CURTISS-WRIGHT

IMR TEST LABS

MATERIALS TESTING FOR THE ADDITIVE MANUFACTURING INDUSTRY

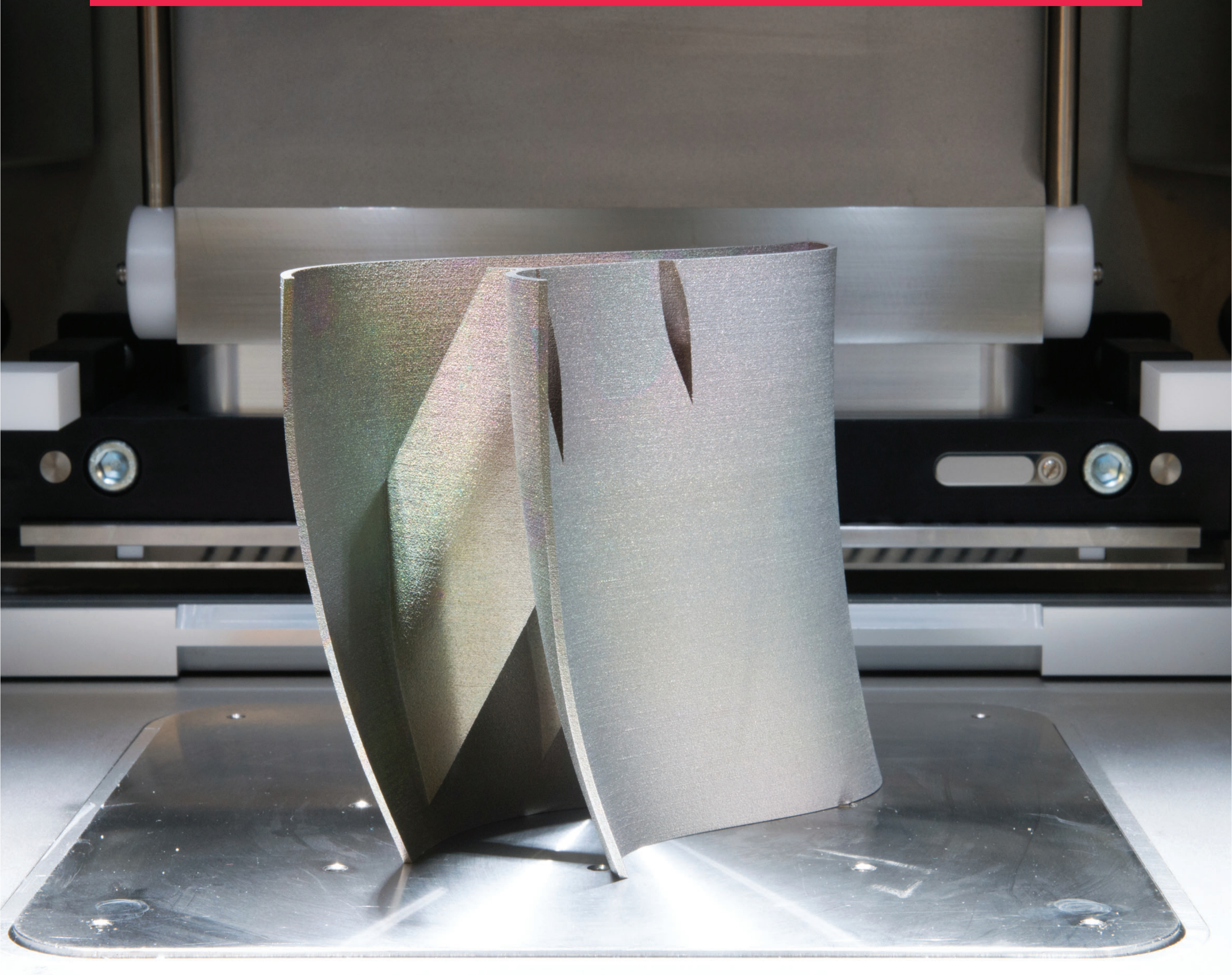


TABLE OF CONTENTS

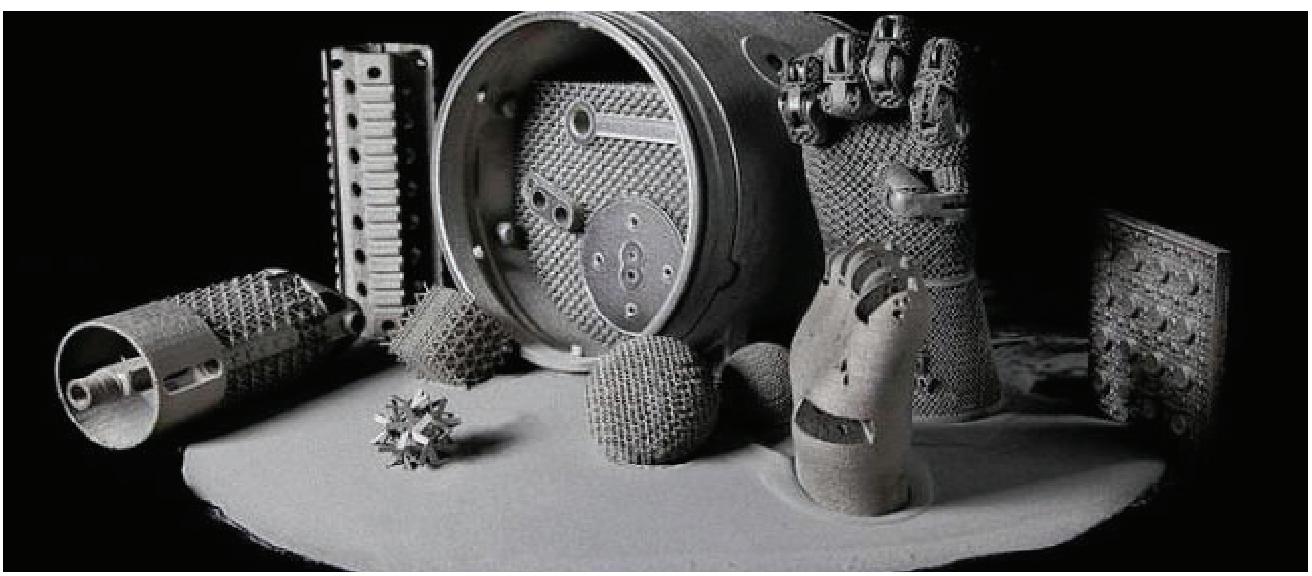
Additive Manufacturing Raw Materials and Finished Products Testing

While the rapid growth of additive manufacturing (AM) technology has helped engineers in many industries create innovative new component designs, the unusual nature of the necessary raw materials and the resulting printed structures has created significant materials testing challenges.

- The intricate designs and the uniqueness of the sintered or deposited alloy microstructures create challenges in mechanical testing and metallography.
- The increasing development of new alloys that improve the performance and strength of sintered structures, as well as minimizing the need for post print processing, create interesting challenges in analytical chemistry.
- The lack of known properties for the many new alloys and materials results in the need for determining a wide range of fundamental properties, such as true microstructure, density, strength, fracture toughness and more.
- In addition, the rapid growth of AM implementation at start-ups and existing companies has resulted in not only materials testing challenges but significant issues with capacities and skilled engineers in the laboratory industry.

The raw materials used in 3D printing are diverse: wire and powdered nickel, steel and titanium alloys; polymer resins and filaments. There has been a constant push towards lighter, stronger, and tougher materials in just about every market sector as AM expands its capabilities to produce ever more varied products. While the technology both in raw materials and production methods has evolved greatly, the need for determining critical material characteristics is vital if AM is to continue to advance its capacity for creating complex and durable products, especially in high performance applications.

To review a list of other additive manufacturing methods, please refer to pages 7-8.



Testing Methods for Raw Materials and Finished Components

With new frontiers of complexity, materials, and applications, many additive manufacturing (AM) challenges are being overcome through the use of materials testing and analysis. This starts with the need for well characterized raw materials such as powders, pastes, and wires. SLS powders especially need continual testing due to the need to reuse unsintered powder without affecting the end product.

Final part quality requires the analysis of a wide array of properties, based not only on the end use of the part, but also the AM process being used to produce them.

Below are some of the many properties that need to be determined through materials testing.

Powder Characterization Methods

Chemical Analysis

- ICP-Atomic Emission Spectroscopy
- ICP-Mass Spectrometry
- Combustion and Inert Gas Fusion
- C, S, N, O, H
- OES
- FTIR

Physical Testing

- Microstructure
- Laser Diffraction
- Sieving

Density

- Skeletal Density/Pycnometry
- Archimedes
- Hall
- Tap

Flow

- Hall
- Carney
- Angle of Repose

Finished Material Testing Methods

Mechanical Testing

- Tensile - Yield - Elongation
- Compression
- Impact

Durability

- Fatigue
  - Axial
  - Rotating Beam Fatigue
- Fracture Toughness

Metallurgy

- Grain Size
- Microstructure
- Porosity

Physical Characteristics

- Density
- Porosity
- Hardness
- Microhardness

Potential Problems Revealed By Materials Testing

Porosity

Created when small pockets of air get formed in the body of the part or component being printed. It can be in the form of a process-induced porosity, or a gas-induced porosity. This can lead to cracks and fatigue due to a reduction in the density of the part.

- **Testing Methods:** **Helium Pycnometer, Metallographic Analysis**

Density

This measurement is in a direct inverse relationship with porosity. A reduction in density due to porosity can lead to fatigue and cracking when pressure is applied. An evaluation of Particle Size Distribution is helpful, since a proportional number of small particles can fill in the gaps around the larger particles, reducing porosity and increasing density.

- **Testing Methods:** **Archimedes, Helium Pycnometer, Microstructure Analysis**

Residual Stress

During the metal 3D printing process, residual stress is created due to the inherent heating/cooling cycles, as well as expansion/contraction. Cracking can occur when the residual stress exceeds the printing material's tensile strength. The most vulnerable location for this issue is the common interface between the part being manufactured and the build plate.

- **Testing Methods:** **X-Ray Diffraction (XRD), Hole Drilling**

Cracking

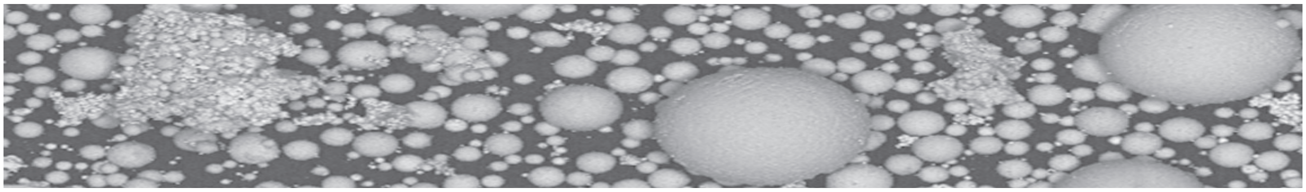
When melted metal solidifies, the risk of cracking increases. Careful monitoring of the energy source to keep its output level consistent and moderate during production/printing will help mitigate the potential for damage. The quality and characteristics of the alloy powder are critical in maintaining the integrity of the printed part. Delaminating can also occur when powder is not melted to an adequate level, or escapes to form a re-melting layer under the melt pool.

- **Testing Methods:** **Ultrasonic, Metallography**

Functional Strength

In addition to providing incredible flexibility in design, additive manufactured products need to meet strength and durability standards. Mechanical testing offers a variety of methods.

- **Testing Methods:** **Tensile, Fatigue, Fracture Toughness**

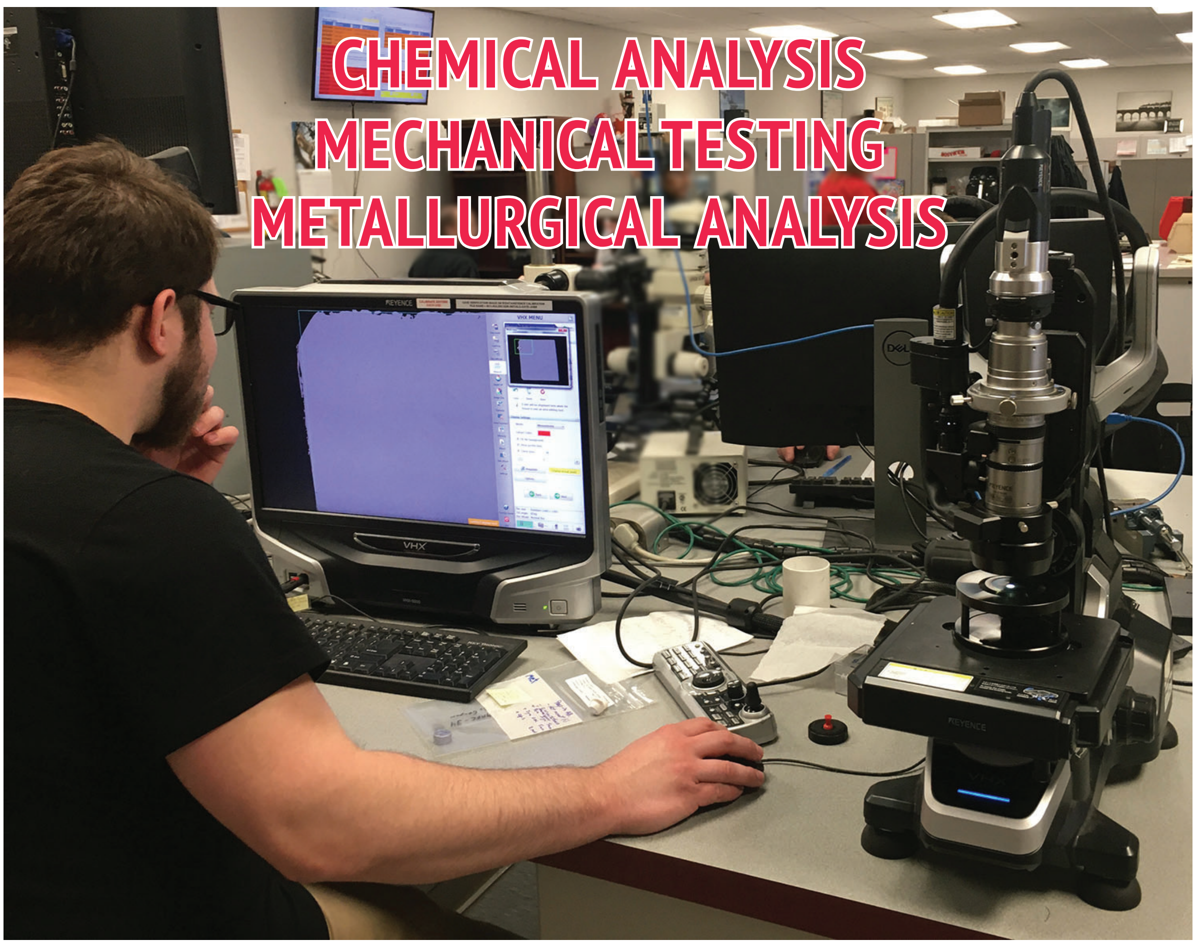


Additive Manufacturing Testing Capabilities at IMR Test Labs

Due to the exponential growth of additive manufacturing over the last several years, IMR Test Labs has invested in additional equipment, technology and experienced technicians to meet our customer's needs.

We've expanded our capabilities in raw material characterization and finished product metal testing & analysis to help manufacturers quickly and accurately make important evaluations in their products design, development and production phases. We've increased efficiencies and dedicated resources to help our AM customers get quicker turnaround on quotes and jobs.

Quality is a priority at IMR Test Labs and IMR has a strict control system in place to ensure testing is completed with the utmost integrity. IMR is a Nadcap and A2LA (ISO 17025) approved laboratory and holds accreditations from Boeing, GE, Pratt & Whitney, Rolls Royce, and many more.



Analytical / Testing Services for Additive Manufacturing

IMR provides comprehensive powder analysis to fully characterize the raw materials via test methods such as chemical analysis (ICP-AES, ICP-MS), particle size testing (Microtrac) and morphology analysis (XRD, SEM and Microscopy).

With the push towards lighter, more durable products created with AM technology, supply chains need to insure that their products meet or exceed physical characteristic specifications. IMR is able to provide an array of analytical services for finished products.

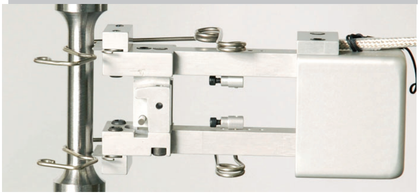
For more information on analytical services offered by IMR visit www.imrtest.com .

Metallurgical Analysis

- Microstructure
- Metallography/ Materialography
- Porosity Evaluation
- Quantitative Image Analysis
- Macroetch/Microetch
- Microhardness (Knoop, Vickers, MacroVickers)
- SEM Analysis
- Failure Analysis
- Fractography/Fracture Mechanics
- Alpha Case
- Decarburization
- Intergranular Attack
- Intergranular Oxidation
- Phase Volume Determination

Mechanical Testing

- Tensile Testing - Metals (to 2000°F)
- Fatigue Testing (Axial, Low Cycle, High Cycle, Rotating Beam, Shear)
- Fracture Mechanics
- Hardness (Rockwell, Brinell)
- Bend Testing (3 Point, 4 Point)
- Bond Strength Testing
- Coefficient of Thermal Expansion by TMA
- Creep & Stress Rupture
- Flexural Properties (Modulus, Strength, Stress-Strain Response)
- Shear Properties
- Charpy Impact Testing (-320°F to 450°F)



Chemical Analysis

- Alloy Chemistry/ Verification
- C, H, O, N, S
- Density
- Heavy Metal Impurities
- ICP-AES Analysis
- ICP-MS Trace Element Analysis
- Material Certification
- SEM/EDX
- Particle Size Analysis
- Sieve Analysis
- Cleanliness Testing
- OES Analysis
- Phase Identification
- X-Ray Diffraction (XRD)
- XRF Chemistry
- Unknown Material ID

Additive Manufacturing Production Processes Reference Guide

To ensure consistent production outcomes, the raw materials used need to have characteristics that will provide reliable reactions to the various AM manufacturing methods, such as:

SLA- Stereolithography

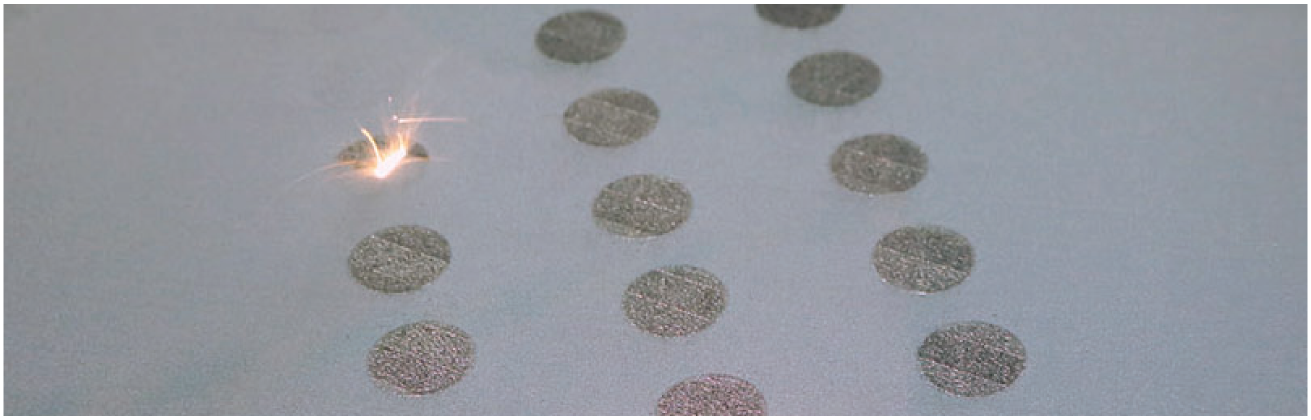
Popular for creating finely detailed shapes. Liquid photopolymers are heated into semi-liquid form, then formed into shapes layer by layer, hardening on contact during the construction

DLP- Digital Light Processing

The oldest and most economical 3D printing technology. Similar to SLA for its ability to handle photopolymers. Very common in prototyping. DLP uses arc lamps instead of Ultra Violet Light to harden the processed plastic. Results in much faster print times, while still delivering high resolution models.

FDM- Fused Deposition Modeling

A popular technology for creating functioning prototypes, proof-of-concept models, and manufacturing jigs and fixtures. Very accurate detailing, and exceptional strength to weight ratio.



SLS- Selective Laser Sintering

A 3D printing machine powder bed is lowered incrementally through the laser scanning process. Un-sintered powders are used to help support the structure during the build, eliminating the need to design support structures in the part. It's a fast, high-quality process that is perfect for end-use, functional parts and prototypes.

SLM- Selective Laser Melting

Using a high-powered laser beam, this process melts and fuses various metallic powders together. The main difference between SLS and SLM, is that SLS only partially melts the powder, where SLM melts the powder completely. SLM products tend to have fewer or no voids, producing a stronger component. This process is especially useful for 3D parts that have complex structures, geometries and thinner walls.

EBM- Electron Beam Melting

Given the broad spectrum of conditional tolerances required by most aerospace components, DMA testing characterizes a material's properties, such as stiffness, as a function of temperature, time, frequency, stress, or atmosphere.

Wire Arc Additive Manufacturing

Unlike the more common metal powder AM processes, Wire Arc Additive Manufacturing works by melting metal wire using an electric arc as the heat source. The wire, when melted, is then extruded in the form of beads on the substrate. As the beads stick together, they create a layer of metal material. The process is then repeated, layer by layer, with a robotic arm, until the metal part is completed. unlike the more common metal powder AM

LOM- Laminated Object Manufacturing

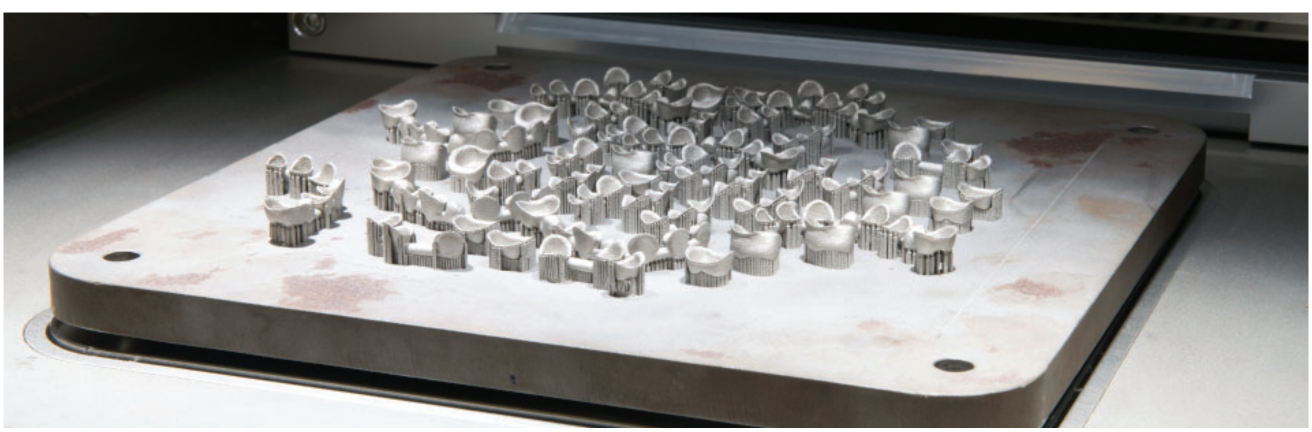
A rapid prototyping system, this process uses heat and pressure to cut a fused material (laminated layers of plastic or paper). A new laminated sheet is rolled out and cut again by the laser nozzle. Despite it's unpopularity as a test process, LOM is one of the fastest and most affordable rapid prototyping systems in existence.

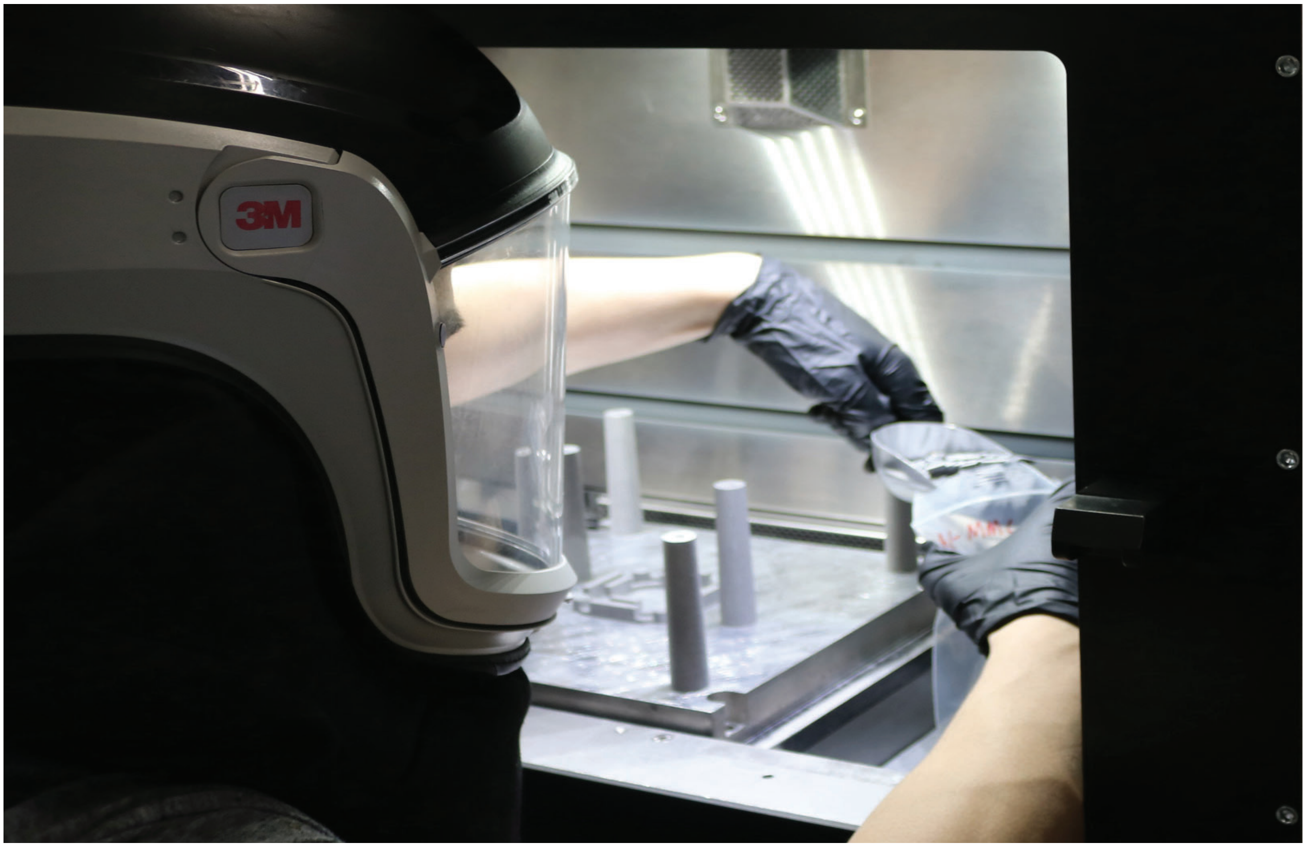
BJ- Binder Jetting

Using a powder-based material and a bonding agent, the printer nozzles extrude the binder in liquid form. After each layer is finished, the build plate lowers the distance equivalent to the thickness of a new powder layer that is swept over the entire fixture.

MJ- Material Jetting

Also known as wax casting, this process is used to produce high-resolution parts, mostly for dental and jewelry industries. No post-curing is needed, but a gel is used to provide support during the layering of more complex geometries. Once cleaned, the parts are completely ready to go – no further post-curing is needed.





Photos on Pages 7 and 9 Courtesy of Incodema 3D

ABOUT US

We are strongly committed to our vision and strategy to ensure that we keep meeting and exceeding your expectations. Our vision is alive and well, and you can see it flourish with each passing year. We build our labs based on what we learn from your needs. This is what sets IMR Test Labs apart from our competitors.

We look forward to continuing serving you today and in the future. Contact any of our labs today to learn more about IMR Test Labs.

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