2005028

Laser Peening Technology Has Come of Age

by Lloyd A. Hackel, Metal Improvement Company

Introduction

It is well known that placing residual compressive stress into the surface of metals provides performance benefits including increased fatigue lifetime, increased fatigue strength, resistance to stress corrosion cracking and resistance to general corrosion. For many years, shot peening has been the mainstay of surface treatment, providing a level of compressive residual stress (CRS) in the skin that is a large fraction of the yield strength of the material and typically extending 10 mils into the surface. This CRS, although shallow, significantly resists crack initiation and gives excellent resistance to stress related corrosion failures. However, in many situations, the depth of residual stress provided by shot peening is too shallow. Cracks can grow past the peened depth or flaws in the material or damage created in use, such as scratches or corrosion, create initiation sites that penetrate beyond the protective layer of compressive stress. In many applications a deeper level of compressive stress is needed.

Laser peening has emerged in the past three years as a very viable and important technology for inducing compressive residual stress that is much deeper and more precisely controlled and is able to retain a high quality surface finish. In laser peening, an intense beam of laser light impinges on a surface ablating material from a thin applied sacrificial layer to create a tailored shock wave that impresses a deep but highly controlled level of residual compressive stress into selected areas of metal surfaces. During processing there is essentially no heating of the part, just a shock wave traveling through it. The laser peening technology is finding a major application in jet engine components and is finding expanded applications in aircraft structures and landing gear as well as uses in military, automotive, medical and energy systems. The high repeatability and excellent quality control/quality assurance of the process strongly suggest that surface treatment can be incorporated directly into the design of high performance components.

Engineered residual stress through laser peening

During the last three years, laser peening has made a major transition from a laboratory research and development activity to a reliable, fully production qualified technology that is making a important impact on commercial aviation. Laser peening offers the designer the ability to place compressive residual stress into key areas of components so as to retard crack initiation and growth and thus enable increased fatigue strength ratings.

The basics of laser peening are shown in Figure 1. A roughly 25J at 25 ns output beam from a Nd:glass laser is propagated onto the workpiece in which it is desired to induce residual compressive stress. The area to be peened has been covered with material to act as an ablative layer and simultaneously as a thermal insulating layer. A thin stream of water is made to flow over the ablative layer. The laser light transparently passes through the water and the leading temporal edge of the laser pulse is absorbed on the ablative layer. This absorption rapidly ionizes

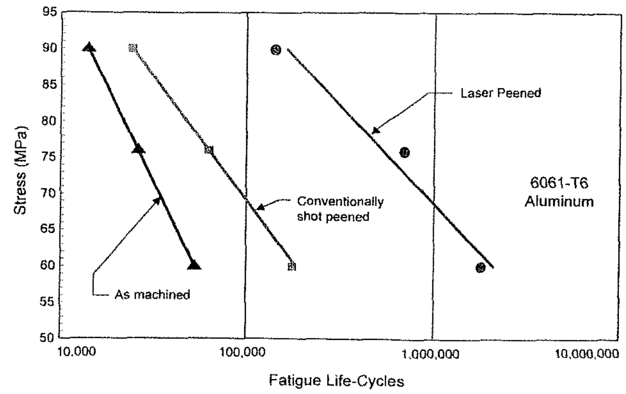

Figure 1. Laser peening concept in which ablation from a sacrificial surface creates a high pressure plasma and consequent shock wave that results in a deep compressive stress in the workpiece.

and vaporizes more of the ablative material to rapidly form a plasma that is highly absorbing for the rest of the laser pulse. The plasma pressure rapidly builds to approximately 100 kBar (1 million pounds per square inch) with the water serving to inertially confine the pressure. This rapid rise in pressure effectively creates a shock wave that penetrates into the metal plastically straining the near surface layer. The plastic strain results in residual compressive stress that penetrates to a depth of 1 mm and up to 8 mm depending on the material and the processing conditions. This deep level of compressive stress creates a barrier to crack initiation and to crack growth and consequently enhances the fatigue lifetime and/or resistance to stress corrosion cracking.

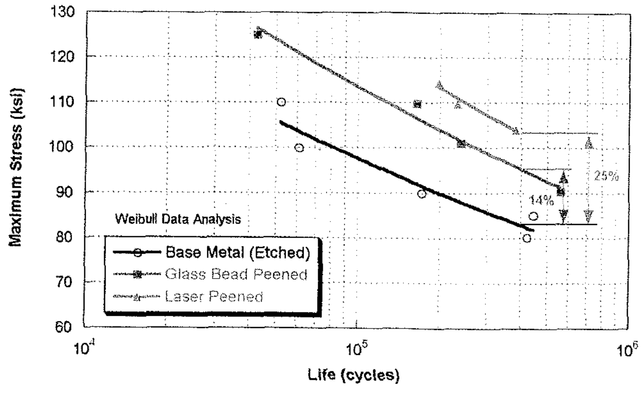

Figure 2. Stress-lifetime curve in BSTOA Titanium 6/4 showing the increased fatigue strength enabled by shot and laser peening over base metal samples. Shot peening adds an excellent 14% increase to the fatigue strength and the deeper compressive stress induced by laser peening provides a 25% increase in fatigue strength over the unpeened samples.

Figure 2 shows an example of the effectiveness of laser peening to enhance the fatigue strength or fatigue lifetime under cyclic loading. The samples, BSTOA Titanium 6/4, were smooth (Kt =1) bend bars fatigue tested in a 4 pt. loading mode. As can be seen, the deep levels of compressive stress retard crack growth and thus increase the fatigue lifetime at a given stress loading or enable application of a great stress loading at a given desired

Continued on page 10

LASER PEENING
Continued from page 8

fatigue lifetime. The fatigue benefits of laser peening can be even greater when geometry influence of real components are considered. As the local stress (Kt value associated with the geometric features) increases, the benefit of deep residual stress becomes even greater as resistance to crack growth becomes a dominating factor. Figure 3 shows fatigue results for a hole and keyway slot cut into an aluminum test sample. In this case, the laser peening benefits of very deep residual stress result in a 10x increase in fatigue lifetime over shot peening and a 20x increase over as machined parts.

Laser peening is also very effective in eliminating stress corrosion cracking (SCC). For a component to stress corrosion crack, three conditions must be met: The material must be susceptible to corrosion, there must be a corrosive environment present and there must be tensile stress in the crack area. Eliminate any one of the three and SCC will not occur. In many cases, changing materials is either not an option or is an expensive option because the material is usually chosen for particular attributes such as yield strength, ductility, etc. Components have to operate in their assigned environment such as salt air and often this exposure cannot be changed. Thus the best option for eliminating stress corrosion cracking is to remove the surface tensile stress. This is well accomplished with laser peening.

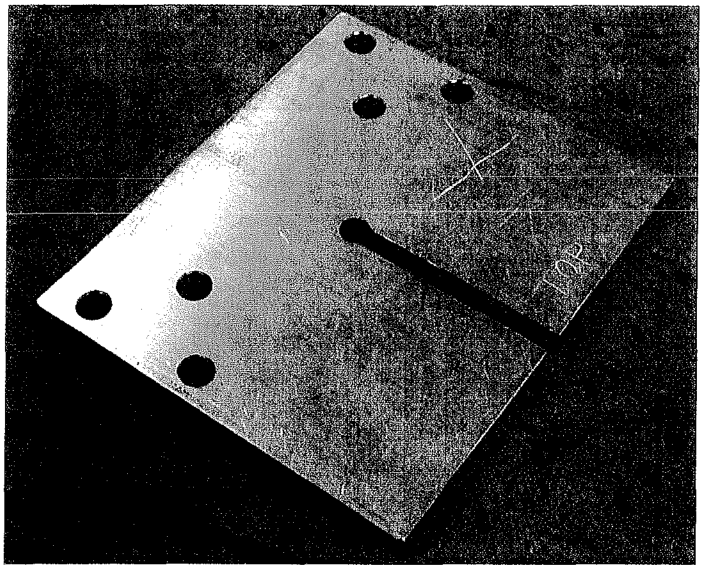

Figure 3. Benefits of the deep residual stress induced by laser peening are even more dramatic in components where geometric features create an increase in stress intensity factor. A notched specimen of Al 6061 as expected shows a significant increase in fatigue life when shot peened but an even greater 20X lifetime improvement when laser peened. The deeper level of compressive stress is especially effective when the Kt factor is greater than 1 as generated by the central hole.

Figure 4 shows a graphic example of the potential for the deep residual stress imparted by laser peening to eliminate stress corrosion cracking. In this example, a 1-inch thick plate of 316 stainless steel is seam welded and then an area on the left 2/3rds is laser peened. Large diameter glass tubes were then epoxied on to the surface (circular black remnants of the epoxy are visible in the photo) and filled with magnesium chloride that is brought and kept at a boiling temperature of 155 C. Cracking and corrosion began to occur. Observation of the plate is dramatic. The area where there was no laser peening shows transverse and longitudinal cracks. These cracks actually go through the full 1- inch thickness of the plate. However, it can be clearly seen that the cracks propagating longitudinal to the weld actually arrest when they hit the laser peened area. There are no cracks at all in the laser peened area and the general corrosion in the peened area is virtually non-existent. Laser peening effectively stopped the stress corrosion cracking.

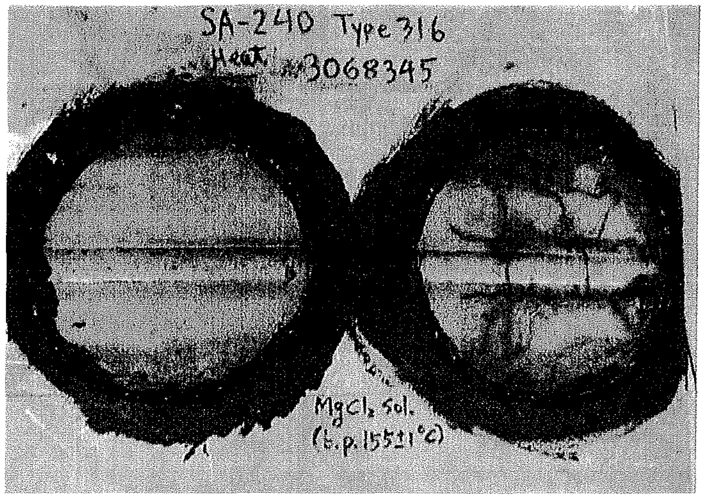

Figure 4. Stress corrosion cracking is essentially eliminated in the laser peened area of the welded 316 stainless plate.

Laser peening is a qualified and reliable production tool

During the last three years, laser peening has made a major transition from a laboratory research technology into a highly reliable production tool. In 2001, Metal Improvement Company introduced a high throughput production system based on a unique high power laser system originally developed at the Lawrence Livermore National Laboratory. The application to laser peening and development of a laser peening process were jointly developed by MIC and LLNL through a Cooperative Research and Development Agreement. Since introduction with the first peening system, three more production systems have been brought on line; two in Livermore CA and two in Earby, Lankishire, UK. Two additional systems have been built including one designed as a fully transportable system. These production systems are currently peening areas on wide cord fan blades and blade hubs. To date, over 12,000 large components have been laser peened and are in routine service on hundreds of wide body and small corporate jets. The Livermore facility is approved as an FAA/JAA Certified Work Station for doing overhaul work and the Earby facility is dedicated to new work with an ISO 9001 certification. Figure 5 shows the interior of the UK facility with the two peening systems in the rear and rows of handcarts holding blades that are being worked through the laser peening process. The lasers have proven to be very reliable with availability exceeding 95% in 24 hour per day operation.

Laser peening can create design margin for new systems

Traditionally surface treatments such as laser peening are used to mitigate cracking problems encountered in the field but are not thought of as repeatable enough for incorporation directly in design. In the laser peening process, all critical processing parameters are measured and recorded on each firing of the laser. The laser energy stability shot to shot is roughly 1% rms and the positioning of impact area by the robotic control is within 10 of microns on the surface. The repeatability of the induced residual

Continued on page 12

Continued from page 10

stress by laser peeing is exceptional. This is the result of the deterministic nature and precise control of the processing. Engineers with critical design critera have a need to take credit for the deep residual stress induced by laser peening. Engineering the deep compressive residual stress from laser peening into components can lead to increased fatigue strength with reduced mass and thus higher performance, increased fuel economy and longer lasting components.

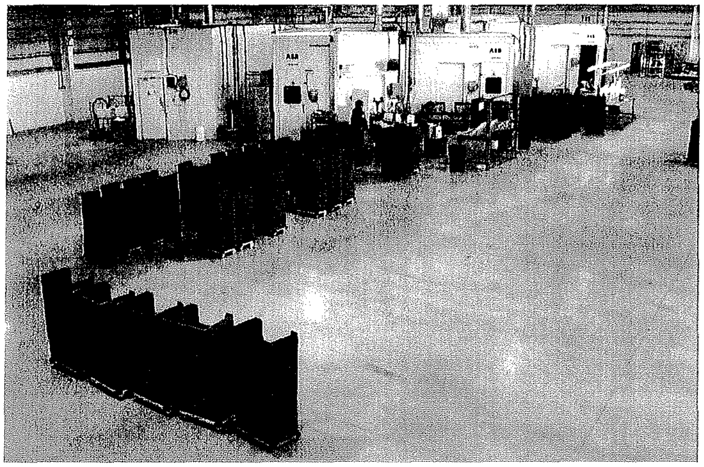

Figure 5. MIC laser peening production system showing processing of wide cord fan blades. Four peening systems are in current operation treating components of billions of dollars worth of commercial jet aircraft. Commercial aircraft with laser peening are achieving record length non-stop service with improved performance and reduced operating costs.