SPALLING OR BRINELLING HAD OCCASIONALLY been noted where a hemispherically shaped part slid on a flat plate. Both parts were of steel, AISI 52100 hardened to 60 Rc. To circumvent what was felt to be a contact fatigue problem, both parts were shot peened since shot peening has been found to be an effective means of increasing fatigue life (1) (2) (3).

The problem persisted. One potential reason for this was felt to be an annealing effect upon the residual stress produced by peening. With the parts operating in a lubricant environment at 250-300°F and with the potential of a 50-75°F higher temperature at the contact zone, the annealing possibility seemed quite realistic and worthy of evaluation.

Consequently, an investigation of the residual stress patterns of shot peened AISI 52100 and AISI H-11 (a more temperature resistant steel) after prolonged exposures to moderate temperatures was conducted.

PROCEDURES

Shot peened specimens of 52100 and H-11 materials were placed in atmosphere furnaces for 1, 10, 100, 1000 and 4000 hours. One sample was used for each period of time except 4000 hours where 2 samples were used. For the 52100 parts

*Numbers in parenthesis refer to references at the end of the paper.

ABSTRACT

Shot peening is commonly used to create residual compressive stresses in part surfaces, thereby reducing the effects of tensile service loads and improving fatigue life.

The research reported here was initiated to determine whether or not the residual compressive peening stresses are rapidly annealed out by elevated temperature exposures. AISI H-11 and 52100 steels were selected for the tests, peened, and subjected to temperatures up to 800°F for times to 4000 hours. Residual stress measurements were made by X-ray diffraction methods.

It was shown that residual stresses are not significantly relieved in 52100 within 10 hours at 400°F, or 4000 hours at 300°F. For H-11, no change was produced within 10 hours at 800°F or 4000 hours at 600°F. It was found possible to relate the reduction in initial residual compressive stress level caused by thermal stress-relief by a parameter of the form P = T (c + log t).

The Effect of Elevated Temperature Exposure on Residual Stresses

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600° F is plotted in Figure 6 while the isothermal data at 800° F is plotted in Figure 7. Figure 8 is the data on H-11 after 4000 hours at temperature.

To check the effect of heat treatment on non-shot peened samples, a number of the H-11 specimens were checked on their non-shot peened surfaces. No effect of temperature was noted as can be seen in Figure 9.

For ease in assimilation of the data in future applications, time-temperature parameter curves were prepared and are shown in Figure 10 and 11. These curves are normally developed for creep or tempering effects, but since this was felt to be a similar phenomenon were compiled also for this stress relieving effect.

### DISCUSSION OF RESULTS

#### A. Isothermal Data for 52100

Figures 2 through 5 present the results of holding shot peened specimens for various lengths of time at moderate temperatures. With the exception of the data for 4000 hours at temperature, where duplicate specimens were employed, only one specimen was used for each period of time. Possibly due to this lack of duplicate sampling, some apparent anomalies exist. For example, there is a higher peak compressive stress after 10 hours at 400° F than there is after only 1 hour at 250° F and there is a higher peak compressive stress after 4000 hours at 250°F than there is after 100 and 1000 hours at 250°F. However, in all of these cases the

![Fig. 1 - Normal high intensity shot peening stress distribution](image1)

![Fig. 2 - Isothermal data on 52100 at 250 F](image2)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Alt. Design</th>
<th>C</th>
<th>Si Max</th>
<th>Mn Max</th>
<th>Cr Max</th>
<th>Fe Max</th>
<th>Ni Max</th>
<th>Mo Max</th>
<th>Cu Max</th>
<th>V Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 52100</td>
<td>AMS 6440</td>
<td>1.05</td>
<td>0.35</td>
<td>0.45</td>
<td>1.5</td>
<td>Bal</td>
<td>0.25</td>
<td>.06</td>
<td>.35</td>
<td>.5</td>
</tr>
<tr>
<td>AISI H-11</td>
<td>AMS 6484</td>
<td>0.4</td>
<td>1.0</td>
<td>0.4</td>
<td>5.0</td>
<td>Bal</td>
<td>1.3</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
difference is less than about 20 ksi which appears to be a reasonable number for the spread or scatter between specimens particularly at the high end of the scale.

In spite of this scatter, looking at Figure 5 which is based upon duplicate specimens, one can state that there is a significant drop in the residual stress and hence upon the effectiveness of shot peening after 4000 hours at 600°F. In fact, comparing the curves in Figure 4 with those in Figures 2 and 3, a general overall reduction in the amount of the residual compressive stress can be noted after relatively short times at 600°F.

Referring now to Figure 2 where the isothermal data at 250°F is plotted, there is no discernible effect of the period of time at temperature upon the residual stress pattern either in shape or magnitude. Basically, the same order of magnitude and values were obtained at 300°F as at 250°F so that Figure 2 can be considered the results for both 250 and 300°F.

Based upon this data, one would expect no appreciable reduction in the effectiveness of the shot peening at temperatures up to 300°F with 52100 for long periods of time. One potential discrepancy in this argument is that all of the data for 250°F and 300°F appears to be about 20-30 ksi lower than the data obtained at room temperature or the normal shot peening stress distribution shown in Figure 1 and 5. Two possible causes for this difference are (1) a slight stress relieving effect or (2) the normal scatter in the stress levels obtained by peening. The data in Figure 5 after 4000 hours at temperature lends credence to the stress relieving concept, while the data at 400°F after 1 and 100 hours tends to point to a scatter phenomena.

The data at 400°F shown in Figure 3 shows the expected trend. That is a slight drop in peak compressive stress as the time at temperature increases. If the data in this figure is compared with the data in Figure 5 and 6 only, no difficulties arise. Comparison with Figure 2 leads to some problem, for
TABLE II
Data on 52100 After 4000 Hours at Temperature
Numbers are compressive residual stress in KSI and the numbers
in parenthesis are the averages

<table>
<thead>
<tr>
<th>Temp. Surface</th>
<th>-004&quot; Below Surface</th>
<th>-008&quot; Below Surface</th>
<th>Average* Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 117</td>
<td>152</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>Temp. 128</td>
<td>154</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>168</td>
<td>133</td>
<td>0</td>
</tr>
<tr>
<td>(133)</td>
<td>(158)</td>
<td>(119)</td>
<td></td>
</tr>
<tr>
<td>250°F 112</td>
<td>125</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>131</td>
<td>107</td>
<td>21</td>
</tr>
<tr>
<td>(120)</td>
<td>(128)</td>
<td>(100)</td>
<td></td>
</tr>
<tr>
<td>300°F 105</td>
<td>122</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>112</td>
<td>88</td>
<td>30</td>
</tr>
<tr>
<td>(109)</td>
<td>(117)</td>
<td>(93)</td>
<td></td>
</tr>
<tr>
<td>400°F 90</td>
<td>105</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>106</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>(95)</td>
<td>(105)</td>
<td>(55)</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>56</td>
<td>2</td>
<td>106</td>
</tr>
<tr>
<td>27</td>
<td>66</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(30)</td>
<td>(61)</td>
<td>(2)</td>
<td></td>
</tr>
</tbody>
</table>

\* This number was obtained by taking the differences between averages and then averaging that.
Standard deviation between data points for the same depth = 14.5

The peak compressive stress after 1 to 10 hours at 400°F is greater than the peak compressive stress after 1 to 10 hours at 250 and 300°F. As mentioned before this does tend to point to a scatter phenomena. However, in spite of this problem a couple of rational conclusions can be drawn. One is that short term exposures (up to 10 hours at least) to temperatures as high as 400°F have no appreciable effect upon the residual stress pattern in 52100. The other is that after long time exposures to 400°F there is a significant drop off in the residual compressive stress.

A temperature of 600°F even for relatively short times causes an appreciable drop in the residual stress as can be seen in Figure 4. Figure 5, which is based upon duplicate specimens, shows a gradual reduction in the residual stress as the temperature is increased. This concept appears valid in spite of the amount of scatter intimated earlier when one compared all of the data to the room temperature or normal distribution curve. This is done in Table II. Looking at the data for 250°F and 400°F, it is much easier to believe a scatter of 21 ksi, the average difference between room temperature and 250°F, than it is to believe a scatter of 52 ksi, the difference between room temperature and 400°F.

The time - temperature parameter curve for 52100 shown in Figure 10 shows all of the data points on the curve. While

Fig. 6 - Isothermal data on H-11 at 400°F and 600°F
some scatter obviously exists, it seems well within the range of experimental error. Thus the validity of the conclusions above is substantiated. One additional comment is that the curve generated is really valid only when the initial compressive residual stress is 150 ksi.

B. Isothermal Data for H-11

The isothermal data for H-11 is shown in Figures 6 through 9. Figure 9 is data on non-peened specimens. It is interesting to note that time and temperature had no noticeable effect upon the original residual stress pattern which was probably obtained from the grinding operation. All
52100 apply here. The basic difference is that higher temperatures are of interest with the H-11 so that larger parameter values are utilized.

CONCLUSIONS

1. With AISI 52100 bearing steel no appreciable change in the magnitude or shape of the residual stress curve due to shot peening, which is indicative of the retention of increased fatigue life, occurs under the following conditions:
   a) Long term (up to 4000 hours) exposure up to 300°F.
   b) Short term (up to 10 hours) exposure up to 400°F.

2. AISI 52100 did show significant residual stress reduction after long term exposure at 400°F and short term exposure at 600°F.

3. AISI H-11 showed no significant change after long term exposure (4000 hours) at 400°F or short term (10 hours or less) exposure at 800°F.

4. AISI H-11 did show significant reduction after long term exposure at 600°F and above.

5. It was found possible to relate the reduction in initial residual compressive stress level caused by thermal stress relief by a parameter of the form $P = T(C + \log t)$.

LIST OF REFERENCES


4. SAE TR182, “Measurement of Stress by X-ray”.

