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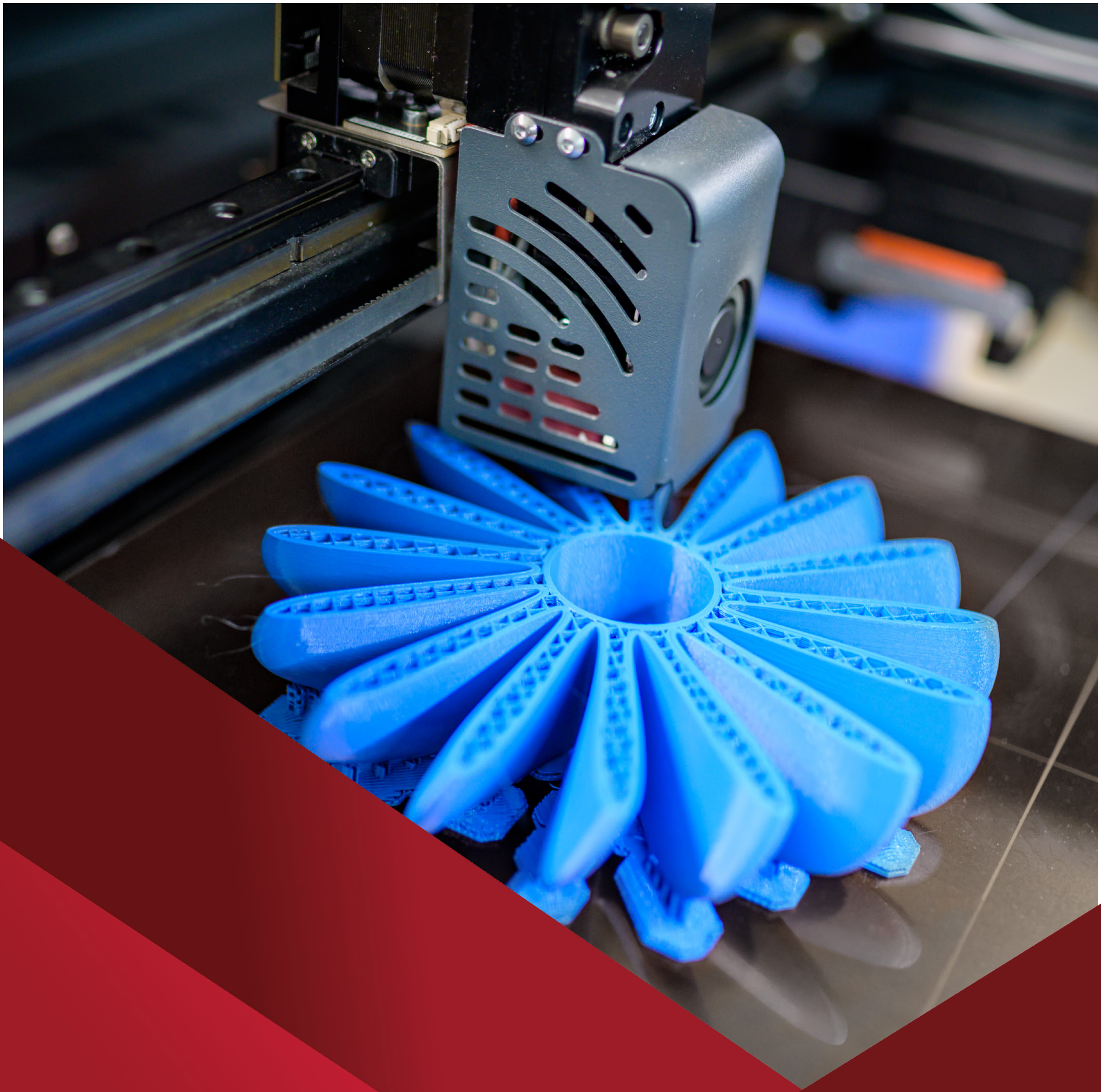
TESTING, TESTING, 1, 2…3D

Mechanical Testing for Additive Manufacturing



INTRODUCTION

Replicators in 1960s sci-fi shows might have seemed like far-flung future tech at the time, but in fact the first copyright for a process of what patent filer Hideo Kodama described as a “photopolymer rapid prototyping system” was granted only a little more than a decade after the original Star Trek series went off the air. In 1987 Charles Hull patented the working model of this technology as a “stereolithography apparatus,” and 3D printing was born.

This promising new technology soon evolved from creating models and templates to making actual, finished products and components. This was achieved by combining reactive materials such as plastic resins, liquids, and powders into a continuous filament of thermoplastic material and using computer-guided injection layering or molding to create the printed object.

This process, called “Fused Deposition Modeling” (FDM), is still the most common function for home and tabletop 3D printers as well as boutique manufacturers. Industrial component manufacturers quickly recognized a way to take the process further and mass produce precision parts with computer-guided accuracy. With this, additive manufacturing (AM) was born.

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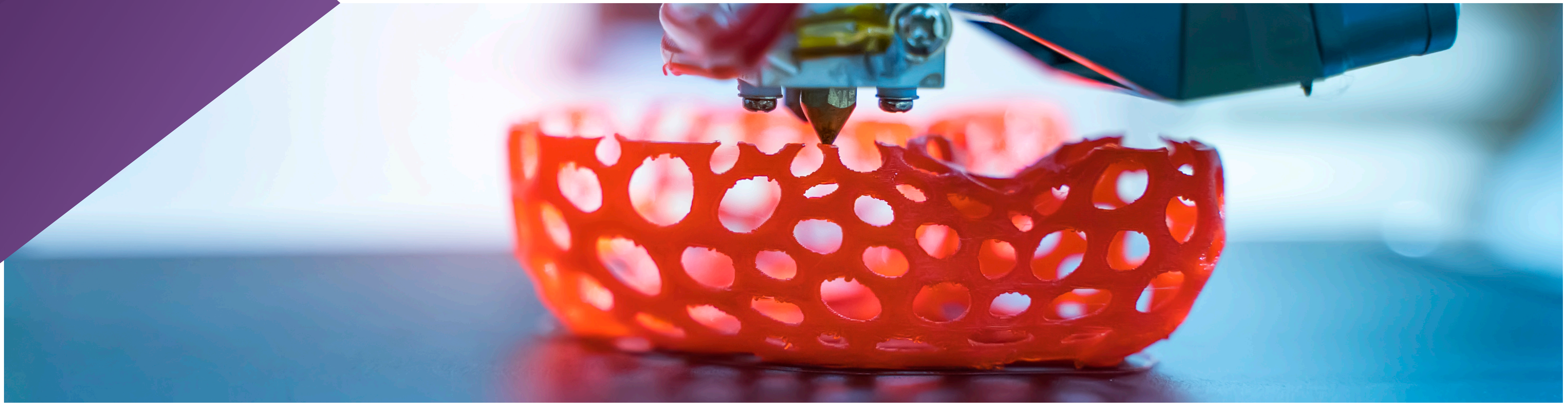


NEW ABILITIES, NEW CHALLENGES

Additive manufacturing of industrial parts allows for the creation of highly complex shapes and unusual geometries such as parts with internal pockets or spaces, parts with multiple internal curves, and parts requiring a high degree of individualization. All of these complex designs must still maintain an appropriate amount of strength when subjected to external pressures. Such parameters would be costly or otherwise prohibitive under standard production methods but are now fully achievable with the use of AM technology. In fact, the manufacture of biomedical replacement parts such as joints, maxillofacial bones, and, most recently, dentures and implants, has become an increasingly common application of the technology.

For all parts and components made via additive manufacturing methods, challenges inevitably arise.

It is critical to ensure that products built with this new technology are reliable, both in terms of repeatability and durability.

Since 3D printing construction involves laying down layers and fusing together one small segment at a time, this manufacturing method creates many opportunities for the development of internal weak points in the product. In order to successfully use additive manufacturing to mass produce real working components—for example, a load-bearing articulating joint for a robotic arm, a pressure-sensitive automatic latching mechanism for a cargo door, or even a reconstructed lower jawbone for an accident victim—manufacturers must be able to guarantee consistency and reliability in their products.

These challenges can be said to multiply by the number of layers each component has compared to a cast, forged, or otherwise produced part or component. As summed up in a 2019 review by biomechanical engineer Lauren Safai and colleagues and published in the technical journal Additive Manufacturing, "As additive manufacturing of polymeric materials is becoming more prevalent throughout industry and research communities, it is important to ensure that 3D printed parts are able to withstand mechanical and environmental stresses that occur when in use, including the subcritical cyclic loads that could result in fatigue crack propagation and material failure."[1]

There are also certain throughput challenges that highlight the vast amount of data needed to create quality 3D printed products versus standard extruded plastics. The goal of testing is to ensure that 3D printed materials perform as well or better than comparable extruded materials in terms of mechanical properties.

Safai further notes that, "There has so far been only limited research on the fatigue behavior of 3D printed polymers to determine which printing or material parameters result in the most favorable fatigue behavior." [1] This underscores the need for testing equipment that can accurately and consistently assess stress concentrations and repeatability of stress to ensure such printed products are, and remain, reliable and deliver consistent performance across an expected lifespan.

DETERMINING MATERIAL INTEGRITY

Companies producing raw materials for 3D printers as well as companies manufacturing the printers themselves achieve best practices by testing those materials and qualifying them with the knowledge of the material properties. They follow standards, such as ASTM D638 for tensile testing and ASTM D790 for flexural testing, to print test specimens with prescribed dimensions.

Testing standards also prescribe the speeds at which to perform tests and calculate results so that customers know the capabilities of the materials used. For manufacturers, this information allows them to spot check final products or material batches. This is especially helpful when combining materials such as reinforcers.

Considerations must also be made to ensure the lifespan of the materials under the stresses of repeated use. Constant exposure to environmental conditions and interactions with other materials and components can render the material brittle or alter its flexibility (or conductivity in the case of an electronic component) over time.

Once the materials have been vetted through testing, the manufactured item itself must be assessed. As product comes off the manufacturing line, a sample set is typically selected for quality assurance (QA) testing to ensure the samples meet the required specifications before the entire production batch is cleared to ship.

One of the greatest challenges facing additive manufacturing is variability.

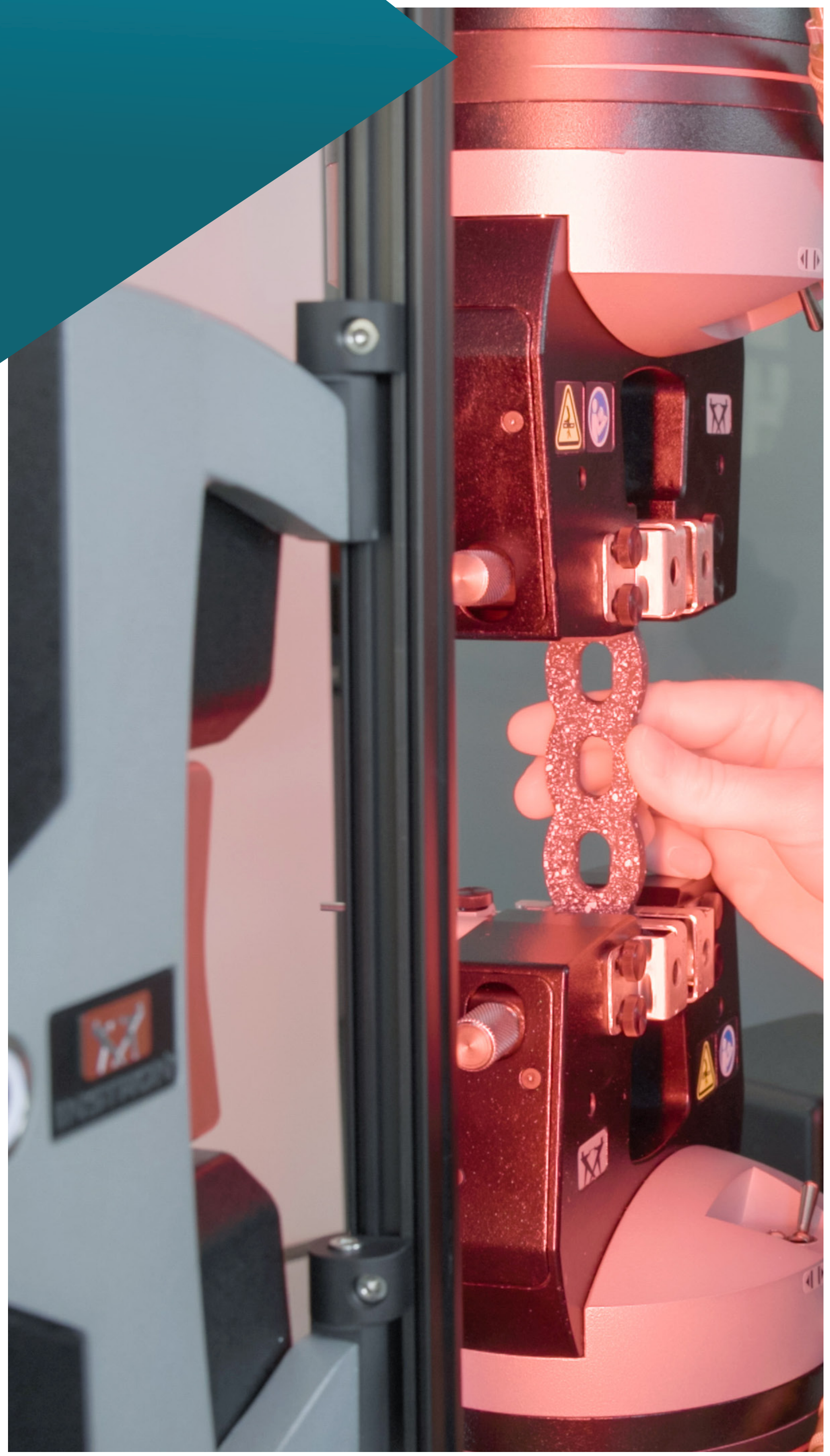
Variability in results can be substantial in some cases, as printing technology is still relatively new and continues to undergoing rapid evolution. To account for this high level of variation, more extensive testing is being conducted on 3D printed materials than on materials produced through other means. For example instead of testing a lot of five specimens, it is more typical to test lots of as many as 10 or 20 additively manufactured specimens. This increased data load requires a data management system capable of handling this increased workload such as TrendTracker software or the enhanced export capabilities of Bluehill Universal software.

In addition to variability found in the product itself, test operators can also create variability in results. It's not uncommon for testing labs in the additive manufacturing industry to have a high level of employee turnover, and it is crucial to train new operators on how to properly test 3D printed materials in order to maintain consistency in data and reduce variability in results. For many labs, incorporating some level of automation, whether it be automated specimen measurement devices or fully robotic testing systems, is an effective way of addressing this issue.

Ramping Up Data Collection

One of the greatest challenges facing the additive manufacturing industry is the wide variety of mechanical properties that different materials can exhibit. This is still a relatively young technology, and material advancements will be a major factor in determining how and where this technology can be leveraged.

Many additive materials are being developed so they can be used in a broad range of 3D printers from different manufacturers. Each printer and post-processing technique represent variables that material developers need to account for. This has many additive material developers collecting vast amounts of data, including what they're making, how they're making it, how they're printing it, how they're cleaning it, how long they're waiting between printing, curing (in the case of curable resins), and testing, and then the final data collected from physical testing. All of this data is essential to developing materials with more reliable mechanical properties to meet the needs of the end application.



TRIED & TRUE

Qualifying printed parts calls for extensive testing to ensure they meet or exceed the relevant quality standards. In many cases, a universal testing system is used to perform a wide variety of static tests to characterize mechanical properties of materials, components, and finished products. These tests, some of which must be performed on the raw materials as well as the final components, can include tensile, compression, bend/flex, torsion, peel, tear, friction, and other tests. In addition to performing static tests there are also cases where manufacturers must also perform heat distortion/ deflection temperature (HDT), Vicat (softening), melt flow, impact, and fatigue tests.

Since the goal of testing materials and components is to ferret out weaknesses or flaws, teams in both R&D and manufacturing will attain incomparable benefit from applying Digital Image Correlation (DIC) to identify strain concentrations within the geometry of materials and components.

Using a video extensometer in combination with DIC software allows manufacturers to capture images of a specimen while it is being tested.

The DIC software then generates full field strain and displacement maps used to visualize strain and displacement, allowing manufacturers to identify strain concentrations. This is especially useful on components where traditional extensometers are impractical, which can often be the case with 3D printed parts.

Great Leap Forward

3D printing technology took another leap forward with the introduction of metals as a medium. Metallic 3D printing can be accomplished in several ways, one of the most popular being the use of metal powders as a base material. Powders are often preferred because they deliver tighter dimensional tolerances and require less post processing. Layers may be laid down and fused together with a precisely focused, high-energy laser that focuses on each small segment at a time. Because internal stresses can develop, a secondary heat treatment is required following the printing step.

For metal components, especially additively manufactured ones, Instron provides universal testing machines that can perform tensile, compression, bend, and other mechanical tests on materials and products and ensure compliance with ASTM, ISO, and other industry standards.

LEADERS IN MECHANICAL TESTING

Instron is celebrating 75 years of designing and manufacturing materials testing systems, accessories, and software based on a core philosophy of data integrity, safety, and protection of investment. As a leading provider of mechanical testing systems, Instron's product line includes a comprehensive range of equipment including universal testing systems, dynamic and fatigue testing systems, drop tower impact, torsion, and melt flow testers, capillary rheometers, and HDT and Vicat testing systems. These systems are available in a range of sizes and force capacities and are suitable for evaluating materials ranging from delicate biomaterials to advanced high-strength alloys and composites.

Instron supports its testing systems with a full range of global resources, from calibration and preventative maintenance to training, technical support, and system repairs and upgrades. In addition, Instron maintains a global network of experienced and skilled service technicians to support its commitment to ensure accurate, repeatable test results and to extend a system's usefulness throughout its lifetime.

Responsible additive manufacturers should perform all the testing necessary in order to verify the properties of their materials and products. Though this may require changes and additions to a lab's existing testing processes, advances in testing technology make it possible to achieve this without sacrificing accuracy or diminishing throughput. A well-thought-out testing strategy and optimized testing equipment can help to position companies to maximize the potential of this exciting new manufacturing technique.

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About Instron®

Instron is part of the Test and Measurement division of the US based Illinois Tool Works (ITW) group of companies with more than 850 distributed business units in 52 countries worldwide and a staff of approximately 60,000.

[1] Safai, Lauren, et al. "A Review of the Fatigue Behavior of 3D Printed Polymers." Additive Manufacturing, vol. 28, 2019, pp. 87-97, https://doi.org/10.1016/j.addma.2019.03.023