

A decorative graphic at the top of the page consisting of a network of white and light green dots connected by thin lines, forming a complex, crystalline or molecular structure against a light green background.

Elevated Temperature Testing Improves Manufacturing Efficiencies

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Quality and quantity. In today's global economy, being able to deliver on both of these manufacturing parameters is proving to be the new norm. The rapid pace of expanding manufacturing demands is saddled against a company's ability to increase yield, maximize operational efficiencies and ultimately deliver high quality products.



Figure 1: The global economy impacts today's manufacturing environment

Modern businesses face new challenges that stem from a global shift in the overall supply chain—from raw material to final product delivery—as well as operational productivity and the implications of an altered workforce dynamic. Staying competitive across all these factors that affect the manufacturing environment is on the minds of plant engineers, product development specialists and CEOs alike. *(Figure 1)*

Manufacturers need lean processes and reliable methods to evaluate products at the beginning stages of product development straight on through to delivery, so they have a clear understanding of any necessary changes during manufacture or potential defects in the final product.

Materials Impact Manufacturing

Not only has the manufacturing environment itself shifted, but the materials used in the production of several products and across different markets have also changed course. Availability of certain materials can no longer be guaranteed and pricing structures continually fluctuate based on global market demand. Even then, the quality of existing raw materials may be subject to change, depending on where and how that material is sourced.

This has also led to inventive methods of sourcing raw materials, such as the development of innovative and hybrid materials for a number of industries across the manufacturing spectrum. Some examples include newly engineered advanced composites, fiber-laden concrete and additive manufacturing of superalloys. (Figure 2)



Figure 2. Concrete, plastic and metal are just a few examples of materials being re-engineered into hybrid compositions, which require materials testing to ensure structural integrity and product safety.

Today's manufactured products are being pushed beyond their original design limits. The physical properties of raw materials are under scrutiny to ensure that the correct material or material formulation is selected for the right application, and that the material is inherently suitable for the process at hand. Confidently bringing new or newly-sourced materials into a production environment relies on proven material testing methods that validate and qualify the integrity of the materials being used. (See *Testing of New Materials*)

Evolutions in Elevated Temperature Testing

Evaluating the behavior and performance of materials under high-temperature conditions is critical to many industries, including aerospace, energy and automotive. Used to study the properties of materials when subjected to elevated temperatures, this type of material testing provides a means to determine the performance of the material at its target use temperature and the maximum temperature that a product or raw material can withstand without degrading, deforming or losing its structural integrity.

It also helps to identify the behavior of materials under different temperature and stress conditions, such as thermal expansion and thermal conductivity, and characterize mechanical properties like strength, ductility and fatigue resistance. (See *Types of Testing*)



Testing of New Materials

Additive manufacturing of superalloys is an area where elevated mechanical testing has been particularly important in recent research initiatives. Superalloys are high-strength, often complex, metal alloys that are resistant to high temperatures and severe mechanical stress and that exhibit high surface stability. Commonly classified into three major categories—nickel-based, cobalt-based, and iron-based—they are used in extreme environments, such as in the aerospace and power generation industries.

Superalloy production is still heavily reliant on precision investment casting, where a wax pattern is used to shape a disposable ceramic mold. This expensive, time-consuming method is typically used when a part is difficult or impossible to create with other casting methods.

Additive manufacturing, also known as 3D printing, has emerged as a promising technique for producing complex geometries and reducing material waste in the production of superalloy components. However, this is still a relatively new process, with its own intricacies, and there is a definitive need for the industry to better understand the mechanical behavior of additively manufactured superalloys under extreme conditions.

Elevated temperature mechanical testing enables the study of the behavior of additively manufactured superalloys as well as simulates the high-temperature, high-stress environments that these materials are often exposed to in real-world applications.

Researchers can gain insights into the material's microstructure and deformation behavior under different conditions, which helps to identify potential weaknesses or failure modes in the material and inform the development of improved manufacturing processes or material designs.

For example, elevated temperature mechanical testing can be used to study the effects of different heat treatments on the mechanical properties of additively manufactured superalloys or to evaluate the performance of different alloy compositions.



Figure 3: Consisting of a frame, chamber, sensors, specimen holders and software to help manage and analyze system data, modern elevated temperature testing systems offer comprehensive analysis and evaluation.

Advanced instrumentation and control technology such as high-temperature furnaces and specialized testing frame and software configurations are now capable of applying precise loads, strains and temperatures to the specimens under test. This delivers improved accuracy and repeatability and equates to more reliable data. Researchers can then make more detailed predictions about material behavior under extreme conditions. *(Figure 3)*

Not only have modern elevated temperature testing methods helped increase the safety and reliability of many critical systems, from aircraft engines to nuclear powerplants, but the material testing industry is exposed to a whole new level of understanding when it comes to material behavior.

And because engineers are equipped with this knowledge of a material's performance in extreme conditions as well as strengths and weaknesses, they can design systems better able to withstand these conditions without failing or causing harm to people or the environment.

Accurately assessing how certain materials behave under high temperatures and under normal and extreme loading forces has enabled insights into the fundamental physics of material behavior. Elevated mechanical testing plays a key

role in not only this enhanced understanding, but has, in turn, significantly supported the development of new materials with improved properties.

(See High Temperature Heat Chambers)

Data Analysis Moves Materials Forward

As elevated mechanical testing continues to evolve and improve with new developments in materials science and technology, one of the most notable advancements in this field is machine learning (ML), a subset of artificial intelligence (AI). The algorithms produced during ML analyze large amounts of data from elevated mechanical testing experiments and identify patterns or relationships that may not be immediately apparent to human observers.



Types of Testing

Test	Description
Compression Testing	Measures strength and deformation of a material under compressive loading at high temperatures.
Corrosion Resistance	Usually in the context of testing metals, determines degradation of material when exposed to a high temperature oxidizing environment.
Creep Testing	Used to evaluate the time-dependent deformation of materials under a constant load and temperature.
Creep-fatigue Testing	Combines creep and fatigue testing to evaluate the behavior and durability of materials under cyclic loading and high temperatures.
Fatigue Testing	Often used to calculate durability, measures the ability of a material to withstand cyclic loading at high temperatures.
Stress Rupture	By evaluating the time-dependent fracture of materials under a constant load and temperature, this test is often used to determine the time to failure of materials under high-temperature conditions.
Tensile Testing	Gives a useful estimate of the ability of metals to withstand the application of applied tensile forces and evaluate properties of materials, such as strength and ductility.
Thermal Cycling Testing	Examines the fatigue behavior of materials under cyclic thermal loading to assess material performance to simulate thermal stresses in real-world applications. Also called Thermo-mechanical fatigue testing.
Thermal Expansion Testing	Method used to determine the thermal expansion coefficient of materials as they change shape, area, volume and density when subjected to high temperatures.

This leading-edge method of data analysis uncovers new insights into material behavior and accelerates the development of new materials with improved properties, such as allowing for more accurate predictions of material behavior and improved understanding of the underlying mechanisms that govern material deformation and failure.



Figure 4: Analyzing data obtained from a materials testing environment helps add new layers of understanding to how materials behave during testing.

Sensors are increasingly being incorporated throughout all aspects of testing and manufacturing, and those found on elevated temperature test systems collect data, such as temperature, strain and load, that is then used to populate ML algorithms and analyze the data to identify important trends or correlations. This helps to improve the understanding of the material behavior under different conditions.

In addition to sensor data, elevated mechanical testing often generates large amounts of visual data, such as images of material microstructure or deformation. The ML algorithms analyze these images, as well, to identify important features or changes in the material, helping to uncover additional insights into material behavior. *(Figure 4)*

By detecting anomalies or outliers in experimental data, ML algorithms identify potential issues with the testing process or with the material being tested. All of these inputs and insights set the stage for predictive modeling, which enables the prediction of future events to anticipate material behavior under different conditions, such as high temperature and high stress. This can help to identify new materials with desirable properties and optimize material design for specific applications.

Current Standards Help Increase Confidence

Today's supply chain is global, which means product and material quality needs consistency and accountability from start to finish. Employing proven standards across a material testing environment helps to improve product safety, quality and repeatability, which all leads to increased end-user confidence.

Industry standards are the cornerstone of material testing. High-temperature elevated testing helps investigate material behavior, evaluate the material's mechanical and thermal characteristics, and study the material's change in

microstructure. These aspects are critical to evaluating materials for extreme environments and emphasize the importance of utilizing common evaluation criteria to ensure performance across different application scenarios.

Especially when employing newly developed or re-engineered materials, having a baseline of understanding for a material's properties and characteristics will reduce failures, increase product yield and enable refinements to the manufacturing process that help to improve overall material quality. Know which standards are applicable for the environment you are testing. (See *Common Industry Standards for Elevated Mechanical Testing*)



High Temperature Heat Chambers

Our new high temperature chamber and furnace perform tensile tests within a temperature range of ambient to 1200°C/2200°F.

A high quality, rigid, stainless steel outer case with a polished finish helps prevent the insulation from cracking during service as well as enables high temperature extensometers to be mounted directly on the furnace case. Supported on a frame post located behind the columns of the testing machine, the furnace can be pushed aside and clear of the operating area when not in use.

Tinius Olsen temperature chambers include several features to ensure ease of use and quality testing. Forced air recirculation ensures uniform heating and a stainless-steel interior eliminates the risk of high temperature oxidization.

Optional internal lighting illuminates the test area for observation on site or via web cam and the removable top and bottom chamber walls means the unit can easily be moved in and out of the testing machine/frame test area.



Continued Evaluation in Materials Testing

High-temperature elevated testing is essential for evaluating the behavior of materials in high-temperature applications. It helps to confirm a material's performance both at its target and intended working use temperature and the maximum temperature that a material can withstand without degrading or losing its structural integrity.

There are several methods available for high-temperature elevated testing, including creep testing, stress rupture testing, thermal expansion testing, thermal cycling testing, and tensile testing. These tests are essential for designing and developing materials for high-temperature applications and ensuring the safety and reliability of industrial processes.

Common Industry Standards for Elevated Mechanical Testing*

- **ASTM E21** - Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials
- **ASTM E139** - Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
- **ASTM E145** - Standard Specification for Gravity-Convection and Forced-Ventilation Ovens
- **ASTM E220** - Standard Test Method for Calibration of Thermocouples By Comparison Techniques
- **ASTM E1457** - Standard Test Method for Measurement of Creep Crack Growth Times in Metals
- **ISO 6892-2** - Metallic Materials - Tensile Testing - Part 2: Method of Test at Elevated Temperature

*You may require other applicable standards, depending on specific materials, testing conditions and testing program requirements. Not sure which ones? Talk to our engineering team, many of which sit on the standards committees and can help determine the right set of standards for your application.



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