PEENING IMPROVES FATIGUE LIFE

Fabricators in the aerospace and automotive industries use shotpeening to extend fatigue life of welded joints. Another benefit: resistance to stress-corrosion cracking.

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Heat generated by welding can induce residual tensile stresses in weld metal and weld heat-affected zone (haz) at levels close to the yield strength of the base material. Stress raisers at the weld toe, porosity, and inclusions may contribute to poor fatigue life of weldments. Two processes can improve fatigue life: grinding to remove stress raisers and shotpeening to induce compressive stress in the weld-metal surface. Shotpeening propels small pieces of metal or glass shot at the surface of a material. The shot hits the material and deforms the surface beyond its elastic limit to form a dimple. Surrounding material moves within its elastic limit like a spring trying to push the deformed material back to its original position, inducing surface compressive stress. This compressive stress counters surface residual tensile stress developed during welding. The American Society of Mechanical Engineers (ASME), American Bureau of Shipping (ABS), American Petroleum Institute (API), and National Association of Corrosion Engineers (NACE) accept shotpeening as a method to improve fatigue resistance and to forestall stress-corrosion cracking in weldments.

Peening cold-works austenitic alloys such as 300-series stainlesses, Inconel, Hastelloy B and C, and Stellite, converting face-centered-cubic. structure to a harder, stronger body-centered-cubic martensitic atomic structure. The microstructural change increases surface hardness from Rc 30 to Rc 50.

Controlled peening can reduce intergranular corrosion of austenitic alloys. These alloys precipitate chromium carbide when held at temperatures between 900 to 1,500 F, depleting areas adjacent to grain-boundaries of chromium. A continuous path of lowered corrosion resistance results. Peening prior to welding triggers random precipitation of chromium carbide at these temperatures to prevent formation of a continuous chromium-depleted path for corrosion to follow.

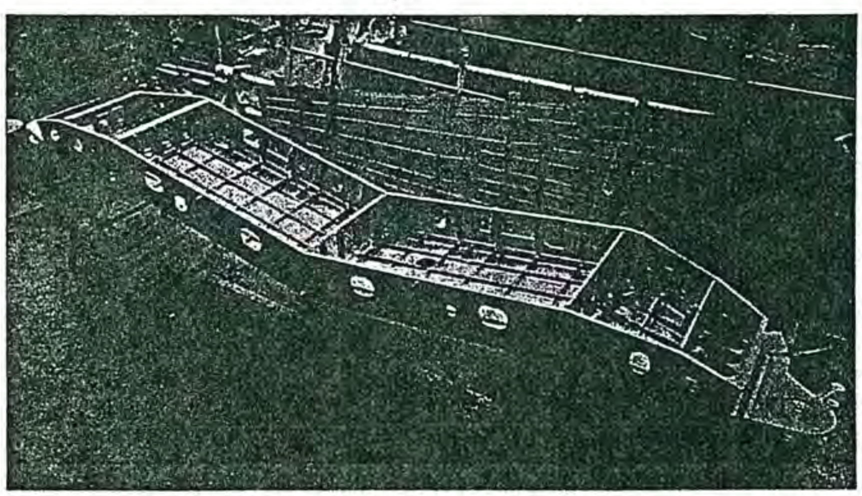
Repair by peening

Fatigue cracks normally appear in the haz of welds. To repair, first grind out the crack, weld, grind the repaired area, then shot-peen under controlled conditions per MIL-S-13165C, *Shot Peening of Metal Parts*, which covers procedure requirements.

An example of benefits of peening: after repair of an ore-grinding ball-mill, a part that was not peened developed fatigue cracks after 7,561 hours of operation. A controlled-peened-repaired part showed no sign of fatigue cracking after 35,629 operating hours.

Equipment and parameters

Shot-peening machines propel shot by air pressure or centrifigal force. The machine either moves the work through the stream of shot, or moves the shot spray over a stationary workpiece. Equipment must consistently reproduce required peening intensities and filter broken and defective shot



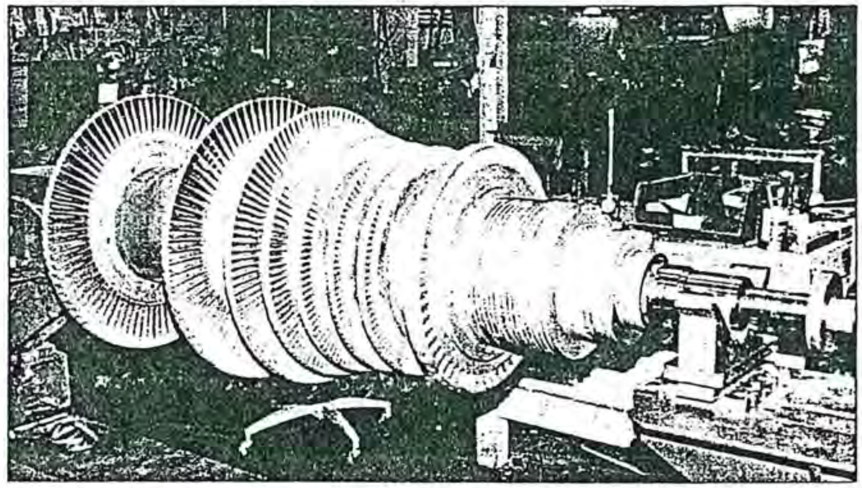
Shotpeening of the center wing box of the F-14 Tom Cat Navy Fighter, a titanium weldment, induces compressive stress on machined and electron-beam-welded surfaces.

from the stream. Air pressure, shot-flow rate, relative motion between workpiece and shot-spray nozzle, nozzle-to-workpiece distance, impact angle, and shot material and size require close control for uniform results. Computer-controlled peening machines, used for critical applications such as aircraft gas turbines and nuclear-power-plant parts, monitor these parameters, shut down the equipment, and alert an operator if they are exceeded. Equipment records process parameters, documenting variations and interruptions.

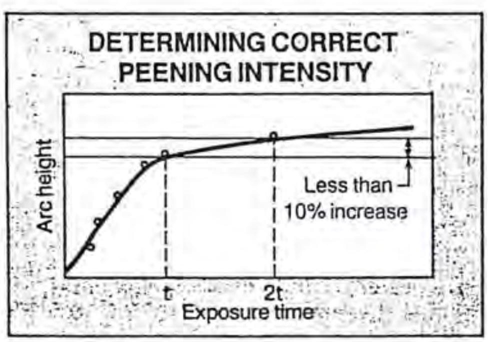
Shot-size control

Shot should be compatible with the metal being peened. Steel shot, preferred for low cost, roundness, and size uniformity, is usually used. Select stainless-steel shot, glass, or ceramic beads when contamination is a concern. A food- or pharmaceutical-grade finish can be obtained by using stainless-steel shot on stainless steel. For steel parts with tensile strength over 200,000 lb/in.^{2} use steel shot 55-65 Rc or ceramic shot 57-63 Rc. Shot size should be chosen based on the shape and thickness of the part.

Controlled peening requires rigorous quality control of the shot medium. The peening facility must qualify steel shot from suppliers. The manufacturer inspects a 500-gram sample of each lot for size, shape, hardness, microstructure, chemical analysis, and breakdown rate before approving the



Shotpeening post-weld-stress-relieves a steam-turbine rotor. After weld repairs, peening protects rotors susceptible to fatigue or stress corrosion cracking. Photo courtesy of IMO Industries, Deltex Division.



Saturation curve shows time vs. arc height of peened test strips, each represented by a data point. A part reaches saturation when doubling the exposure time increases the teststrip arc height less than 10 percent. In production, peening intensity must fall to the right of the knee of the curve.

Steps to successful peening

Follow procedures per MIL-S-13165C for consistent shotpeening results.

Heat-treat, machine, and grind parts to size before shotpeening. Form fillet radii and remove burrs to provide access for the shot stream. Clean the part and mask areas that should not be peened. Perform magnetic-particle and dye-penetrant tests.

Determine compressive-stress depth, then select the proper intensity based on residual-stress curves for the appropriate alloy. Limit thin sections (under 3/8 inch) to maximum intensities in Table VI of MIL-S-13165C. For example, use 0.008 to 0.012 A intensity for 0.09- to 0.38-inch-thick steel under 200,000 lb/in.^{2} tensile strength; 0.006 to 0.010 A intensity for steel over 200,000 lb/in.^{2} If a minimum intensity is specified, variation will be minus 0, plus 30 percent. Example: Peening intensity 6A denotes an arc height of 0.006-0.009 inch on an Almen specimen. Parameters for production should be the same as for the test strip. Keep parts free of external loading during peening unless specified for strain peening.

Shotpeen parts to complete visual coverage. An obstructed surface can be covered by reflected shot if it is impossible to peen by direct impact. Keep boundaries of peened areas to minus 0, plus 1/8 inch. Nominal shot size on fillet surfaces should be less than 1/2 the fillet radius. For slots made to access areas protected by a mask, shot diameter should be less than 1/4 the slot width.

Metallic and glass shot may contain no more than 10 percent defective shot. Check metallic shot every eight hours of operation, glass beads every two hours. Change wet-glass slurry every two hours of operation. Ceramic beads require a check every four hours—no more than 5 percent of the shot may be defective. In all cases, inspect shot before starting a new part or run.

Some post-peening operations may relieve stress developed by peening. When heating shotpeened parts—to bake protective coatings or relieve hydrogen embrittlement after electroplating, for example, stay below these maximum temperatures:

Steel, 475 F; stainless steel, 750 F; aluminum alloys, 200 F, magnesium alloys 200 F; titanium alloys, 600 F; nickel and cobalt alloys, 1,000 F.

After shotpeening, remove protective masks and shot, taking care not to erode or scratch the surface. Chemically clean aluminum alloys peened with metallic shot. Protect shotpeened parts from corrosion during processing and until final coating and packaging.□

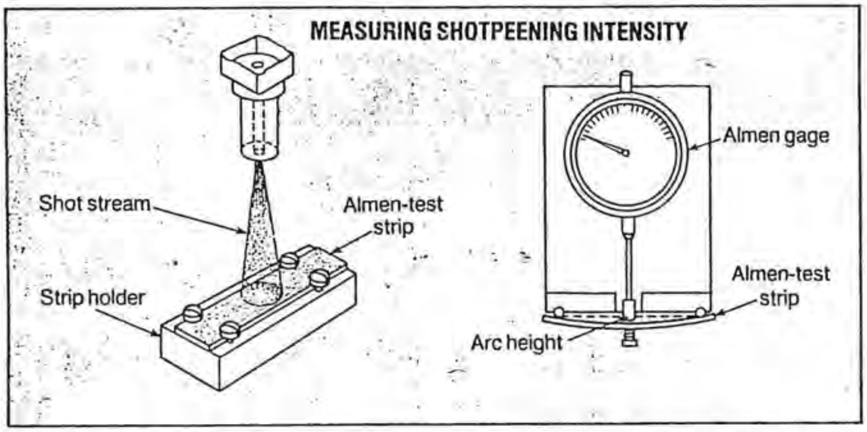
lot for shipment. During peening shot must be monitored continuously for uniformity and roundness and be replaced or recycled when 10 percent of the shot is defective. Broken pieces that strike the work create stress risers that initiate fatigue cracks.

Intensity, the kinetic energy caused by shot peening, is measured on test coupons called Almen strips. Almen intensity, a function of shot size, material, hardness, velocity, and spray angle, determines the depth of compression of peening. The higher the kinetic energy of shot impact, the more the test strip bows. This bow over a 1-1/4 inch span, called the arc height, is proportional to the depth of compressive stress. Shot should be of uniform size to control intensity—with mixed-size shot, all particles travel at the same speed, but the intensity is not consistent.

To verify the intensity, an unpeened strip of spring steel fastened to a steel block is exposed to the shot stream for a specified time. The shot stream curves the strip. This arc height is due to residual compressive stress and surface plastic deformation.

Different thickness coupons measure different ranges of intensities. The A strip measures arc height between 0.004 to 0.024 inch, the C strip measures arc height over 0.024 in, and the N strip measures light impacts below 0.004 inch on thin cross sections.

Before peening a part, engineers must develop a saturation curve to qualify the specified peening intensity. Saturation occurs when doubling exposure time does not increase the arc height more than 10 percent. To develop the curve, expose Almen test strips to a set intensity for varying amounts of time. Measure the arc height for each of the samples and plot time against arc height. At least four points should define the curve. After plotting the curve, run a test part for the saturation time. If the measured arc height is not within the intensity range, adjust process parameters and develop new saturation curves. Critical applications and parts that have hard-to-reach areas may need multiple exposures. Use smaller size shot to fit into small radii and corners.



Kinetic energy induced by a shot stream bows an Almen test coupon. This bow over 1-1/4 inches is the arc height. After exposure the strip is measured with an Almen gage to determine arc height. The arc height is proportional to the depth of compressive stress.

Checking coverage

Uniform and complete dimpling of the surface indicates that coverage is complete. Parts are inspected two ways: examining a part coated prior to peening with fluorescent tracer under ultraviolet light, and visual inspection with a 10 × magnifying glass, which is impractical for very large parts. Examining the coated part after peening shows remaining dye not removed during peening. Only a blow by the shot removes the dye.

WHO USES PEENING?

The automotive industry developed shotpeening in the early 1930's to extend fatigue life of dynamically loaded metal-alloy parts—valve springs, valves, cam shafts, connecting rods, crankshafts, universal-joint crosses, axles, leaf and coil springs, torsion bars, and transmission and differential gears.

Aircraft manufacturers, who pay a premium to minimize weight of engines and frames, use controlled peening to protect high-strength light alloys that exhibit low fatigue life and stress-corrosion cracking.

Electric-utility companies post-weld-stress-relieve with shot peening to protect steam-turbine rotors from fatigue and stress-corrosion cracking. They peen welded mid-span sections on last-stage, low-pressure, steam-turbine blades and forced- and induced-draft fan weldments.

Deaerators that develop corrosion cracks after 5 to 20 years in operation may require thermal stress relief of the repaired welds. Peening welds to MIL-S-13165C after thermal stress relief prevents recurring corrosion cracks.

Thick-walled vessels require thermal stress relief according to ASME code. Peening is not a substitute for thermal stress relief, but it can supplement to counter tensile stress introduced during bolting or due to poor alignment, pressure, thermal stress, and dead load. Hydroelectric plants routinely peen large welded-steel blower wheels and turbine runners after thermal post-weld-stress relief.

Controlled shotpeening retards stress-corrosion cracking (scc) in fabricated stainless-steel equipment for the chemical industry. Stainless steel Type 316L polyvinyl chloride reactors, centrifuges, and scrubbers with shot-peened interior surfaces will be free of scc. Peening improves fatigue life of welded mixer blades and mixer-shaft attachments of stainless steel, Inconel, and titanium.

The paper industry uses controlled peening to retard scc of weld repairs in continuous pulp digesters of carbon steel.□

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