CONTROLLED SHOT PEENING STRENGTHENS ELECTRO AND FLAME DEPOSITED COATINGS

Metal Improvement Company, Inc., Carlstadt, N.J., has been specializing in shot peening since 1945. Today it has 17 plants located in key cities of the U.S., Canada, France and England. The Peenamatic Division of the Company designs and manufactures a full range of automated peening and blast-cleaning equipment.

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The application of electro and flame deposited metallic coatings is becoming increasingly widespread in industry to restore dimensionally worn machine parts, to impart greater surface wear characteristics, and more traditionally, to protect against surface corrosion. In each case, the coatings perform admirably, but they often cause an undesirable drop in the fatigue strength of the basis metal — sometimes as much as 58 per cent[1].

In an electrodeposited plating such as hard chromium or nickel, there are several factors that contribute to the reduction of the endurance limit:

1. High magnitude tensile stresses are induced in the surface of the basis metal in the plating baths.
2. The plated layer often has in it, minute cracks which will propagate into the basis material when cyclic stresses are applied.
3. The hard, brittle, plated layer is extremely notch-sensitive and susceptible to fatigue cracking.
4. The hazards of hydrogen embrittlement are ever present.

One of the most effective means of restoring fatigue strength and retarding or eliminating fatigue failure is controlled shot peening. This is a process in which the critical surfaces of a part are cold-worked by bombardment with millions of tiny steel balls or glass beads. Their action indents the surface, building a layer of residual compressive stress of a very high magnitude that equals about 60 per cent of the ultimate tensile strength of the peened metal. Since all fatigue failures result from tensile stresses, if the surface is preloaded in compression, any applied tensile load must first overcome this compression before fatigue failure can occur.

METAL FATIGUE

Fatigue failure usually starts on the surface of a part where there is a concentration of high tensile stress. At this point the surface fibers are essentially being pulled apart as the result of cyclic mechanical stresses such as repeated bending.

These stresses may come from very high applied loads of low frequency — like those occurring in aircraft landing gear axles each time the plane touches down, or from relatively low stresses produced by high frequency vibrations that act on compressor blades in a jet engine. In either case, the result can be the formation of minute cracks on the tensile-stressed surface that will eventually spread into the core metal, causing a potentially catastrophic failure. A vast range of mechanical parts are subject to such fatigue failures.

Closeup of nozzles used to shot peen turbine blades. Steel shot can be seen atop turntable.

SHOT PEENING APPLICATIONS

Metal Improvement Company is probably the largest shot peening job shop in the world. Here an amazing variety of parts are peened with shot or glass beads. As might be expected, many parts are peened for the aircraft industry, for example: wing skins peen-formed to exacting aerodynamic curvatures for the new F-15 fighter plane; 30-ft lengths of titanium hydraulic tubing; helicopter rotor spindles and heads; many jet engine parts for several of the leading passenger airlines.

The variety of commercial applications is even more impressive: thousands of coil springs of all sizes and descriptions; staple drivers; hammers and anvils for impact tools; rock drill bits; bull gears and titanium ball valves for submarines; motor shafts; fan and impeller blades; huge parts for steam and gas turbines; tiny extractor claws for ejecting spent shotgun cartridges; paper-thin flapper and reed valves for compressors and small engines; clutch springs for electric typewriters; even a selection of crankshafts and connecting rods for "hot rod" enthusiasts.

Shot peening this great variety of parts requires more than 30 different, fully automated machines in the Carlstadt plant. Numerically controlled machines are used for

Portable shot peening equipment was used to improve fatigue strength of huge herringbone gear teeth in customer's plant.

complex-shaped parts. Highly-trained field crews use semi-portable equipment to shot peen parts too large to move. Recently, the landing gear of two C-5 Galaxy planes of the Air Transport Command were glass bead peened "on location" to avoid totally dismantling the gigantic landing gear.

STRESS CORROSION CRACKING

As the name implies, stress corrosion cracking occurs in high strength alloys of most metals when a significant tensile stress is present on a surface exposed to an atmosphere that may be only slightly corrosive to the metal. For example, an aircraft landing gear attach fitting, forged and machined from 7075-T6 aluminum, if sufficiently tensile-stressed in bolting to the wing or from carrying the weight of the gear itself, can crack from stress corrosion on exposure to moist salt air. This can happen even though the part may have been coated during manufacture.

Frequently, a part will stress crack just sitting on a stockroom shelf. This occurs because extremely high residual tensile stresses can be generated in the surface during machining — particularly in grinding. Unfortunately, these so-called "heat checks" are all too familiar whenever the grinder takes too deep a cut on a hard material. They are caused by the spontaneous relief of residual tensile stresses induced by the heat of grinding which may actually exceed the ultimate tensile strength of the material. If the grinder is "backed-off", cracking may not be apparent, but the stresses are still there. If allowed to remain, their action, together with a slightly corrosive environment, will precipitate stress corrosion cracking. These same residual tensile stresses when added to by applied "safe" cyclic loads are often responsible for premature fatigue failures.

Stress corrosion cracking can be a very definite problem with such materials as high strength steels, austenitic stainless steels, copper alloys of aluminum, even brass: in fact, stress corrosion cracking was first recognized when live mortar shell casings began falling apart for no apparent reason in the South Pacific during World War II. Significantly, after the shell was exposed to the heat of firing, no cracking occurred.

PRACTICAL SHOT PEENING

Two facts should be firmly engraved in the mind of anyone before getting involved in shot peening:

1. Though a relatively inexpensive process, peening does cost money so no part will be peened unless the peening is highly critical to the life of that part.
2. There is at present no non-destructive production test to determine how well a part has been peened.

These two facts alone make it imperative that peening be carried out under highly controlled conditions. Plainly put, peening with a hand-held nozzle is not permitted except under very special circumstances.

Next, we are faced with determining the exact peening parameters required for a particular job and ensuring that they are being met. Looking at the part after it has been peened will reveal very little. Most aircraft and military peening applications have the parameters tied down by the manufacturers' or military specifications, manuals or bulletins. Where there are exceptions, the following information will be useful.

Cast steel shot ranging in size from 0.007 to 0.250 in. dia is used for most applications. Glass beads are used when very small spheres are required for a very light peening intensity or when ferrous contamination could cause a problem, such as using steel shot on aluminum, although an acid bath decontamination may also be employed after shot peening to remove this contamination. Glass beads range from 0.0015 in. nominal dia to 0.023 in. in the practical peening sizes. With either beads or shot, the particles used must be essentially round so little or no abrasion will occur. Shot classifying equipment is available to separate the broken particles from round shot and grade it by size for reuse.

The choice of shot size is governed by two factors: since the highest stresses in a part are most often concentrated in a fillet radius, the nominal diameter of the shot should not exceed half that radius. And, the shot diameter should be large enough to conveniently deliver the desired intensity of peening .

Intensity of the peening refers to a method of measuring the relative kinetic energy delivered by the shot which was developed a number of years ago by Dr. John Almen at the General Motors Research Laboratory in Warren, Michigan. Since he was at that time concerned with peening springs, Dr. Almen used strips of spring steel (SAE 1070) 3 in. long and ¾ in. wide. Today these strips are available in three different thicknesses: 0.031, 0.051 and 0.0938 in., known respectively as "N", "A" and "C" strips. Each has a 3:1 ratio to the others, permitting readings in the full range of peening requirements.

Such an Almen strip is held in a fixture simulating the part to be peened. One side of the strip is exposed to the same shot stream the part will receive. An intensity curve is then developed to determine the point at which the strip is totally covered by peening impressions. This gives the strip a spherical curvature (convex on the peened side) which can be measured on an Almen gage. Essentially the harder the strip is hit by the shot, the greater the curvature, which is then read to determine the relative kinetic energy governing the depth of the compressive stress generated in the surface of a part. The reading also provides a means of ensuring repeatability of the peening from one batch of parts to the next.

In selecting the proper intensity with which to peen a particular part, several factors must be considered:

1. If the shot size is determined by the presence of a small fillet radius, then the high intensity call-out will have been selected by the maximum intensity which that particular size of shot is capable of delivering at reasonable air pressures or centrifugal wheel speeds (Fig. 1).
2. The intensity of the peening determines the depth of the compressive layer (Fig. 2). The magnitude of the compressive stress is a function — about 60 per cent — of the ultimate tensile strength of the material (Fig. 3), and is not normally affected by the peening intensity, provided

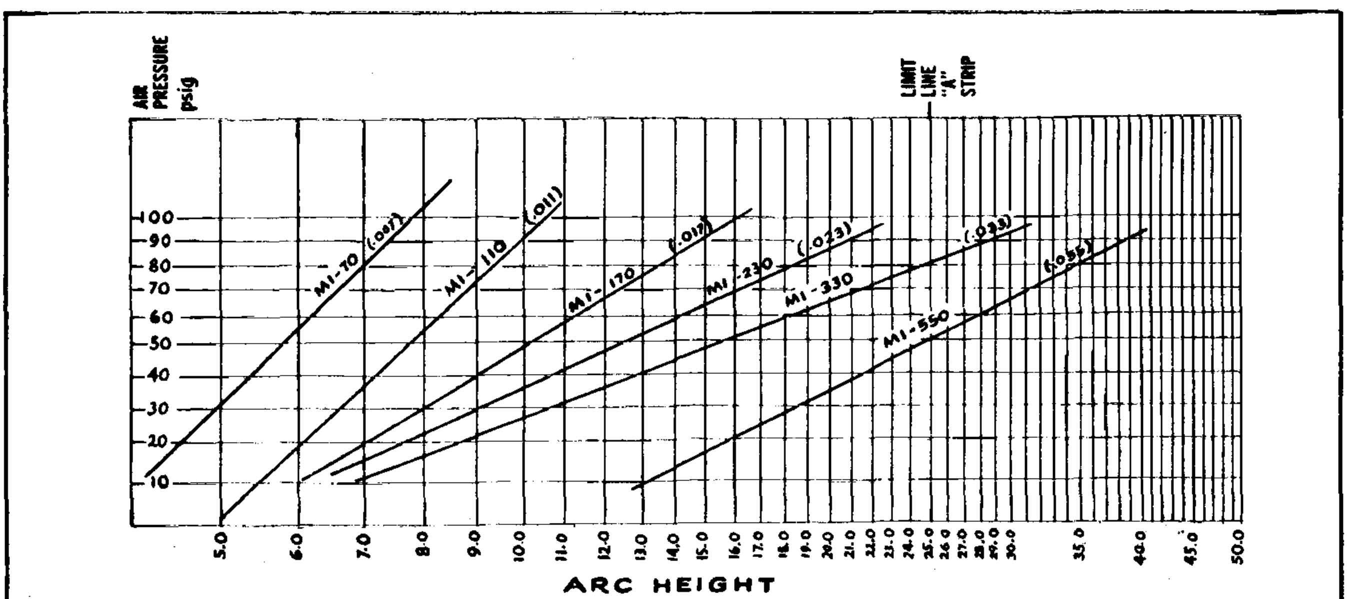
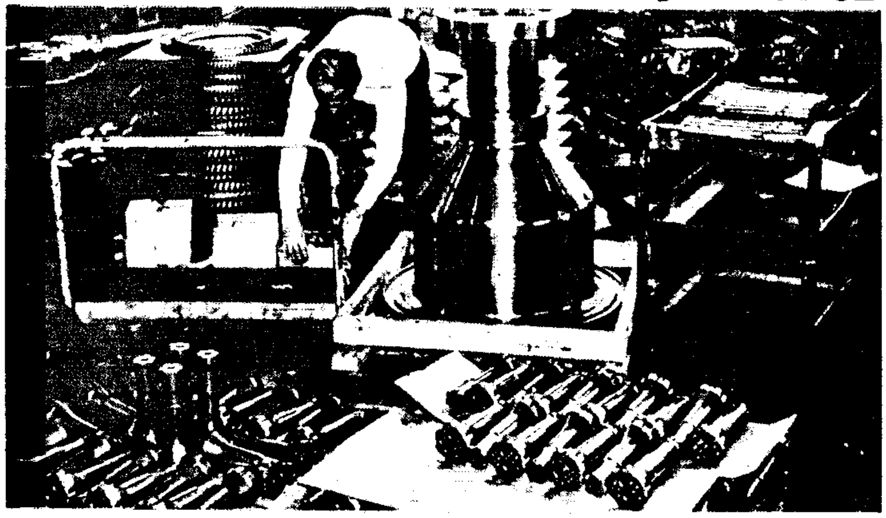


Fig. 1. Shot peening intensity curves.

the shot is harder than the material being peened. The peening must produce a depth of compression deeper than any surface discontinuities, such as tool marks which would continue as points of crack initiation. If the surface is rough, a high intensity is required.
3. Selection of the proper intensity becomes most critical when very thin sections are involved, since over-peening will cause warping.
4. The hardness of the part has a marked effect on the depth of compression as well as the magnitude of the residual compressive stress.
5. Most shot peening specifications and good practice preclude the use of hand-held nozzles: there can be little or no guarantee that the part will have an even layer of compression, particularly when long runs of parts are involved. Fully automated equipment is generally required.
6. The "coverage" given to a part is also critical. It is essential that all the critical surface be covered with peening dimples. Overpeening must be avoided because it can damage the surface, while insufficient peening will expose detrimental tensile stresses.
7. Final surface finish: higher intensities will produce a rougher finish, but for a given intensity, larger shot will render a smoother finish.
8. There are occasions when two factors may be present on a single part, e.g., a thin web area adjacent to roughly machined sections may require a dual intensity peening using two shot sizes and considerable masking.
9. It is often less expensive to peen an entire part to avoid extensive masking with rubberized tape, molded rubber or hardened steel tooling.



Variety of shot peened parts ready for shipment include: rock drill bits, jet engine blade discs, gas turbine hub, shafts, coil springs, etc.

PEENING BEFORE PLATING

A precisely controlled shot peening will increase the fatigue strength of most parts from 20 to as much as 50 per cent. In cases where the parts are to be chromium plated, the hard plated layer will cause a substantial reduction in fatigue strength (Fig. 4). By shot peening the part before the plating is applied, propagation of fatigue cracks can be effectively blocked through the introduction of a layer of compressive stress under the plating.

Federal Specification QQC-320A,

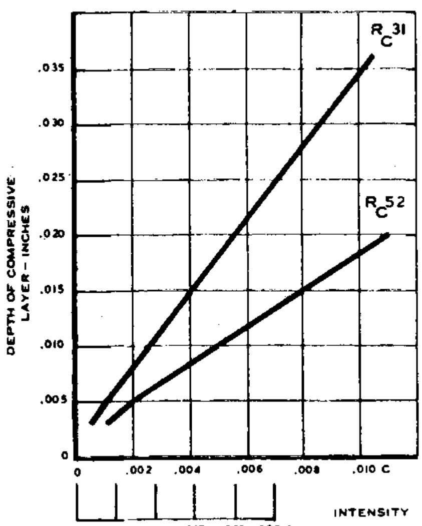


Fig. 2. Depth of compressive stress *vs* Almen intensity for steel.

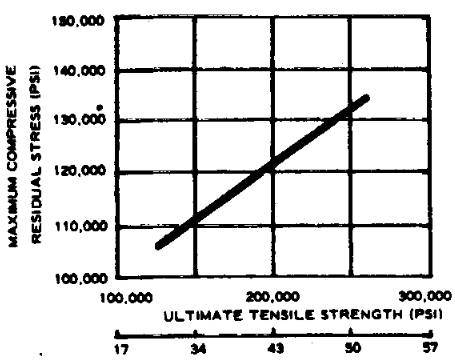


Fig. 3. Residual stress produced by shot-peening *vs* tensile strength of steel.

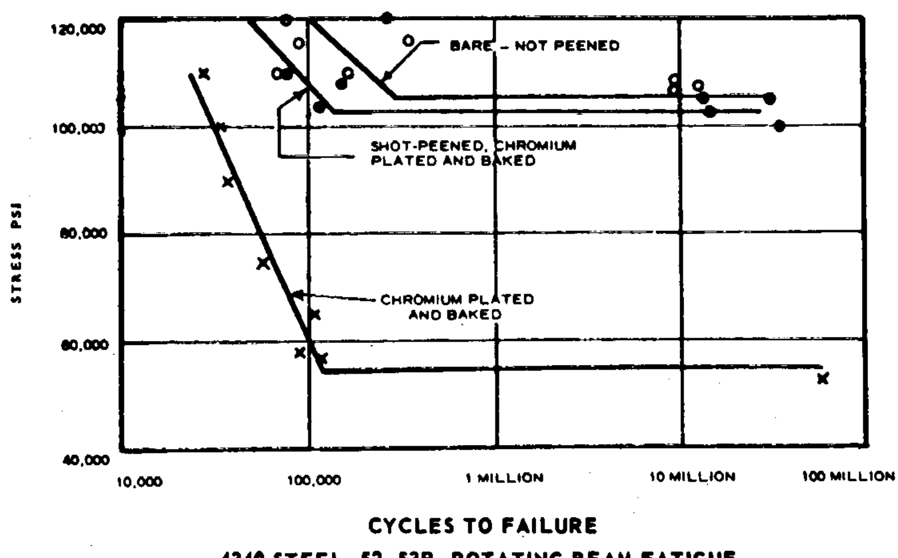
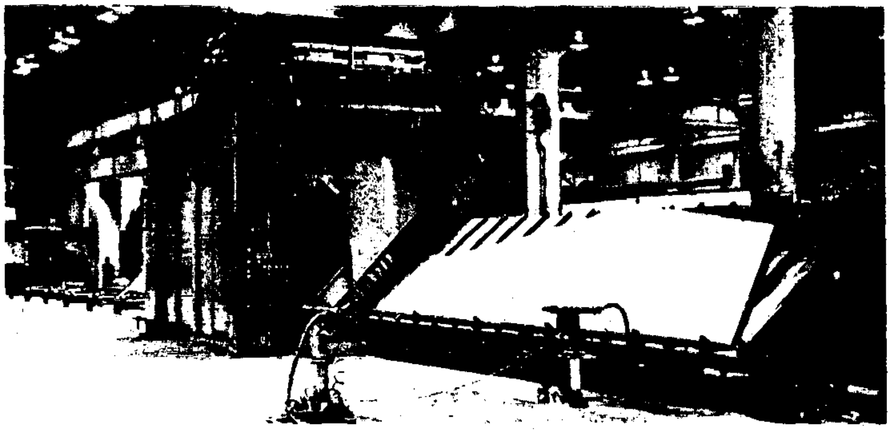


Fig. 4. S-N curves for chromium plated steel.

which covers "Chromium Plating (Electrodeposited)," states, "plated parts . . . which are designed for unlimited life under dynamic loads, shall be shot peened in accordance with Military Specification Mil-S-13165 prior to plating." For high strength steels of Rockwell C40 hardness or above, it further requires that they be baked after plating at 375F for not less than three hours, to drive out free hydrogen from the surface which would otherwise cause severe embrittlement. It should be remembered that shot peened parts should not be exposed to temperatures high enough to cause stress relieving, although there are exceptions to this rule.



Peen forming 85-foot wing panel for DC10 aircraft. Curvatures must be held to tolerances of 0.035 in. Peening machine (center) is stationary while wing moves through barrage of shot until entire surface is compressively stressed.

Working together, Metal Improvement Company and Superior Plating Company of Fairfield, Conn., recently developed two new processes of significant value to the aircraft and metal working industries:

The first is a patented process whereby titanium alloys can be plated with non-porous hard chromium achieving full adhesion and no significant loss of fatigue strength.

The second development is for high strength steels which employs an unusual combination of shot peening and hard chromium plating. Preliminary tests show this process could greatly increase the fatigue life of plated specimens over that of even the bare, polished control specimens as well as normally shot peened and plated specimens. This process showed values of more than 2,000,000 cycles against 75,000 cycles for conventional peening and plating, and 84,000 cycles for the control specimens—all at the same stress levels. Further testing is being conducted to confirm these results.

J. S. Eckersley examines peen formed wing panel.

Neither of these two processes violate any existing specifications, military or commercial.

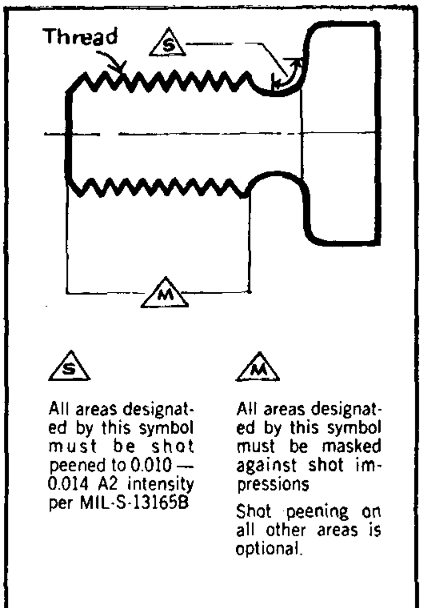
A third development reported some time ago by the Naval Air Development Laboratory[2] shows improved anti-corrosion properties of chromium plated steel by peening after plating. There also was an improvement in fatigue life which would be expected because the chromium layer was only 0.002 in. thick and the compressive stresses from the shot peening could penetrate into the basis metal. It would be interesting to see test results from shot peening heavy chromium layers such as those used in rebuilding shaft diameters.

FLAME DEPOSITED COATINGS

Shot peening prior to flame deposited coatings produces results very similar to that of shot peening before chromium plating. Recent beehive tests on jet engine blades, conducted at Curtiss Wright Corporation, showed that, "all the coatings (flame deposited) tested on 6Al-4V titanium, AISI 9310 and H-11 steels significantly reduced both high cycle endurance limit and the low cycle fatigue life."[3] Careful grit blasting brought the fatigue reduction closer to acceptable limits. Controlled shot peening used prior to a fine grit blasting, or by itself as a pre-spray conditioner, returned the fatigue strength of the flame coated specimens to that of the basis metal.

REFERENCES

1. G. Nachman, *Metal Finishing*, **66**, 48 (Sept. 1968).
2. J. Viglione, Report No. NAMC-AML-AE 1098, Aeronautical Materials Laboratory, July 20, 1959.
3. V. Meringolo, "The Effect of Plasma Spray Coatings on Fatigue Properties of Titanium 6AL-4V and AISI 9310 Steel", Curtiss-Wright Corporation, Metallurgical Report B-725, March 1971.



Drawing of typical part, with peening notes and specifications.