DESIGN FOR ADDITIVE MANUFACTURABILITY:

Finishing for FDM and PolyJet

Finishing or secondary operations encompasses a broad range of processes that change a manufactured part's properties. Engineers can employ finishing simply to improve a part's appearance and reshape it to meet certain dimensions, or use it to enhance functionality, such as increasing strength, chemical resistance, electrical conductivity and more. Secondary operations basically turn raw parts into finished goods. And this isn't limited to traditional manufactured parts. 3D printed parts can also be enhanced with secondary operations, but much like designing for additive manufacturing, different processes and best practices apply.

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DIRECT MANUFACTURING

In our first three additive manufacturability guides (Material Selection for FDM and PolyJet, FDM Basics and CAD Output for FDM), we emphasized design considerations for the functionality of 3D printed parts. Throughout the product design and manufacturing process, engineers should also be thinking about how 3D printed parts can be finished.

Determining the appropriate finishing operations depends on the additive process, material and geometry as well as the desired aesthetics and functionality. The first step is getting to know what's possible with each process. For example, since Fused Deposition Modeling (FDM) builds parts with engineering-grade thermoplastics, parts are compatible with many of the same post-manufacturing processes available for injection molding, such as sanding, drilling, tapping, priming and painting. Models built using PolyJet have a smooth surface right off of the machine so they don't require smoothing, but are often coated to achieve certain properties.

This guide explains the primary finishing operations additive manufacturing service providers implement for FDM and PolyJet 3D printing technologies, grouped by possible finishing objectives, and compatible materials and applicable design considerations. We recommend first reading our Blueprint for FDM & PolyJet Material Selection to understand how to choose the best material for the job.

SMOOTH THE SURFACE

SANDING

Plastic parts made with FDM can be sanded by hand or with orbital sanders to remove the stairstepping effect that is inherent to the process. Finishing experts use a variety of grits to smooth the surface to the desired aesthetic. PolyJet forms parts in layers as fine as 16 microns (0.001") so layer lines are not a problem and sanding is unnecessary.

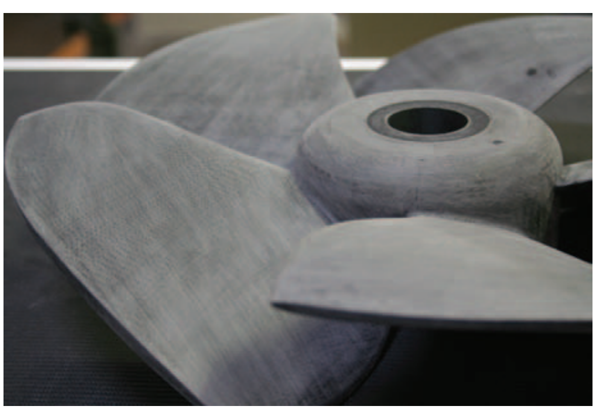
HAND SANDING AN FDM ABSI PART

Materials & Applications

Sanding is the most common form of finishing for parts produced with FDM because it's a simple way to remove layer lines without affecting mechanical properties. Finishers must also sand parts smooth before applying coatings, such as primer, paint or plating to ensure a smooth surface finish. All FDM materials can be sanded to a certain degree, but consult with an additive manufacturing project engineer to find the best grit for your application.

Design Guidelines

Depending on the amount of material that will be removed with sanding, it may be necessary to adjust the part design to include supplemental material. Also, keep in mind it's difficult to reach small undercuts, overhangs and holes so you may need to implement an alternative smoothing method.



FAN PROTOTYPE PRODUCED WITH FDM AND SANDED WITH AN ORBITAL SANDER

VAPOR SMOOTHING

Vapor smoothing addresses stair-stepping on the surface of parts built with FDM by slightly melting the outer surface with a solvent. A part is dipped into a vapor chamber for a few seconds which causes the plastic to liquefy, then the part is immediately dipped in a cooling chamber to stop liquefaction. The result is a smoother, shinier part. Bead blasting, defined in the next section, may be used after vapor smoothing to deliver a matte finish that is often preferable for secondary filming, coating and plating operations. Vapor smoothing also preserves dimensional integrity and can help eliminate the inherent porosity of FDM parts for liquid or gas-holding applications.

VAPOR SMOOTHED MANIFOLD

Materials & Applications

Vapor smoothing is a fast way to achieve a surface finish of 32 – 63 microns on standard ABS and ABS-M30 when costs or time prohibit slower, hand smoothing methods. It is often selected to prepare the surface for electroplating or investment casting or for liquid-holding geometries, such as bottles or cooling lines in molds. However the surface isn't completely flat after vapor smoothing and may require additional operations in order to be paint-ready.

Stronger FDM thermoplastics like polycarbonate (PC), PPSF, ULTEM 9085 and ULTEM 1010 cannot be vapor smoothed because of the chemical reactions with solvents.

Design Guidelines

Make sure the material is an ABS-based FDM thermoplastic as the process can alter other plastics' mechanical properties. The changes to the part are insignificant (no more than 0.0009 inch/0.023 mm) so there is no need to include extra material. However, we recommend avoiding small feature details such as text or sharp edges that may become distorted through this process.

BEAD BLASTING

Bead blasting is a faster alternative to sanding to smooth the surface of a part and often an easier way to reach small features or internal channels. Bead blasting is performed with a spray gun and plastic media that is blasted on a part's surface at a high velocity (around 100 psi). Bead blasting is typically not required for PolyJet parts because of the fine surface finish.

BEAD BLASTING A PC-ISO PART

Materials & Applications

Bead blasting is often used to remove the sheen from a vapor-smoothed surface if a matte surface finish is required. All FDM materials can be bead blasted, but we recommend consulting with an expert on the best media size and abrasive level for your specific application.

Design Guidelines

Although bead blasting removes material, it is usually very minimal and does not affect the overall dimensional accuracy.

RAW FDM VAPOR SMOOTHED BEAD BLASTED

TUMBLING

Tumbling is most commonly found in the metals industry to process and polish metal parts, but Stratasys has developed vibratory methods to apply the same technique to plastics using softer media. The parts are placed in a vibratory unit filled with either ceramic, plastic, synthetic or corn cob media, in which the machine rotates for several hours until the media burnishes the surface.

TUMBLED ULTEM 9085 AIR DUCT

Materials & Applications

Tumbling is a great option for finishing the more durable FDM materials, including polycarbonate (PC) and ULTEM materials. A major advantage of tumbling is the ability to smooth multiple parts at once—a good option for uniform mass finishing a low-volume production run. Relatively aggressive ceramic media is typically used with ULTEM 9085 parts while less aggressive ceramic media is used with PC.

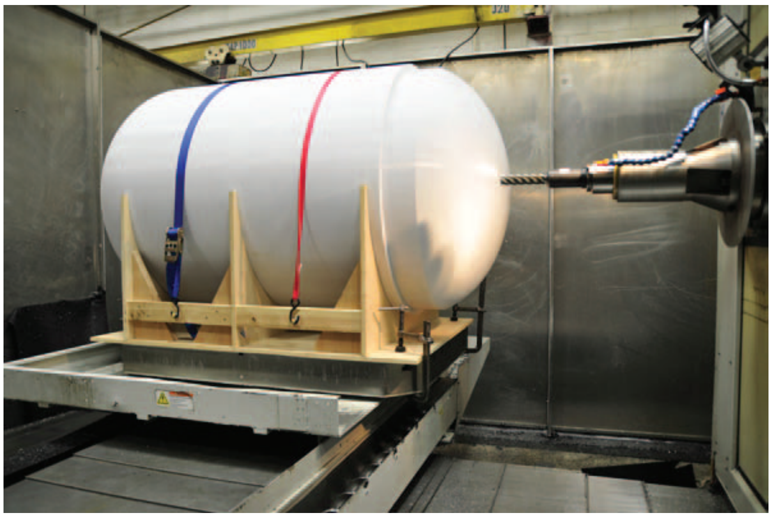
Design Guidelines

Tumbling works best on round parts, such as duct work, with minimal sharp edges and corners. Basing media choice on your design is critical. Small parts require small media, and highly detailed or featured parts require complex media shapes such as a star shape. Be aware that manufacturer descriptions of desired finish, such as "brushed" or "satin," describe results for metal parts, not plastic. Project engineers choose media based on material, geometry and desired surface finish. Also, mass finishing smooths the material from the outside surface, removing 0.0015 – 0.003 inches from the surface, so depending on the required dimensional accuracy, you may want to design your parts with thicker outer walls.

MEET DIMENSIONAL TOLERANCE

MACHINING

CNC machining is typically used to mill a part out of a block of material. But with complex, additive manufactured parts, machining can function as a secondary operation to achieve very specific dimensional tolerances that cannot be met with 3D printing alone. It's also often used to add threads for inserts.



LOCKHEED MARTIN FUEL TANK SIMULATION BUILT IN TEN SECTIONS, HOT AIR WELDED TOGETHER AND MACHINED TO THE DESIGN'S CRITICAL DIMENSIONS

Materials & Applications

All FDM materials can be easily machined using operations such as drilling, tapping, sawing, turning and milling. Most PolyJet materials are also able to be machined, except for certain grades of Tango (rubber-like family of materials) and digital materials with low durometers that tend to tear during machining.

Design Guidelines

Machining does not change the mechanical properties of a 3D printed part, but when designing the part, adjust the part geometry to include extra material that will be removed during the machining process.

ASSEMBLE COMPONENTS

INSERTS

A wide range of metal inserts like nuts, bolts and washers canbe implanted during or after building a part with FDM. A common approach is to use a machining process to size a hole and then heat the insert and press it into the part—this is called heat staking. The heated plastic flows into the insert knurls and ridges and as the plastic cools, it solidifies to resist torque and pull-out. Press-fit expansion inserts or helicoils are a better fit for PolyJet photopolymers because they do not involve heating the plastic.

Since FDM builds parts one layer at a time, hardware can also be inserted during the build. The machine is stopped at a certain layer, the insert is embedded and then the build resumes from that point.

HEAT STAKED INSERT

MID-BUILD INSERT

Materials & Applications

Inserts are commonly added to functional prototypes or end-use parts to fasten or attach to other components in a larger assembly. High performance FDM thermoplastics, such as PPSF and ULTEM resist the melting point with heat-set inserts, but embedding smaller mid-build inserts is possible. Discussing how and where the part will be used with a project engineer will help you determine the appropriate material for the insert.

Design Guidelines

You can either include a built-in cavity in the design file to account for an insert or ream a hole, which can be more accurate, but also more time consuming.

If you are adding hardware during the FDM build process, there is an additional guideline. The FDM machine can only be paused on the Z axis so the part should be oriented in the X/Y plane in order to place the insert in the cavity.

HOT AIR WELDING

Hot air welding allows you to create parts larger than the machine build platform. A CAD design is split into separate parts with dovetail joints which are built on separate 3D printers and then welded together after printing. A hot air welding tool is slowly drawn along the joint to melt the filament, which then fills the seam. An advantage of hot air welding is that it does not add any foreign material to the part— it uses the same model thermoplastic. For example, instead of gluing flame-retardant ULTEM material with epoxy that could potentially be flammable, it is bonded with ULTEM, preserving the overall mechanical properties of the part.

HOT AIR WELDING A SEAM WITH FDM THERMOPLASTICS

Materials & Applications

Engineers use welding to assemble parts that are too large to fit on one machine build platform by sectioning the design, building separate pieces and joining them together. Sectioning and welding is also used to save time. Project engineers can strategically section parts to eliminate excessive amounts of support structure by cutting overhanging features from the part and building them separately.

Design Guidelines

For the best results, parts should be sectioned in non-load-bearing areas and on thicker walls of the part with dovetail joints to optimize overall strength. An additive manufacturing project engineer can help you decide where and how to section the part based on the geometry, to optimize strength, build-time and costs of large parts.

BONDING

Bonding is another way to connect multiple sections to create large parts. Additive manufacturing project engineers usually use two-part epoxies because they exhibit excellent mechanical strength and are easy to use. The epoxy components are mixed and then applied with dispensers, brushes or infiltration.

Cyanoacrylate, also known as super glue, is a popular fast-curing adhesive applied for light-duty bonding applications and repairs on PolyJet parts.

URBEE IS AN ECO-FRIENDLY VEHICLE THAT WAS 3D PRINTED IN SECTIONS AND BONDED TOGETHER

Materials & Applications

Some chemically resistant FDM materials will not adhere with some solvents or glues. Consult with an additive manufacturing project engineer to determine the best joining process and bonding chemicals for your part material.

Design Guidelines

See design guidelines for hot air welding.

COATING FOR FUNCTIONALITY OR APPEARANCE

SEALING

FDM parts are naturally porous right off of the machine which presents an obstacle for containing gases and liquids. The solution is sealing the part with a water or chemical resistant epoxy coating. Vapor smoothing also seals an FDM part's surfaces, but is limited to applications with no higher than atmospheric pressure. Two-part epoxy brushed onto the surface of a part generates an airtight seal and is resistant to many chemical agents. The other option is immersing FDM parts in epoxy resin and using a vacuum to infiltrate the epoxy to create a watertight seal and resistance to chemical agents and high temperatures.

PolyJet materials are not porous and generally do not require sealing processes.

EPOXY SEALED INTAKE VALVE FOR THE UNIVERSITY OF MINNESOTA COLLEGE OF SCIENCE & ENGINEERING'S FORMULA SAE VEHICLE

Materials & Applications

Epoxy coating and infiltration enhance FDM parts for many applications from prototype to end-use, including cooling lines for molding tools, fuel-holding, intake manifolds, ductwork and more. All FDM materials are compatible with either method and maintain an airtight seal up to a pressure of 65 psi (448 kPa) after being treated.

Design Guidelines

Avoid intricate features and internal channels which can be difficult to reach with coating. If your part needs to meet tight dimensional tolerances, we recommend epoxy infiltration which doesn't affect dimensions.

ELECTROPLATING

Electroplating deposits a thin layer of metal, such as chromium, nickel, copper, silver or gold, on a part's surface. The electroplated coating gives the appearance of production metal and provides a hard, wear-resistant surface with reflective properties. Prior to plating, FDM parts need to be sanded smooth and sealed with either a vapor smoothing process, solvent dipping or paint to aid chemical adhesion.

ELECTROPLATED
FDM MANIFOLD

Materials & Applications

Plating is often applied for cosmetic reasons, but also increases strength and surface durability. In tests, the tensile strength of an electroplated FDM test bar increased 10 - 12 times and the results of the flexural tests showed an increase of 21 - 24 times. The added strength makes electroplating a good fit for automotive applications and the decorative value benefits home fixture and appliance applications. ABS-M30, ABS and ABSplus have been tested for electroplating. Electroplating can also be applied to rigid and ABS-like PolyJet materials, including Digital ABS and the Vero family of materials.

Design Guidelines

In order for the metal to properly adhere to the part's surface, it must be extremely smooth. An additive manufacturing project engineer will work with you to optimize FDM build orientation to minimize layer lines. You will also need to offset additional thickness that comes with electroplating in the CAD model.

PRIMING AND PAINTING

FDM parts can be primed and painted to produce attractive conceptual models, functional prototypes and end-use parts. Prior to painting, FDM parts should be polished with vapor smoothing, application of body filler and sanding. Models 3D printed with PolyJet are smooth right out of the build chamber and will accept paint without initial polishing.

THOMAS JEFFERSON STATUE REPLICA AT THE SMITHSONIAN MUSEUM, BUILT USING FDM AND PAINTED BRONZE.

Materials & Applications

Painted 3D printed parts are ideal for concept and display models or applications with virtually any cosmetic requirements. All FDM materials can be painted, but ABS and ABS-M30 generally require the least smoothing effort. All PolyJet materials can also be painted and are compatible with most plastic coatings, such as acrylics and lacquers.

Design Guidelines

If your part is going to be painted, it needs to be as smooth as possible and that starts with design. For FDM, choose a build orientation that will generate a smooth surface, but keep in mind orientation also affects strength. Project engineers will often choose the smallest tip size and thinnest slice to create a smooth surface while maintaining strength. Holes, undercuts and cavities must also be taken into consideration, since they are difficult to reach when sanding, priming and painting.

BREAK FREE OF CONVENTIONAL DESIGN CONSTRAINTS WITH FINISHING

3D printing technology breaks the rules of conventional manufacturing. It allows engineers to build complex geometries, create massive parts, consolidate multiple part components and design solely for form, fit and function rather than for the manufacturing process. So why trade the wide range of possibilities for nice aesthetics on a mediocre part? With the right secondary operations from additive manufacturing experts, you don't have to—you can build hard working parts with great surface quality. Finishing enhances what a 3D printer can do, improving both aesthetic and mechanical properties, from providing impeccable, near injection molded finishes, to meeting tight tolerances and achieving added durability and chemical resistance.

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