4.2
3 (Figure 2-4)	12h 14m	12.7	4.2

Table 2

One design technique that can be used to mitigate the use of support material is the use of self-supporting angles (>45° from the build platen) for interior and exterior features. Horizontal holes (relative to the X-Y build plane) as in Figure 2-5 will have poor resolution due to stair-stepping. A slightly undersized diamond shape pilot hole will print without support material and can be used in place of circular holes and then reamed to size as a secondary operation. Notice the feature on the far right in Figures 2-6 and 2-7 used self-supporting angles in both horizontal axes resulting in no support material use.

Other factors such as material, slice height and interior fill density can also be changed to optimize build time during the processing stage after the design is complete.

2.3.4. Aesthetics

An often overlooked characteristic of the design phase is the necessary aesthetics of the final product. The FDM process naturally generates a layered look with a surface roughness of 500-600 µin Ra in the X-Y plane and mostly flat surfaces in the Z direction. Any surfaces that have an angle in the Z direction are subject to “stair-stepping” (shown in figure 2-8), which can drive the Ra up into the 1,200-1,500 range based on layer thickness and geometry of the surface. If the desired surface needs secondary finishing, trials and methods have been developed in order to sand, seal and paint FDM parts with a final surface finish of <10 µin Ra. For more information regarding finishing processes, see the Stratasys website **Finshing Processes**.

Surfaces that have high aesthetic requirements should be oriented in the vertical direction if possible. Faces that are flat can also be oriented perpendicular to the XY build plane to eliminate stair-stepping. Figure 2-9 shows sloped surfaces starting at 5 degrees from horizontal all the way to vertical (45°) and how the surface finish is affected by the build angle.

Slice height is an important factor when considering surface finish. Using a smaller slice height produces a higher resolution part with a better surface finish. Larger slice heights produce more visible layer lines. The steeper the angle becomes, the less this can be seen. Figure 2-10 shows the difference between larger and smaller slice heights.

Toolpath seams also have an impact on aesthetics. A seam is defined as the start and stop location of a contour tool path. Seams can create a blemish

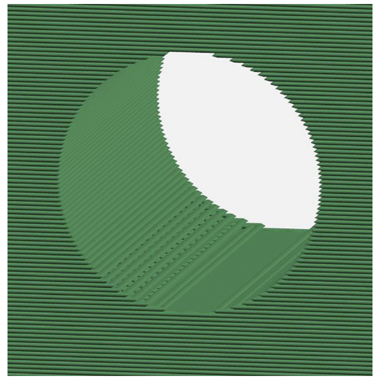


Figure 2-5: Poor resolution of horizontally printed hole

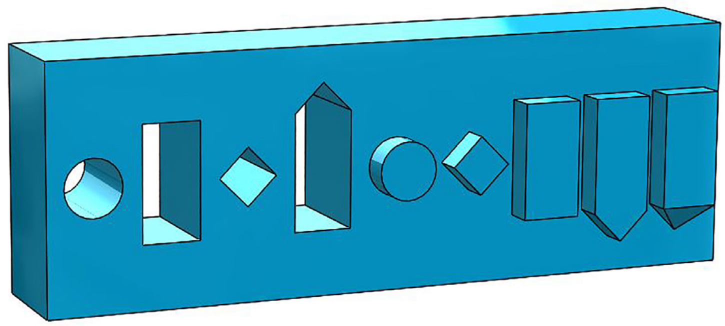


Figure 2-6: Example with internal and external features in CAD

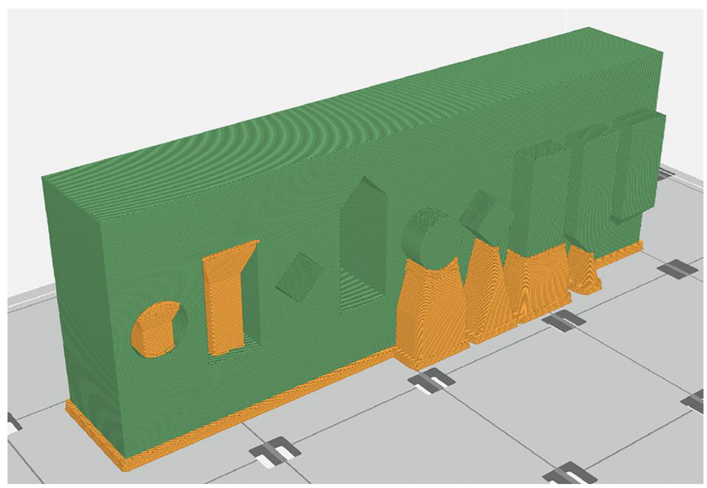


Figure 2-7: Example with internal and external features showing support material (shown in orange)

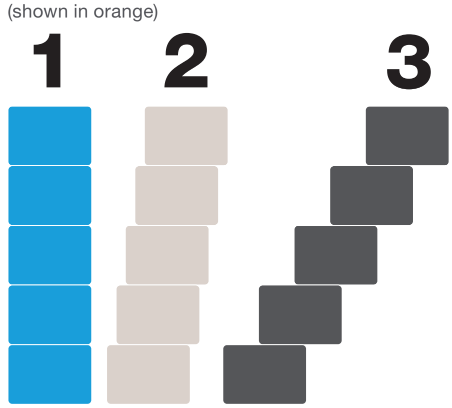


Figure 2-8: Visual representation of stair stepping — as the angle from vertical increases, surface roughness increases.

on the surface where they occur. Placement of seams is important when processing in Insight for this reason. A seam should be placed on the least important side of the part or a face where they can easily be smoothed by light sanding after the part has been built. Figures 2-11, 2-12 and 2-13 show three different examples of seam placement methods.

Knowing surface finish requirements up front should inform how the part is designed as well how it is processed. Choosing the correct slice height and build orientation are critical to achieving the desired surface finish.

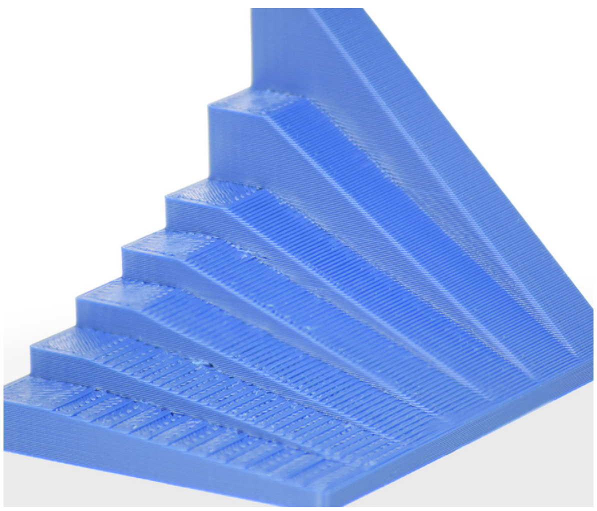


Figure 2-9: Effects of stair stepping on surface finish.

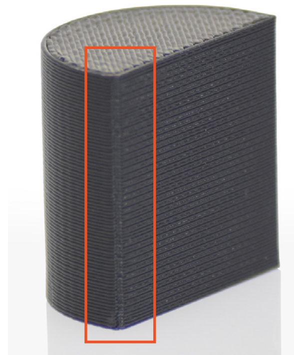


Figure 2-11: Seam placement on edge.

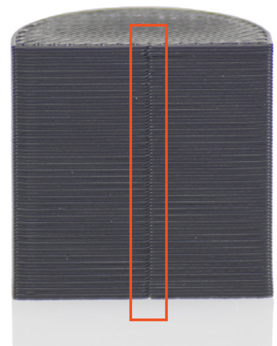
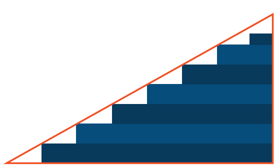


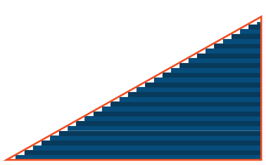
Figure 2-12: Aligned seam placement in center.

Figure 2-13: Random seam placement.



Low Resolution *Thicker Layers*

Lower resolution parts have a larger slice height resulting in thicker layers. This creates a large horizontal step between layers and produces a rougher edge.



Higher Resolution *Thinner Layers*

Higher resolution parts have a smaller slice height resulting in thinner layers. This decreases the horizontal step between layers and produces a smoother edge.

Figure 2-10: Low vs. high resolution.

2.4. Leveraging Design Freedom

FDM offers an unprecedented level of design freedom compared to traditional manufacturing processes. While many benefits for using FDM lie in cost and time reduction and mitigation of supply chain issues, the true value is in leveraging the design freedom. This freedom allows tool designers to produce parts with higher levels of performance and functionality than what is possible with other manufacturing processes. This level of functionality is up to the creativity of the designer. Unconstrained thinking has led to the creation of parts that perform complex interactions to achieve a simple goal.

2.4.1. Weight and Durability Considerations

The FDM process gives the designer freedom to make large parts without requiring large amounts of material and the weight associated with those large parts. This is accomplished through the use of variable fill patterns for the internal structure of the tool. The CAD model of the bell crank example part shown in Figure 2-14 was modeled with six different solid bodies to represent the areas that will have different infill patterns. In order to retain a press fit bearing, the red features were printed solid. To add strength, the internal ribs shown in yellow were printed with a sparse double dense infill at 30% density. The rest of the body shown in green was printed with a sparse infill at 60% density. To add rigidity, the outer shell of the tool was thickened by adding additional contours on the edge of the part. The actual printed part can be seen in Figure 2-15. Using variable fill patterns will affect the moment of inertia of the part and is something to be considered in tools that are in motion or subject to dynamic loads.

2.4.2. Tool Assembly Consolidation

In many cases, it is possible to consolidate what would otherwise be an assembly of multiple components into a single component. For example, because it does not impact the cost greatly, a lifting device lifter can be printed with its attachment brackets integrated as seen in Figure 2-16. In general, components of an assembly should be combined when it does not violate any engineering constraints such as material performance, part cost, or lead time. Additionally, the decision to combine parts must be evaluated for the ability to select a build orientation that meets requirements for each individual component.

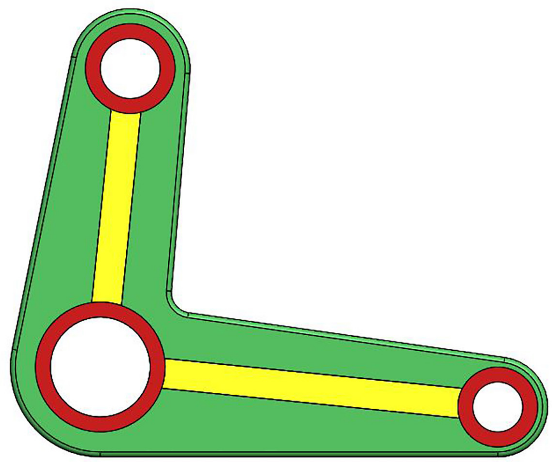


Figure 2-14: CAD model of bell crank example with multiple infill. patterns

Figure 2-15 Printed bell crank example with multiple infill patterns.

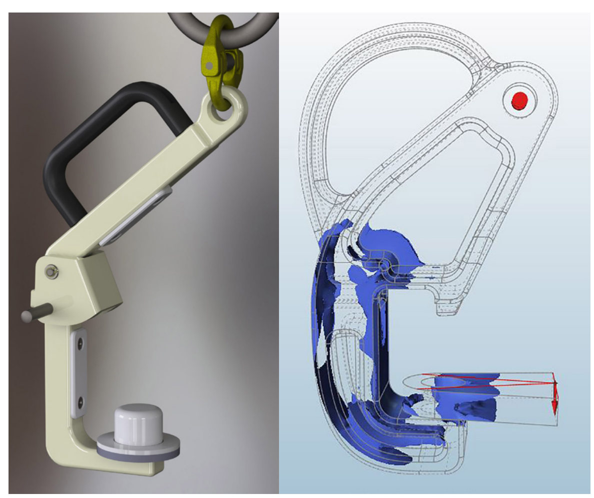


Figure 2-16: Part assembly consolidation resulted in a 96% reduction of tooling assembly components.

2.4.3. Part Bonding Considerations

Bonding of FDM tooling has many of the same issues as bonding of generic plastics, with a few caveats. The layered surface produced by the FDM process creates additional mechanical bonding for adhesives but the surface will still need to be cleaned to assure no debris is caught in the bond area.

Adhesive gaps of 0.005 inch are standard and allow for material clearance from part to part with a solid bondline control. Thermoplastic materials do not have a large functionalized surface so their chemical bonds with thermoset adhesives can be greatly increased by using an activator prior to bonding. With that in mind, most thermoset adhesives suitable for plastics and the temperature requirements of the application will operate effectively with FDM tooling. For most practical applications, Stratasys tends to use epoxy-based adhesives.

Joint design is again made easier with the design freedom of FDM. The connection surface can be as simple or as complicated as desired. An example of two parts joined together using round joint connections is shown in Figure 2-17. A detailed view showing the desired clearances is shown in Figure 2-18. Dovetail, butterfly or lap joint are all good options for joint connections as well. The same clearances apply to those joints.

Another bonding method for FDM tooling is hot air plastic welding. Hot air welding uses the same material as the FDM tool to join the sections together. The strength of the joint can be increased by using adhesives in conjunction with the welding process. Coating the interior keeps the epoxy within the tool and away from the outer surface. When designing a tool to be hot air welded it is advisable to incorporate a chamfer, as shown in Figure 2-19, allowing for deeper weld penetration and more material contact than just a surface weld. Much like metal welding, the more material added to the joint, the stronger the weld will be.

For more information regarding bonding please refer to **Comparison of Bonding Methods of FDM Materials**.

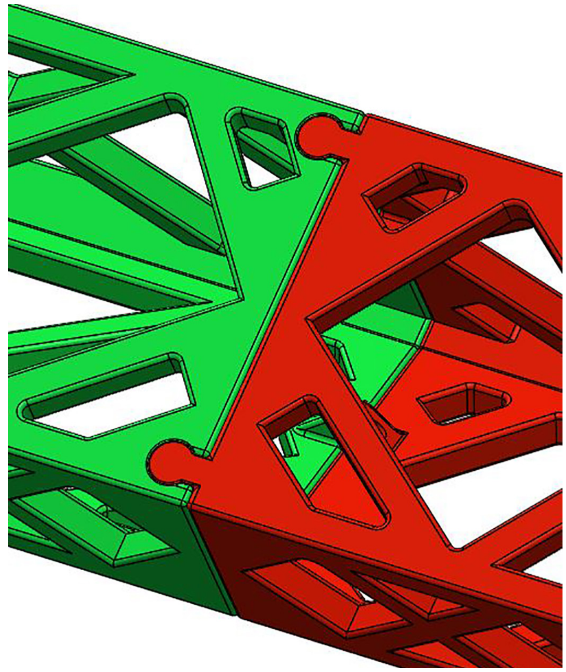


Figure 2-17: Assembly utilizing circular tab and slot joints.

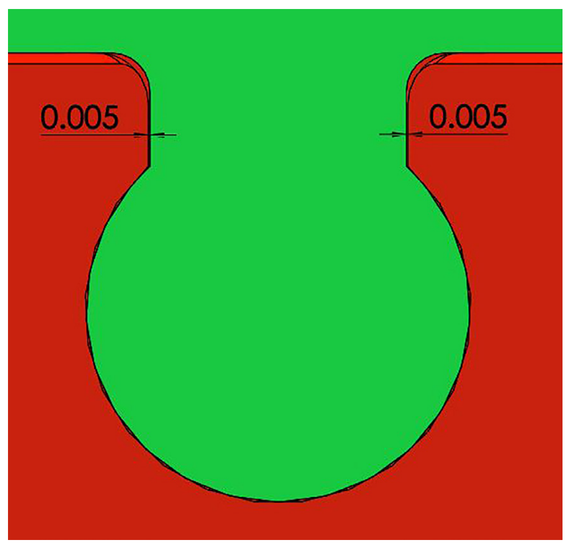


Figure 2-18: Recommended clearances between male and female features.

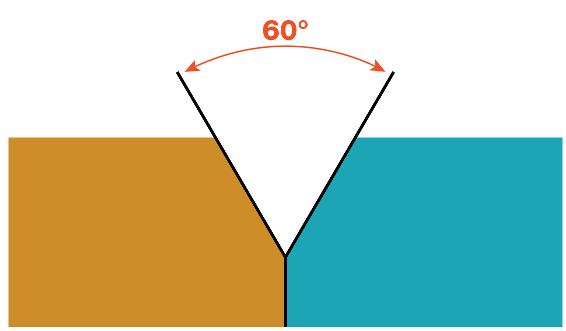


Figure 2-19: Chamfer added to parts for better penetration during hot air welding.

2.4.4. Integrating Inserts

As mentioned in section 2.3.2, hardware may be added to FDM production tooling in a secondary operation. For example, threaded inserts, bushings, magnets and other hardware can be inserted into finished parts. These inserts can be secured with a variety of processes including but not limited to: heat set, press fit, tapping/threading and bonding.

Figure 2-20: Threaded inserts for plastics.

Threaded inserts are a great solution for fastening multiple parts together as well as adding tooling components like hardened rest pads or clamps to a printed tool. There are many different types of threaded inserts available to choose from depending on how the insert is expected to perform in the tool. In addition to design requirements, labor should also be taken into account. Traditionally these inserts are used for injection molded parts or in various metal applications, however they work just as well in FDM parts. Inserts can be broken down into five general categories with each category having multiple styles.

1. Heat-Set/Ultrasonic – easy installation and high torque-out and pull-out resistance
2. Self-Tapping – higher pull-out strength than heat-set/ultrasonic
3. Press-In – quick and easy installation but poor torque-out and pull-out resistance
4. Press-In Expansion – quick and easy installation but poor torque- and pull-out resistance
5. Helical – labor-intense installation but high torque- and pull-out resistance

From an ease-of-installation and performance standpoint, Stratasys recommends heat-set/ultrasonic style inserts. Although they take longer than press-in style inserts to install and also require additional installation equipment, they offer much better performance in terms of torque-out and pull-out resistance.

There are no physical differences between heat-set and ultrasonic threaded inserts. Insert manufacturers refer to this style of insert with a dual name because it can be pressed into thermoplastics with heat or ultrasonic vibrations. Stratasys recommends heat installation as the preferred method of installation due to the simplicity and consistency of the process.

There are options for heat installation equipment depending on budget and/or the volume of inserts to be installed. An economical, low-cost and low-volume choice would be to purchase a simple heat soldering gun and the corresponding tip sizes for the inserts that will be installed. A second, more expensive option is a manual heat installation driver. These machines control heat, pressure and depth during the installation process but cost upwards of $1,000. They also provide a better means of installing the insert co-axial to the pilot hole as the plunger is normal to the build plate. Further measures can be taken to guarantee installation accuracy by creating fixturing that can attach to the build plate to locate the part. Figure 2-21 shows a manual heat installation driver during the installation process.

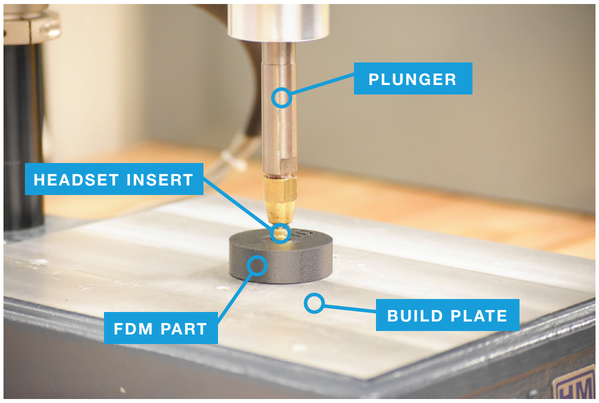


Figure 2-21: Heat insert driver machine.

Stratasys recommends following the threaded insert manufacturer's design guidelines for hole size and geometry. Keep in mind these are only recommended values so they may need to be adjusted slightly based on installation results. These manufacturers also have troubleshooting guides for installation issues and how to address them. It is recommended to follow their procedures to ensure proper installation of the inserts. Figure 2-22 shows heat set threaded inserts integrated into the tool. For details on installation, see the

[**Best Practice: Inserting Hardware into FDM Parts.**]

2.4.4.1 Considerations for Dynamic and Static Loading

Design in hard mounting points through the use of metallic or ceramic bushings. Holes can be designed and printed in the part if there are not tight tolerance requirements. If hole location accuracy is required, it is recommended to print slightly undersized holes and machine after printing. Bushings can then be pressed into the tool. Figure 2-23 shows a check fixture that uses press fit bushings and pins to verify part quality of a stamped sheet metal bracket.
For tooling that will see abrasion from loading and unloading or other motion, incorporate hardened rest pads. They can be attached to the tool with fasteners and the threaded inserts mentioned above.

2.4.5. Interaction Considerations

Similar to traditional tooling design, considering the interaction assemblers and technicians will have with the tool is an important part of the design. The design freedom detailed in Section 2.3 aided in the ability to add an ergonomic handle to the fixture shown in Figure 2-24. Tooling customized to individual assemblers can reduce operator fatigue and speed up cycle times.

2.5. Finite Element Analysis (FEA) Optimization Considerations

When designing parts to be produced by FDM technology, computer aided engineering (CAE) tools can be used to ensure the final part meets the design requirements and can also be used to minimize unnecessary features. FEA and topology optimization are two CAE tools that can be used to design additively manufactured tooling. FEA

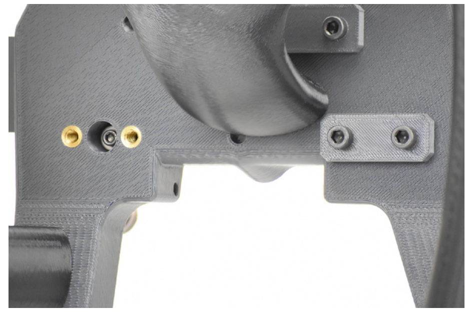


Figure 2-22 Fixture utilizing brass heat set.

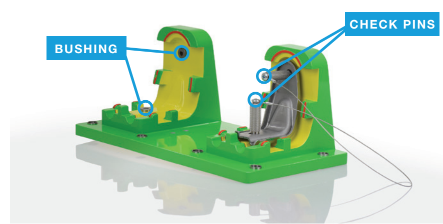


Figure 2-23: Check fixture with press fit bushings.

Figure 2-24: BMW badge locating fixture with ergonomic handle.

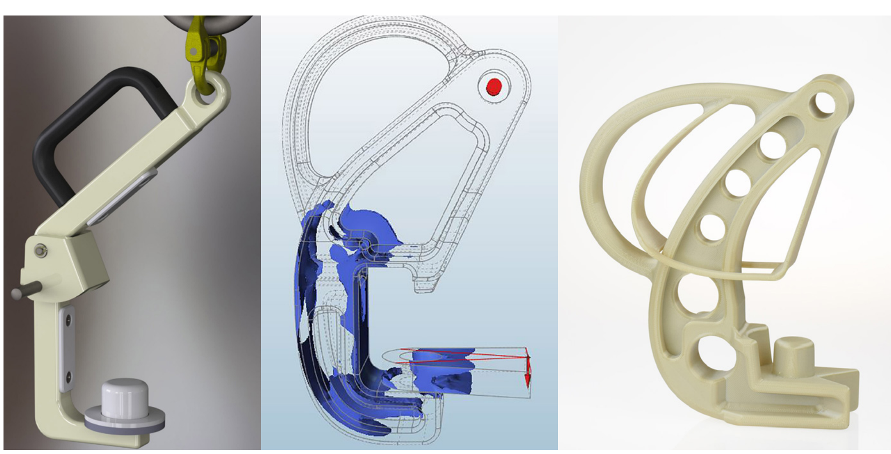


Figure 2 25: Utilizing CAE tools for FDM design optimization aids in designing for the intended form, fit and function of the tool.

tools analyze parts that have been previously designed and show the effects of the applied loads and boundary conditions. Topology optimization calculates and shows the distribution of material within a user-defined boundary based on the design requirements. The algorithm can optimize for things like aerodynamic efficiency, electrical performance or heat transfer. Structural topology optimization has the most well-defined workflow, with several simulation companies offering streamlined software that automates the workflow. Stratasys has specifically partnered with Simulia to further develop their functional generative design software for additive manufacturing. Simulia has incorporated constraints such as build orientation and infill pattern into their optimization algorithm. Typically, the results of a topology optimization will yield a geometry that is highly complex and organic in shape.

The design freedom allowed by additive manufacturing provides a path to more directly utilize the results of CAE tools. In cases such as topology optimization, the results can be directly sent to a printer after basic cleanup of the output mesh. Considerations must be made when interpreting the results of CAE tools for use in FDM tooling. The complexity of the internal structure resulting from porosity and layered construction will cause the FDM part to perform differently than the solid CAD representation. Currently, CAE tools should be mainly used to analyze and guide designs.

There are companies in the CAE tools market that are actively pursuing solutions to improve both process and simulation of additive manufacturing.

3.0 Conclusion

FDM production tools have many similar design and use considerations as traditional tooling, although the technology provides greater design capability and freedom. This guide described considerations for the adoption of additively manufactured tooling using Stratasys FDM technology, an optimal candidate for production of tooling.

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