

Prevention of Stress Corrosion Cracking by Shot Peening

By J. H. Milo

The presence of stress corrosion and its associate corrosion fatigue are not new at our table. Unfortunately, this unwelcome guest is showing up more often and with frequently more grave consequences than in the past. It is increasingly important that we devote our efforts to the elimination or at least control of this menace. Of course, this means confrontation of the problem in all its aspects -- from the fundamental review of cause and effect to the final evaluation of applied hardware. In recent times, there have been some definitive studies made to show what can be done, within the limits of our current technology, to understand and control this kind of equipment limitation. In this paper, I will review some of the recent tests and their results along with some case histories that help to illustrate the effect of surface compressive stresses as a means of preventing stress corrosion cracking.

While many industries are faced with the need to control or eliminate stress corrosion, the aircraft manufacturers probably are most intimately concerned. As is most often the case, problems of this nature are first generated in field testing or in field use. Here is an example that did not appear as a problem for approximately 15,000 hours of operation (see Figure 1). This is one of the largest aluminum forgings used in aircraft. It weighs approximately 700 pounds. The material is 7075 and it is used in the T6 condition. Original failure showed up as a crack originating in a trunion hole into which a bushing is pressed (see Figure 2). The opposing fracture faces are shown in Figure 3. An enlargement of the fracture area shown in Figure 4 illustrates the flaky texture typical of stress corrosion. Areas A, B and C were chosen for subsequent examination with an electron microscope. The first two show clearly the brittle intercrystalline mode of failure with ready evidence of corrosion products. The third area is one of transition from brittle to ductile failure. A survey of the area near the failure point showed many other sources of stress corrosion cracks. The failure could have originated from any of several points.

After careful review of the fracture, a test, which will be described later, was performed. Following the test, the decision was made to require controlled shot peening through the trunion holes, and on the surface immediately adjacent to them.

In the course of an investigation into another problem, the careful inspection of the manufacturer uncovered a crack in another part, in a completely different area (see Figure 5). The crack apparently had two points of origin. This was a rather massive crack extending clear through the section. The fracture surface is shown with the two points indicated as the crack origins, in Figure 6. Following the discovery of the second cracked area, the decision was made to shot peen all surfaces of the finished forging. In addition, forgings already in service were processed in place to avoid a rather difficult and involved removal procedure.

The next example was a chance discovery that precipitated a massive shot peening program. The part in question is a wing spar having largely a channel shape. Length of the component is approximately 8 ft with a 5 in dimension at the widest end, tapering down to approximately 1 1/4 in at the narrower end. Section thickness varied from approximately 0.125 to 0.060. Material was 7079-T6 and originated as a forging.

The part 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 resulted during anodizing. During the investigation, numerous cracks were noted in the flange. These cracks were closely checked and the decision was made to take a look at some other parts in inventory that were subject to the same processing. An inspection was made of all the parts formed from 7079-T6 in inventory. Many were found to have similarly cracked areas. Figure 7 is a photograph of the side of one of the spars showing some of the cracks. Sections taken through the cracks showed them to be primarily intergranular. This is shown in Figure 8. The photomicrograph was taken at 500 X. Figures 9 and 10 are electron fractographs and were taken at 12,000 X. The first of these shows the brittle, intergranular mode of failure. In the second, the grain boundary oxidation is evident. There was no doubt that 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 cure was a comprehensive program of surface protection during manufacturing processing, plus -- and

this is an important plus -- the addition of shot peening to the processing sequence. 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. As with all tools and processes, shot peening must be properly utilized and properly performed to be beneficial.

This next example of the use of shot peening in a stress corrosion application again comes from the aircraft industry. The part in question 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 shown in Figure 11 was removed from service. While sitting on the ground, the cylinder lost its hydraulic capability and the strut went flat. The crack can 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. The ultrasonic indication is shown in Figure 12. The part was then opened along the fracture line. The crack was shown in Figure 13. Figure 14 is an enlargement of the preceding illustration. This definitely shows the flaky appearance which is characteristic of stress corrosion. The crack origin indicated by the original inspection is at the center of the lower edge of the photograph. Crack location is at the forging parting line. This, of course, puts the short transverse grain structure in the worst possible orientation. Figure 15 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 cure 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 was some serious problems in this instance in connection with the need to maintain accurate dimensions in some of the bored holes. Only through careful control of the peening variables is 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 have never originated. Use of 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 to support previous efforts to establish the validity of the process under controlled conditions.

One recent test was performed specifically to evaluate the susceptibility to or the effectiveness in preventing stress corrosion in aluminum bores having steel sleeves. The test parts were constructed as shown in Figure 16. The ring material was 7075 in both the T6 and T73 tempera.

CONDITIONS	RESULTS
T6, Press Fit, .004 interference	Failure in as little as 120 hours
T73, Press Fit, .004 interference	No Failure
T6, Shrink Fit, .004 interference	Failure in as little as 120 hours
T73, Shrink Fit, .004 interference	No Failure
T6, Anodized, baked fluid, resistant primer, press fit, .004 interference	Failure in as little as 216 hours
T6, Press Fit, .004 interference shot peened.	No Failure

The above chart 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 the use of shot peening. Of course, the T73 temper involves an accompanying loss in strength.

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

As new high strength steels are made available, they are frequently tested to determine their susceptibility to stress corrosion. One that was recently examined is 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 percent

of the yield strength of the material. Small variations were made in the test specimens for the various test conditions. Included in the test of stress corrosion influences were welding, grinding, drilling, cadmium plating, and shot peening. Residual stress measurements were made on better than 25 percent of the specimens. These were made using X-ray diffraction techniques. The results of this comprehensive examination are shown in Figure 17.

This indicates that only one process produced immunity to stress corrosion. All others experienced some degree of failure. Only shot peening, of all those evaluated, was 100 percent 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, it was only limited improvements.

It is interesting to note that merely the presence of tensile stress did not promote failure. Figure 18 summarizes the stress picture for several of the variables -- note as the magnitude of the net surface tensile stresses increase, the time for failure decreases. It clearly shows that 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.

So far we have seen how peening has remedied stress corrosion problems in both aluminum and in high strength steel. Now we will direct our attention to a third metal, titanium -- that element so vital to the aerospace industry which also has its stress corrosion problems. Small titanium tank shells used for liquid propellant were found to fail prematurely ostensibly 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 the problems of 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. The second tank was vibratory cleaned and failed after approximately 200 hours at 105 F. The third tank was glass bead peened and successfully withstood 720 hours of exposure at 105 F.¹

In each of the examples cited, whether field service originated or laboratory originated, shot peening successfully arrested destructive 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 in order for

stress corrosion cracking to occur -- surface and sub-surface 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. It is important to recognize that the availability 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
Shot Coverage

These four variables are collectively referred to as "intensity". Unfortunately, there is at the present time no economic non-destructive means for checking the actual part for its intensity. Currently, the only accepted standard is an arbitrary one called the Almen strip. The Almen strip is a steel strip 3 inches long and 3/4 inches wide. Its thickness depends on the intensity of the specified peening. This strip is positioned so that it may as closely as possible simulate the surface to be peened. The strip is then processed with the 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 as shown in Figure 19. When the strip is fully saturated, the arc height, measured over a chord of 1 1/4 in is expressed in thousandths and termed the intensity. You can see from this brief description that controls are essential in order to maintain any reasonable kind of uniformity.

Just what are the dangers to be considered if these controls are not maintained? Let us look at the mechanism by which shot peening provides this 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 loads. To understand the danger, look at the typical stress pattern produced by peening shown in Figure 20. There is a high compressive stress at the peened surface, increasing slightly just below the surface. It may be well to point out that 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 as the investigation proceeds into the material until the point of zero stress is reached. Then, the stress changes to one that is tensile in nature. As has been mentioned the benefits of shot peening are due to the compressively stressed layer and the depth which is induced by the process. The depth must be compatible to the thickness of the part. A general rule of thumb used, i.e., "...the induced surface compressive layer should not be greater than 20 to 25 percent 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." For illustration, let us look at the photomicrograph shown in Figure 21. This shows a single dimple indentation such as you might get from one piece of shot impacting a metal surface. The metal was then heat treated to promote grain growth in the section affected by the cold work. It also provides a representative picture of the typical stress pattern. Let us say that the large grain portray the compressive zone. From the previous figure, we know that immediately below this is a tensile layer. Picture a group of dimples close together providing an even compressive layer. If we then come to an area that 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 wide open to attack by stress corrosion. Peening

alone for stress corrosion resistance is not enough. Controlled peening is essential in order to adequately retard stress corrosion.

To sum up, the successful outcome of this costly battle can only result from coordination of efforts between the Engineer, the Metallurgist, and the Shot Peening Specialists. It has been said that the fight against stress corrosion starts on the drawing board.

ACKNOWLEDGMENT

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REFERENCES

1. Stress Corrosion Cracking of Ti6 Al-4V Titanium Alloy in Nitrogen Tetroxide. By W. Barry Lisagor, Chas. R. Manning, Jr. and Thomas T. Bales. NASA Langley Research Center.
2. Recrystallization as a Measurement of Relative Shot Peening Intensities. By K. B. Valentine, A.S.M., Vol. 40, pp. 420-434 (1948).



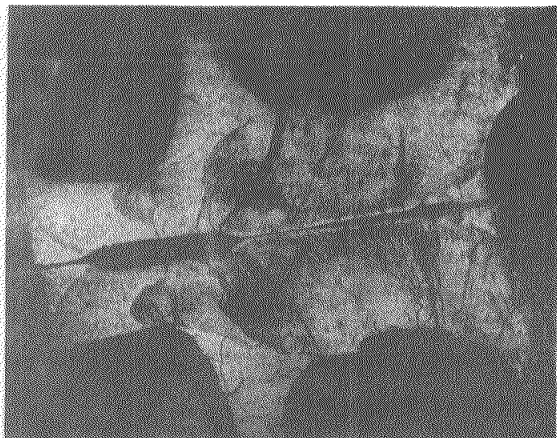
Main Landing Gear Fitting

Fig. 1



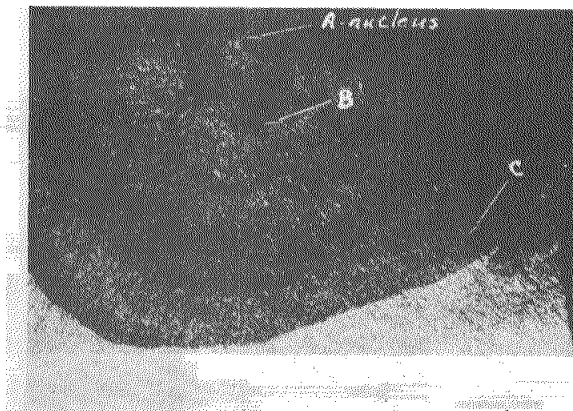
Location of Failed Area

Fig. 2



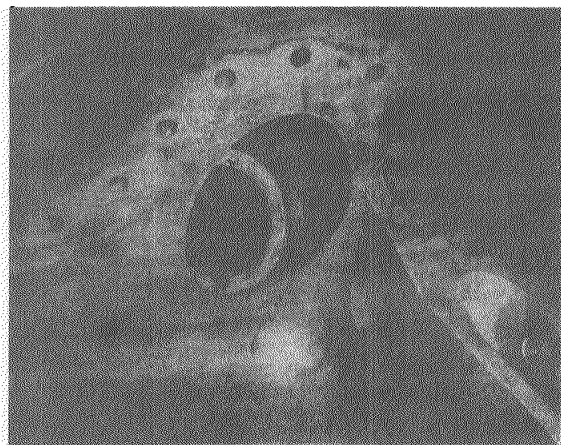
Opposing Fracture Faces

Fig. 3



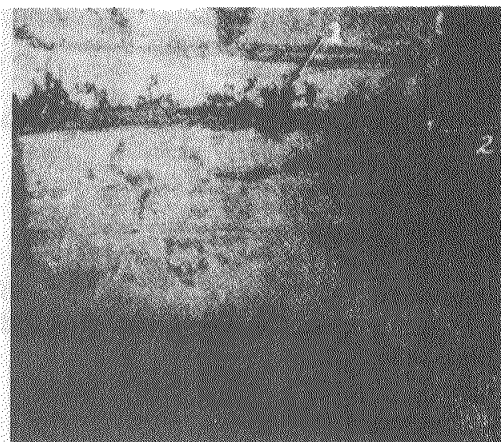
Typical Stress Corrosion Showing Flaky Texture

Fig.4



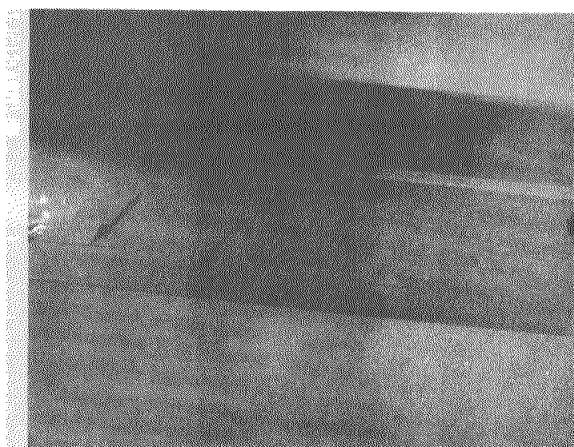
Failed Area Showing Crack

Fig. 5



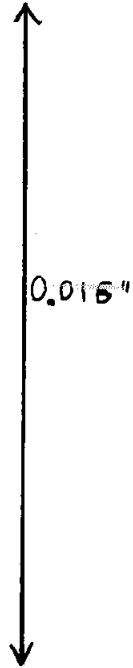
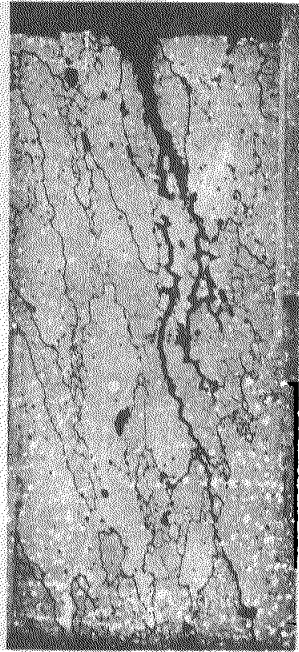
Two (2) Points Showing Crack Origin

Fig. 6



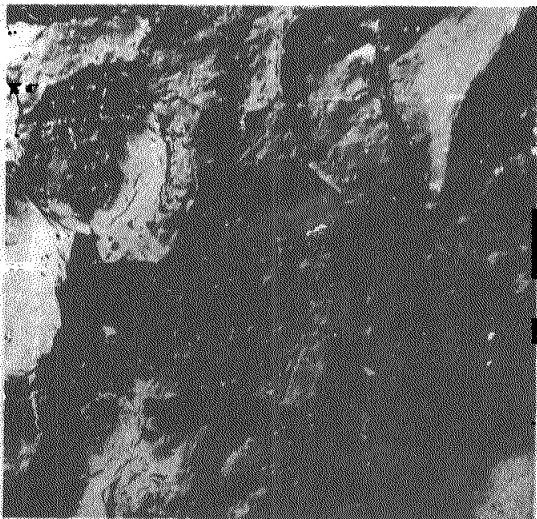
Spar Section Showing Crack Areas

Fig. 7



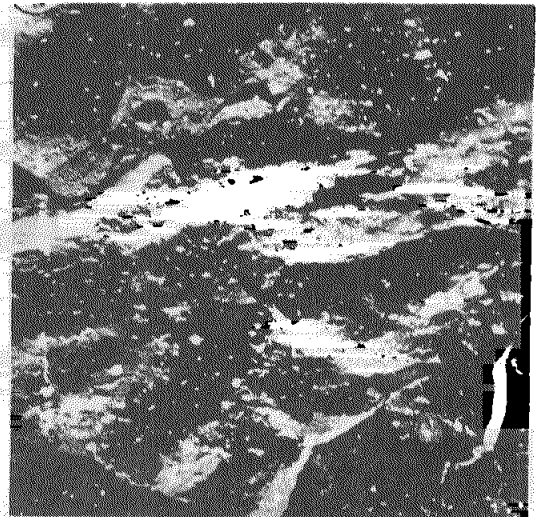
**Photomicrograph of Crack in 7079
T6 Forging Magnification -500X**

Fig. 8



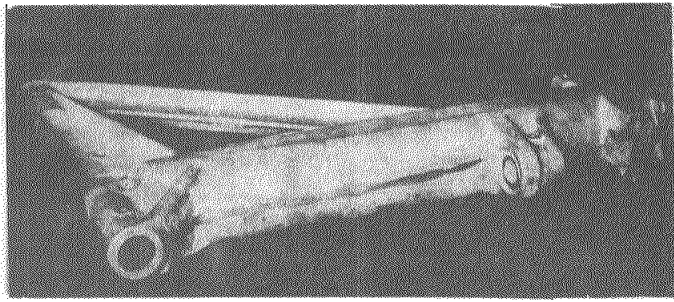
**Intergranular Type Brittle Failure
12,000X Showing Precipitates**

Fig. 9



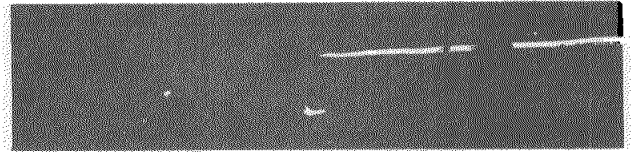
Grain Boundry Oxidation

Fig. 10



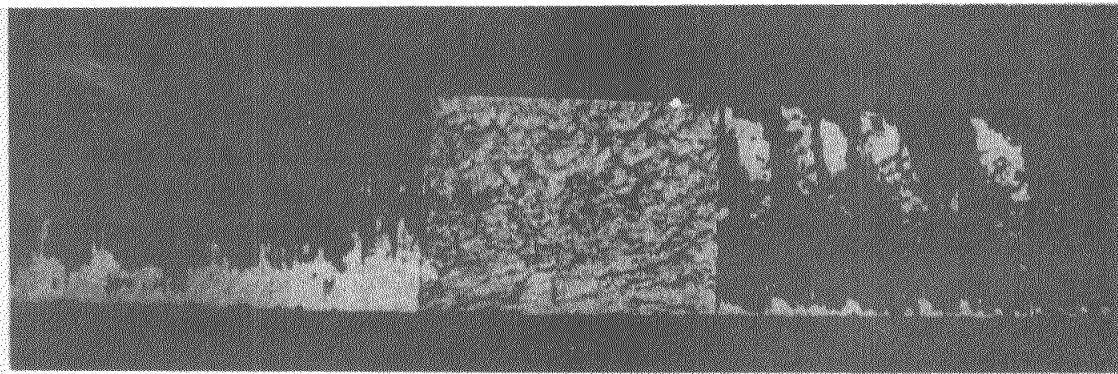
Crack in Cylinder into
Trunion Hole

Fig. 11



Ultrasonic Indication Showing
Defect in Main Landing Gear
Cylinder

Fig. 12



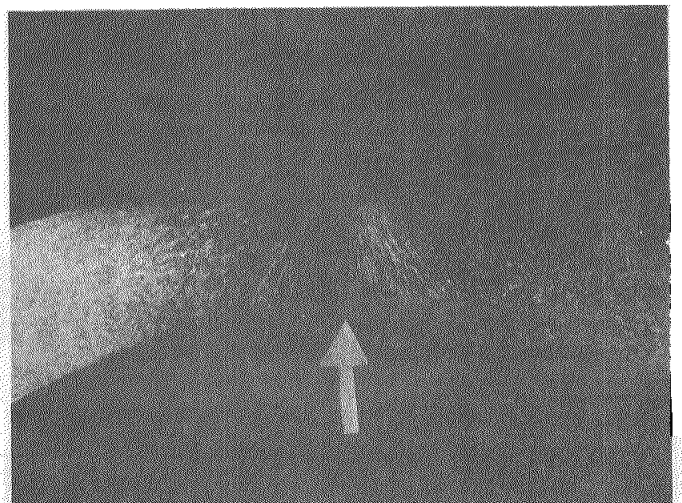
Defect Surface Showing Fracture Appearance

Fig. 13



Enlargement Showing Flaky Appearance
Characteristic of Stress Corrosion

Fig. 14



Etched Surface - Showing
Forging Lines

Fig. 15

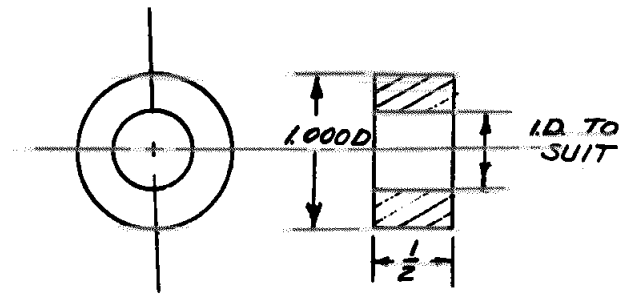
Processing Variable	Specimen Code	Residual Surface Stress (KSI) Ⓞ	Applied Stress (KSI)	Net Surface Stress (KSI) Ⓞ	Hours to SCC Failure Ⓞ
Basic Temper (As Heat Treated)	M20	+ 3.0	+100.4	+193.4	F 21
	M21	+14.4 Ⓞ		+204.8	NF177
	M30	+ 7.5		+197.9	F 30
	M31	+17.5		+207.9	F377
Flashfold	M74	+15.0		+205.4	F177
	M75	+14.4 Ⓞ		+204.8	F 54
	M76	+14.0		+204.4	F 21
	M77	+ 3.5		+195.9	NF244
Normal Grind (After Heat Treat)	M78	+14.4 Ⓞ		+204.8	NF232
	M47	-42.4 Ⓞ		+141.0	F 43
	M48	-42.4 Ⓞ		+141.0	F 98
Shot Peen	M49	-42.4 Ⓞ		+141.0	F 55
	M64	-115.2 Ⓞ	+ 75.2	NF354	
	M70	-115.2 Ⓞ	+ 75.2	NF334	
	M71	-115.2 Ⓞ	+ 75.2	NF312	
	XM6	-115.2 Ⓞ	+ 75.2	NF1000	
	XM7	-115.2 Ⓞ	+ 75.2	NF1000	

Ⓞ + = Tension, - = Compression.
 Ⓞ Net Surface Stress = Net - Residual
 T_{res} = Applied.

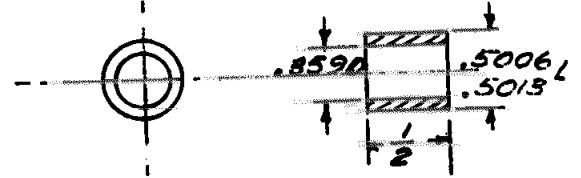
Ⓞ Average Surface Stress from Table XXIV.
 Ⓞ NF = No Failure, F = Failure

HP 9-4-45 Alloy
 Residual and Net Surface Stress and
 SCC Test Data

Fig. 18



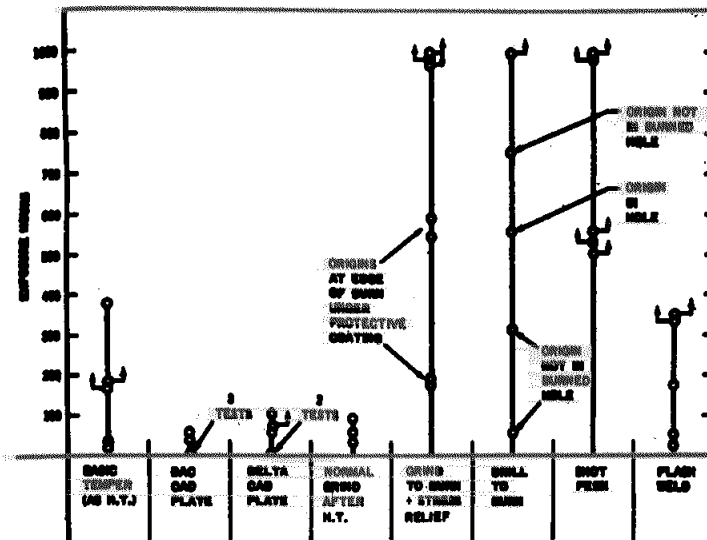
7075 RING



STAINLESS STEEL
 BUSHING

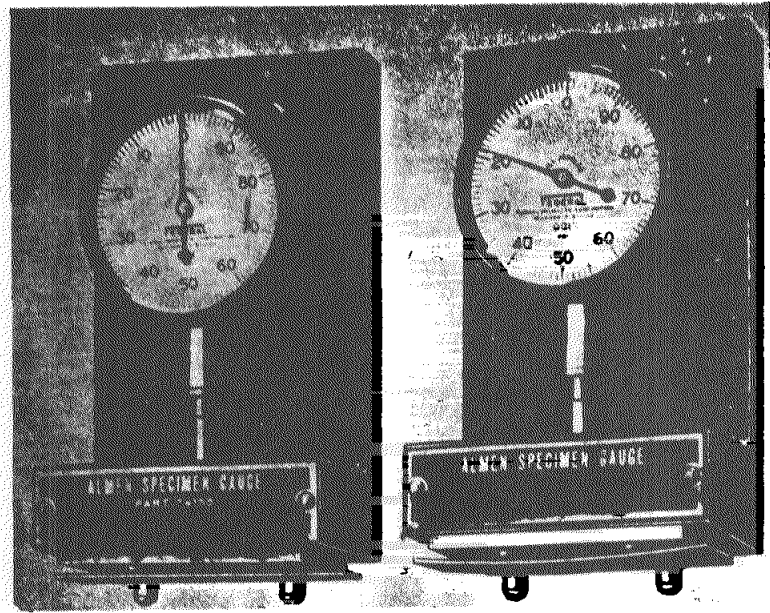
Test Bushings
 Fig. 16

Ⓞ NO HOT HAIL
 NO SCC
 ○ NO HAIL WITH
 SCC EVIDENT
 ALTERNATE MARKER:
 SUSTAINED STRESS = 500.4 MPa
 (500 FTU)



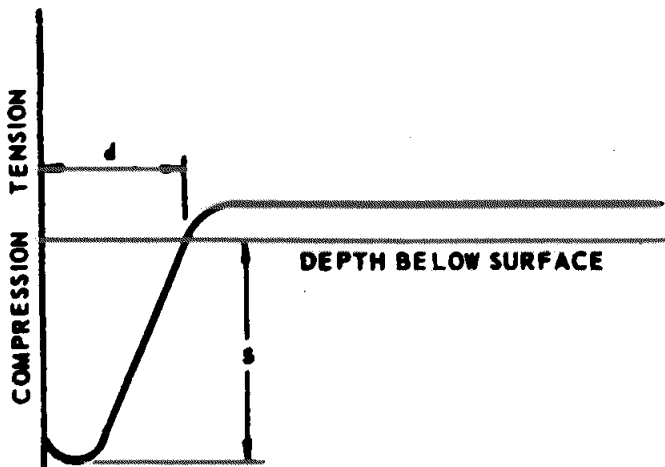
Processing Variables on SCC of
 HP 9-4-45 Materials

Fig. 17



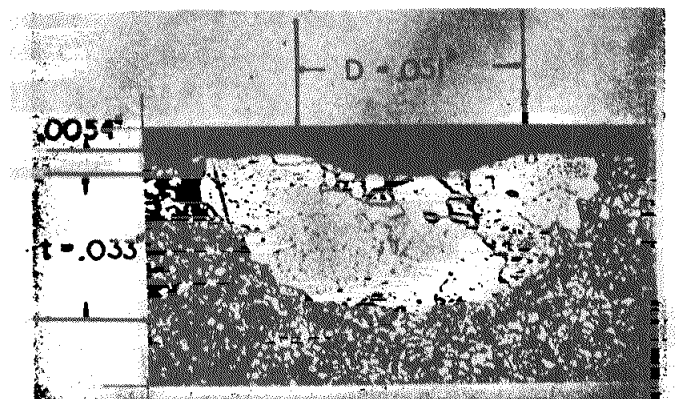
Almen Gauge

Fig. 19



DISTRIBUTION OF RESIDUAL STRESS
BELOW A SHOTPEENED SURFACE

Fig. 20



Photomicrograph of Grain Growth
Under Single Indentation

Fig. 21