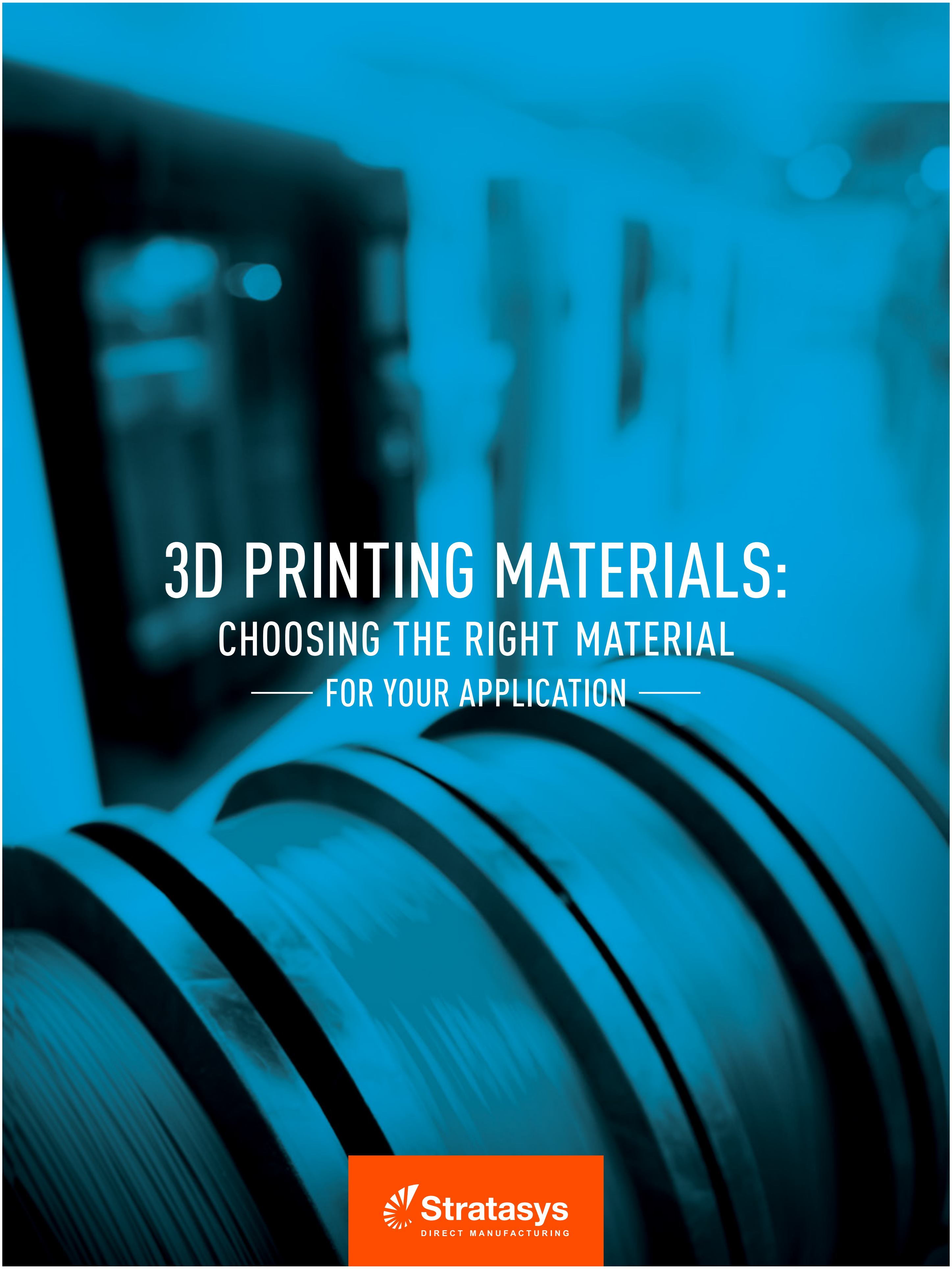


3D PRINTING MATERIALS:

CHOOSING THE RIGHT MATERIAL FOR YOUR APPLICATION

Stratasys DIRECT MANUFACTURING

INDEX

3D printing material achievements have skyrocketed over the past five to ten years. Today, the 3D printing processes available are substantial for creating prototypes and end-use production parts in hundreds of plastic and metal materials. The advancements in additive manufacturing technology coupled with corresponding advancements in material evolutions have hugely impacted the way 3D printing is viewed and relied upon by engineers, designers and manufacturers during product development and production.

Materials in additive manufacturing technology systems are defined by the technology. Each 3D printing technology transforms material through external heat, light, lasers and other directed energies. The ability of a material's mechanical composition to react positively to a certain directed energy marries that material to a technology which can deliver the desired change. These material-technology partnerships will expand as materials are advanced and material chemistry explored. Advancing technologies encourages more positive material reactions, layer by layer, to directed external energies. The mechanism of material change—unique to individual 3D printing technologies and processes—defines the material in terms of state changes, final mechanical properties and design capabilities. By extension, developments in 3D printing materials correspond with developments in 3D manufacturing; as the build process improves to encourage more positive reactions from materials, material selections will expand.

TODAY, 3D PRINTING IS SUBSTANTIAL FOR CREATING PROTOTYPE AND END-USE PRODUCTION PARTS IN HUNDREDS OF PLASTIC AND METAL MATERIALS.

3D printing offers many of the thermoplastics and industrial materials found in conventional manufacturing. Plastics commonly used in injection molding have been developed to work with thermoplastic 3D printing technologies like Fused Deposition Modeling (FDM). Traditionally machined metals, such as stainless steel and titanium, have been created as powdered metals for manufacturing with Direct Metal Laser Sintering (DMLS) 3D printing. Biocompatible materials like ULTEM 1010 and polycarbonate have been developed to deliver 3D printed parts using Laser Sintering and FDM technologies. These materials exhibit highly beneficial mechanical properties while delivering complex designs impossible to achieve using conventional manufacturing.

MATERIAL SELECTION CONSIDERATIONS

APPLICATION

Certain 3D printing materials offer biocompatibility, sterilization capabilities, FDA certifications for skin contact, heat smoke toxicity certifications, fire retardant certifications, chemical resistance or other certifications which may be critical for your project. When choosing a material and 3D printing process for your project it is important to ensure your material can deliver on these certifications. A 3D printing service provider with ISO 9001 and AS 9100 certifications like Stratasys Direct Manufacturing can ensure strict material and engineering requirements are met.

FUNCTION

3D printing materials are subjected to rigorous testing in order to answer the kinds of stresses it can endure and the level of taxing environment the material will excel in. The ability of a material to function in a desired application relies partly on design.

GEOMETRY

As we mentioned before, 3D printing materials are often inseparable from their corresponding technology. Additionally, each technology, whether it's FDM, Stereolithography or Laser Sintering, excels in delivering unique geometric executions. Consider the dimensional tolerances, minimum feature execution and wall thicknesses of your design when choosing a material and 3D printing technology.

POST PROCESSING

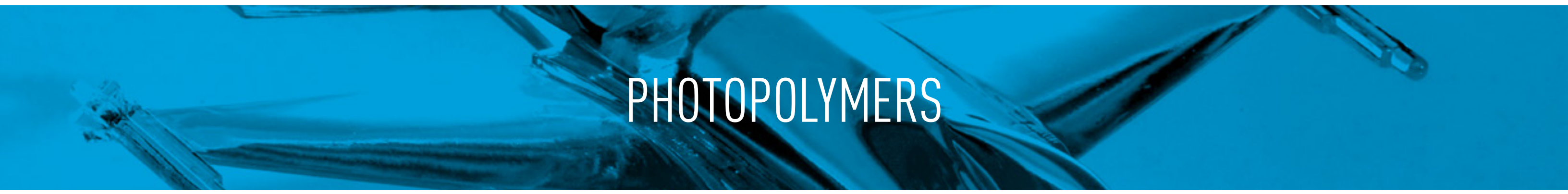
3D printed designs can result in beautifully finished products with the right post-processing. Some materials may be better suited to certain post-processing methods than others – heat treating stainless steel versus post-curing a photopolymer, for example.

The most popular 3D printing manufacturing technologies to date include PolyJet, Stereolithography (SL), Laser Sintering (LS), Fused Deposition Modeling (FDM) and Direct Metal Laser Sintering (DMLS)[1]. These technologies develop plastic and metal designs layer by layer using unique processes. PolyJet is a technology which deposits photopolymer resins layer by layer; the resin is cured simultaneously as it deposits using UV laser energy. Stereolithography also uses photopolymers and UV energies, however its photopolymer resins are held in a vat of liquid resin. UV energy is directed via dynamic mirrors to cure parts in precise designs. FDM, also a material depositing process, extrudes heated thermoplastics layer by layer through a precise nozzle. Laser Sintering and Metal Laser Sintering are powder based processes which use IR lasers and a heated, enclosed build chamber to melt

[1] These technologies are trademarked properties of their respective owners.

plastic or metal materials. These processes, tailored to the materials they utilize, bring unique and varied offerings to the 3D printing industry.

When beginning material selection for your next 3D printing project, it will be necessary to consider the application, function and design of your product. Materials available with 3D printing technologies range in heat deflection, chemical resistance and durability and material viability greatly depends on design, application and desired product life. To determine the material and 3D printing process which will best support your application, consider the materials and technologies below [2].



PHOTOPOLYMERS

Photopolymer materials in 3D printing begin as liquid resins which are cured and hardened with ultraviolet (UV) energy to result in plastic prototypes and parts. Photocurable materials range in colors, opacities and rigidities. In 3D printing, two widely adopted technologies use photocurable materials in their manufacturing processes: Stereolithography (SL) and PolyJet.

SL materials deliver fine feature details with dimensional tolerance implementations between 0.020" or ± 0.004"/" (whichever is greater) in X/Y and ± 0.005" or ± 0.002"/" (whichever is greater) in Z. SL materials react to UV laser energy in independent and unique ways based on the mechanical properties of each material; these variances in reaction can determine the tolerance and feature, or it may determine the shrinkage rate and speed of print among other factors. The choice of SL material best suited to a particular design will factor speed, shrinkage and feature detail requirements for optimum design execution.

SL materials with lower shrinkage and higher print speeds include, or are similar to, SC 4500, SL7810, Accura25, Next and Somos 18420; we refer to these materials as SLA White. In addition to SLA White materials is a category of clear or transparent and colorless SL materials, which we'll refer to as SLA Clear materials. SLA Clear materials include, or are similar to, Somos 10122, Accura 60 and Somos 11122. Materials used specifically for their micro or high definition feature abilities include Somos NeXT and the Stratasys Direct Manufacturing proprietary material SC 5500.

---

[2] Materials listed are collected by relevancy throughout the industry. Often, 3D print machines allow only material certified and manufactured by the machine provider to be used in conjunction with the machine itself. Other 3D printing technologies allow for third party materials providers. 3D printing materials will additionally be provided varying monikers. To ensure you have access to the best material for your project we recommend speaking with a 3D printing engineer. You can reach one at StratasysDirect.com.

While any of these SL material categories accomplish excellent prototype parts, the strengths each material exhibits define best application pairings. SLA White materials are typically used in the production of more durable prototypes and, depending on part geometry, SLA White materials may offer the fastest print speed of all three SL material categories. SLA White materials can provide valuable feedback for design studies, such as the fit of a design within a larger product context, the response of a design to certain non-taxing environments and the feel of a design within its desired application. SLA Clear materials provide similar feedback, with the additional benefit of a clear, transparent appearance and a similar flexural strength to polycarbonate; flexural strength for SLA Clear materials typically lands around 87-101 MPa (depending on part design)[3]. SLA Clear, SLA White and Somos NeXT are available in μHDSL and can achieve the finest feature details for small, rigid prototypes and models while maintaining a decent flexural strength between 67.8 - 70.8 MPa (depending on part design).

In addition to these standard SL materials is a less widely available material known as SC 1000. This SL material was developed specifically for the investment cast industries. SC 1000 is used in the creation of investment cast patterns to create medium to large sized patterns with involved geometries. This SL material exhibits higher resistance to humidity when compared with other SL resins, which mitigates in-vat swelling; its high green strength minimizes the mass of the final pattern and its low/ stable viscosity assures consistent drainage. SC 1000 has been a staple for many foundries requiring large, accurate patterns at a more economical cost than lost wax patterns of the same size (this material is only offered from Stratasys Direct Manufacturing).

THIS PHOTOPOLYMER MATERIAL, SC 1000, WAS MANUFACTURED USING STEREOLITHOGRAPHY TECHNOLOGIES FOR THE INVESTMENT CAST INDUSTRY.

[3] Material strengths, flexural modulus, Izod impact strengths etc. are based upon testing performed by both the materials provider and Stratasys Direct Manufacturing material performance tests. Mechanical properties may vary.

POLYJET OVER-MOLD PARTS USE FLEXIBLE AND RIGID MATERIALS TO REVEAL DESIGN FEATURES AND TEXTURES.

As we mentioned in our introduction, PolyJet technology deviates from SL technology in that PolyJet deposits and cures photopolymer materials simultaneously rather than curing materials in a vat of liquid resin. PolyJet materials are capable of manifesting the highest resolution of any 3D printing technology or material, with layer thicknesses as thin as 16 microns (on the Z axis). PolyJet's fine resolution eliminates the need for extensive surface post-processing; the thin layer thicknesses result in designs with a smoother texture than other 3D technologies. PolyJet is also the only 3D printing process to currently print in multiple materials with ranging durometers. There are hundreds of photopolymer composites available with PolyJet, but we'll focus on seven standard materials that give the widest example of what PolyJet photopolymers are capable.

PolyJet VeroWhitePlus, VeroBlue, VeroGray, Amber Clear, GreenFire, Endur and Flex comprise the mechanical properties found in the more popular PolyJet material options. VeroWhitePlus, VeroGray and Amber Clear sit around a flexural strength of 93 MPa while VeroBlue, GreenFire and Endur afford flex strengths between 52 and 67. These materials are capable of 16 micron layer thicknesses and 300 micron feature details. GreenFire and Endur are PolyJet materials with a slightly higher heat deflection and higher elongation at break. GreenFire HDT ranges between 124° and 131° (at 264psi) while Endur HDT ranges between 120° and 129°. The elongation for both materials hit 20% - 40% ranges, with GreenFire falling higher on the scale than Endur.

PolyJet Flex materials range between shore 27A and shore 95A hardness for elastomeric material simulations. This material has the added benefit of printing in conjunction with rigid PolyJet materials; this is termed PolyJet Over-Mold and can be used to develop prototype models with critical design reveals. To create PolyJet Over-Mold, PolyJet Flex is infused with PolyJet VeroWhitePlus to create durometer variations. PolyJet Flex materials print in slightly thicker layers, at 30 microns, with similar feature details to PolyJet rigid materials.

COMMON APPLICATIONS

PolyJet and SL materials are commonly used to create high resolution concept models, master patterns for urethane casting processes and as form and fit prototypes for a multitude of industries during early product development. Both photopolymer materials, with their corresponding processes, have been used as medical device models, anatomical educational pieces, industrial design reveals for consumer products, show models, among many other applications. PolyJet offers smooth surfaces and a variety of colors while SL offers easily sanded surfaces for cosmetic paint finishes. Both processes have been used to answer to niche and widespread needs during product development.

SPECIAL CONSIDERATIONS

PolyJet and Stereolithography (SL) have a much lower HDT than other 3D printing processes and are more susceptive to warp when exposed to heat or prolonged UV rays. Their market spotlight isn't in the functional end-use product but rather the end-use or prototype model that helps relay a product's critical design features, feel and form to new and existing markets.

> PLEASE REFERENCE **CHARTS I & II** —IN THE APPENDIX.

POWDERED PLASTICS

Plastic nylons used in 3D printing begin as powdered composites. These powdered nylons are then "sintered", or heated and fused, layer by layer via a CO_2 laser to form dense plastic designs. Nylon materials in 3D printing are relied upon for their heat deflection, high strength and excellent elongation properties. The process does not require support materials and is therefore capable of more complex designs and geometric executions than any other 3D printing technology.

Laser Sintering (LS) nylon composites mainly derive their base from two nylon powders: Nylon 12 and Nylon 11. These two nylons are then enhanced or reinforced with different fillers, including aluminum, glass and even carbon-fiber, to deliver specific mechanical properties. LS materials typically build at 0.004" – 0.006" layer thicknesses with tolerances around ± 0.020" or ± 0.003 "/" (whichever is greater). There are a wide variety of nylon powder composites available to Laser Sintering technologies. Some pass smoke and toxicity certifications and many offer higher heat resistance. We'll focus on general purpose powders on one end of the spectrum and the nylons which perform well within taxing environments on the other end, though there are a range of durable materials which fall in-between. Nylon 12 is a general-purpose unfilled nylon. This material's heat deflection lands around 187°F (@264psi) with a flexural strength around 47 MPa. Its decent strength and HDT have made it a staple in functional prototyping, architectural modeling and even fine arts. Nylon 12 has an elongation between 4-15%, which lands it on the more brittle end of nylons; however certain fillers can heighten elongation. To reinforce strength and heat deflection, Nylon 12 can be filled with glass and carbon. Nylon 12 Glass Filled (GF) has an HDT of 273°F (@264psi). Carbon fiber filled Nylon 12 results in similar HDT with higher flexural strength than unfilled nylon. Aluminum is an additional filler used in nylon. Nylon 12 Aluminum Filled (AF) has a higher flexural and tensile strength, but its lower elongation makes it more applicable for prototyping or models when compared to other nylons. Its striking appearance has made it popular for nonfunctional units. Aside from these general nylon composites, there is a more flexible nylon available. Flex TPE is an elastomeric nylon which has the highest elongation of any other 3D print nylon. Flex TPE can be infiltrated with additives to increase the durometer of the material (from shore 40A to shore 70A). Uninfiltrated, Flex TPE has an elongation at break of 110%. It's excellent for stretchy applications.

In addition to the above general use nylon materials are FAR 25.853 certified for fire, smoke and toxicity performance nylons for 3D printing. FAR 25.853 nylons are used in commercial, corporate and civil aircraft interiors. These materials pass 15 and 60 second vertical burn tests as well as smoke and toxicity requirements for aerospace or similar applications. Nylons available to the 3D printing

AIR DUCTS BUILT WITH LASER SINTERING INCORPORATE INNER FEATURES CRITICAL TO THE DESIGN WHICH WOULD BE IMPOSSIBLE TO EXECUTE EASILY VIA CONVENTIONAL MEANS.

industry today which meet these standards include reinforced Nylon 12 (also called 606-FR or NyTek™[4] 1200 FR) and enhanced Nylon 11 (also called FR-106). The most notable difference between these highly heat and toxic-resistive materials lies within their elongation properties. Nylon 12 FR (NyTek 12 FR) has an elongation at break similar to regular Nylon 12 while Nylon 11 FR (FR-106) has a much higher elongation, around 21 - 38% at break. Nylon 12 FR has also proven to have a lower shrink rate than Nylon 11 FR, which is important when considering the build of larger part volumes; lower shrink rates results in more accurate parts.

APPLICATIONS

LS materials are excellent as end-use or prototype parts in a variety of taxing environments. Its faculty for producing intricately involved units is unparalleled in conventional or advanced manufacturing. 3D printed nylons have zero minimum part requirements which has made the process invaluable in high performance one-off parts. However, the LS process also supports medium to large volumes of small to medium sized parts, and it is increasingly being used for its end production capacities.

SPECIAL CONSIDERATIONS

When designing for LS, consider the minimum features of your part and factor potential shrinkage. LS designs may experience some shrinkage during building; designing for that shrinkage will result in a more accurate part. Reinforcing thinner areas of your design can help to enhance the strength of your part. Stratasys Direct Manufacturing project engineers can help assess your part's geometry to determine the best adjustments to make.

> PLEASE REFERENCE **CHART III** —IN THE APPENDIX.

[4] NyTek is a trademark of Stratasys Direct Manufacturing.

METALS

Metal 3D printing begins with metals in a powder state. The powdered metals are heated and fused by a powerful Yb-fibre laser, whose energy essentially welds designs layer by layer into the powder. While 3D printing with metal is a very involved process requiring highly trained build engineers and post-processing team, it can achieve complex, dense parts that consolidate old designs into one fluid build. The complexity 3D printing with metal can achieve has led to faster production.

Metal additive manufacturing can eliminate the welding and machining of multiple units by building designs in a singular part. Materials available with metal 3D printing include popular metals used in aerospace, medical, oil and gas and transportation.

Metal 3D printing can achieve incredibly thin layer thicknesses, with the thinnest layers at 40 microns. The minimum feature size of metal parts is 0.012" with standard tolerances around ± 0.005" for the first inch and ± 0.002"/" thereafter. Metals available for 3D printing include Stainless Steel 17-4PH, Stainless Steel 316L, Aluminum (AlSi10Mg), Inconel 625, Inconel 718, Titanium (Ti64) and Cobalt Chrome (CoCrMo)[5]. In general, these materials exhibit weld-ability and strength comparable to conventionally built metals. Higher tensile strength materials include INCONEL 625 and CoCrMo. Ti64 is a biocompatible material; parts 3D printed with this material meet ASTM F1372 requirements for gas distribution system components.

Metal materials created with 3D printing won't always exhibit identical mechanical properties to machined or cast parts; the metals do undergo changes unique to 3D printing which will affect the mechanical properties of these metals. However, 3D printed metals will deliver dense, corrosive resistant and high strength parts which can be further treated through heat, coating or sterilization to meet required specifications.

---

[5] These materials are developed by the machine provider as well as third party suppliers and are used by 3D print suppliers.

SMALL, INTRICATE PARTS ARE PERFECT FOR ADDITIVE METAL MANUFACTURING.

APPLICATIONS

Metal 3D printing, with its advanced metals offering, is best utilized in highly complex and involved designs. It can significantly reduce the assembly of designs by consolidating parts into a single build.

THE MECHANICAL PROPERTIES OF THESE MATERIALS HAVE PROVEN INVALUABLE TO AEROSPACE, MEDICAL AND DENTAL PROTOTYPING AND PRODUCTION MANUFACTURING.

SPECIAL CONSIDERATIONS

3D printing with metal requires supports be added to parts with each layer of the build. These supports are manufactured using the same metal powder which composes the final part and therefore require advanced equipment and trained personnel to remove properly. Features below a 45° angle require build supports to prevent ablation. Due to the build supports required with this process, certain extremely complex designs should factor the support removal process. Speaking with a metal 3D printing project manager can help to determine the best build orientation of your part to achieve the least amount of build supports.

> PLEASE REFERENCE **CHART IV** —IN THE APPENDIX.

THERMOPLASTICS

Thermoplastics used in 3D printing are high performance, engineering-grade materials which exhibit many of the same properties of injection molded plastics. 3D printing thermoplastics include polycarbonate (PC), acrylonitrile butadiene styrene (ABS), acrylonitrile styrene acrylate (ASA) and even ULTEM. These materials are typically manufactured using Fused Deposition Modeling (FDM) 3D printing technologies.

FDM thermoplastic materials range from general purpose functional materials for prototyping and end-use production to high performance materials used in medical and aerospace applications. General purpose 3D printed thermoplastics, such as ABS, ABSi, ASA, Nylon 12 and polycarbonate, have good flexural strength properties and exhibit high tensile and impact properties. These general purpose thermoplastics have been further enhanced to create specialty materials. Specially advanced FDM thermoplastics include ABS-ESD7, a conductive material which prevents static buildup; PC-ISO, a polycarbonate with biocompatible properties and certifications; and ABS-M30i, a material engineered for the food and pharmaceutical packaging industries. For aerospace applications, flame retardant and chemically resistant ULTEM 9085 has been developed to work with FDM processes. ULTEM 9085 is a true production thermoplastic for extreme environments, with a HDT around 307°F @ 264psi and good tensile and flexural strength.

FUSED DEPOSITION MODELING (FDM) CAN EXECUTE COMPLICATED DESIGNS USING HIGH PERFORMANCE MATERIALS FOR AEROSPACE APPLICATIONS.

APPLICATIONS

With their ability to incorporate thermoplastics used in injection molding and the design complexities of 3D printing, FDM materials have found wide acceptance in aerospace, medical, packaging and other low volume, customized production applications. ESD safe materials have found a niche spot in the electronics industries as jigs and fixtures as well as in the packaging of static sensitive materials. FDM production is a good, all-encompassing choice for functional, durable and complex parts or products.

AS WITH MOST 3D PRINTING PROCESSES, FDM HAS VIRTUALLY NO COST FOR COMPLEXITY WHICH MAKES IT IDEAL FOR TRADITIONALLY DIFFICULT TO ACHIEVE DESIGNS WHICH BETTER ADHERE TO SPECIFIC PART NEEDS.

SPECIAL CONSIDERATIONS

FDM is an additive manufacturing process which extrudes molten materials layer by layer to result in a final product. While there are many post-processing options available to ensure FDM parts are fully sealed, designing a part with these naturally porous layer lines in mind can be essential in certain applications. Applications requiring load bearing or similar functions should consider the orientation of the part before building. Project engineers at 3D printing service bureaus like Stratasys Direct Manufacturing can assist in orientating your part for an optimum build.

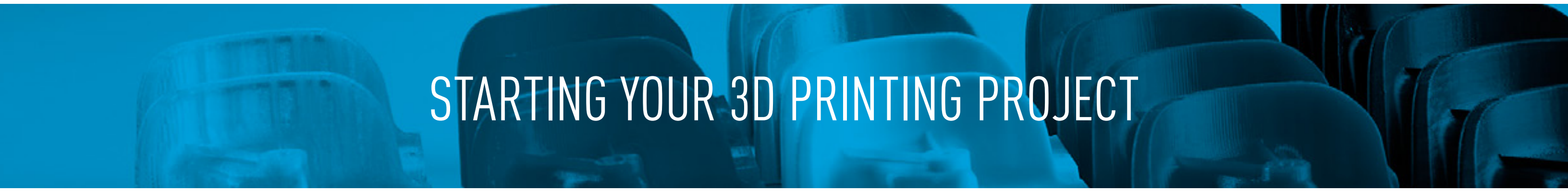
FDM layer lines will also be very visible prior to post-processing and will require an expert in sanding to smooth the surface without losing any important features. Hand sanding can be the best post-processing solution for FDM, as other methods like acetone baths or bead blasting can round the part or diminish tolerances.

> PLEASE REFERENCE **CHART V** —IN THE APPENDIX.

CERTIFICATION CONSIDERATIONS

Many 3D printing materials have been formulated to meet strict industry standards and requirements. FDM material PC-ISO preexisting certifications meet ISO 10993-1 and UP Class VI classification 1 certification for its strength and medical compatibility. FDM ULTEM 1010 offers food-contact and bio-compatibility application solutions. Multiple SLS and a few FDM materials pass FAR 25.853 15 and 60 second vertical burn tests. These certifications increase the fields 3D printing can make an impact within. When designing and manufacturing for applications requiring certifications akin to those listed above it is important to ensure your project is handled in an appropriately certified facility. Stratasys Direct Manufacturing was one of the first 3D printing service providers to achieve AS9100 certification in two of its facilities; it is now certified in three facilities, with additional ISO9001 certifications in eight facilities.

THIS REMOTELY OPERATED UNDERWATER VEHICLE'S ORANGE BODY WAS MANUFACTURED USING FDM WHILE ITS CONTROL SURFACES WERE MANUFACTURED WITH LASER SINTERING.



STARTING YOUR 3D PRINTING PROJECT

While our collection of available 3D printing materials is expansive, it isn't all inclusive. The breadth of 3D printing material options is growing, bridging gaps between prototype and end-use production. Machine manufactures and third party materials developers have seen huge implications in the world of 3D printing and materials are evolving to reflect what engineers need. Today, low volume production for a complicated product can benefit from 3D printing production manufacturing, negating the need for complex and hefty tooling.

> 3D PRINTING PROCESSES CAN MEET THE CRITICAL, TIME-SENSITIVE NEEDS OF MANUFACTURERS WHILE STILL DELIVERING ON THE COMPLEX GEOMETRIES THAT HAVE OPENED DOORS IN DESIGN FOR THE PAST FEW DECADES.

The possibilities are expanding with each new, ground breaking application, boosting research and development in furthering 3D printing materials.

Visit StratasysDirect.com for a complete list of materials and their corresponding certifications, strengths and weaknesses.

APPENDIX

I. POLYJET MATERIAL CHART[6]

MATERIAL	HARDNESS	ELONGATION @ BREAK	TENSILE STRENGTH	FLEXULAR MODULUS	HEAT DEFLECTION TEMP @264 psi	@66 psi
VeroWhitePlus (a.k.a. PolyJet White)	85 (Shore D)	10 – 25%	8,350 psi (58 MPa)	392.5 ksi (2,700 MPa)	118°F (48°C)	118°F (48°C)
PolyJet GreenFire (a.k.a. Digital ABS RGD5160-DM)	86 (Shore D)	25 – 40%	8,000 – 8,700 psi (55 – 60 MPa)	245 – 320 ksi (1,000 – 2,200 MPa)	124 – 131°F (51 – 55°C)	136 – 154°F (58 – 68°C)
VeroBlue (a.k.a. PolyJet Blue)	85 (Shore D)	15 – 25%	7,975 psi (55 MPa)	315 ksi (2,200 MPa)	118°F (48°C)	118°F (48°C)
VeroGray (a.k.a. PolyJet Gray)	85 (Shore D)	10 – 25%	8,350 psi (58 MPa)	392.5 ksi (2,700 MPa)	118°F (48°C)	118°F (48°C)
PolyJet Amber Clear (a.k.a. FullCure RGD720)	85 (Shore D)	15 – 25%	8,350 psi (58 MPa)	435 ksi (3,000 MPa)	118°F (48°C)	118°F (48°C)
Endur (RGD450)	80 – 84 (Shore D)	20 – 35%	5,800 – 6,500 psi (40 – 45 MPa)	217 – 246 ksi (1,500 – 1,700 MPa)	113 – 122°F (45-50°C)	120 – 129°F (49-54°C)
PolyJet Flex & Over-Mold	27 –95 (Shore A)	25 – 220%	72 – 3,626 psi (0.5 – 25 MPa)	—	—	—

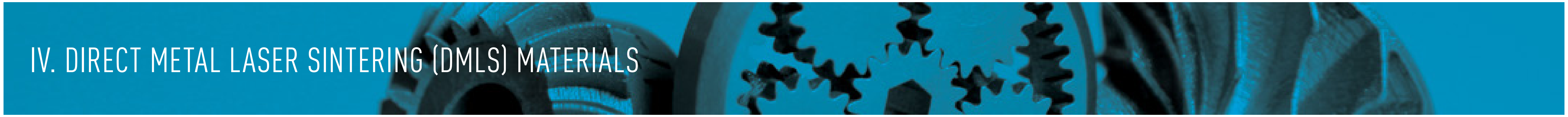
II. STEREOLITHOGRAPHY (SL) MATERIAL CHART

MATERIAL	HARDNESS (SHORE D)	ELONGATION @ BREAK	TENSILE STRENGTH	FLEXULAR MODULUS	HEAT DEFLECTION TEMP @264 psi	@66 psi
SLA White Prior Formulations: (SC 4500, SL7810, Accura 25, Next and Somos 18420)	80	4 – 7%	5,262 psi (36 MPa)	280 ksi (1,930 MPa)	107°F (42°C)	107°F (42°C)
SLA Clear Prior Formulations: *(Somos 10122, Accura 60 and Somos 11122)*	86	5 – 13%	6,800 psi (47 MPa)	296 ksi (2,041 MPa)	107°F (42°C)	115°F (46°C)
SC 5500	86	9 – 12%	7,120 psi *(49 MPa)*	335 – 350 ksi (2,275 – 2,413 MPa)	109 – 115°F (43 – 46°C)	120 – 127°F (49 – 53°C)
Somos NeXT	82	8 – 10%	5,961 – 6,280 psi (41.1 – 43.3 MPa)	350 – 366 ksi (2,415 – 2,525 MPa)	118 – 124°F (48 – 51°C)	131 – 134°F (55 – 57°C)
SLA Investment Cast Patterns	83	4 – 8%	7,758 psi (53 MPa)	280 ksi (1,930 MPa)	122°F (50°C)	127°F (53°C)

[6] Material charts are based on Stratasys Direct Manufacturing testing as well as the testing of materials by their respective manufacturers.

III. LASER SINTERING (LS) MATERIALS

MATERIAL	ELONGATION @ BREAK		FLEXURAL STRENGTH		FLEXURAL MODULUS		DENSITY	HEAT DEFLECTION TEMPERATURE @ 66 psi		HEAT DEFLECTION TEMPERATURE @ 264 psi		IZOD IMPACT STRENGTH		TENSILE MODULUS		TENSILE STRENGTH	
	XY AXIS	Z AXIS	XY AXIS	Z AXIS	XY AXIS	Z AXIS		XY AXIS	Z AXIS	XY AXIS	Z AXIS	NOTCHED	UNNOTCHED	XY AXIS	Z AXIS	XY AXIS	Z AXIS
NyTek™ 1200 PA	15%	4%	6,850 psi (47 MPa)	—	188.6 ksi (1,300 MPa)	—	0.034 lb/in³ (0.95 g/cm³)	350°F (177°C)	—	187°F (86°C)	—	4.12-lb/in (220 J/m)	8.24 ft-lb/in (440 J/m)	246.5 ksi (1,700 MPa)	—	6,815 psi (46 MPa)	—
Nylon 12 AF	1.5 – 3.5%		7,832 psi (54 MPa)		289.3 ksi (1,994 MPa)		0.049 lb/in³ (1.36 g/cm³)	351°F (177°C)		279°F (137°C)		—	—	373.8 ksi (2,577 MPa)		4,628 psi (32 MPa)	
Nylon 12 PA	4 – 15%		6,850 psi (47 MPa)		188.6 ksi (1,300 MPa)		0.034 lb/in³ (0.95 g/cm³)	350°F (177°C)		187°F (86°C)		4.12 ft-lb/in (220 J/m)	8.24 ft-lb-in (440 J/m)	246.5 ksi (1,700 MPa)		6,815 psi (46 MPa)	
Nylon 12 GF	1.5 – 3%		8,800 psi (61 MPa)		325 ksi (2,241 MPa)		0.045 lb/in³ (1.25 g/cm³)	354°F (179°C)		273°F (134°C)		0.8 ft-lb/in (40 J/m)	2.3 ft-lb-in (120 J/m)	420 ksi (2,896 MPa)		5,200 psi (36 MPa)	
Flex TPE	110%		—		—		0.214 lb/in³ (0.37 g/cm³)	—		—		—		1,160 psi (8 MPa)		—	
NyTek™ 1200 GF	3%	2%	10,500 psi (72 MPa)	8,800 psi (61 MPa)	411 ksi (2,834 MPa)	325 ksi (2,241 MPa)	0.045 lb/in³ (1.25 g/cm³)	354°F (179°C)		273°F (134°C)	—	0.8-lb/in (40 J/m)	2.3 ft-lb/in (120 J/m)	520 ksi (3,585 MPa)	420 ksi (2,896 MPa)	6,400 psi (44 MPa)	5,200 psi (36 MPa)
NyTek™ 1200 CF	5.7%	5.3%	16,400 psi (113 MPa)	10,200 psi (70 MPa)	880 ksi (6,067 MPa)	360 ksi (2,482 MPa)	0.0387 lb/in³ (1.07 g/cm³)	354°F (179°C)	350°F (177°C)	341°F (172°C)	260°F (127°C)	—	—	530 ksi (3,654 MPa)	357 ksi (2,461 MPa)	8,750 psi (60 MPa)	7,500 psi (51 MPa)
NyTek™ 1200 FR	8%	4%	—	—	217 ksi (1,500 MPa)	—	0.0368 lb/in³ (1.02 g/cm³)	351°F (177°C)	—	187°F (86°C)	—	4.12 ft-lb/in (220 J/m)	8.24 ft-lb/in (440 J/m)	247 ksi (1,700 MPa)	—	6,815 psi (46 MPa)	—
NyTek™ 1100	21%	12%	6,400 psi (44 MPa)	—	126 ksi (869 MPa)	—	0.0376 lb/in³ (1.04 g/cm³)	315°F (157°C)	—	122°F (50°C)	—	1.30 ft-lb/in (70 J/m)	26 ft-lb/in (1,370 J/m)	238.9 ksi (1,647 MPa)	—	6,817 psi (47 MPa)	—
FR-106	38%	21%	8,000 psi (55 MPa)	7,800 psi (54 MPa)	225 ksi (1,551 MPa)	220 ksi (1,517 MPa)	0.0376 lb/in³ (1.04 g/cm³)	—	—	—	—	1.30 ft-lb/in (70 J/m)	—	230 ksi (1,586 MPa)	210 ksi (1,448 MPa)	6,700 psi (46 MPa)	5,600 psi (39 MPa)



IV. DIRECT METAL LASER SINTERING (DMLS) MATERIALS

MATERIAL	ULTIMATE TENSILE STRENGTH	YEILD STRENGTH	ELONGATION AT BREAK	MODULUS OF ELASTICITY	HARDNESS	MAXIMUM OPERATING TEMPERATURE	THERMAL CONDUCTIVITY	COEFFICIENT OF THERMAL EXPANSION (CTE)
Stainless Steel 17-4 PH	142 ± 7 ksi (980 ± 50 MPa)	73 ± 7 ksi (500 ± 50 MPa)	25% ± 5%	25 ± 3 msi (170 ± 20 GPa)	230 ± 20 HV1	~1022 °F (~550 °C)	97 Btu/(h ft^2 °F/in) (14 W/m°C)	7.8 x 10^{-6} in/in°F (14 x 10^{-6} m/m°C)
Stainless Steel 316L	93 ± 7 ksi (640 ± 50 Mpa)	77 ± 8.7 ksi (530 ± 60 MPa)	40 ± 15 %	—	typ. 85 HRB	—	—	—
Aluminum AlSi10Mg	49 ± 6 ksi (340 ± 40 Mpa)	36 ± 2 ksi (250 ±15 MPa)	1.5 % ± 0.5 %	—	120 ± 5 HBW	—	—	—
Inconel 625	130 ± 7 ksi (900 MPa ± 50 MPa)	89 ± 7 ksi (615 MPa ± 50 MPa)	42% ± 5%	20.3 ± 3 msi (140 GPa ± 20 GPa)	~30 HRC (287 HB)	~1200 °F (~650 °C)	—	—
Inconel 718	142 ± 7 ksi (980 ± 50 MPa)	92 ± 7 ksi (634 ± 50 MPa)	31% ± 5%	—	~30 HRC (287 HB)	~1200 °F (~650 °C)	—	6.9 – 7.2 x 10^{-6} in/in°F (12.5 – 13 x 10^{-6} m/m°C)
Titanium Ti64	166 ± 9 ksi (1,150 ± 60 MPa)	150 ± 10 ksi (1,030 ± 70 MPa)	11% ± 2%	16 ± 1 msi (110 ± 7 GPa)	~400 – 430 HV (41 – 44 HRC)	~660 °F (~350 °C)	—	—
Cobalt Chrome CoCrMo	174 ± 22 ksi (1,200 ± 150 MPa)	116 ± 15 ksi (800 ± 100 Mpa)	24 % ± 4%	28 ± 3 msi (190 ± 20 GPa)	35 - 45 HRC	2100 °F (1150 °C)	90 Btu in/(h ft^2 °F/in) (13 W/m°C)	7.6 – 8.4 x 10^{-6} in/in°F (13.6 – 15.1 x 10^{-6} m/m°C)

V. FUSED DEPOSITION MODELING (FDM) MATERIALS

MATERIAL	TENSILE STRENGTH		TENSILE MODULUS		TENSILE ELONGATION @ BREAK		FLEXURAL STRENGTH		FLEXURAL MODULUS		IZOD IMPACT STRENGTH (NOTCHED)		HEAT DEFLECTION TEMPERATURE @ 264 psi
	XY AXIS	Z AXIS	XY AXIS	Z AXIS	XY AXIS	Z AXIS	XY AXIS	Z AXIS	XY AXIS	Z AXIS			
ABS	3,200 psi (22 MPa)		236,000 psi (1,627 MPa)		6%		6,000 psi (41 MPa)		266,000 psi (1,834 MPa)		2 ft-lb/in (106.78 J/m)		169°F (76°C)
ABS-M30	5,200 psi (36 MPa)		350,000 psi (2,400 MPa)		4%		8,800 psi (61 MPa)		336,000 psi (2,300 MPa)		2.6 ft-lb/in (139 J/m)		180°F (82°C)
ABS-ESD7	5,200 psi (36 MPa)		350,000 psi (2,400 MPa)		3%		8,800 psi (61 MPa)		350,000 psi (2,400 MPa)		0.5 ft-lb/in (28 J/m)		180°F (82°C)
ABSi	5,400 psi (37 MPa)		277,700 psi (1,920 MPa)		4%		8,980 psi (62 MPa)		278,000 psi (1,920 MPa)		1.8 ft-lb/in (96.4 J/m)		163°F (73°C)
ABS-M30i	5,200 psi (36 MPa)		350,000 psi (2,400 MPa)		4%		8,800 psi (61 MPa)		336,000 psi (2,300 MPa)		2.6 ft-lb/in (139 J/m)		180°F (82°C)
ASA	4,720 psi (33 MPa)	4,300 psi (30 MPa)	290,000 psi (2,010 MPa)	280,000 psi (1,950 MPa)	9%	3%	8,700 psi (60 MPa)	6,900 psi (48 MPa)	270,000 psi (1,870 MPa)	240,000 psi (1,630 MPa)	1.2 ft-lb/in (64 J/m)		196°F (91°C)
PC	9,800 psi (68 MPa)		330,000 psi (2,300 MPa)		5%		15,100 psi (104 MPa)		324,000 psi (2,200 MPa)		1.0 ft-lb/in (53 J/m)		261°F (127°C)
PC-ISO	8,300 psi (57 MPa)		289,800 psi (2,000 MPa)		4%		13,100 psi (90 MPa)		310,400 psi (2,100 MPa)		1.6 ft-lb/in (86 J/m)		260°F (127°C)
PC-ABS	5,000 psi (34 MPa)	4,300 psi (30 MPa)	260,000 psi (1,810 MPa)	250,000 psi (1,720 MPa)	5%	2%	8,500 psi (59 MPa)	6,000 psi (41 MPa)	250,000 psi (1,740 MPa)	225,000 psi (1,550 MPa)	3.7 ft-lb/in (196 J/m)		205°F (96°C)
ULTEM 9085	10,400 psi (71.6 MPa)		322,000 psi (2,200 MPa)		6%		16,700 psi (115.1 MPa)		362,600 psi (2,500 MPa)		2.0 ft-lb/in (106 J/m)		307°F (153°C)
NYLON-12	7,000 psi (48 MPa)	6,400 psi (44 MPa)	190,000 psi (1,310 MPa)	180,000 psi (1,241 MPa)	NO BREAK	10%	10,000 psi (69 MPa)	8,600 psi (59 MPa)	190,000 psi (1,310 MPa)	180,000 psi (1,241 MPa)	2.8 ft-lb/in (150 J/m)		131°F (55°C)
ULTEM 1010	11,735 psi (81 MPa)	4,209 psi (29 MPa)	402,000 psi (2,772 MPa)	325,000 psi (2,241 MPa)	3.3%	1.3%	20,835 psi (144 MPa)	11,184 psi (77 MPa)	409,000 psi (2,820 MPa)	324,000 psi (2,234 MPa)	0.8 ft-lb/in (41 J/m)	0.4 ft-lb/in (24 J/m)	415°F (213°C)