A GUIDE TO 3D PRINTING JIGS AND FIXTURES

Material guidelines and best practices for successful additive manufacturing results

ESSENTIUM™

Introduction

In every facet of manufacturing there's a constant need for speed. Speed in design, speed in production, speed in getting new products to market. That puts a lot of pressure on manufacturing engineers to design the jigs and fixtures that will facilitate efficient mass production and assembly.

Advances in additive manufacturing systems and new filaments have closed the gap with traditional subtractive manufacturing tooling methods, enabling faster, cheaper iterations of the parts needed to support production. However, the expanded choice in materials complicates matters, as different filaments have various properties and work for different applications.

The specific purpose of the jig or fixture is immaterial. This document is not about what you're making, but why and how to make it better through additive manufacturing. On the following pages you'll find tips for proper material selection, some best practices for 3D printed jig and fixture design and execution, and why Essentium's HSE™ 3D Printing Platform is the best tool for the job.

WHY FIXTURING MATTERS

Does This Sound Familiar?

A much anticipated new product introduction may be delayed due to problems creating accurate fixtures for the assembly lines. A series of last-minute design changes threatens to push back production, which may cause the company to miss the critical start of the buying season. This can impact revenue projections through lost sales as well as inflate R&D expenses for modified tools. Management is not happy. The delivery date cannot be changed and there's a lot of pressure to make fixtures quickly to meet deadlines. Even though many of the late change requests came through customer feedback, it's the manufacturing engineers who get the blame. Why? Because some in management don't appreciate how complex and expensive the tooling process is, and since engineers are the last people to touch a part before approval for production, the buck stops with them.

The issue is that for most companies, a new product introduction is a relatively rare event. Contract manufacturers that are in the business of constantly making new products have the equipment and workflows in place, but companies that do not often release new products usually do not have internal resources dedicated to fixturing. As a result, they turn to outside suppliers to create the fixtures they need. This is perhaps the slowest, most expensive path to product development as it takes weeks between iterations, is fraught with delays and the potential for errors, and leaves the company totally at the mercy of the supplier when time is a limited resource.

It's All About Agility

Have you ever worked on a new product introduction that did *not* experience at least one late design change? With a 3D printer on site, what took outside suppliers weeks to make can be printed in days or hours; what cost thousands can be printed for pennies on the dollar. Additive manufacturing shrinks development cycles and reduces costs by facilitating *speed to part.*

In new product development, flexibility in design is inversely proportional to time to market release. Anything is possible when plans are on the drawing board. The closer it gets to physical product launch, the less flexibility there is for design changes. But sometimes, changes are unavoidable due to a last-minute customer request or a previously undiscovered design flaw. Additive manufacturing provides needed agility in the least agile part of the production process: nailing down the final design. And therein lies the value proposition of additive manufacturing: If you're not saving 85% to 90% in time and cost over traditional tooling methods, you're doing something wrong.

Additive manufacturing allows engineers to rapidly progress through multiple iterations at low cost until the perfect fixture design is achieved and ready for use. Oftentimes, several iterations can be designed and printed in the same day. Compare that to the high costs and prolonged timelines of using an outside supplier and the benefits of additive manufacturing are clear.

Skeptics may question the skill of the engineer who requires multiple versions before "getting it right." But the point here is not that engineers need to make multiple iterations, it's that they can make multiple iterations—quickly and at low cost—to get everything just right. Engineers are no longer forced to accept an imperfect tool made from the one and only mold because of time or cost constraints. They do not have to suffer through extended development cycles and long lead times between receiving iterations from the machine shop. They have the freedom and flexibility to incorporate design changes right up until production. If it is known that the final fixture cannot be made using the additive process, engineers can test concepts on 3D printed prototypes before committing to a more expensive mold. In situations where the final part or fixture is to be made with additive manufacturing, 3D printing supports rapid increases or decreases in production volume to quickly address changes in market conditions.

> *If you're not saving 85% to 90% in time and cost over traditional tooling methods, you're doing something* ***wrong.***

So, when the perfect fixture is designed to make the perfect product on time and under budget, who gets the publicity? Management. But behind the scenes, it's the manufacturing engineers who get to enjoy the technology that made it all happen, even if they don't get the glory. 3D printing buys *time,* a most precious resource in new product introductions. It speeds the development of fixtures by manufacturing engineers, which in turn speeds getting new products to market for management. A win-win!

Know Where Your Fixturing Dollars are Going

Printing jigs and fixtures using additive manufacturing saves significant time and money. It can eliminate the need for highly skilled labor and/or outsourcing to mill fixtures from solid materials or create tools from tube and sheet metal. Additive manufacturing also allows for better tracking of fixture expenditures for greater overall accountability. In fact, most companies do a poor job of tracking actual fixturing expenses; they are lumped into general design costs or business expenses because they are one-time occurrences. Parts or raw materials sourced through the supply chain outside of Engineering's purview may not be allocated to the proper internal budget. Vendor overcharges for late design changes and rush fees get buried. As a result, many companies do not know the true cost of a new product introduction. That can add up to real dollars when multiple iterations of expensive fixtures are required before moving into production—money that could be saved or spent elsewhere.

With additive manufacturing, companies can easily monitor fixturing expenses. Once the printer is purchased and online, the only expenses are engineers' development time and the cost of filaments. Creativity is free. Engineers are able to experiment with multiple materials and test complex designs internally with greatly compressed turnaround and cost.

Once a design is approved, replacement fixtures can be printed as needed for only the cost of materials. Bypass Purchasing and shorten supply chains. Eliminate expensive vendor contracts, rush job fees, and budgetary confusion for miscellaneous product development expenses. 3D printed fixtures are also lightweight and easier to handle than metal versions. That translates into greater worker productivity, fewer workplace injuries, and a safer manufacturing environment. All of which contribute to a faster return on investment. And for some companies, 3D printing can even become a profit center by charging customers a premium for a faster delivery than they could get from their traditional fixture supplier. People will pay a premium for speed.

JIGS & FIXTURES

The Real Opportunity for Additive Manufacturing

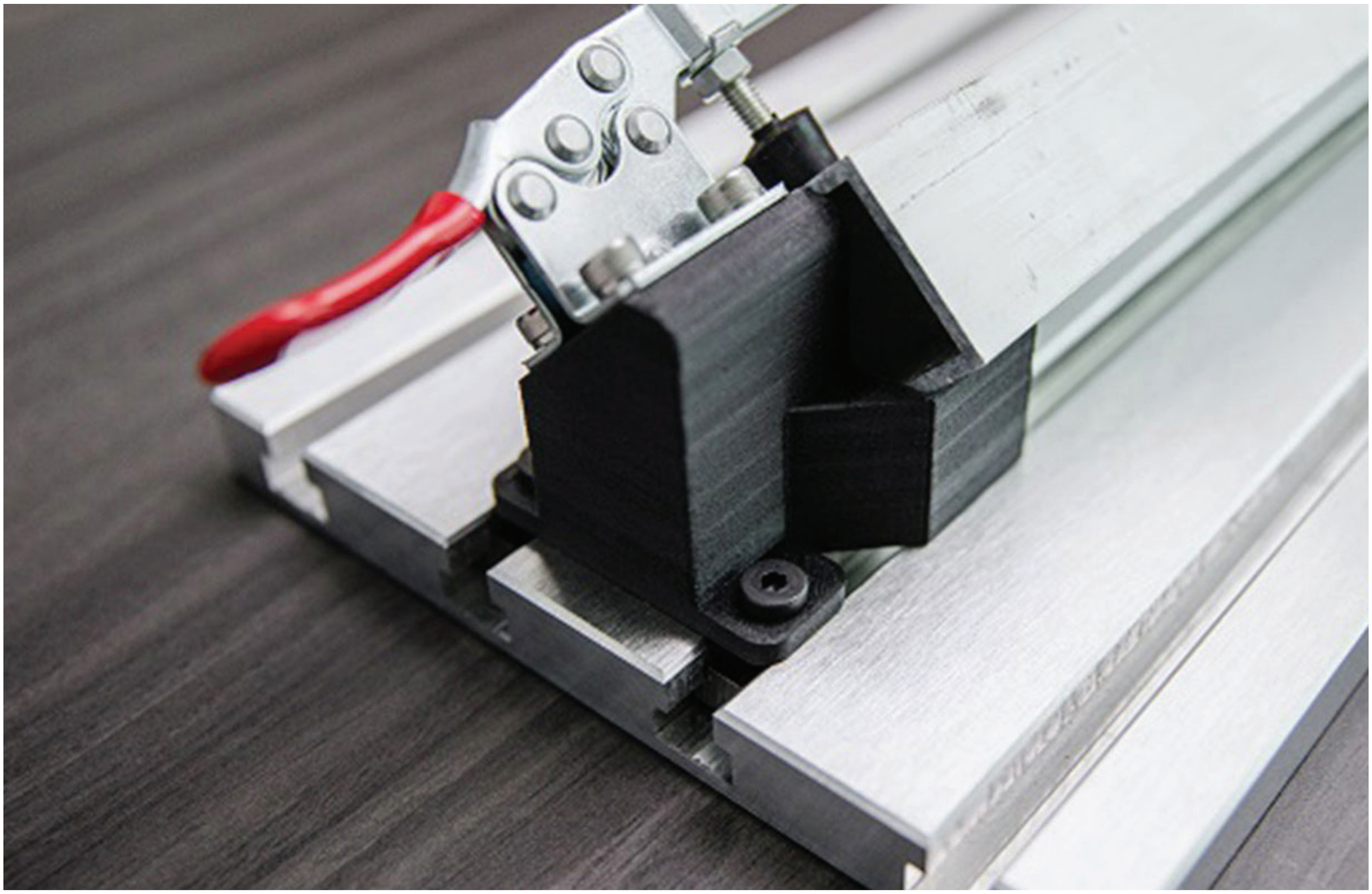
In truth, there are many 3D printers out there that offer the advantages of flexibility, agility, and cost savings to support new product introductions. But only Essentium's High Speed Extrusion (HSE) technology delivers the missing link of *production at scale.*

Got an idea for a new product and need a rapid prototype? Need one or two fixtures to keep the assembly line moving? Most any commercial 3D printer can handle the job.

Need 100 or 1,000 fixtures to equip an entire factory floor for a new product launch? That's where Essentium comes in. Our exclusive HSE 3D Printing Platform is five to 15 times faster than any other extrusion printer on the market to deliver the speed and agility required for production at scale. The Essentium HSE 180•S Series uses linear servo motor technology to precisely deposit filament at speeds up to 500 mm per second with 1 micron accuracy for required consistency. Plus, the HSE 180•S build area is large enough to fit up to 85% of all global jigs and fixtures, or to print fixtures in volumes large enough to support mass production. An array of HSE 180•S printers on the factory floor could easily replace a number of outside suppliers while returning control over quality, cost, and innovation to internal decision makers.

While prototyping remains an important 3D printing application, fixturing to support mass production represents a greater opportunity for additive manufacturing. Whereas prototypes are needed periodically for new product development, fixtures are needed every day in every step of the production line. Prototypes are usually limited in number. After a product is designed, large quantities of jigs and fixtures are needed for workers and robots on the assembly line, with a constant need for replacement as fixtures get lost, worn, or damaged.

Sometimes, fixtures are just plain *bad.* They are poorly designed or cumbersome to use, but the factory keeps using them because they are too expensive to replace using traditional methods. Additive manufacturing allows engineers to create improved tools to match workers' exact requirements. Ergonomics can be constantly enhanced by incorporating end-user feedback, all while making tasks lighter, safer, more repeatable, and accurate for workers on the assembly line.



Every manufacturing company in every industry has a need for fixtures; either for assembly or inspection. They come in all shapes and sizes depending upon the market, but their common purpose is to hold a part in an exact, mistake-proof orientation while another operation is performed on it by a worker or another machine.

There are jigs and fixtures for drill guides and fastener positions, cradles for the efficient assembly and disassembly of subcomponents (a part should be as easy to remove from a fixture as it is to insert), badge placement guides, and label marking masks. There are soft vices and customized grips for the ends of robotic arms, ESD fixtures for assembling electronics and circuit boards, and gap measurement gauges for post-manufacturing inspection of the finished product to minimum tolerances.

Due to advancements in manufacturing technologies such as the incorporation of robotics, miniaturization, and the use of lightweight materials in many products, not a lot of force is needed to hold parts in place, and too much force can damage a part. This demands new materials to replace the heavy, expensive metal fixtures of yesteryear as well as fixtures milled from newer machinable polymers like high density polyethylene (HDPE).

However, there are other variables that must be considered when transitioning to additive manufactured jigs and fixtures. Whereas the strength and durability of metal or aluminum fixtures are well known, the different properties of various extrusion materials with respect to tensile strength, flexibility, impact resistance, chemical and thermal exposure make proper material selection critical.

While we may not know the specifics of what you are making, we can offer some general guidance for material selection and best practices to ensure your 3D printed jigs and fixtures are the best they can be.

MATERIAL GUIDELINES FOR 3D JIG & FIXTURE PRINTING

There was a time when many fixtures were made from metal or aluminum. They were heavy and expensive, and as tenured engineers will attest, required long lead times between iterations and offered little flexibility in design. Metal fixtures are still used in some situations, but only when the part it supports is extremely heavy.

Today, very few fixtures are made from metal, in fact, most fixtures cannot be metal. Besides being heavier and harder to handle, metal scratches other materials, so it cannot be used to handle products with finished surfaces. Their weight puts additional strain on robotic (and human) arms, which either slows movement or requires more robust support mechanisms (or more people). Rather, fixtures made from non-marring, lightweight materials are needed in today's hi-tech manufacturing environments.

Many manufacturers have already turned to next-generation polymers as a replacement for metal fixtures. Materials like GSM, Nylatron, Delrin, and Garolite are examples of high density lightweight plastics that can be machined into precise shape. They provide the needed strength and non-marring properties, but are very expensive. Still a subtractive process, tool makers encounter the same issues with these substitute materials as when creating fixtures from metal: whether milling, routing, drilling, or grinding, customers are paying for the material that is cut away as well as for the material used; the materials are expensive, and machine shops still require long lead times between iterations.

So it's not that additive manufacturing should be viewed as an alternative to metal fixturing—most tool makers have already moved on—but to subtractive fixture manufacturing in general. There are high performance fiber-reinforced materials that can replace aluminum, and others like PCTG that can substitute for machinable polymers like Delrin.

Most are very affordable, and manufacturers only pay for the materials consumed with very little waste, creating a huge price advantage for the additive process. On the other hand, there are additive materials like PLA that are not recommended for jigs and fixtures due to its inherent flexibility and low melting point.

The following table presents Essentium's family of high speed extrusion materials with guidelines for filament selection based upon the primary properties of the material and required attributes of the fixture to be printed:

MATERIAL CLASS	ESSENTIUM PRODUCT	EQUIVALENT INDUSTRY MATERIAL	PRIMARY PROPERTIES	COMMON APPLICATIONS	COST
Antistatic	**TPU 58D-AS**	• Antistatic PP • Antistatic Rubber	• ESD Safe • Available in red, blue, and white	• ESD Safe applications • Color-coded ESD safe applications	$$
ESD Safe	**HTN-Z**	• ESD-safe Acetal (Delrin®)	• Tensile Strength • Good solvent resistance • Low anistrophy	• ESD-safe fixtures • Electrical housings • Hand held tools	$$
Fiber Filled	**PET-CF**	• Glass filled Delrin® • Phenolics • Light-duty aluminum	• Stiff and strong • Lightweight • Moisture insensitive • Excellent price/ performance ratio	• Clamping fixtures • Hydroforming tools • Brackets • End-effectors	$$
Flexible	**TPU 74D**	• Urethane rubber • ABS	• When extreme toughness is needed • Impact resistance	• Backing plates for cutting	$$
General Purpose	**PCTG**	• Delrin®	• Easy, fast prints • Low cost • The *go-to* general stiff fixture material • Least affected by moisture • Low anisotropy	• Medium load bearing fixtures • Hand held tools	$

MATERIAL CLASS	ESSENTIUM PRODUCT	EQUIVALENT INDUSTRY MATERIAL	PRIMARY PROPERTIES	COMMON APPLICATIONS	COST
High Temperature	**Essentium 9085**	• Aluminum • Garolite • Phenolics	• High strength and temperature resistance • UL flammability application • FST rated	• Aerospace ducting • Aircraft interiors • High temperature tooling	$$$
High Temperature	**HTN (HT Nylon)**	• Nylons	• Tensile strength • Good solvent resistance • Low anisotropy	• Fixtures that need durability	$$
High Temperature	**PEEK**	• PEEK • Aluminum	• Extreme chemical resistance • Excellent temperature stability • High strength and durability • Wear resistance	• Medical tools and fixtures • Oil and gas • Semiconductor processing	$$$$
High Temperature Nylon Fiber-filled	**HTN-CF25 (HT Nylon 25% Carbon Fiber)**	• Aluminum • Composites	• High tensile strength • Good solvent resistance • Excellent thermal resistance • Good heat transfer • Naturally ESD safe	• High stiffness jigs and fixtures • High strength end use parts • SMT lines • Wave solder • Selective solder fixtures	$$$

BEST PRACTICES FOR 3D PRINTING JIGS AND FIXTURES

The 3D Printing Workflow

The place to start is at the end.

Ask yourself, *what do I want to accomplish?* Understanding the purpose for the jig or fixture—what it will do and what physical, chemical, or thermal forces will act upon it—goes a long way towards proper material selection.

Consider quantity. Do you have enough material? Is the volume of fixtures something that can be handled by the additive process, or will subtractive methods be required for mass production?

Does the 3D printer support the software application used to design the part? Is the design rock solid? Will any post-printing drying or machining be needed? How will you deburr and clean the piece? Do you have the proper tools for dimensional inspection available? How will you validate quality?

Once you have the answers to these questions, you'll be ready to hit the Print key. But first, consider these tips and techniques for the three phases of 3D printing—CAD design, printing, and part validation—to improve the quality of your 3D printed jigs and fixtures.

Best Practices for Effective CAD Design

A well-designed jig or fixture takes into consideration not just what the tool will do, but also how the part will be handled by workers to minimize cycle times.

- **Design the jig or fixture so that it can be used with one hand,** leaving the other hand free for measuring or using another tool on the part.
- **Consider release as well as insertion mechanisms,** like soft springs, sliders or levers. How a part will be ejected is just as critical as how it will be inserted into the jig or fixture. It should be easy to move the part on to the next step of the assembly process.
- **Incorporate curved surfaces and recessed channels** for waste into part design for easy cleaning. Jigs and fixtures with hard corners can make it difficult to remove debris which can impact positioning of the next part.
- **Leave space around drill holes** to account for burr creation. Allow waste to fall away without interfering with accuracy or visibility to the tooling point.
- **Implement the Japanese concept of *Poka-yoke*** into the design. There should only be one correct way to hold, insert, or assemble the part. Build incorrect geometries and odd dimensions into the design that make placement insertion errors obvious.
- **Build connecting locators into the part for exact seating.** An extension of the Poka-yoke concept, incorporating small diamond or hex shaped protrusions into the jig or fixture will guarantee assembly in the proper orientation or allow for two parts to easily mate. (These are usually difficult to incorporate into machined tools.)
- **Build datum points into the design.** Eliminate secondary stamping or engraving steps by printing fiducial points into the fixture to make inspection easier, or print serialized part numbers, fabrication dates, and other data onto each part for inventory and identification purposes.
- **Be sure to use electrostatic discharge safe (ESD) materials** for surface mount technology and circuit board production to eliminate worries of sparking during electronics assembly. Essentium's ESD safe materials are rated among the best available and are certified for cleanroom use.
- **Build hard tooling points into jigs and fixtures** using heated metal shafts and inserts to increase the accuracy and durability of drill guides, for example.
- **Migrate to native CAD formats for more accurate design.** Printing from 3MF and SDL formats can result in translation errors when printing.

Best Practices for Successful 3D Printing

- **Narrow your toolkit to a subset of four or five materials that offer the necessary properties for the fixture in question and stick with them.** There are dozens of types of materials available for a wide range of applications. This complicates filament selection, and you don't have the time or budget to test them all. Practice with different shapes and thicknesses. Print prototypes in each material to see which provides the best performance.

- **Always ensure polymers are dried at the appropriate time and temperature as recommended by the manufacturer prior to use.** Filaments with excess absorbed moisture can produce brittle parts. Water molecules form microscopic bubbles when heated. After evaporating, the bubbles become tiny internal voids that weaken the structure, leading to premature failure. Properly dried materials are critical to achieving desired, consistent results.

- **Expose candidate materials to known chemicals and solvents** in the end-use environment to ensure the filament has the necessary resistance and will not degrade from exposure.

- **Add a little bit of carbon fiber to the material mix for additional strength.** Just 10% makes a stiffer part. Some manufacturers recommend adding ribs or using extra material to reinforce a fixture for strength. Adding carbon fiber increases strength without adding to build time or cost per part.

Best Practices for Part Validation

- **Use a micrometer or caliper to measure critical dimensions against the CAD model and the SDL file.** This is especially important if the design has been printed from a 3MF or SDL file format rather than the original CAD file. This can tell you if errors are occurring during printing or in the file translation process, and make appropriate adjustments.

- **Check for a snug fit.** Insert a sample part into the fixture to test for any unwanted movement or rotation.

- **Check for excessive clamping force.** Will pressure from the jig or fixture damage the part, change a dimension, or leave an impression?

WHY ESSENTIUM?

Building jigs and fixtures using additive manufacturing offers several advantages including time and cost savings for faster speed to part, as well as increased flexibility and agility in the design stages.

Essentium's unique High Speed Extrusion technology magnifies the power of additive manufacturing by enabling speed and strength, at scale, to meet the volume production needs that other 3D printers just cannot match. In fact, the Essentium HSE 3D Printing Platform was developed by and for manufacturing and semiconductor engineers who could not find all these qualities in a single solution. So we built our own.

Combined with a world-class material set that can substitute for most metals and high density plastics used in subtractive manufacturing, the Essentium HSE 3D Printing Platform can address any application including volume jig and fixture production. For manufacturing engineers, it provides fast, accurate, in-house fixture making and iteration capabilities to improve production processes. For management, it delivers the fastest possible route to market for new product introductions while lowering costs.

If you would like to learn more about the processes, materials, and best practices for 3D printing high quality jigs and fixtures in your enterprise, we invite you to contact us at Essentium.com.