Commercial Testing of Forgings

Sophisticated fatigue testing is often done under various loads and temperatures.

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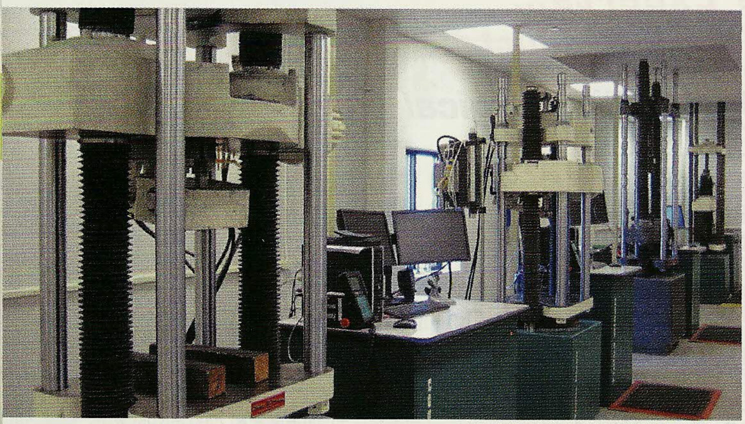
Commercial testing laboratories perform a variety of tests that help a forge verify the quality of its output and certify test results to the forge's customers. Tests performed include the use of chemical, mechanical, nondestructive and metallographic techniques.

Much has changed over the years. What has stayed constant, however, is that modern designers continue to push the envelope for new and exciting projects and designs. Forgers today manufacture a variety of products in a vast assortment of shapes and sizes from a variety of materials.

The many industries served by the forging industry include automotive, trucking, motorcycle, marine, commercial and military aerospace, off-highway, agricultural, power generation, defense and ordnance, valves and fittings, and industrial tools. The scope is wide and varied.

Consequently, the requirements called out for material properties are ever-changing. Today's forgings are regularly specified where strength, reliability and resistance to shock and fatigue are vital considerations. Unlike other manufacturing processes, forged materials offer a higher ability to meet varied performance temperatures. Thus, improved ductility and hardness, along with machinability, are added benefits.



The diversity of machinery used in the area of dynamic testing of materials

Most of the producers of basic metal (i.e., steel, aluminum, copper, titanium and nickel) produce forged product. As a result, testing is often varied and unique to the material, application and specification called out.

Product Testing

Much has changed during the past 30 years, but the principal mechanical properties of interest to design engineers in the forging industry today are strength, ductility and hardness. The term *testing of requirements* focuses on mechanical testing and includes both destructive and nondestructive types. The types of testing will, in most cases, depend on customer requirements and prevailing specifications.

Testing specifications within the forging industry are generally governed by ASTM standards. In many cases, it is necessary for forging companies to turn to a laboratory that has the designated Nadcap and A2LA approvals.

Types of Testing

When it becomes necessary to verify material characteristics, mechanical properties or the existence of flaws, standard inspection methods are available. Many of the tests are classified as nondestructive because the sample is not harmed, but the rest are destructive tests. Some of the most commonly utilized test methods include chemical analysis, mechanical testing, nondestructive testing and metallography.

Chemical Analysis

The chemistry of the material used in forging usually has a pedigree that comes from the metal producer and is known as a Mill Certificate or Mill Report. These reports indicate the chemistry of the material at the time that it was melted. There may have been one or more processes done on the material before it reaches the forger. Often, the forger's customer requires verification from a third party that the material is in fact what it is supposed to be and still within specification. In these cases, the forger will submit a sample to an independent laboratory for third-party verification. The methods of analysis can vary from lab to lab and will depend on the type of material and its size and shape at the time of analysis.

Usually, the quickest and most inexpensive type of analysis is direct reading atomic emission spectroscopy (AES), from which the chemistry is derived at the surface of the solid material. This works well for most common materials that are big enough to yield a sample able to be analyzed via this method. Uncommon materials or common materials that have been modified may not work as well. Since this is a surface method, anything that has been done to the surface of the material could cause inaccurate results.

When the material is not a common material (steel, nickel or cobalt alloys) or if modifications or surface treatments exist, then the chemistry may have to come from an instrumented wet chemical method such as atomic absorption (AA) or inductively coupled plasma atomic emission spectroscopy (ICP-AES). With these methods, material removed from the sample away from any surface condition and/or material drilled or machined from the sample is dissolved and analyzed. This methodology has more flexibility than the AES method, but it is generally more time-consuming and costly. This may, however, be the only route open for the chemistry, depending on the material or sample size.

Analysis of carbon and sulfur is usually completed via combustion analysis. Gases like nitrogen, oxygen and hydrogen can be analyzed using inert gas fusion to provide accurate results of these elements, if required.

When trace analysis of elements is required, the sample may be subjected to graphite furnace atomic absorption spectroscopy (GFAA) or inductively coupled plasma mass spectrometry (ICP-MS) in order to elucidate the very small quantities of some elements that can be contained in some alloys.

All of these types of analysis can be employed by the laboratory to provide the forger with the confidence and information they need to supply a good product.

Mechanical Testing

Several mechanical-testing methods are in use today.

Hardness testing is widely used for steel forgings because sample preparation and the test procedure are simple and nondestructive. Also, material hardness correlates closely with tensile strength. Common methods used include Brinell, Rockwell and Vickers hardness testing. Portable equipment is available for forgings that are too large to test with stationary equipment.

Tensile testing can determine a material's ultimate strength, yield strength and ductility. The tests are performed on specimens taken from the forging according to specifications or guidelines explaining location and orientation, and they usually constitute destructive testing. In some cases, particularly for open-die forgings and rolled rings, specimens may be taken from a prolongation. This is an area of the forging at a defined location that is used for testing and is not part of the finished part. When prolongations are used, the tensile test is nondestructive.

ICP-AES analysis is an instrumented wet chemistry method.

Charpy notched-bar impact tests are also performed on specimens taken from the forging. The tests are dynamic and used to define impact strength, notch toughness and fracture mode (i.e., brittle, ductile or combination).

Fracture toughness testing measures the resistance of a given material in a given condition to catastrophic failure in the presence of a pre-existing crack. Often, a certified lab will be called upon to design custom fixtures to account for different materials and specimen sizes. For example, engineering will often call out specific areas of a forging from which to pull samples. This will vary due to grain-structure refinement being dependent on the type of forge process being utilized. This process is important because it allows forge shop designers to get a better understanding of potential failure modes.

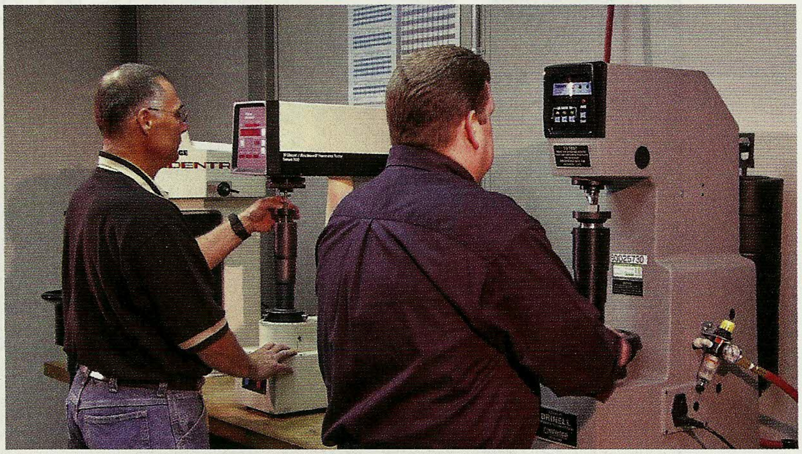
Bend tests are performed on samples taken from the forging to test for ductility by bending the specimen through a specified angle to a specified inside radius of curvature. The criterion for failure is whether cracks form on the tension surface after bending.

Nondestructive Testing

Both radiography and ultrasonic testing are the most frequently used methods of testing for internal flaws, partly covering the application range and partly extending it. This means that many tests are possible with the more economical and non-risk ultrasonic test method. In contrast, special test problems are often solved using radiography. In cases where the highest safety requirements are demanded (e.g., nuclear power plants, aerospace industry), both methods are used. In both ultrasonic and radiography methods, full certification of the test technician is required.

Ultrasonic testing is the use of sound waves to evaluate the internal quality of forgings, usually by observing the reflections from internal features. Testing can be conducted using dedicated systems or portable instruments. These use either a direct contact

A technician conducts Charpy impact testing.



A variety of hardness-testing equipment is often utilized.

technique or are performed while the part or a portion of the sample is immersed in water. The process can give information on the size, location, orientation and nature of discontinuities. For example, in looking for a burst in a large forged block, a probe is scanned over each of the surfaces. Sound reflections from the burst travel back to the probe, and an indication is displayed on the instrument screen. The technician can determine the location and approximate size based on how the indication behaves as the probe is moved.

Radiographic testing is a method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high-energy photons) to penetrate various forged parts.

Eddy current testing detects surface imperfections in bar and rod stock, cold forgings and fully cooled warm and hot forgings. It can be used for 100% automatic production testing.

Magnetic particle testing (MP) is used for detecting surface discontinuities in ferromagnetic materials and some subsurface discontinuities under ideal conditions. The fluorescent wet MP method, which requires inspection of parts under a high-intensity black light, is more reliable and is required for the inspection of aerospace materials. The visible MP method uses standard white lighting. Forged parts that are routinely MP inspected include forged fasteners for use by the U.S. military, forged rolled rings for helicopter gears and many types of forged aircraft hardware.

Liquid dye penetrant testing (LP) is used to detect discontinuities that are open to the surface. As a result, processes (such as grit blasting) that could peen the discontinuities shut are generally prohibited prior to LP. For the same reason, processes (like plating, painting and others) that can mask discontinuities must be done after LP has been completed. LP is used mostly on nonferrous materials but can also be used for ferrous parts, plastics and glass. Similar to MP testing, the dyes used for LP testing are available in two main types: fluorescent and visible. The fluorescent-dye LP method is required on aerospace materials. LP is often used to inspect forged pipe fittings for the U.S. Navy and nuclear industry, forged fasteners for the U.S. military, rolled rings for helicopter gears and many types of forged aircraft hardware.

Metallography

The metallographic examination of forgings allows the physical characteristics of the materials to be evaluated. These attributes, which are for the most part microscopic, give rise to the mechanical properties displayed by the forging. Some of the properties that are often examined are microcleanliness, grain size and microstructure.

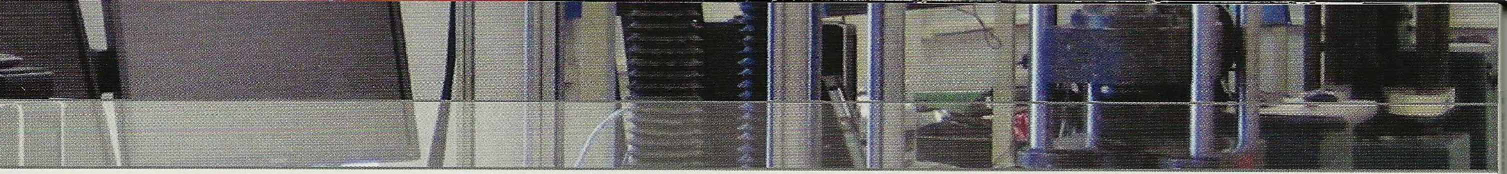
The biggest function of metallography most likely comes into play when defects or flaws are identified in a forging, and all of the above tools can be used to help identify and correct the situation causing the problem.

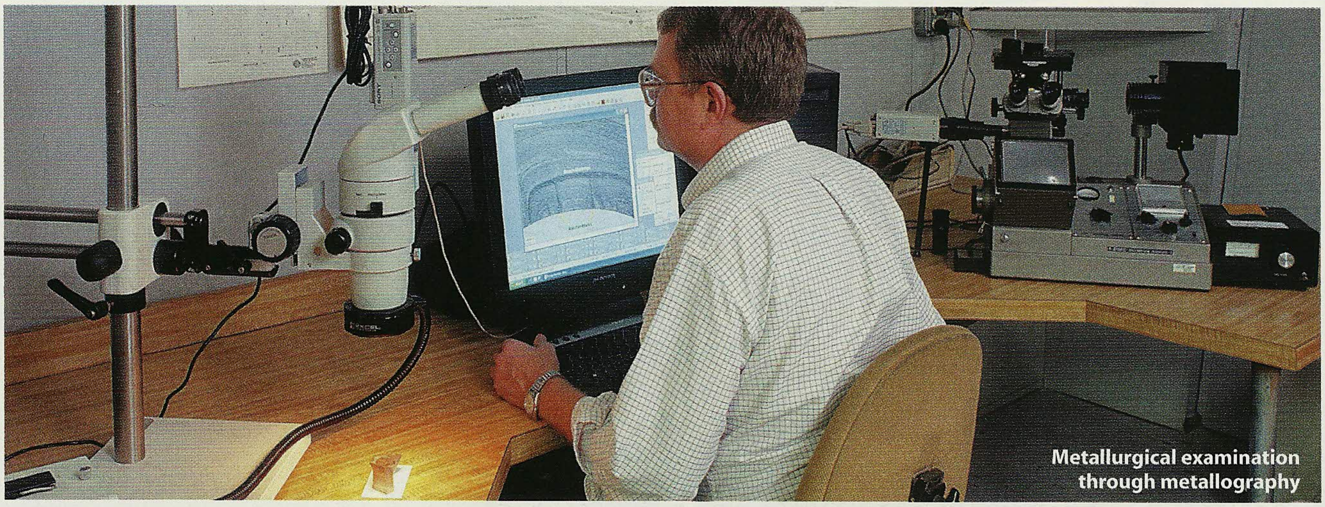
Microcleanliness allows for the identification of inclusions contained within the material. These inclusions will affect the chemistry and the mechanical properties of the forging.

Grain size and microstructure can tell important information about the metallurgical history of the forging and about any treatments – such as heat treatment, carburization, decarburization, case hardening or nitriding – that were applied.

A macrostructure of the cross section of the forging can provide information about the flow of metal during the forming process.

At the conclusion of the testing conducted, a certified test report is provided to the forging company. This assures both the forge and their customer that the results





Metallurgical examination through metallography

found either meet or do not meet the required specification.

With demanding customer needs and shorter lead times becoming the norm, having the testing done quickly and accurately is of paramount concern. In most cases, certified test reports are provided electronically to allow the customer to have the results in the timeliest fashion.

Future Direction

The increasing demands from many customers who buy forgings today are pushing the envelope from all sides. This involves starting with the actual manufacturing processes used. This includes isothermal forging, which often reduces the amount of machining required by producing near-net shapes. In aerospace alone, in an effort to make the engines more fuel efficient and reduce emissions, engines are running at higher temperatures and pressures. New high-temperature superalloys are being designed, developed and introduced into the forging supply stream. These higher temperatures – often exceeding 2000°F (1093°C) – are pushing the limits of both fatigue testing and defect analysis.

Design engineers in the automotive and aerospace industries are taking materials such as aluminum, titanium and steel and seeking to manipulate them in ways that achieve both weight reductions and cost savings. This, in turn, is inciting new material-testing requirements that are often not fully developed but still required.

When a new material is developed or revised, whether for the automotive or aerospace industries, materials engineers must first familiarize themselves with the properties of the material. Coupled with mechanical engineering, metallurgical engineering must analyze the various conditions that they will likely encounter. This includes the various loads and temperatures that exist in a real-time situation. Under such circumstances, it is possible that current test standards may someday no longer be appropriate and that new specifications will have to be developed for these new materials.

As forging projects and product requirements become more demanding, full-service laboratories are often looked at as extensions of their own forging organizations. Moving forward, the world of product testing will continue to be a vital link and called upon to meet the needs of the forging industry.

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