Update on AMEC's Decarburization Program

By Robert H. Gassner

In an earlier article, I indicated that the Aerospace Metals Engineering Committee (AMEC) of the Aerospace Materials Division of SAE had set its sights on answering the question, "What's wrong with a little decarburization?" This article presents the results of the first phase of a program aimed at determining realistic limits for decarburization. It also touches on some peripheral information developed during the investigation.

Decarb Limits: In this phase, we tested the hypothesis that mild decarburization does not degrade the fatigue performance of shot peened surfaces. Our approach was simple: compare the fatigue performance of decarburized and non-decarburized 300M steel specimens peened with hard and regular shot. A key part of the study was the characterization of the severity of decarburization by a hardness vs depth profile to within 0.00015 in. (0.004 mm) of the surface using the Chord Method.1

Material: Vacuum melted, normalized and tempered 300M steel with a cleanliness rating of 0/0. Form: 0.625 in. (16 mm) in diameter rounds. Composition: 0.43C, 0.78Mn, 0.007P, 0.002S, 1.67Si, 0.86Cr, 1.84Ni, 0.41Mo, 0.16Cu, 0.09V, bal Fe.

Tensile specimens (0.250 in. [6.3 mm] in diameter), decarburization disc specimens (0.500 in. [13 mm] in diameter), and tension fatigue specimens (0.220 in. [5.5 mm] in diameter, K_t = 1) were finish machined from the starting material.

![Image: Microhardness traverses obtained on decarburized specimens (A) and non-decarburized specimens (B) of 300M steel, using the chord method. The data for (A) represent four microhardness traverses made from both ends of 0.158 to 0.159 in. (~4 mm) long chords of two ½ in. (13 mm) in diameter discs of 300M steel, austenitized at 1600 F (870°C) for 3 h in a mildly decarburizing, endothermic atmosphere (dewpoint 57 to 58 F (~14 C)). The data for (B) represent two microhardness traverses made from both ends of a 0.154 in. (3.9 mm) long chord of a ⅛ in. (13 mm) diam copper-plated disc of 300M steel, austenitized with the (A) specimens.](image-url)
stock. Half of each of the three types of test specimen plated with copper to a thickness of 0.002 to 0.004 in to 0.10 mm.

A heat treating procedure was then developed would produce the desired degree of mild decarburizing in the unplated specimens. All specimens were heat treated in a single load, following this procedure: austenitize at 1600 F (870 C) in an endothermic atmosphere (dew point 57 to 58 F [~14 C]), oil quench.

Fatigue and tensile test specimens were subsequently tempered for 4 h at 575 F (300 C). The copper plate stripped in an alkaline solution and the specimen retempered for 6 h at 575 F (300 C). This temper was followed by a light blast cleaning with 150 grit alumina oxide.

All fatigue specimens were then peened with either (Re 55 to 60], or regular (Re 50 to 55) shot. The intent was to attain 0.008 Almen A in both cases.

**Intergranular Oxidation Posed A Problem**

Decarburization specimens were prepared for hardness testing by grinding the peripheral surf to produce a chordal surface. This magnifies the decarburized zone and permits valid 500 g Knoop microhardness indentation measurements to be made at a true depth of 0.0015 in. (0.02 mm below the surface. This is the basis of the Chord Method.

Depths were calculated from the formula,

\[ d = r - \sqrt{r^2 - \Delta(c - \Delta)} \]

where \( d \) is the true depth below the surface, \( r \) is the meniscus radius, \( c \) is the length of the chordal surface, and \( \Delta \) is the apparent depth (distance from the end of the chordal surface). Results of these microhardness tests are plotted in Fig. 1.

Tensile Strength: Results of the tensile tests are given in Table I. The strength differences between decarburized and nondecarburized (plated) specimens were somewhat less than expected. However, they're considered a result of the decarburized, low strength surface on small size specimens.

Fatigue Data: A frequency of 1800 cycles/min minimum to maximum stress ratio of +0.2 was used for fatigue tests. Initial test results at a maximum stress of...
A 90,000 psi (1310 MPa) revealed a gross disparity between three decarburized specimens and the three non-decarburized specimens (Table II) — the decarburized specimens’ endurances were 90 to 95% lower.

We noted that the crack initiation sites of the short lived specimens were at the surface, while those of the long lived specimens were internal. Scanning electron microscope (SEM) examination of decarburized specimen fractures showed that all origins were at least 0.005 in. (0.13 mm) below the surface. Examination under an optical microscope of cross sections through the surfaces of those specimens revealed: 1. The presence of an outer layer of intergranular oxidation approximately 0.0004 in. (0.01 mm) thick. 2. The presence, after etching in alkaline chromate, of a subsidiary oxygen enriched layer approximately 0.0003 in. (0.008 mm) thick.

All decarburized specimens were subsequently polished before testing to remove 0.0015 in. (0.04 mm) from the diameter of the reduced section. Although this reduced the depth and severity of decarburization, the amount remaining was still well within the desired range.

Table I — How Decarburization Affects Tensile Properties

<table>
<thead>
<tr>
<th></th>
<th>Yield Strength, 10^3 psi (MPa)</th>
<th>Tensile Strength, 10^3 psi (MPa)</th>
<th>Elongation, %</th>
<th>Reduction in Area, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-decarburized (copper plated)</td>
<td>248.0 (1710)</td>
<td>291.3 (2009)</td>
<td>8.5</td>
<td>48.0</td>
</tr>
<tr>
<td>Non-decarburized (copper plated)</td>
<td>248.4 (1713)</td>
<td>291.9 (2013)</td>
<td>6.5</td>
<td>46.0</td>
</tr>
<tr>
<td>Decarburized (unplated)</td>
<td>—</td>
<td>284.0 (1958)</td>
<td>12.0</td>
<td>47.8</td>
</tr>
<tr>
<td>Decarburized (unplated)</td>
<td>235.6 (1624)</td>
<td>280.7 (1935)</td>
<td>13.0</td>
<td>49.0</td>
</tr>
</tbody>
</table>

Test Data Indicate That Mild Decarb Isn’t Harmful

All fatigue test results are given in Table II. Data considered valid and comparable are plotted in Fig. 2.

The data in Fig. 2 indicate that mild decarburization does not degrade the fatigue performance of shot peened surfaces. The interpretation: peening introduced sufficient compressive stresses in the surface layers to force cracks to initiate internally.

The scatter band in Fig. 2 should be considered only as representative of the fatigue performance of this lot of 300M. There is, of course, a possibility that the validity of the results may have been compromised by the removal of 0.00075 in. (0.02 mm) from the decarburized surface. This is not, however, considered likely.

Oxidation: Several additional tests were made to try to determine the source of the intergranular oxidation that severely degraded the fatigue performance of decarburized specimens.

Decarb specimens were first heat treated with 200 lb (90 kg) of scrap to see whether the oxidation was related to a disruption in the furnace atmosphere caused by charging the original, very light load of specimens. The intergranular
Table II — How Decarburization and Shot Hardness Affect Fatigue Properties

Kilocycles to Failure

<table>
<thead>
<tr>
<th>Maximum Stress, 10^3 psi (MPa)</th>
<th>Decarburized, Hard Shot Peened</th>
<th>Nondecarburized, Hard Shot Peened</th>
<th>Decarburized, Regular Shot Peened</th>
<th>Nondecarburized, Regular Shot Peened</th>
</tr>
</thead>
<tbody>
<tr>
<td>185 (1275)</td>
<td>4050^1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>190 (1310)</td>
<td>234^2</td>
<td>2283^1</td>
<td>95^2</td>
<td>1858^1</td>
</tr>
<tr>
<td>190 (1310)</td>
<td>224^2</td>
<td>1847^1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>190 (1310)</td>
<td>4442</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>190 (1310)</td>
<td>3395</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>200 (1380)</td>
<td>2491</td>
<td>1322^4</td>
<td>2331</td>
<td>1119</td>
</tr>
<tr>
<td>205 (1415)</td>
<td>—</td>
<td>1499</td>
<td>766</td>
<td></td>
</tr>
<tr>
<td>210 (1450)</td>
<td>841</td>
<td>106^2</td>
<td>1165</td>
<td>648</td>
</tr>
<tr>
<td>210 (1450)</td>
<td>—</td>
<td>141^2</td>
<td>966</td>
<td>814</td>
</tr>
<tr>
<td>210 (1450)</td>
<td>—</td>
<td>554</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>215 (1480)</td>
<td>599</td>
<td>731</td>
<td>437</td>
<td>367</td>
</tr>
<tr>
<td>220 (1515)</td>
<td>302</td>
<td>340</td>
<td>517</td>
<td>648</td>
</tr>
<tr>
<td>225 (1550)</td>
<td>361</td>
<td>281</td>
<td>222</td>
<td>290</td>
</tr>
<tr>
<td>230 (1585)</td>
<td>364</td>
<td>275</td>
<td>374</td>
<td>213</td>
</tr>
<tr>
<td>235 (1620)</td>
<td>364</td>
<td>—</td>
<td>89^3</td>
<td>270</td>
</tr>
</tbody>
</table>

1. Not polished, internal crack initiation. 2. Not polished, crack initiation at surface. Points not plotted in Fig. 1.

Oxidation produced was essentially identical to that previously observed.

Decarb specimens were then dropped through the ports of two furnaces operating with stable atmospheres to see whether the production of intergranular oxidation was an inherent characteristic of endothermic atmospheres.

The depth of oxidation produced was less than that previously observed, but was still an appreciable 0.00016 in. (0.004 mm).

One of the specimens was grit blasted, following a procedure used in production for preplate cleaning. The objective: determine whether intergranular oxidation should be expected in production parts heat treated without a protective copper plate.

Microscopic examination revealed that the blasting operation removed about half of the oxidized layer.

The frequent presence of slight intergranular oxidation on specimens austenitized in endothermic atmospheres has been confirmed by other metallurgists.

Peening: Test results also indicate that there's no difference in fatigue performance between hard and shot peened specimens. With hard shot peening, it's to inspect part surfaces for complete coverage. On the hand, if high stress cycling is anticipated, more material would probably have to be removed to eliminate perturbations.

Flaws in Peened Surfaces Degrade Fatigue Properties

The study also disclosed that the fatigue performance of shot peened specimens is severely degraded by the press of minute surface flaws. Previously, we thought that compressive stresses introduced by peening would mask effects of any minor surface irregularities.

Apparently, the sensitivity of a specimen to early initiation of fatigue failure is a surface flaw is directly related to the magnitude of the maximum stress.

In the presence of intergranular oxidation, the three
stress is probably between 185,000 and 190,000 psi (1275
and 1310 MPa). If the only surface defects are the pertur-
bations caused by peening, the threshold stress appears to be
between 205,000 and 210,000 psi (1415 and 1450 MPa). For
polished surfaces, the threshold stress is about 235,000 psi
(1620 MPa).

Testing at lower maximum stresses was considered, but
not pursued because we felt that the cycles-to-failure
numbers generated would be larger than desired for use in
the design of most aircraft components. It's also quite likely
that if the specimens had been transverse or made from
much larger stock, the scatter band would have been shifted
to the left and no threshold stress would have been dis-
covered.

Grit Blasting: During the investigation, we decided that it
would be valuable to determine whether the surface pertur-
bations caused by peening could be readily removed by grit
blasting.

Nine decarburized fatigue specimens were polished to
remove 0.0015 in. (0.04 mm) from their diameters, hardened
shot peened, and then blasted with 150 grit aluminum
oxide.

The first specimen failed prematurely with crack initia-
tion at the surface. The cause was assumed to be surface
roughness resulting from excessive blasting.

Because of this, the remaining specimens were lightly
polished to remove 0.0005 in. (0.01 mm) from their
diameters. Six of these were reblasted under less severe
conditions. One of the two remaining polished specimens was
polished again to remove an additional 0.0005 in. (0.01 mm)
from its diameter.

Results of the fatigue tests on the nine specimens are
given in Table III.

It appears that 150 grit blasting cannot be successfully
used to remove the surface perturbations resulting from
shot peening. Blasting not only doesn't remove enough
material, but it also introduces sharp micronotches at
which fatigue cracks can nucleate. It's possible, however,
that a practical production technique could be developed
for removing material from irregular surfaces by combining
polishing with a coarser-grit blasting operation.

More Work's Needed: Additional work is still required
to fully determine the effects of mild decarburization and
carburation, coupled with hard and regular shot peening,
on fatigue performance.

The results of this initial phase of the study have,

<table>
<thead>
<tr>
<th>Surface Condition</th>
<th>Maximum Stress, $10^6$ psi (MPa)</th>
<th>$10^3$ Cycles to Failure</th>
<th>Crack Initiation Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grit blasted</td>
<td>220 (1515)</td>
<td>49</td>
<td>Surface</td>
</tr>
<tr>
<td>Grit blasted, polished to remove 0.0005 in.</td>
<td>195 (1345)</td>
<td>137</td>
<td>Surface</td>
</tr>
<tr>
<td></td>
<td>(0.01 mm), and reblasted</td>
<td>195 (1345)</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td></td>
<td>195 (1345)</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>195 (1345)</td>
<td>1178</td>
</tr>
<tr>
<td>Grit blasted and polished to remove 0.0005 in. (0.01 mm)</td>
<td>195 (1345)</td>
<td>1477</td>
<td>Internal</td>
</tr>
<tr>
<td>Grit blasted and polished to remove 0.001 in. (0.02 mm)</td>
<td>195 (1345)</td>
<td>4140</td>
<td>Internal</td>
</tr>
</tbody>
</table>

I. Initial condition of all specimens: decarburized, polished to remove 0.0015 in. (0.04 mm), and hard shot peened.

However, answered a few questions and, perhaps fortunate-
ly, raised several new and challenging ones. To answer
them, new programs are needed on the prevention of
intergranular oxidation, the effects of varying peening
intensity, alternative replace cleaning techniques, and the
removal of perturbations from peened surfaces.

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Reference