Laser Process Forms Thick, Curved Metal Parts

MANY industries, most notably the aircraft industry, must precisely shape large metal parts while maintaining the material's structural properties. Shaped parts must also resist cracks from corrosion and fatigue. The traditional techniques manufacturers use to shape metal, such as shot peening, have significant limitations, especially regarding the thickness of pieces that can be formed.

A team of Livermore researchers has developed a new approach that overcomes these problems by using a laser to form parts. Called Lasershot℠ Precision Metal Forming, the technique is especially effective for forming pieces greater than 2 centimeters thick—pieces so thick they are difficult to shape without weakening the material structure. The Livermore team, led by physicist Lloyd Hackel, won an R&D 100 Award for this innovative technology.

Lasershot℠ Precision Metal Forming shapes parts to exact curvature and contour specifications, preserves a smooth surface finish, and leaves the parts resistant to stress corrosion cracking and failure from fatigue. The process can be applied to any metal or alloy and is particularly effective with the aluminum alloys used for structural aircraft components. As the process is introduced commercially, manufacturers can significantly reduce aircraft design weight, thereby increasing payloads and fuel efficiency and making new designs possible.

The process can also be used to precisely form the final shape of nuclear waste canisters. Because it offers higher precision than current methods and the ability to exactly shape local areas, manufacturers can reduce the number of processing steps and the amount of material needed for machining components.

Lasershot℠ Precision Metal Forming was developed jointly with New Jersey–based Metal Improvement Company, Inc. The technique uses a solid-state laser system that induces a compressive stress to a depth of 1 millimeter or more on the desired surface of a section of metal. The strain from the deep level of compressive stress elongates the treated surface, effectively bending the metal within the processed area. The straining process also confers a beneficial compressive stress on both the treated and untreated surfaces.

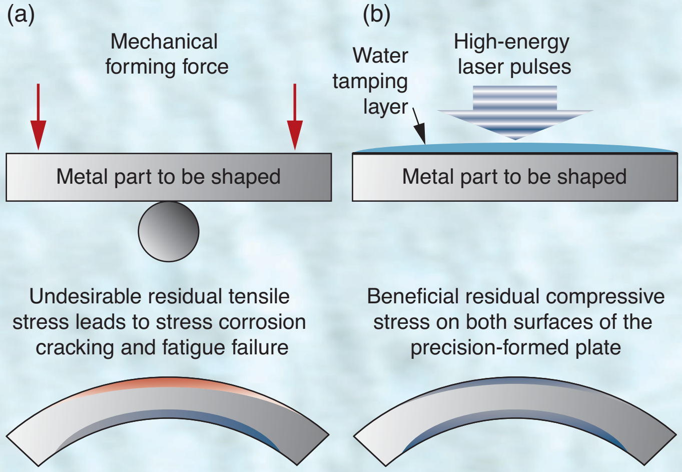
By applying a much deeper stress, Lasershot℠ Precision Metal Forming can produce curvatures three to eight times greater and a surface six times smoother than the shot-peening process can produce. Manufactured sections also can be larger, which will reduce the number of welds or joints and, thus, strengthen the structure while reducing its overall weight. In addition, the precision of the process results in fewer manufacturing steps required to form large panels and assemble aircraft.

Members of the Lasershot℠ Precision Metal Forming team (left to right): Hao-Lin Chen, Andre Claudet, Tania Zaleski, C. Brent Dane, Laurie Lane, and Lloyd Hackel. Not pictured: Fritz Harris and John Halpin.

Third R&D 100 Award for Lasershot℠ Technology

The metal-forming technology builds on Lasershot℠ Peening, a technique that uses lasers to strengthen metal components, which received an R&D 100 Award in 1998 (see *S&TR*, October 1998, pp. 12–13). It is also related to Lasershot℠ Peenmarking, an R&D 100 Award winner in 2001 (see *S&TR*, September 2001, pp. 8–9).

Lasershot℠ Peening has since been deployed commercially to arrest cracking problems in critical components of jet engines. In its first 14 months of commercial production, many aircraft engines have been treated—from large jumbo jets to fast, long-range corporate jets. As a result of these improvements, the jets are now allowed to remain in operation as much as 12 times longer between engine teardown and maintenance. The technique is also being applied to engine components in other commercial aircraft and is slated for use in manufacturing military aircraft. Hackel says, "Those of us on the team expect Lasershot℠ Precision Metal Forming to have an effect on the aviation manufacturing industry equal in significance to Lasershot℠ Peening."



Comparison of (a) a conventional metal-forming process and (b) the Lasershot℠ Precision Metal Forming process.

The heart of the metal-forming process is a neodymium-doped glass laser, a type of solid-state laser that Livermore scientists have been using for more than two decades. The laser emits up to 6 pulses per second of 1-micrometer wavelength light with 25 joules of energy. The pulses, each lasting only 20 billionths of a second, pass through a 1-millimeter-thick layer of water that flows over the area to be shaped. This material absorbs the laser light, creating a high-pressure plasma. The water protects the metal from scarring or melting, thereby maintaining a high-quality surface finish.

The laser beam's high irradiance (5 to 10 gigawatts per square centimeter) and short pulse duration cause a rapid ablation of the absorption material and form a high-pressure plasma. The plasma is trapped by the thin film of water and creates an intense pressure wave (nearly 7 gigapascals). The pressure wave travels into the metal, plastically straining it and thereby inducing a residual stress that is 5 to 10 times deeper than the stress achieved by traditional shot peening. The metal responds to this residual stress by elongating at the peened surface and effectively bending the overall shape. In production, the laser beam is scanned across the metal surface with such accuracy that shaping can be precisely controlled. The intensity and depth of compressive stress to be applied to each area is determined by finite-element analysis. The exact desired stress is then created by controlling the laser energy, the pulse duration, and the number of pulses.

Hackel explains that many structural aircraft components, such as wing skins, elevator and rudder panels, and winglets, must be formed to precise complex curvatures so they can carry structural loads, meet aerodynamic requirements, and fit precisely on the airframe. It is undesirable to bend these components using hydraulic or other force-forming techniques because mechanical bending reduces the component's structural strength and lowers its fatigue and corrosion resistance.

Lasershot℠ Precision Metal Forming also performs better than shot peening in its ability to shape tight curves—curves with a small radius—in metal whose cross section is less than 2 centimeters thick. Of greater importance, similar curves can be formed in metal plates more than 2 centimeters thick—plates that would be too thick for shot peening to effectively curve.

Process Ideal for Aerospace-Grade Aluminum

Hackel foresees two immediate uses for Lasershot℠ Precision Metal Forming. One is shaping structural components for new designs of very large jet aircraft, which will require bending thick material without reducing its mechanical strength. The second is precision final-forming of nuclear waste canisters. The technology can also be applied to the automotive and nuclear industries to make complex parts with fewer or no joints without suffering losses from cracks caused by corrosion or fatigue. Another potential application is to use it to precisely straighten components such as automotive and aerospace drive shafts, struts, and spars.

Lasershot℠ Precision Metal Forming offers many desirable characteristics in shaped metals: high surface finish quality, tight curvature on thick material, excellent control and repeatability, and high resistance to fatigue and corrosion cracking—all of which should make it a valuable technique for producing components for a range of industries.

—Arnie Heller

Key Words: aircraft industry, Lasershot℠ Precision Metal Forming, nuclear waste canisters, R&D 100 Award, shot peening.

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