MATERIALS MATTER:

Selecting the Right Material for 3D Printing

proto labs®
Real Parts. Really Fast.®

3D PRINTING
CNC MACHINING
INJECTION MOULDING

TABLE OF CONTENTS

RESOURCES

Our online library of 3D printing content includes design tips, case studies, videos and other comprehensive white papers. We also have experienced customer service engineers who can discuss any design questions that may arise.

Find us online at **protolabs.co.uk** or call us at **+44 (0) 1952 683047**.

Materials must be suited to the application in order to have successful results. The properties of any material become increasingly important as a product progresses from concept and functional prototyping to production.

However, material properties can only be evaluated when the manufacturing process is considered. It is the combination of the material and the process that dictates the characteristics. For example, an alloy processed by die casting has different properties when it is metal injection moulded. Likewise, a thermoplastic will have different properties if it is injection moulded or CNC machined.

Additive manufacturing (AM), or 3D printing, is unique. It is different from all other manufacturing processes, so the material properties and characteristics of parts that it produces are different, even when using a nearly identical alloy or thermoplastic. In terms of material properties, it is not a matter of being better or worse; it is simply important to recognise that the results will be different.

Recognising that there is a difference, the following information will aid in the characterisation, and ultimately the selection, of materials from three widely used industrial 3D printing processes: direct metal laser sintering (DMLS), selective laser sintering (SLS) and stereolithography (SL).

Material Advancements

The materials used in 3D printing have been improving, as would be expected. These advancements have allowed the technology to move beyond models and prototypes to functional parts for testing, shop floor use and production.

And while the output of 3D printing is different from that of other manufacturing processes, it can offer a suitable alternative when seeking a direct replacement. Yet, its advantages increase when users experiment with the possibilities that it offers.

However, experimentation is a bit challenging because of 3D printing's differences that extend beyond, but are related to, material properties. However, experimentation is a bit challenging because of 3D printing's differences that extend beyond, but are related to, material properties.

Another complication is that 3D printing produces anisotropic properties where the values differ predominately in the X and Y (draw plane) vs. the Z orientation. The degree of anisotropism varies with each additive technology — direct metal laser sintering is the closest to isotropic, for example — but it should always be a consideration.

However, the material suppliers may not publish material specifications that document the change in properties from one axis to another, as the data behind these specifications can vary greatly by material, process and even type of machine.

By designing specifically for the 3D printing process, and adjusting the build orientation, anisotropism or inadequate material properties can be overcome. To achieve this, designers can leverage the experiences from past projects (or that of a qualified service organisation) to fill in the data gaps that exist because of the limited material properties data. When performance is critical, also consider independent lab testing of additive materials.

While success is dependent on material properties, they are not the only considerations. Each additive material and build process will also dictate characteristics such as maximum part size, dimensional accuracy, feature resolution, surface finish, production time and part cost. So it is advised to select a suitable material and then evaluate its ability to meet expectations and requirements related to time, cost and quality.

Material Selection

Generally, one or two material properties distinguish an additive material from all others. For example, if seeking the average tensile strength of polyamide (PA) 11, a stereolithography photopolymer maybe be a better option than a selective laser sintering PA. Conversely, if the heat deflection temperature (HDT) of an ABS is needed, the best option would be a sintered nylon.

Recognising that a few properties will separate one material from the others, the recommended approach for selecting a material for 3D printing is to first define what mechanical or thermal properties are critical. Then review the material options to find a fit. With the options narrowed, review other remaining properties to determine if the material will be acceptable for the project.

Since 3D printing is unique, a goal of finding a perfect match to a cast, moulded or machined material is ill-advised. Instead, investigate the material options to find the material that satisfies the most critical requirements.

Direct Metal Laser Sintering (DMLS)

DMLS uses pure metal powders to produce parts with properties that are generally accepted to be equal or better than those of wrought materials. Because there is rapid melting and solidification in a small, constantly moving spot, DMLS may yield differences in grain size and grain boundaries that impact mechanical performance. Research is ongoing to characterise the grain structures, which can change with the laser parameters, post-build heat treatment and hot isostatic pressing. However, the results are not widely available. Ultimately, this difference will become an advantage when grain structure can be manipulated to offer varying mechanical properties in a part.

Of the three additive manufacturing processes discussed here, DMLS produces parts with material properties that approach an isotropic state. However, there will be some property variance when measured along different axes. For a visual comparison of DMLS material properties, see Chart 1 for tensile strength, Chart 2 for elongation and Chart 3 for hardness.

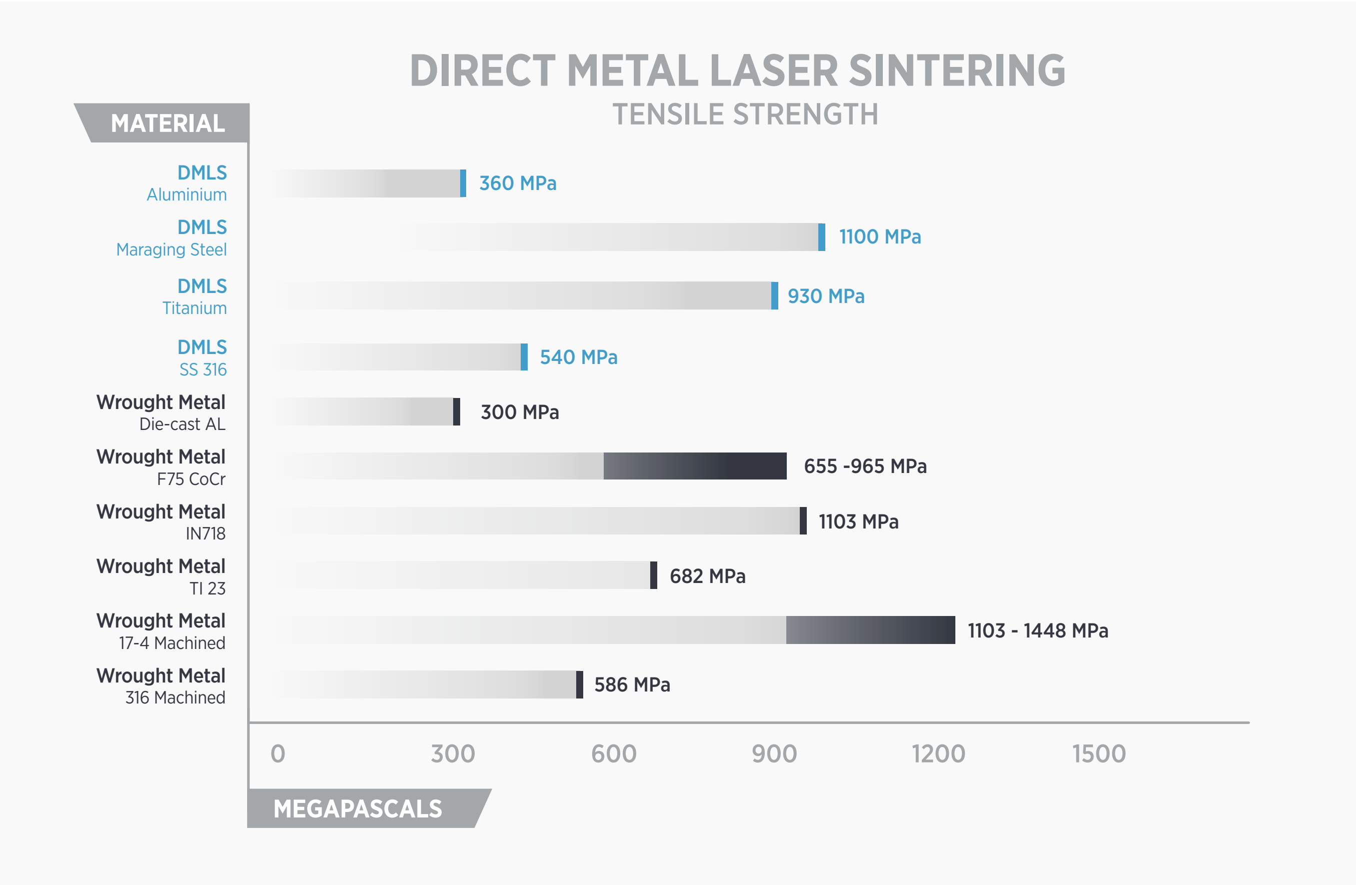


Chart 1

Stainless steel is a commonly used DMLS material and is available from Proto Labs in 316L, which has excellent elongation, offering 30% at break, making it very malleable. 316L offers acid & corrosion resistance and is more temperature resistant than most other materials in its stress relieved state.

DMLS aluminium (Al) is comparable to a 3000 series alloy that is used in casting and die casting processes. Its composition is AlSi10Mg. Al has an excellent strength-to-weight ratio, good temperature and corrosion resistance, and good fatigue, creep and rupture strength.

Compared to die-cast 3000 series aluminium, the Al properties for tensile strength (360 MPa +/- 30 MPa) and yield strength (240 MPa +/- 30MPa) far exceed the average values. However, elongation at break (EB) is significantly lower (3% vs. 11%) when compared to the average for 3000 series aluminiums.

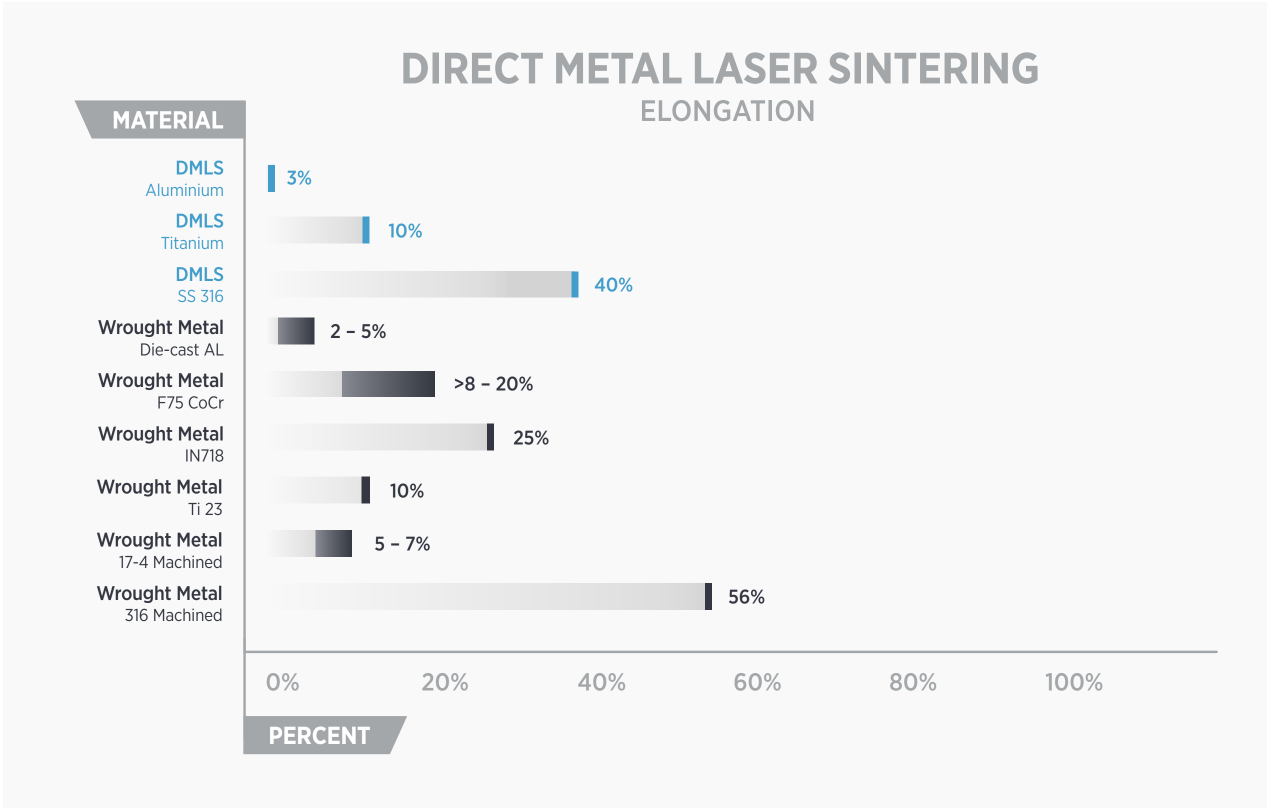


Chart 2

DMLS titanium (Ti6Al4V) is most commonly used for medical applications due to its strength-to-weight ratio, temperature resistance and acid/corrosion resistance. It is also used in medical applications. Versus Ti grade 23 annealed, the mechanical properties are nearly identical with a tensile strength of 930 MPa, elongation at break of 10% and hardness of 36 HRC.

Maraging steel is known for possessing superior strength and toughness without losing malleability. It is a special class of low-carbon ultra-high-strength steels that derive their strength not from carbon, but from precipitation of intermetallic compounds. It is curable up to 37 HRC with high temperature resistance. Its uniform with its uniform expansion and easy machinability before aging makes maraging steel useful in high-wear components of assembly lines and dies.

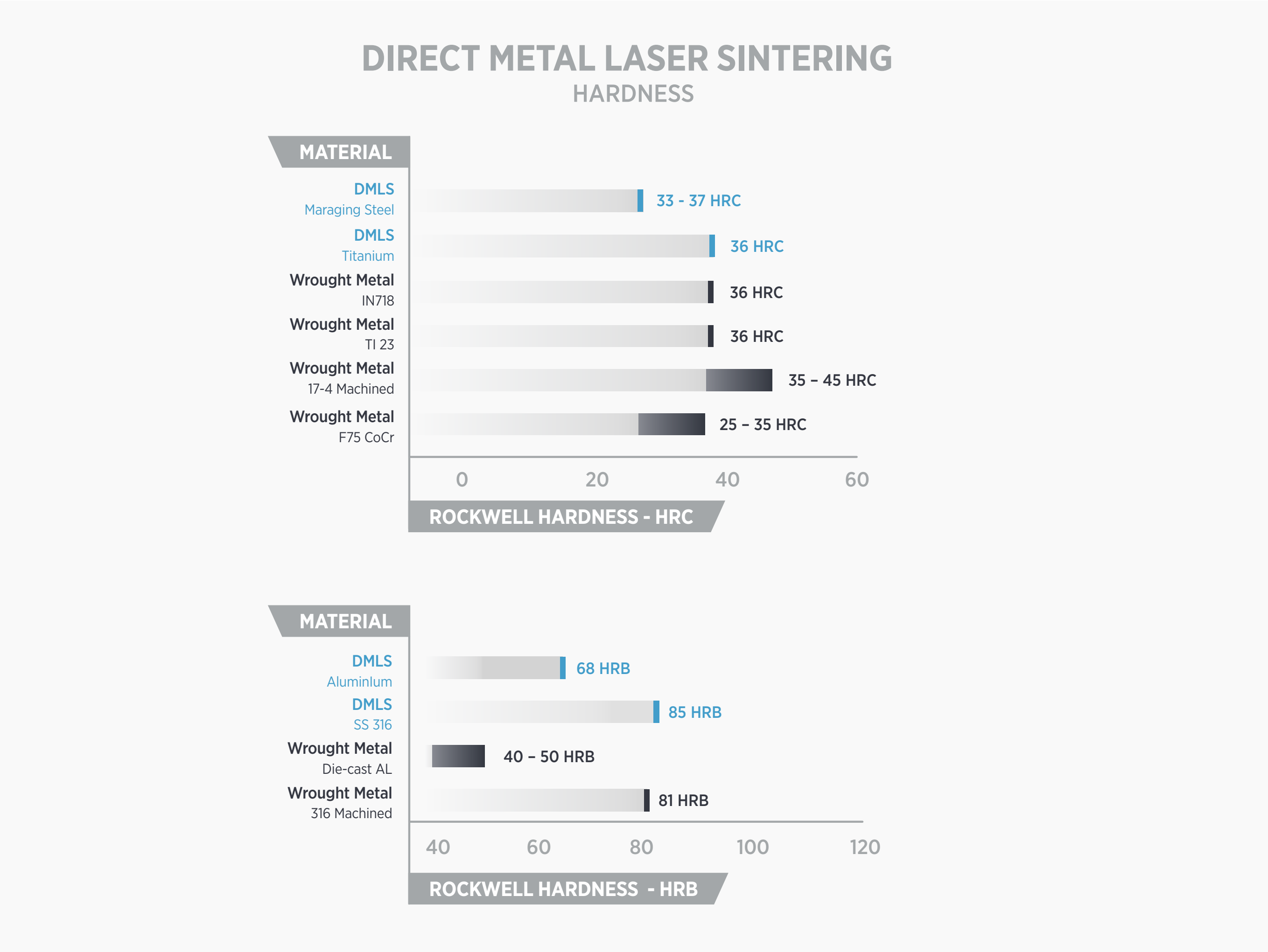


Chart 3

Selective Laser Sintering (SLS)

SLS uses thermoplastic powders, predominantly polyamide (PA), to make functional parts that have greater toughness and higher impact strength than parts produced through stereolithography (SL), as well as high HDTs (177°c to 188°c). The tradeoffs are that SLS lacks the surface finish and fine feature details available with SL.

Generally, SLS PAs, when compared with the average values of their injection moulded counterparts, have similar HDT values but lower values for the mechanical properties. In a few instances, SLS PAs report properties that document the degree of anisotropism. For a visual comparison of SLS mineral properties, see Chart 4 for heat deflection, Chart 5 for elongation at break and Chart 6 for tensile strength.

PA 850 Black delivers ductility and flexibility with a tensile modulus of 48 MPa and EB of 51%, all without sacrificing tensile strength (48 MPa) and temperature resistance (HDT of 188°c). These characteristics make PA 850 a popular general-purpose material and the best solution for making living hinges for limited trials.

When compared to the averages for injection-moulded PA 11, PA 850 has a higher HDT (188°c vs 140°c) with similar tensile strength and stiffness. However, its EB, while the highest of all AM plastics, is 60% less than that for a moulded PA 11.

Another factor that distinguishes PA 850 is its uniform, deep-black colour. Black has high contrast, which makes features pop standout, and it hides dirt, grease and grime. Black is also desirable for optical applications due to low reflectivity.

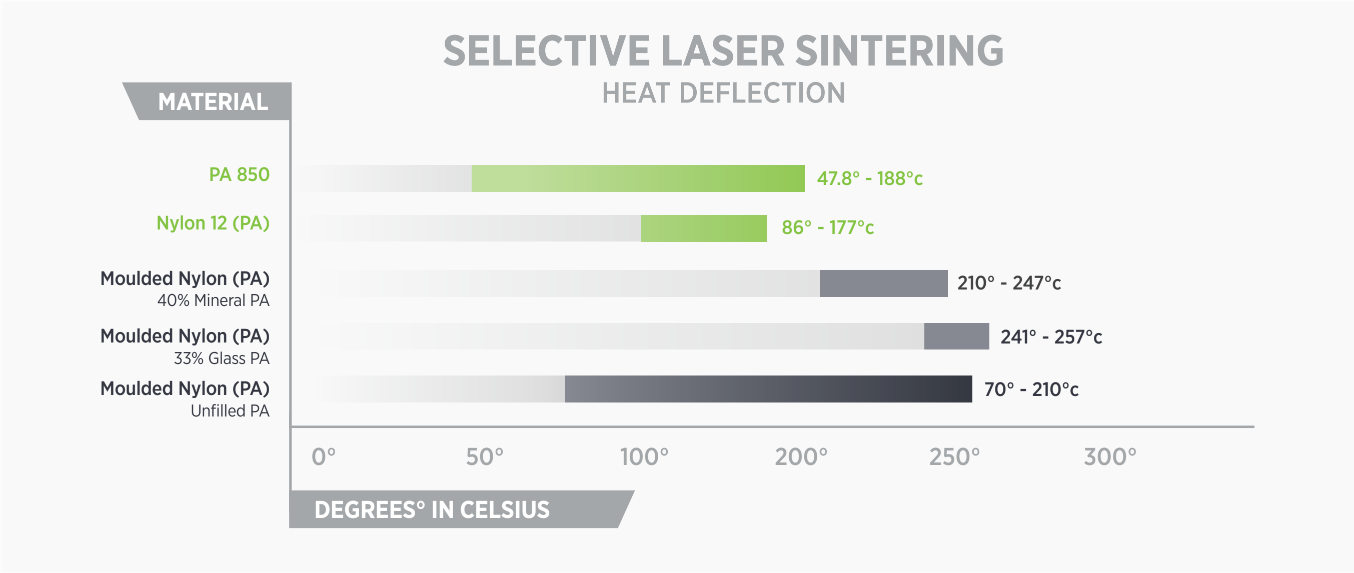


Chart 4

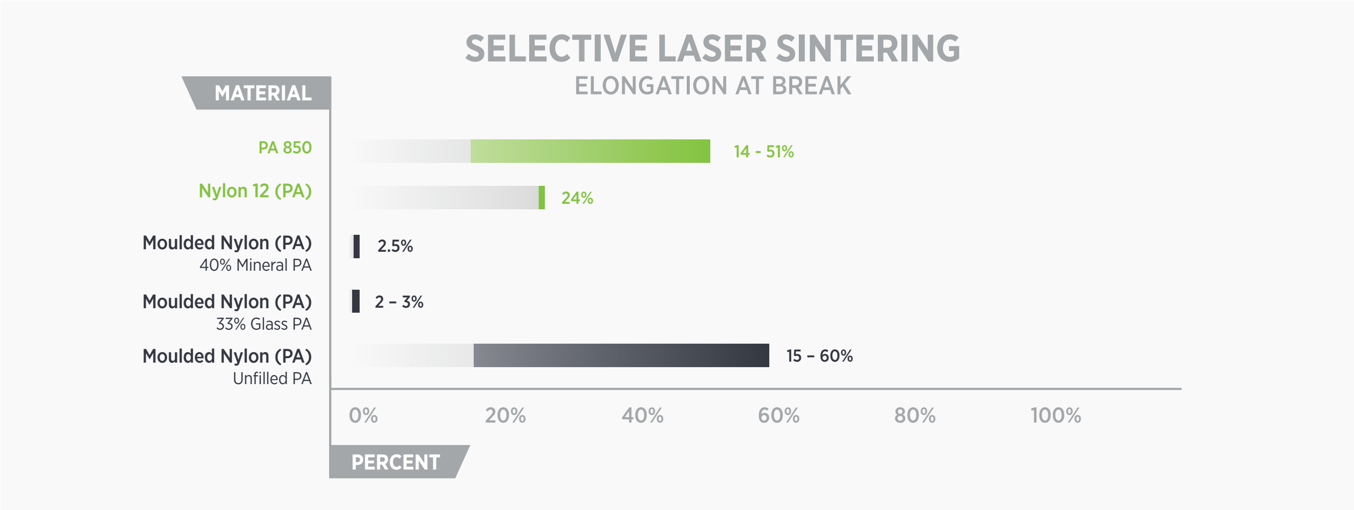


Chart 5

Nylon 12 PA is a balanced, economical, go-to material for general-purpose applications. Nylon 12 PA is stiffer than PA 850 (tensile modulus of 1703 MPa vs. 1475 MPa) and has a similar tensile strength (48 MPa. While its EB is half that of PA 850, at 24% it's still one of the top performers in terms of ductility. Nylon 12 PA is loosely comparable to the average properties for an injection moulded PA 12. It has similar stiffness but roughly half the tensile strength and EB. However, its HDT is significantly higher: 177°c vs. 138°c.

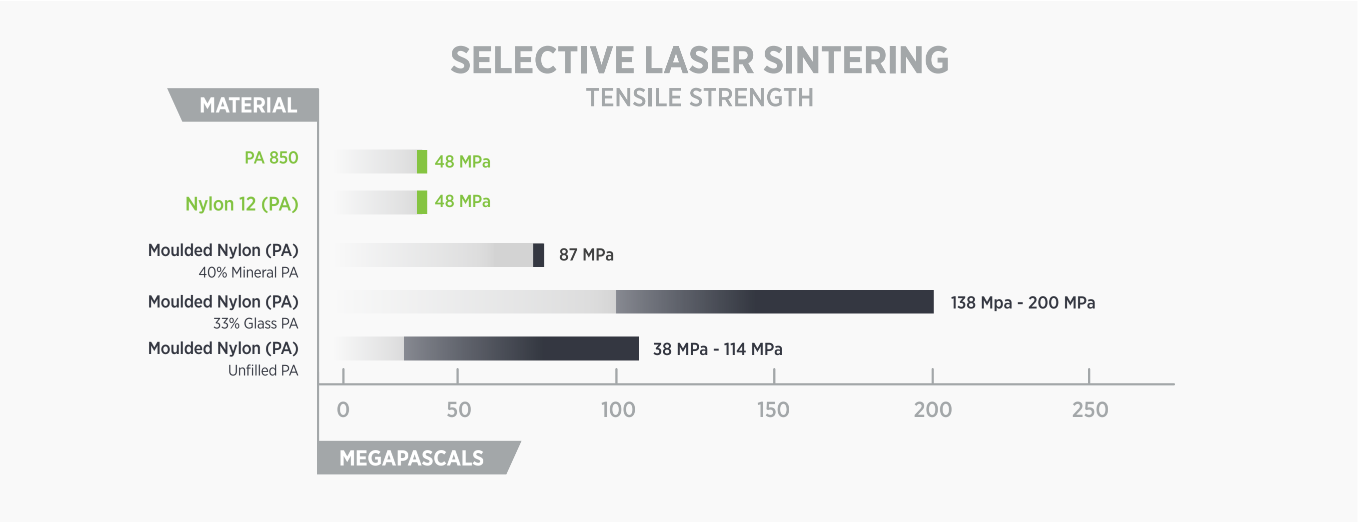


Chart 6

Stereolithography (SL)

SL uses photopolymers, thermoset resins cured with ultraviolet (UV) light. It offers the broadest material selection with a large range of tensile strengths, tensile and flexural moduli, and EBs. Note that the impact strengths and HDTs are generally much lower than those of common injection-moulded plastics. The range of materials also offers options for colour and opacity. Combined with good surface finish and high feature resolution, SL can produce parts that mimic injection moulding in terms of performance and appearance.

The photopolymers are hygroscopic and UV sensitive, which may alter the dimensions and performance of the part over time. Exposure to moisture and UV light will alter the appearance, size and mechanical properties. For a visual comparison of SL material properties, see Chart 7 for heat deflection, Chart 8 for elongation at break and Chart 9 for tensile strength.

Accura Xtreme White 200 is a widely used SL material. In terms of flexibility and strength, it falls between polypropylene and ABS, which makes it a good choice for snap fits, master patterns and demanding applications. Xtreme is a durable SL material; it has a very high impact strength (64 J/M.) and a high EB (20%) while mid-range in strength and stiffness. However, its HDT (47°c) is the lowest of the SL materials.

Compared to the average value for injection-moulded ABS, Xtreme can have a slightly higher tensile strength (45 MPa - 50 MPa) but slightly lower EB (20% vs. 30%).Under a flexing load, Xtreme is 26% less rigid, and its impact strength is 70% lower.

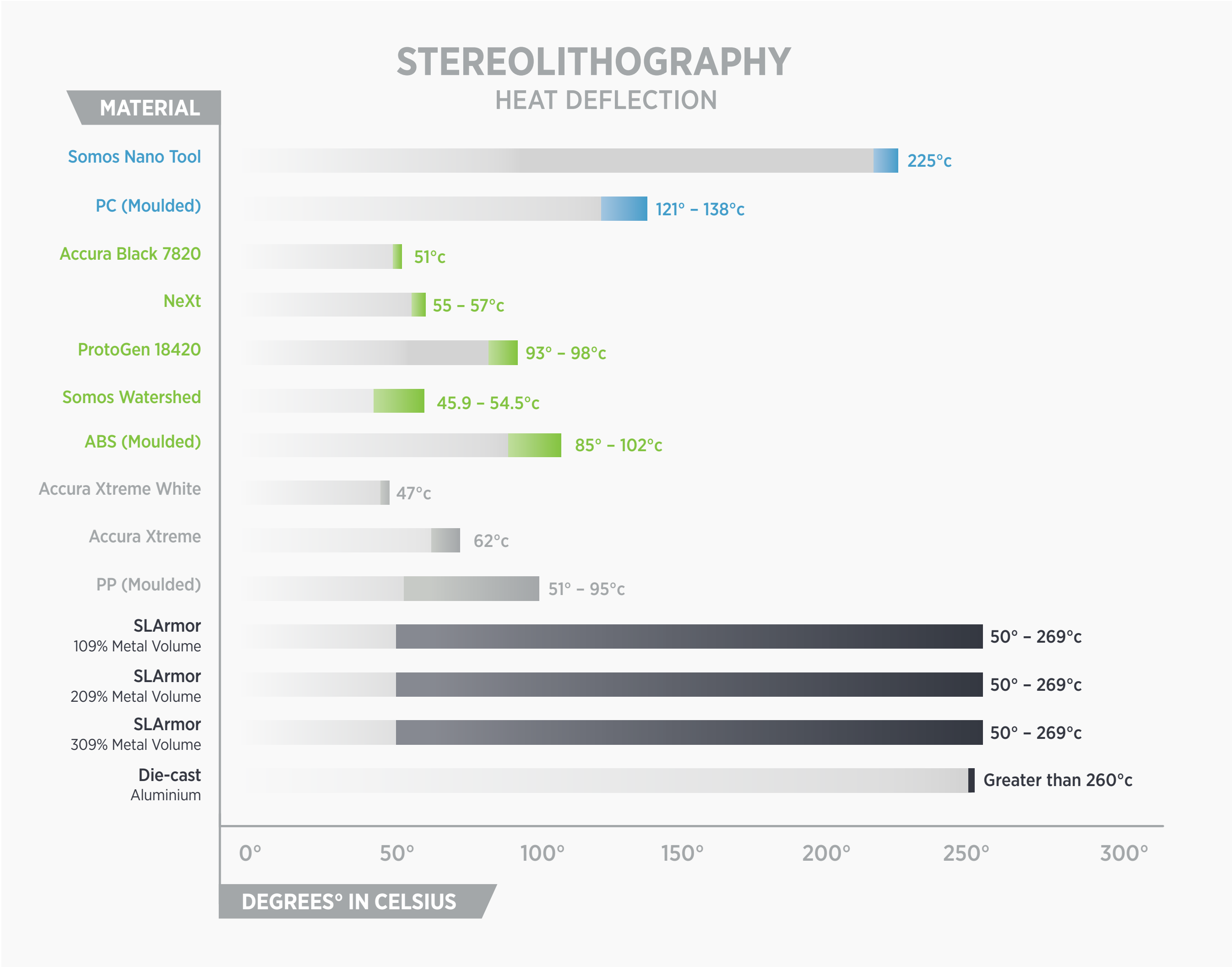
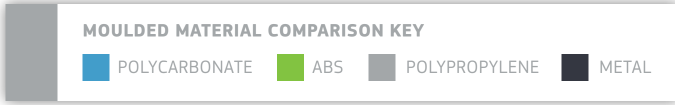


Chart 7



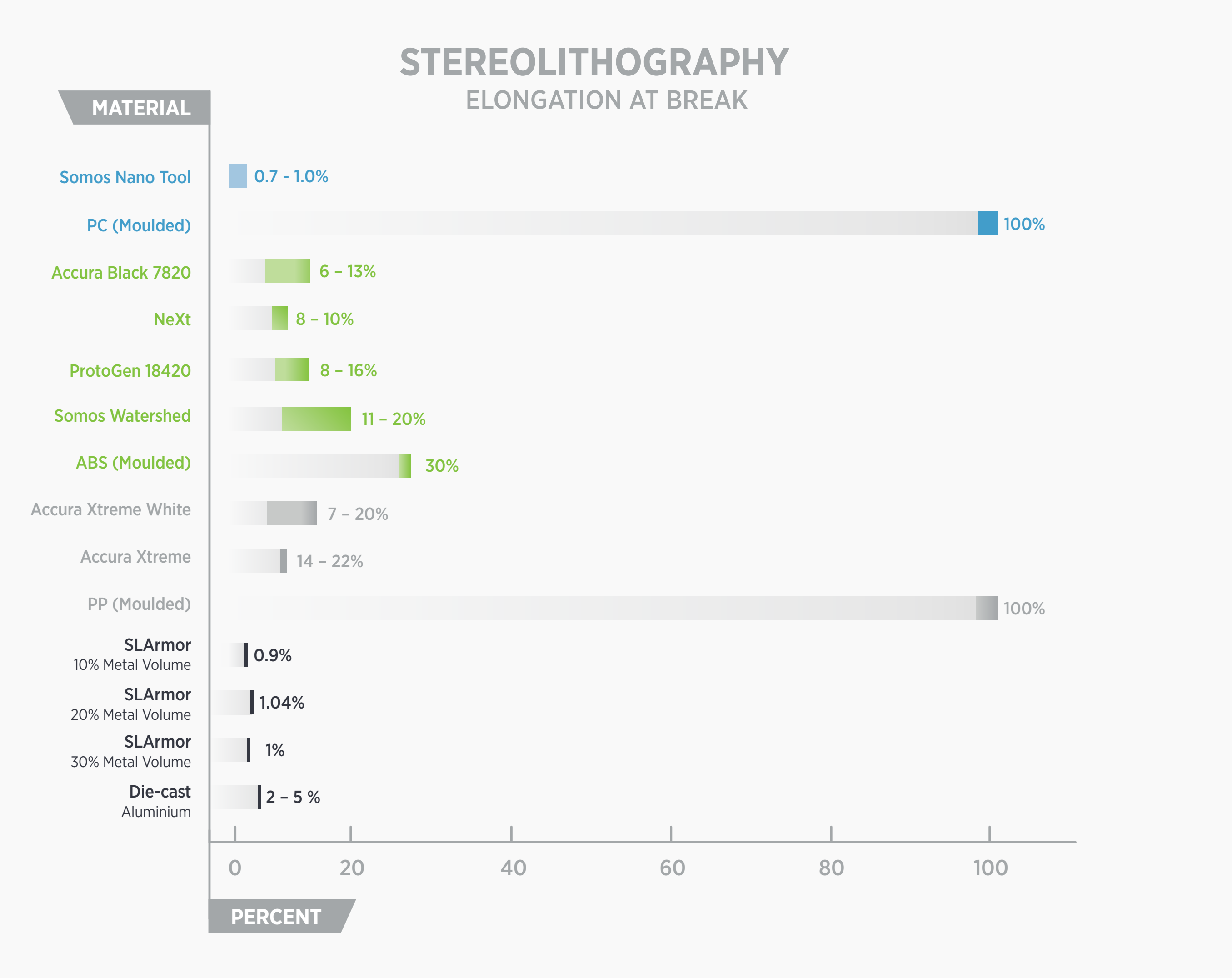
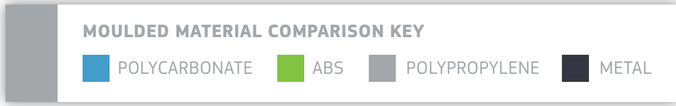


Chart 8



Accura Xtreme is similar to polypropylene (PP)/ABS and is a tough, durable material. It is very suitable for snap fits, assemblies and demanding applications.

Somos WaterShed XC 11122 offers a unique combination of low moisture absorption (0.35%) and near-colourless transparency — secondary operations will be required to get the material completely clear, and it will also retain a very light blue hue afterward. While good for general-purpose applications and pattern-making, WaterShed is the best choice for flow-visualisation models, light pipes and lenses.

Watershed's tensile strength and EB are among the highest of 3D-printed, thermoplastic-like materials, which makes it tough and durable. Compared to average injection-moulded ABS values, Watershed offers a slightly higher tensile strength (50.4 MPa vs. 53.6 MPa), but falls short in EB (15.5% vs. 30%) and HDT at 50°c vs. 102°c.

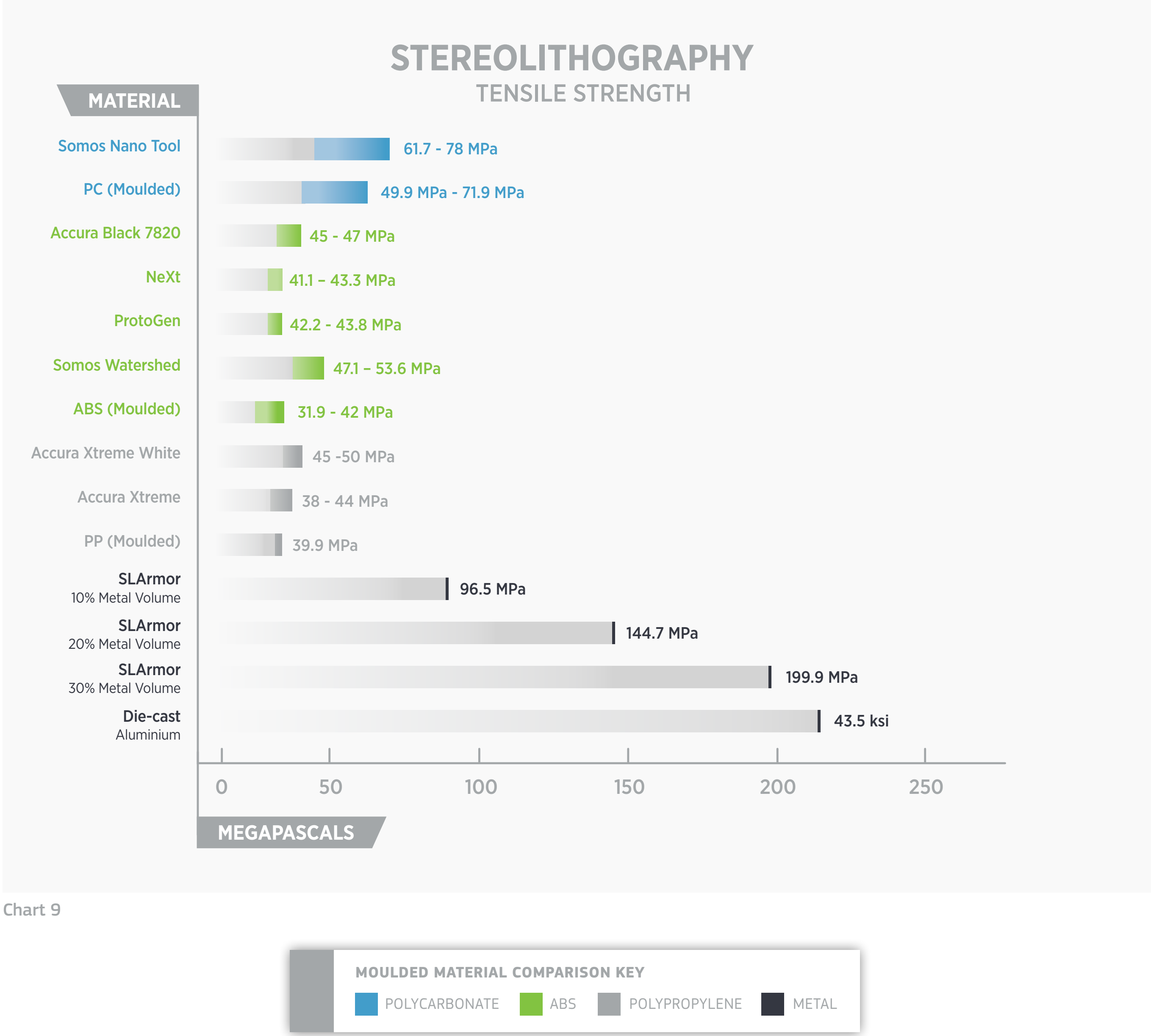


Chart 9

Accura Black 7820 is a liquid that produces strong black models and prototypes with good surface finish and detail, and ABS-like appearance. It offers a large working envelope of physical properties, high EB (6-13%) and impact strength suitable for building concept models, and functional prototype parts.

DMS Somos Nano Tool produces strong, stiff, high temperature resistant composite parts on conventional stereolithography machines. This material is heavily filled with non-crystalline nanoparticles allowing for faster processing. It exhibits superior sidewall quality, along with excellent detail resolution compared to other composite stereolithography materials.

NeXt is an extremely durable stereolithography (SL) resin that produces very accurate parts with high feature detail. It is a next generation of material that facilitates the production of tough, complex parts with improved moisture resistance and greater thermal properties.

ProtoGen 18420 is a liquid, ABS-like, photopolymer that produces accurate parts ideal for general purpose applications. It offers superior chemical resistance, and excellent tolerance to a broad range of temperatures and humidity, both during and after the build.

Conclusion

Spanning metals, thermoplastics and thermosets, 3D printing provides many different materials that can simulate, if not replace, those that are processed through conventional means. While an exact match is not possible, since the fundamental processes are different, the material breadth means that there is a strong likelihood that the important material characteristics are satisfied.

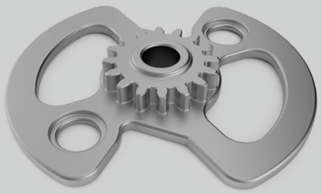
The key to success is being open to, and cognizant of, the differences. With the support of an informed, qualified 3D printing resource that can fill in the data gaps, this mindset opens the door to leveraging the unique advantages that 3D printing technology can offer.

>>Sources:

matweb.com, ulprospector.com, vendor datasheets and protolabs.co.uk.

Decision Tree: DMLS Material

METAL



ATTRIBUTES	DMLS
STRENGTH	Titanium Ti6Al4V Maraging Steel
LIGHTWEIGHT	Aluminium Titanium Ti6Al4V
TEMPERATURE RESISTANCE	Titanium Ti6Al4V
CORROSION RESISTANCE	Titanium Ti6Al4V Stainless Steel 316L
STRENGTH-TO-WEIGHT RATIO	Aluminium

DIRECT METAL LASER SINTERING (DMLS)

Stainless Steel TS: 540 MPa Elongation: 40% Hardness: 85 HRB	**Aluminium** TS: 360 MPa Elongation: 3% Hardness: 68 HRB
Titanium TS: 930 MPa Elongation: >10% Hardness: 36 HRC	**Maraging Steel** TS: 1100 MPa Elongation: 4% Hardness: 33 - 37 HRC*

*50 - 56 HRC with optional heat treatment

KEY

TS — TENSILE STRENGTH

Decision Tree: SL and SLS Material

STEREOLITHOGRAPHY (SL)

Accura Xtreme White 200 Similar to: PP/ABS HD: 47°c EB: 7 – 20% TS: 45 – 50 MPa	**Accura Xtreme** Similar to: PP/ABS HD: 62°c EB: 14 – 22% TS: 38 – 44 MPa	**Somos WaterShed XC 11122** Similar to: ABS HD: 45.9 – 54.5°c EB: 11 – 20% TS: 47.1 – 53.6 MPa
Accura Black 7820 Similar to: ABS HD: 51°c EB: 6 – 13% TS: 45 – 47 MPa	**NeXt** Similar to: ABS HD: 55 – 57°c EB: 8 – 10% TS: 41.1 – 43.3 MPa	
Somos NanoTool Similar to: 10% GF PC HD: 225°c (258 – 263°c*) EB: 0.7 – 1% TS: 61.7 – 78 MPa	**ProtoGen 18420** Similar to: ABS HD: 53 – 56°c (93 – 98°c*) EB: 8 – 16% TS: 42.2 - 43.8 MPa	

* With Optional Thermal Postcure

SELECTIVE LASER SINTERING (SLS)

PA 850 Black Material Type: Nylon 11 HD: 188°c EB: 51% TS: 48 MPa	**Nylon 12 PA** Material Type: Nylon 12 HD: 177°c EB: 18 – 24% TS: 48 MPa

KEY

- **HD** – HEAT DEFLECTION
- **EB** – ELONGATION AT BREAK
- **TS** – TENSILE STRENGTH

PLASTIC

ATTRIBUTES	SL / SLS
STRENGTH	NeXt Accura Xtreme Accura Extreme White Nylon 12 PA
TRANSPARENCY	Somos WaterShed XC 11122
WATER RESISTANCE	NeXt Somos WaterShed XC 11122
TEMPERATURE RESISTANCE	Somos NanoTool ProtoGen 18420 Nylon 12 PA
HIGH RESOLUTION	Accura Black Somos WaterShed XC 11122 Accura Xtreme White 200
DURABILITY	NeXt Accura Xtreme White 200 Nylon 12 PA PA 850 Black
STIFFNESS	Somos NanoTool NeXt Accura Xtreme Nylon 12 PA
IMPACT RESISTANCE	Accura Black 7820 Accura Xtreme White 200 Nylon 12 PA
COLOUR	Accura Black 7820 NeXt ProtoGen 18420 Accura Xtreme PA 850