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Shot Peening Prevents Stress Cracking in Aircraft Equipment

SUMMARY

Stress corrosion-cracking occurs in metal if the surface is stressed and subjected to a corrosive environment. Shot peening, which has been used for over 30 years to prevent fatigue failures of metal parts, induces an extremely high residual compressive stress in the surface. The proper controls of shot peening are an important aspect in obtaining the full benefits. The author discusses these controls, but not before presenting recent tests and their results, along with case histories that help to illustrate shot peening as a means of preventing cracking.

WHILE MANY INDUSTRIES are faced with the need to control or eliminate stress corrosion, aircraft manufacturers are the most intimately concerned. Recently, there have been some definitive studies made to show what can be done, within the limits of current technology, to understand and control this kind of equipment failure. This paper discusses some recent tests and their results, along with case histories that help to illustrate the effect of shot peening as a means of preventing stress corrosion cracking.

Case Histories

Aluminum Forging

Figure 1 is an example that did not appear as a problem for approximately 15,000 hours of operation. It is one of the largest aluminum forgings used in aircraft, weighing approximately 700 lbs. Part of the main landing gear fitting, the material is 7075 used in the T6 condition. Original failure appeared as a crack starting in a trunion hole into which a bushing is pressed. The opposing fracture faces are shown in Figure 2. Three areas were chosen for subsequent examination with an electron microscope.

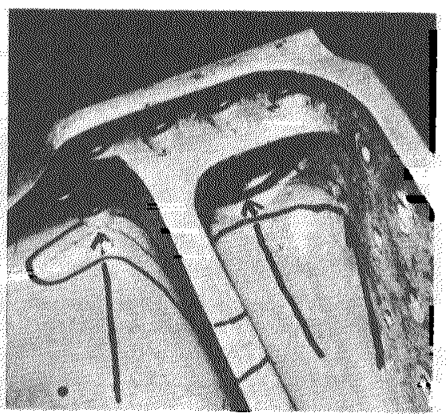

Figure 1—The original failure of the forging in the main landing gear fitting appeared as a crack starting in a trunion hole into which a bushing is pressed. The corrosion did not appear for approximately 15,000 hours.

The first two showed clearly the brittle intercrystalline mode of failure with ready evidence of corrosion products. The third area was one of transition from brittle to ductile failure. A survey of the area near the failure point showed many other sources of

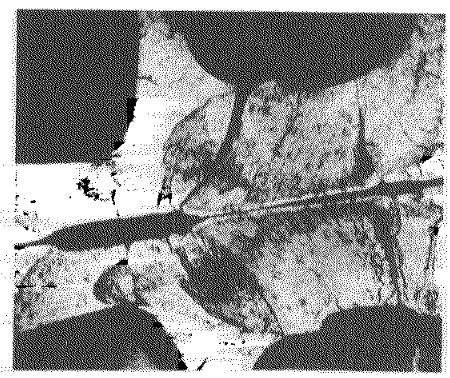

Figure 2—Opposing fracture faces of the corroded aluminum forging.

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stress corrosion cracks. The failure could have originated from any of several points.

After careful study of the fracture, the decision was made to require controlled shot peening on all new parts before putting them in service.

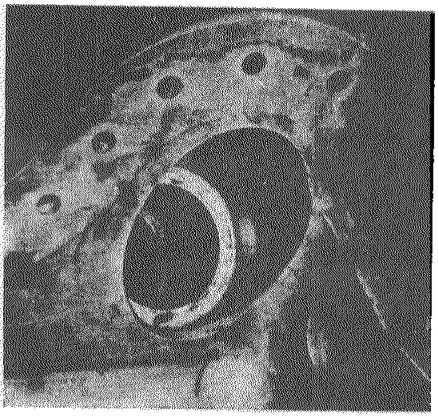

Figure 3—This massive crack, which seems to have two origins, extended completely through the forging.

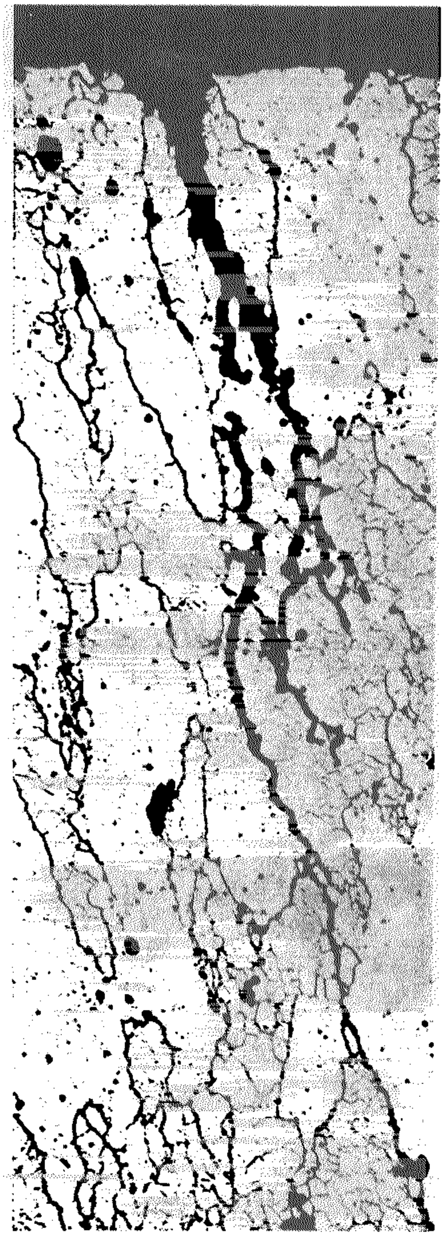

Figure 4—Photomicrograph of a crack found in the 7079-T6 forging. 500X.

While investigating another problem, careful inspection uncovered a crack in a different area (see Figure 3). The massive crack, extending completely through the section, apparently had two points of origin. Following the discovery the decision was made to shot peen all surfaces of finished forgings. In addition, forgings already in service were shot peened in place to avoid a difficult and involved removal procedure.

Wing Spar

The next example, a channel-shaped wing spar, precipitated a massive shot peening program. The component was approximately 8 ft in length with a 5-inch dimension at the widest end, tapering down to approximately 1¼ inches at the narrower end. Section thickness varied from approximately 0.125 to 0.060. Material was 7079-T6 aluminum and originated as a forging.

This wing spar first came to the attention of the metallurgical engineering group as the result of a request to evaluate the effects of pitting corrosion that apparently had occurred during anodizing. During the investigation, numerous cracks were noted in the flange. These cracks were closely checked and the decision was made to check other parts subject to the same processing. An inspection was made of all the parts formed from 7079-T6. Many were found to have similarly cracked areas. Sections taken through the cracks showed them to be primarily intergranular. This is shown in Figure 4.

Figures 5 and 6 are electron fractographs. The first of these shows the brittle, intergranular mode of failure. In the second, grain boundary oxidation is evident. Undoubtedly these were stress corrosion failures. (It is well to emphasize that these components had never seen service).

The failures were caused by lack of adequate protection during processing and the existence of residual tensile stresses. The method was a comprehensive program of surface protection during manufacturing processing and the shot peening. Of course, in this and in all other examples cited, the use of shot peening automatically infers the use of adequate controls to insure maximum benefit.

Table 1—Test Specimens after Exposure to the Alternate Immersion Cycling.

Conditions(1)	Results
T6, press fit	Failure in 120 hrs
T73, press fit	No failure
T6, shrink fit	Failure in 120 hrs
T73, shrink fit	No failure
T6, press fit, anodized, baked fluid, resistant primer	Failure in 216 hrs
T6, press fit, shot peened	No failure

(1) 0.004 interference

Landing Gear Cylinder

This next example of the use of shot peening in a stress corrosion application also comes from the aircraft industry. The part is the main landing gear cylinder of a small fighter-bomber. It is a forging made from 7075-T6 aluminum. Approximately 100 units from the vendor were put into service with no apparent problems. The next group of parts came from another vendor.

The cylinder was removed from service. While on the ground, the cylinder lost its hydraulic capability and the strut flattened. A crack could be seen running the length of the cylinder and into the trunion hole. Another cylinder was removed from service in the course of a regular maintenance check. Crack location is at the forging parting line, which puts the short transverse grain structure in the worst possible orientation.

Figure 7 is a photograph of a section through the cylinder. The surface was etched to bring out the forging lines; failure originated in the area indicated by the arrow. Here again, the method was to shot peen all surfaces. This was approached in steps, with the crack moving each time from a peened area to one that had not been specified as requiring peening. There were serious problems in maintaining accurate dimensions in some of the bored holes. Only through careful control of the peening variables was this possible.

Previous examples were all field failures. Had the proper information (including information on peening) been in the hands of the design and material people, these failures would never have originated. Using shot peening as a design metal process instead of as an aid to get out of trouble would help in minimizing service difficulties.

Some recent work has been done supporting previous efforts to establish the validity of shot peening under controlled conditions.

Aluminum Bores

One test evaluated the susceptibility to and the effectiveness in preventing stress corrosion in aluminum bores having steel sleeves. The ring material was 7075 in both the T6 and the T73 tempers.

Table 1 shows the test specimens after exposure to the alternate immersion cycling. The surface corrosion clearly indicates the severity of the test and the accompanying validity of the stress corrosion results.

Obviously, the bare material in the T6 condition would not be satisfactory in a stress corrosion application. Protective coatings do little better, if for no other reason than their susceptibility to surface damage. Shrink or interference fit made no apparent difference. The only two means that produced immunity to stress corrosion failure were the T73 heat treat or shot peening.

With the T73, though, temper would involve an accompanying loss in strength.

High Strength Steels

While much of the field-gathered information concentrates on aluminum, stress corrosion is certainly not limited to aluminum alloys. High strength steels are one of the most critical considerations. In fact, one of the influential government laboratories required, as a matter of course, thorough preventative measures in all steel fittings used in the high strength range (260,000 psi and above). They now have comparatively little difficulty with stress corrosion failures.

As new high strength steels are made available, they are tested to determine their susceptibility to stress corrosion. Recently examined was the HP 9-4-45 alloy produced by Republic Steel. Stress corrosion testing was done using alternate immersion in synthetic sea water under sustained load of 80% of the material's yield strength. (Small variations were made in the test specimens for other test conditions.) Included in the test of stress corrosion influences were welding, grinding, drilling, cadmium plating and shot peening. Residual stress measurements on better than 25% of the specimens were made using X-ray diffraction techniques.

The results indicate that only one process produced immunity to stress corrosion. All others experienced some degree of failure. Only shot peening was 100% successful. Both the grind-to-burn and the drill-to-burn samples indicated some improved resistance from the oxide layer produced by the machining. However, these were only limited improvements.

It is interesting to note that merely the presence of tensile stress did not promote failure. A stress diagram for several of the variables notes that as the magnitude of the net surface tensile stresses increase, the time for failure decreases. Under load, even the shot peened pieces experienced exposure to tensile stress. Although high stresses (approaching the yield point) are generally needed for stress corrosion cracking, frequently stresses that are small relative to the yield produce failure. Apparently though, there is a critical limit below which stress corrosion does not occur. The team that did the evaluation set the threshold value between 89 ksi and 127 ksi.

Titanium

A third metal, titanium—that element so vital to the aerospace industry —also has its stress corrosion problems. Small titanium tank shells used for liquid propellant were found ostensibly to fail prematurely due to material pressures. On investigation it was proven that the failures were not due to pressures, but to stress corrosion.

Tests were made for possible solutions to stress corrosion. Three tanks were used; the first served as a control and was used as received; it failed after approximately 115 hours at 105 F (76 C). The second tank was vibratory cleaned and failed after approximately 200 hours at the same temperature. The third tank was glass bead peened and successfully withstood 720 hours of exposure at 105 F.[3]

Process Control

In each of the examples cited, whether field service or laboratory originated, shot peening successfully arrested stress corrosion. It is a well known fact that cold plastic surface deformation converts harmful tensile surface stresses to compressive stresses. It is also evident that for stress corrosion cracking to occur, surface and subsurface tensile stresses must be present. Therefore, if the net harmful tensile stress can be lowered or converted to beneficial compressive stresses, failures can be minimized. The benefits will only be fully realized if the proper *control* of the process is exercised. The control of the shot peening process depends on four important variables: shot materials, shot size and uniformity, shot velocity, and shot coverage.

These four variables are collectively referred to as "intensity." Presently there are no economic non-destructive means for checking a part for its intensity. The only accepted standard is an arbitrary one called the Almen strip.

The Almen strip is a steel strip 3 inches long and ¾ inch wide. Its thickness depends on the intensity of the specified peening. The strip is positioned so that it may simulate as closely as possible the surface to be peened. The strip is then processed with the same peening variables held at the same value as for the part. Since the strip is peened only on one surface, it curves. This curvature is measured on an Almen gauge. When the strip is fully saturated, the arc height, measured over a chord of 1¼ inches, is expressed in thousandths and termed the intensity. Evidently controls are essential in order to maintain uniformity.

Just what are the dangers to be considered if these controls are not maintained? Consider the mechanism by which shot peening provides stress corrosion immunity. Simply stated, the benefits accrue from the imposition of a compressive stress. The magnitude of this stress must be sufficiently high to afford protection after the application of the service pattern produced by

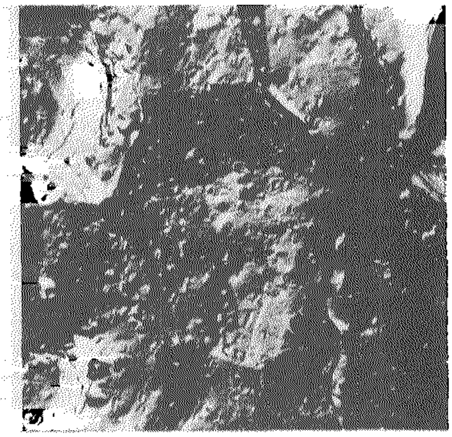

Figure 5—Electron fractograph showing the intergranular type brittle failure. 12,000X.

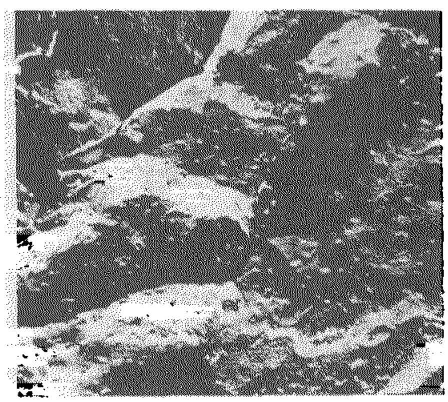

Figure 6—Electron fractograph showing grain boundary oxidation. 12,000X.

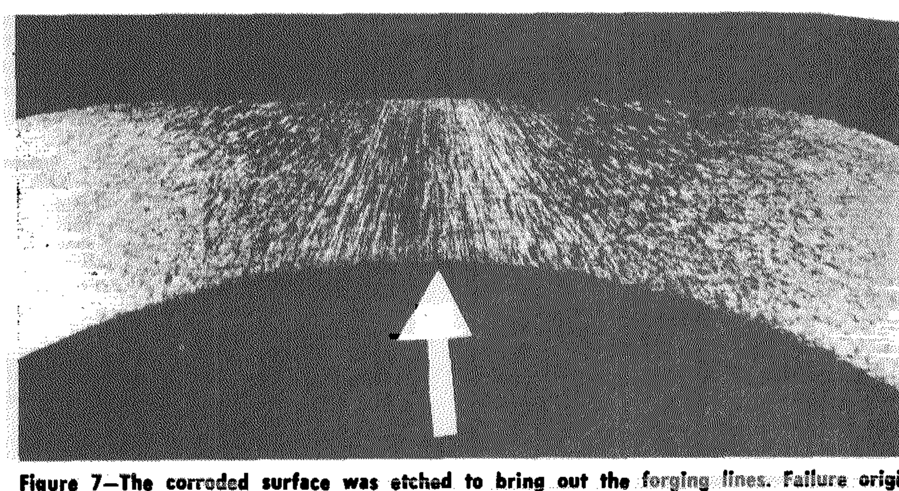

Figure 7—The corroded surface was etched to bring out the forging lines. Failure originated in the area indicated by the arrow. The surface was shot peened.

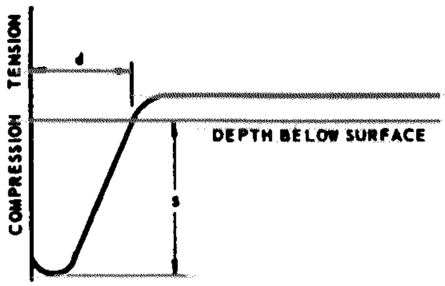

Figure 8—Typical stress pattern produced by peening. There is a high compressive stress at the peened surface, increasing slightly just below the surface.

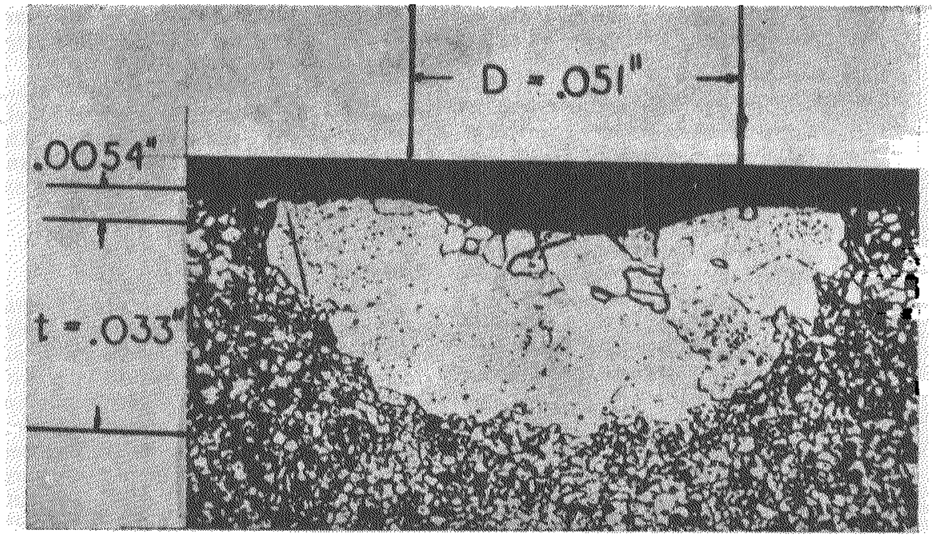

Figure 9—Photomicrograph showing a single dimple indentation that might result from one piece of shot impacting a metal surface.

peening (Figure 8). There is a high compressive stress at the peened surface, increasing slightly just below the surface.

The magnitude of the residual compressive stresses induced by shot peening is a function of the yield strength of the material. The level of compression decreases until the point of zero stress is reached. Then the stress changes to one that is tensile. As has been mentioned, the benefits of shot peening are due to the compressively stressed layer and the depth induced by the process. The depth must be compatible to the thickness of the part. Generally the induced surface compressive layer should not be greater than 20 to 25% of the cross section of the thinnest section, nor should the layer be too thin for it could corrode or wear away, thereby negating the benefits of peening. The photomicrograph shown in Figure 9 shows a single dimple indentation that might result from one piece of shot impacting a metal surface.[2] The metal was heat treated to promote grain growth in the section affected by the cold work. It also provided a representative picture of the typical stress pattern. The large grains portray the compressive zone. Immediately below this zone is a tensile layer. A group of dimples close together provide an even compressive layer. If an area has no dimples (or dimples that are of lower intensity), the surface stress will either be a lower compressive or a tensile stress. This then leaves the material vulnerable to stress corrosion.

Peening is not enough. *Controlled* peening is essential to adequately retard stress corrosion.

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